AN INVESTIGATION INTO WEAR CHARACTERISTICS

OF A DIRECT DRILLING COULTER (OPENER).

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ABSTRACT.

Wear on a promising chisel coulter, developed at Massey University, was considered to be marginally unacceptable. A functional lifespan of approximately 20 hectares for non-rolling blade components necessitated relatively frequent coulter replacement, and thereby incurred increased costs for components and machine downtime.

Three experiments were carried out with an improved version of the Massey University chisel coulter concept. The respective objectives were as follows:

1. To determine whether soil particles were passing between the rotating disc and stationary coulter blade components during normal field machine operation.

2. To determine the patterns of coulter blade wear.

3. To compare several selected blade treatments in their abilities to prolong functional coulter blade life.

In the first (laboratory) experiment, a stationary test rig was constructed. This closely simulated coulter assembly operation in the field. Measurements of changes in soil particle size with time for "soil" and "no soil" introduction to the disc/blade interface did not detect any soil breakdown which might have indicated a soil "lubrication" effect at that interface. However, observations of the patterns of abrasion and of photographs did indicate that some form of soil "lubrication" had occurred.

In the second experiment, a hard-facing welded (Hardcraft 700 over mild steel) and a control treatment (mild steel) were evaluated to establish patterns of wear on a three row field-operating test rig. The former treatment displayed potential for resisting dimensional changes at various stages throughout blade life. The rotating action of the disc against the inner shank of the blade was responsible, in the prevailing conditions, for wear at the inside lower leading edge/wing intersection of the blade. This action eventually accelerated wing wear.

The weld bead pattern was modified for use in Run A of Experiment 3 (top pattern); and another pattern (bottom pattern) was designed to prevent possible increased penetration forces associated with the original weld pattern.

The third experiment involved evaluation of selected treatments during routine field drilling operations, using a pre-production prototype direct drill. Carbonitrided mild steel blades offered an almost three-fold increase in relative wear resistance (in terms of metal weightloss per hectare) compared to the standard mild steel blades. The carbonitrided treatment also resisted dimensional changes more effectively, and was more cost effective than all other treatments.

The influence on wing and shank dimensions exerted by left and right side blade positioning on each coulter assembly, appeared to reflect continual anti-clockwise machine cornering during operation and seed/fertiliser dispersal differences. Coulter wings on the outside of field turns were subjected to greatest wear, as were the shank regions of blades dispersing fertiliser. Lateral and fore/aft positioning of coulter assemblies appeared to have no effects on blade life.

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1 INTRODUCTION.

Research into direct drilling (zero tillage) of seeds into undisturbed seedbeds has demonstrated considerable potential for this technique of plant establishment, compared with conventional methods. Documented advantages include conservation of fuel (Hughes and Baker 35), time (Cannell and Ellis 18, Bakerman 13, Phillips and Young 55, Phillips *et al.* 54), soil structure (Baeumer 5, Unger *et al.* 73, Phillips *et al.* *loc cit.*), soil moisture (Moschler *et al.* 49, Barnes *et al.* 14, Phillips and Young *loc cit.*, Phillips *et al.* *loc cit.*) and earthworm populations (Mai 44, Moschler *et al.* 50, Cannell and Ellis *loc cit.*) as well as probable reductions in soil temperature fluctuations (Mathews 45, Moody *et al.* 46), operational costs (Baker 12, Allen 4, Frengley 29) and risk to the farmer (Cannell and Ellis *loc cit.*, Bakerman *loc cit.*, Phillips and Young *loc cit.*, Phillips *loc cit.*).

Several disadvantages of direct drilling have precluded the universal acceptance of the techniques involved by the farming community. Such disadvantages have included uncertainty of yields (Cannell and Ellis 17), the need for new machinery (Baker 7), insect infestations (Pottinger 56, Carpenter *et al.* 19), the necessity for new skills to be mastered (Kahnt 39, Baker 12) and the restricted availability of technical advice (Baker *loc cit.*, Kahnt *loc cit.*).

Wear on existing coulter designs in direct drilling is a major mechanical problem. This wear is primarily due to the fact that soil bulk densities are considerably higher than those for cultivated seedbeds, requiring larger penetration and draught forces from the drill.

It is generally accepted that disc coulters have offered reduced wear rates in both tilled and untilled soils, but there is doubt about their biological function in direct drilling (Baker 7, Choudhary and Baker 20, 21). Non-rolling coulters, or even components of coulters, sometimes may offer biological advantages but they apparently do so at the expense of wear. The cost benefits of non-rolling and rolling components in relation to wear may be argued for years to come, but there appears to be sufficient evidence to justify examining ways and means of reducing wear of at least one promising non-rolling coulter.

Wear on the redeveloped Massey University experimental chisel coulter was thought to be marginally unacceptable, with the functional life of the non-rolling blades being approximately 20 hectares. This necessitated relatively frequent coulter replacement with inherently increased costs for components and downtime.

The research reported below, therefore, had the following aims:

1. To determine the patterns of wear on the soil engaging components of the Massey University redeveloped chisel coulter.

2. To determine relative wear between individual components of the coulter.

3. To compare various methods of prolonging the working life of the coulter.

2 LITERATURE REVIEW.

2.1 INTRODUCTION.

This review attempts to present both biological and mechanical factors that influence direct drilling machine design. These factors impose constraints on the extent to which any existing coulter may be altered when considering treatments that may prolong functional life of that component.

Interactions between coulter design and wear are also reviewed, together with factors influencing wear of soil engaging tools. The latter section includes soil flow dynamics and effects of tool shape, speed and metallurgical properties.

2.2 FACTORS DETERMINING COULTER DESIGN (GROOVE SHAPE).

2.2.1 BIOLOGICAL FACTORS.

There appears to be little specific information published regarding interactions between biological factors and component wear.

Direct drilling may have modified important soil physical characteristics within the slot such as moisture content, organic residues, mechanical impedance, aeration and temperature (Baker 7, Baeumer 5). It has been suggested (Baker 8) that designs of direct drilling coulters were influenced by the extent of alterations made to these soil characteristics and that they, in turn, influenced the biological responses of plants. Table 1 summarises a number of claimed biological responses attributable to groove shape, and serves to illustrate the wide diversity of opinion in this field. Comments are also included to focus attention on the likely relevance of wear in relation to biological functions of individual coulters.

TABLE 1.

BIOLOGICAL FACTORS DETERMINING GROOVE SHAPE.

CRITERIA.	AUTHOR.	COULTER DESIGN.	REPORTED COMMENTS.
SEED GERMINATION	Baker (7) Robinson and Cross (60)	Angled flat and dished disc coulters.	Disc coulters (and even varying shapes thereof) may have given rise to different patterns of germination than non-rolling coulter designs.

It is likely that wear of non-rolling disc coulters would primarily reduce the diameter of the disc. Such a dimensionional change is unlikely to influence the groove opening function unless the geometrical relationship between this component and any other (eg. seed delivery tube) is important.

CRITERIA.	AUTHOR.	COULTER DESIGN.	REPORTED COMMENTS.
SEEDLING EMERGENCE.	Taylor (cited by Baker 7)	Angled dished disc coulter.	Varied success reported. Failure from deep sowing on turf or heavy soil, where the flap inhibited seedling emergence.
	Triplett and Van Doren (70)	"Hollow" tools sometimes preceded by a disc.	Corn percentages: 65% and 82% in silt loams and silty clay loams respectively compared with traditional seedbeds which were 85% and 87%.
	Hood _et al._ (34)	"Knife coulter" preceded by a disc.	Similar counts for emergence to those above (70) when comparing ploughing and direct drilling.
	Karonka (40)	"Rotoseeder"- rotary hoe-like action at each drilled row.	Slot had "not been very successful" and hence lost favour with many workers.
	Dunbar _et al._ (28)	Powered rotary coulter	Design produced up to 52.3 % better grass seed emergence than the triple disc in two contrasting tussockland climates.

Brown	(16)	Triple disc coulter	V-shaped slot was reported as not being the most suitable environment for sown seeds. Emergence problems especially in wet soils due to discs smearing slot walls.
Baker	(7)	"Chisel" tool-vertical pre-disc followed by a sharpened tool with angled lateral wings at the base.	In dry soils, the maximum emergence was 77.1% compared to 27.6% (hoe) and 25.5% (triple disc). Soil manipulation largely confined to sub-surface layers. Attributed performance to dead mulch cover over groove.

Wear of individual disc components is not likely to have any major influence on seedling emergence, since groove opening is likely to be unaltered as disc size is reduced. However, where disc components operate in close proximity to other tools or other disc components, disc diameter reduction may be responsible for altering tolerances between coulter components and thereby changing the biological functions of the assembly. There appears to be no such definitions of tolerance in the literature, however, and comments must therefore remain speculative.

Non-rolling "hollow" and "chisel" components are likely to be affected by wear. Soil is manipulated by the shape and speed of coulter blades in order to maximise seedling emergence. Any alteration to blade shape, therefore, is likely to affect seedling emergence, although the literature contains few clear definitions of tolerances in this respect.

Non-rolling "knife coulters" are less likely to be affected by wear, since the frontal area might be expected to remain relatively constant throughout blade life.

Powered rotary coulters are likely to show reduced in-row cultivation as a result of wear, unless corresponding ground speed changes also occur. Again, however, the literature gives no indication of the biological significance of any change in tilth.

SEED GROOVE MOISTURE.	Hood et al. (34)	Dished disc coulter.	Higher speed gave a greater tendency for the groove sides to be disturbed and left exposed for undesirable drying.
	Baker (8)	Chisel, hoe and triple disc coulters.	Seedling emergence differences in dry soils indirectly related to soil water availability to the seed as a function of groove shapes and cover material.
	Baker (7) Choudhary and Baker (20) Ibid. (21)	Chisel, hoe and triple disc coulters.	Matrix soil water important in dry soils with either hoe or triple disc tools. Conditions less important with the chisel coulter or if using the other units in moister soils.

Disc size reduction is unlikely to affect moisture retention by the seed groove, unless ineffective residue cutting resulted in a torn U-shaped groove. All of the other listed coulter types are likely to be affected by wear, since the shape of the opener appears to influence water availability to the imbibing seed.

AMBIENT HUMIDITY.	Choudhary and Baker (20)	Chisel, hoe and triple disc coulters.	Increasing r.h. resulted in better germination and emergence counts in dry soils. In moister soils, humidity had no significant effects.

Wear on these coulter types, if sufficient to influence the seedbeds prepared or the maintenance of an undisturbed mulch cover, is likely to affect the responses of seeds to ambient humidity. These different responses would be due to differing gaseous exchange between the seed groove and the atmosphere.

SEED GROOVE HUMIDITY.	Choudhary and Baker (20) Ibid. (21)	Chisel, hoe and triple disc coulters.	Grooves that were inadequately buffered from ambient conditions responded quickly to changes in these conditions. Chisel coulter grooves retained higher humidity than the hoe design which was higher than the triple disc design. Correlation coefficient between r.h. loss and seedling survival, r= -0.75.

Relevance of wear to seed groove humidity has been shown to be similar to that outlined for ambient humidity above.

SEED GROOVE DISTURBANCE AND COVER.	Baeumer (5)	Triple disc coulter.	Shortcomings were due to leaving seeds uncovered and depth control problems, particularly on soils with little tilth and during dry periods.
	Baker (7) Ibid. (8)	Chisel coulter	Seeds appeared to germinate and emerge more quickly and vigourously where a flap of dead turf overlay the seed. This was independent of the extent of soil shattering. Correlation coefficient for emergence versus grade of cover was r= 0.97.

This performance parameter for disc components is not likely to be affected by wear. The triple disc configuration is responsible for an open V-shaped seed groove, and this is not likely to be affected by wear, except perhaps if the front disc of this configuration changes its relationship to the other two discs.

Performance of the improved chisel coulter is likely to be affected by wear. As the inside leading edge of the shank is worn against the disc, the shank/disc angle would increase, leaving a more disturbed seed groove after coulter passage.

Speed of discs increases with decreasing diameter for any given ground speed. The triple disc coulter, at least, is commonly regarded as having an upper limit of disc speed before some seeds are ejected out of the rear above ground (Baker pers.comm. 1981)

SEED GROOVE COMPACTION AND SMEARING.	Dixon	(26)	Chisel, hoe and triple disc coulters.	At low soil water, no measurable compaction was evident with any coulters. The hoe and triple disc both smeared the seed slots in moist conditions. The latter also compacted the slot base in the same conditions, however mechanical impedance to roots was not evident.
	Mai	(44)	Chisel, hoe and triple disc coulters.	Confirmed smearing action by the triple disc design. The only effects on plant development were in high bulk density soils and with embryonic tap roots. Chisel design showed no smearing for all soils tested.

Wear on disc components is unlikely to affect these parameters. They are caused by the passage of angled disc faces whereas disc wear primarily affects the disc diameter.

When the wings of the chisel coulter are worn away, the remaining shank forms a seed groove not unlike that of the hoe coulter. Hence wear of this design is likely to affect groove smearing and compaction.

Hoe coulter compaction and smearing are likely to be affected by blade wear in the base region due to the eventual elimination of relief behind the leading point. This relief would be replaced instead by a sliding sole capable of smearing in this region.

SEED GROOVE TEMPERATURE.	Baker (7) Choudhary and Baker (20)	Chisel, hoe and triple disc coulters.	Maximum and minimum in-groove temperatures differed little between coulters and it was considered unlikely to have had any significant effect on seed germination and establishment.

It is likely that this parameter would be the least affected by wear on the coulters cited, since there were only minor temperature differences reported even with diverse unworn coulter shapes.

PLANT ROOT DEVELOPMENT.	Dixon (26)	Chisel, hoe and triple disc coulters.	Appeared that the chisel coulter gave higher top : root ratio than both other designs after 10 weeks growth. After 20 weeks, chisel sown plants showed greater rooting rather than top growth.
	Mai (44)	Chisel, hoe and triple disc coulters.	Effects of coulter shape on young lupin root development were distortion, reduced branching and flattening. It was difficult to segregate mechanical impedance to roots and root response to hydrotropic stimuli.

As a result of changes in compaction and smearing, it is likely that any change in blade shape is going to affect plant root development. Such changes are inevitable when the blades are worn. The triple disc design is likely to be the least affected in this respect, as wear is primarily confined to a reduction in disc diameter.

2.2.2 MECHANICAL FACTORS.

Some authors have compared coulters on more mechanical grounds.

In the same way that biological functions might be altered as a result of component wear, it is reasonable to expect mechanical functions to be similarly affected. As with the previous section, the literature contains few specific references to such interactions. The reported desirable mechanical features of different coulters are therefore summarised in Table 2, along with comments to focus attention on the likely relevance of wear in relation to mechanical functions of individual coulters.

TABLE 2.

MECHANICAL FACTORS DETERMINING GROOVE SHAPE.

CRITERIA.	AUTHOR.		COULTER DESIGN.	REPORTED COMMENTS.
COULTER PENETRATION.	Taylor	(68)	Triple disc and others.	Coulter penetration was often obtained by a "pull-in" effect, weight of the assembly and spring pressure. Suggested up to 68 kg per coulter was required by the triple disc design.
	Dixon Baker Mai Baker et al.	(26) (7) (44) (11)	Chisel, hoe and triple disc coulters.	Triple disc needed more downward force to obtain penetration compared to the early chisel and hoe coulters due to its wedging action with little relief from soil heaving. Latter designs gave sub-surface strain relief hence lower penetration forces. Redeveloped chisel coulter needed 125 kg per tool in dry silt loam, which was equal to the triple disc.

Wear on disc components primarily affects the disc diameter, and hence is likely to influence coulter penetration. As disc size is reduced, penetration force is correspondingly reduced.
Non-rolling components are likely to require increased penetration forces as the blade leading edges are worn in, and parabolic wear patterns increase the footprint area.

TRASH CLEARANCE.	Davies Taylor Blackmore	(23) (67) (15)	Hoe coulter.	Trash clearance and coulter penetration aided by addition of a preceding rolling disc component.

Wellings (76) Young (77)	"Disc and knife" coulter.	Appeared similar to the hoe coulter in design and biological performance but had wear and trash handling problems.
Jeater (37) Karonka (40) Lillard and Jones (43)	Triple disc coulter.	Design preferred as it overcame the main disadvantages of the disc and knife unit. Trash clearance took a high priority among design criteria listed.
Lillard and Jones (43) Jones <u>et al.</u> (38) Triplett <u>et al.</u> (71)	Various direct-drilling maize planters.	Some trash problems averted by using wavy discs or power driven rotary cultivators to carry out limited in-row cultivation.
Baker <u>et al.</u> (9) <u>Ibid.</u> (11)	Redeveloped chisel coulter.	Trash handling was cited as one of the most satisfactory design features to date. Continuous good performance was ensured by featuring components with self - adjusting properties.

Disc components are likely to have reduced trash clearing performance when diameter reduction is such that initial trash clearance tolerances for components are exceeded.

Non-rolling coulters are unlikely to alter greatly in performance as wear proceeds. Without associated disc components, trash clearance is generally poor to begin with, and this situation would remain as the blades are worn.

DRAUGHT.	Baker <u>et al.</u>	(11)	Redeveloped chisel plus triple disc coulters.	Chisel design created 2.2 times the draught of the triple disc. Hence the former was confined to drills pulled by tractors in the medium to large power range. Claimed that energy was put to good use in carrying out extensive sub - surface tillage in one machine pass.

Wear on the chisel coulter is known to reduce draught, since the blade wings (at an angle inclined to the direction of travel) generally wear away before other wear problems arise, and these wings cut substantial root material (Baker pers.comm. 1981). Draught on disc components is likely to be increased in a similar manner to increases in rolling resistance reported for small wheels (Baker pers. comm. 1981).

DEPTH CONTROL.	Baker	(7)	Various modified conventional seed drills.	Prior to 1969 units lacked strength for direct drilling and had limited vertical coulter movement.
	Baker <u>et al.</u>	(11)	Redeveloped chisel coulter.	Re-design shifted depth control to behind the zone of coulter action and closer to the seed zone. Sowing depth was improved, especially with parallelogram drag - arms.

Depth control is likely to be unaffected by chisel coulter wear, since independent press wheels carry out this function.

2.3 INTERACTIONS BETWEEN COULTER DESIGN AND WEAR.

2.3.1 NON-ROLLING COULTER COMPONENTS.

There appears to be only limited data available pertaining to effects on seed groove shape due to wear on non-rolling coulter components.

Baker and Badger (10) reported that non-rolling coulter shanks were subjected to considerable wear at the pressure point of ground entry. In tests to compare wear resistant materials on a chisel coulter, horizontal shank wings were often worn away completely so that the coulter resembled a suffolk or knife coulter. The worn tool produced a "U" shaped seed groove not unlike that of a hoe coulter in configuration. Using percentage weight loss per hectare for soil engaging portions, only a weak relationship was established between hardness values of the construction or treatment materials and wear rates.

In a later paper, Baker <u>et al.</u> (11) commented that components that were operating in close contact with one another needed to be free from close working tolerances, and if possible, self-adjusting. Wear had to be minimised, and components had to be simple, inexpensive and easily removed for replacement.

Baker and Badger (10) commented that the high wear rate on chisel coulter shanks was partly due to their being non-rolling devices and partly due to the relatively large penetration force (up to 1.25 kN) required to reach sowing depths in some untilled soils. Between the extremes of the original seed groove shape (starting with an inverted "T") and the possible "U" shape as outlined above, these authors assumed that there was a range of tolerance beyond which further wear was undesirable. No attempt was made by the authors to quantify this tolerance. Thus an arbitrary wear limit was imposed which corresponded to the reduction of overall length of coulter wings at the widest point to 50% of original dimensions. In an effort to maintain profiles of coulters during wear, they were selectively hardfaced on faces of maximum wear. This was on the underside of the leading edge of the shanks and the lateral wings.

Wear of treatments behind tractor wheels appeared similar to that outside the wheel widths (Baker and Badger 10). Wheel marks were expected to provide a more consolidated and hence more wear-promoting soil medium. However, in well structured and settled soil, common under undisturbed pasture, effects of external compaction were minimal. The authors commented that in many conditions the draught of the drilling machine was sufficient to provide some wheel slip with the effect that the track area was, in fact, often disturbed and loosened rather than compacted.

2.3.2 ROLLING COULTER COMPONENTS.

There appears to be virtually no reported data regarding the effects on groove shape from wear of rolling coulter components in direct drilling.

Baker et al. (11) observed that wear on the plain faces of otherwise scalloped disc components of an improved chisel coulter assembly appeared to be negligible if the discs were of a more wear resistant material than the non-rolling shank components. Certainly there were occasions when the special scalloping of the disc had worn to a point where disc traction was insufficient to maintain trash cutting performance of this design, but at the same time, wear on the flat faces had been barely discernable (C.J. Baker pers.comm. 1981).

As far as other rolling coulter designs are concerned, it appears that wear of individual components has had only a low priority during coulter development, although Karonka (40) rated this factor highly in his list of desirable design criteria.

2.4 FACTORS INFLUENCING WEAR OF SOIL ENGAGING TOOLS.

2.4.1 GENERAL

Friction and wear are not inherent material properties. They are the result of the particular characteristics of the engineering system(s) employed. Hurricks (36) considered that large changes in the wear rate on one surface, or on both surfaces that were contacting, may have been caused by any change in particle loading, speed or environmental conditions. Thus care must be taken when prescribing general solutions for specific problems.

2.4.1.1 WEAR CLASSIFICATION.

Wear processes in agricultural machinery were classed as those of adhesion, abrasion, fatigue, corrosion and erosion (Hurricks loc cit., Krushchov 41).

1. Adhesive wear, or severe wear, was a process involving surfaces mechanically adhering. This was

identified by material displacement from those surfaces, which could result in debris in a loose form (Hurricks 36, Rigney and Glaeser 59).

2. Abrasive wear involved penetration and ploughing out of material from a surface by another body. This body could be a free abrasive grit particle (Hurricks loc cit.).

3. Fatigue, in strict terms, is the tendency for materials to fracture under cyclic stresses (Van Vlack 74). As a wear category presented by Hurricks (loc cit.), this term apparently implied fracture through non-cyclic stresses as well. Fatigue was the result of localised microstructural movements that lead to crack propagation. This fracture may have been brittle, (that is, in the absence of significant ductility) or it may have been ductile, where crack propagation was accompanied by plastic deformation (Van Vlack loc cit.).

4. Corrosion was defined as the deterioration and removal of material by chemical attack (Van Vlack loc cit.).

5. Erosion was the impact of loose abrasive particles upon a body (Rigney and Glaeser loc cit.).

Abrasive wear can be further classified into three types (Sare 61, Rigney and Glaeser loc cit.):

1. Gouging abrasion; typified by macroscopic penetration of the working surface by coarse abrasive particles.

2. High stress grinding abrasion, where abrasive

particles were crushed under the grinding influence of moving surfaces. This class was often labelled as three body abrasion. Abrasive particles may have been internally generated or from an external source.

3. Low stress scratching abrasion, where stresses were only sufficient to cause microscopic penetration of the working surface without crushing the abrasive.

Abrasive particles are likely to be moving in an agricultural situation. It is apparent that such factors as soil dynamics, coulter configuration, speed of operation and metallurgical properties of materials used must be reviewed if improving the functional life of tillage tools is to be contemplated.

2.4.2 DYNAMICS OF SOIL FLOW OVER SOIL ENGAGING IMPLEMENTS.

2.4.2.1 GENERAL.

Bainer et al. (6) cited Clyde regarding subdivision of soil reactions: Useful soil forces were those that the soil tool had to overcome to carry out the cultivation process, such as those that involved cutting, breaking and moving the soil mass. Parasitic soil forces were those that acted on stabilising surfaces such as landsides, soles and supporting wheels on ploughs. They included friction and rolling resistance.

This division is the basis of the primary format of this review. Factors affecting soil flow are further classified into those due to implement passage and those due to soil condition. It must be stressed however, that these factors seldom operate in isolation - interactions may be considerable and effects of a specific factor may be inseparable from several others.

2.4.2.2 SOIL EFFECTS ON SOIL FLOW.

2.4.2.2.1 GENERAL.

It had been assumed in soil mechanics theory (Terzahgi 69) that when soil was subjected to compressive or tensile stresses, it failed along definite surfaces of slip. Inclination of these surfaces to the principle stresses was defined by the properties of a soil. In experiments to evaluate whether agricultural soils failed in a comparable regular pattern for shallow depths and small loadings on cultivation implements (compared with upheaval of foundations and failing loads), Payne (52) found that cultivated soils could, within limits, be treated as engineering materials. It should be noted that these were all cultivated soils, thus it would seem unlikely that the above situation would be the same in more "biological" uncultivated soils where root binding might be expected to account for much of the draught force involved.

2.4.2.2.2 USEFUL SOIL EFFECTS.

Some of the interactions between soil properties and particle displacement are summarised in Table 3.

TABLE 3.

INTERACTIONS BETWEEN SOIL PROPERTIES AND SOIL MOVEMENT.

SOIL PROPERTY.	AUTHOR.	REPORTED COMMENTS.
TEXTURE.	Sineokov (63)	Friction coefficients increased with clay particle content. Attributed to forces of molecular attraction between soil and steel.
STRUCTURE.	Sineokov (loc cit.)	Soils without structure had more cohesion than structured soils.
MOISTURE.	Stafford (64)	Two distinct failure regimes: Low moisture: Soil failed as a brittle material along a surface of maximum stress extended in the direction of travel from tine tip to soil surface in a semi-ovoid shape. High moisture: Volume of soil ahead of tines flowed plastically without a "main" failure surface. Transition occurred at around the plastic limit.
	Dalliene (22) Sineokov (loc cit.)	Adhesion increased with moisture until soil water lubricated particles involved.
SHEARING RESISTANCE.	Nichols, cited by Bainer et al. (6)	In plastic soils, shear force at a given pressure increased with moisture content up to the plastic limit and decreased to zero at the liquid limit. In non-plastic soils, shear force was essentially constant for all moisture levels.

COHESION AND FRICTION.	Sineokov	(63)	With small tine working angles: In moist, soddy loam soil: furrow slice formed essentially as a continuous strip without furrow expansion. In slightly cohesive sandy soil: failure led to formation of prismatic lumps. In loamy soils: tine penetration resulted in crack propagation to form "chips" of soil. This and the former soil both showed slice expansion. In dry cohesive soil: individual lumps of irregular shape formed. No furrow slice.
COMPACTION RESISTANCE.	Mai	(44)	Compaction depended on mineral and mechanical compositions and internal consolidation. External soil compression affected soil air, temperature, strength, stresses and implement draught. Drying increased soil strength which in turn increased soil resistance to flow.
	Dransfield	(27)	Draught increase with working depth and speed of vertical tines, was greater for more compacted soils.
	Dexter et al.	(25)	Draught due to soil flow around tool edges varied with depth, cohesion and a parameter that appeared to reflect soil compressibility.

2.4.2.2.3 PARASITIC SOIL EFFECTS.

Undesirable soil effects on flow are less obvious than useful effects. Perhaps the only distinct parameter would be plastic flow of soil since this was reported (Dalliene 22) as reducing the effects of shock and cracking under the influence of a passing tine. However, this same state of soil enabled disc tools or powered implements to be more effective in their division and shearing actions on the soil (Dalliene <u>loc cit.</u>). Thus plasticity would effectively be useful in this situation.

2.4.2.3 IMPLEMENT EFFECTS ON SOIL FLOW.

2.4.2.3.1 GENERAL.

Soil-blade friction, although an interface, is included in this section as, in contrast to purely soil influences, there is a measure of control exerted by both the designer and operator over this parameter just as for other aspects in this section.

2.4.2.3.2 USEFUL IMPLEMENT EFFECTS.

Many of the reported interactions between implements and particle displacement are summarised in Table 4.

TABLE 4.

INTERACTIONS BETWEEN IMPLEMENTS AND SOIL MOVEMENT.

IMPLEMENT PROPERTY.	AUTHOR.	REPORTED COMMENTS.
DISPLACEMENT.	Payne (52)	Confirmed that classical soil mechanics (Terzahgi 69) could be applied to dynamic implements. Reported the mechanisms of soil failure preceding flat vertical tines.
	Payne and Tanner (53) O'Callaghan and Farrelly (51) Godwin and Spoor (31)	Confirmed compacted soil wedge formed on leading face of tines.
	Sineokov (63)	Confirmed observations of soil failure for flat tines. Reported mechanisms for three edged (prismatic) tines as for flat tines.
SPEED.	Dransfield (27)	Draught little affected by up to 8 km/hr in loose soils. In compacted soils, draught increased 16-25% per km/hr.
	Payne loc cit.	Draught increased 20-30% within the speed range 0.2-2.7 m/s.
	Stafford (64)	Draught / speed in most published results approximates a square law for narrow tines.
	Wismer, cited by Stafford loc cit.	Draught / speed varied as a power law: In saturated clay soil, draught tended to an asymptotic value at high speeds.
	Dalliene (22)	Usually more speed gave more soil fragmentation. Two exceptions: In clay soils, increased speed reduced soil / metal adhesion hence more lumps formed. In humid soils, increased speed crumbled the whole soil mass hence more lumps formed.

	Tanner	(66)	In soils with difficult scouring conditions, soil wedge and stationary tip cone became more and less clearly defined respectively when speed was increased.
	Stafford	(64)	Reported a speed - inclusive soil flow model for narrow and wide blades based on a model expounded by Hettiaratchi <u>et al.</u> (33).
ASPECT RATIO.	Godwin and Spoor	(31)	Ratio < 6: Soil preceding the wedge moved forwards and upwards. Distinct shear plane formed from the tine base (crescent failure). As the ratio increased: Crescent failure occurred to a critical depth. Below this, soil moved without forming a shear plane (lateral failure).
RAKE ANGLE.	Sineokov	(63)	Small angle: Continuous furrow slice formed on the tine face. Large angle: Furrow slice ceased to slide up the tine face and collected in front of it. Angle of transition depended on soil type.
	Payne and Tanner Tanner	(53) (66)	Rake angles in the range of 20-160°: cleavage patterns essentially similar to those around vertical tines. Rake angle affected the dimension of crescent failure and movements of the soil wedge. Draught was at least 5 times greater for 20° tines than for 160° tines.
SOIL / BLADE FRICTION.	Sineokov (63)		Dependent on: Magnitude of the force normal to the surface, soil mechanical composition and moisture, metal surface roughness, velocity of sliding, unit pressure plus others.

2.4.2.3.3 PARASITIC IMPLEMENT EFFECTS.

Within each of the tine aspects that affect soil flow, it is conceivable that a component of that influence, no matter how small, will be parasitic. The summation of these less desirable components would be evident as tine or implement wear. Thus wear will represent the "cost" incurred by obtaining a particular tilth with an implement.

On a plough, parasitic effects included friction of the landside, sole and support wheel(s) (Bainer et al. 6). For a tine with no supportive structure, these parasitic effects are not as obvious, however tines still wear so these effects are still real. It would be very difficult to separate purely parasitic tine effects from the influences that the soil exerts on implements. Hence mechanisms of wear are very complex, involving interactions between all aspects reviewed thus far.

2.4.3 SOIL PROPERTIES.

This section reviews soil aspects apart from those influencing particle dynamics that affect wear on soil engaging tools.

Average wear rate was of little significance when it depended mainly on the proportion of stones present in the soil (Richardson 57). This author stated that much information could be obtained from soil samples including any coarse fractions and from knowledge of soil condition and prospective uses. Quartz was the most important abrasive in agricultural soils. Silica, which made up a stiffening network in many plant structures, may also have been an important abrasive in plant materials. A mathematical model relating wear rates to soil particle dynamics was presented. The greater contribution from larger soil particles (such as stones) to wear may have been partly accounted for by the fact that they caused compaction and strengthening of the fine soil matrix when they were displaced by the cutting edge of a tool.

Richardson (57) further reported wear variations using several materials in different soils. Differences in wear resistance (equal to volume wear of a reference material divided by volume wear of a test material for an equal distance run) were almost four-fold in the trials cited. There was no current evidence that chemical effects, heating or moisture content of the soil had any direct importance over the range of conditions investigated.

2.4.4 TOOL SHAPE.

In a study on the movement of hemispheres embedded in a non-cohesive soil and disturbed by a moving tine, Studman and Field (65) reported the motion as basically geometrical in nature and dependent on the shape of the disturbed zone of soil and the position of the obstruction. This motion was relatively independent of velocity, mass and density of the obstruction over the ranges considered. The disturbed soil zone shape dictated a minimum diameter below which impacts did not occur. The authors concluded that if an implement were designed to produce soil flow ahead of and below cutting edges giving a large failed zone, then impact damage should be reduced.

Richardson (57) observed that as speciman thickness increased by a factor of three, parabolic wear edges became 25% more slender as measured by focal length / thickness. The author theorised that this relationship was due to the total wear path being the sum of the distance that a particle slid around a cutting edge plus the distance that the edge slid on the particle surface.

2.4.5 TOOL SPEED.

The effect on tines in the speed range 0.8-8.0 km. per hour (0.5-5.0 miles/hr) was to increase wear rate by about 20% and to alter wear distribution (Richardson 57).

Moore and McLees (48) measured speed effects on four hardfacing materials during wear in the range 2.0-7.0 m/sec. No increase in wear in the field situation was reported. An hypothesis was presented suggesting that since the bulk load on specimens (draught force) probably increased with speed, then either the load which was effective in wear did not increase and / or the sliding distance that was effective in wear was decreased. This may have happened if the mode of soil failure changed as speed was increased. Although there was no evidence of this phenomenon having occurred in visco-elastic (cohesive) soils, a change in the soil failure mode did occur in sandy soils as the rate of failure was increased.

Davies (24) commented that in laboratory experiments in loose sand, as speed was increased soil may have been more compacted thereby masking the true effect of speed on wear.

Dovlatyan (cited by Moore and McLees 48) suggested that wear on cultivator points decreased due to loosening of soil, reduction in loading and in contact time of the abrasive particles as speed was increased. This is in contrast to studies on deep working tines by Richardson (57) who suggested that an increase in wear with speed was due to soil being stronger at high strain rates. Deformation of the wearing material became more difficult at higher strain rates (Moore and McLees loc cit.). Khruschov and Babichev (42) and Richardson (58) considered that this may have affected wear at different speeds. Frictional heating has been suggested by the latter authors as likely to increase wear at speed.

As strain rate sensitivity increased, materials became more resistant to deformation (Moore and McLees 48). More importantly, the stress needed to initiate deformation was increased. The overall effect was that volume wear increased with speed. It appeared to the authors that the load due to soil inertial effects may have increased whilst the loading due to bulk deformation and penetration were decreased as speed increased within a certain range in cohesive soils. Loading effective in wear may have been independent of speed in that range. Similar effects may have occurred in other soils at higher rates of deformation and if so, could have accounted for insensitivity of wear rates to speed in the range investigated. It was also plausible that the sliding distance effective in wear decreased with increasing speed thus counteracting any effects due to increasing load. That sliding distance may have been reduced if stationary soil bodies were formed on the implement or if the soil failure mode changed.

2.4.6 METALLURGICAL PROPERTIES.

2.4.6.1 GENERAL.

Hurricks (36) stated that surface resistance against abrasive wear was primarily a function of "effective hardness" as a result of the destructive action of abrasive particles. Effective hardness depended on the strain hardening rate of the material under the conditions prevailing.

The material typically used for agricultural soil-working parts was a eutectoid (approximately 0.8% carbon) carbon steel or silico-manganese steel with a hardness around 500 kg/mm^2 (Richardson 57). At this hardness level, wear resistance was usually "reasonable" and notched tensile strength and fatigue strength were maximised. When impact and other conditions (such as thickness) permitted, chilled iron was used. High hardness materials or surface treatments were only commonly used when contact stresses were low, such as on plough mouldboards, and when frictional characteristics were important. Hardfacing alloys of the high carbon type were sometimes used, particularly for repair or reclamation. However, in many cases conditions involved high contact stresses and materials were relatively ineffective because matrix materials were not sufficiently strong, relative to soil quartz, with hardness averaging 1000-1140 kg/mm^2.

The following section is restricted to those aspects of metallurgy pertaining to treatments utilised in this study, see Section 3.7.

2.4.6.2 SURFACE TREATMENTS.

A wide range of surface treatments and coatings exists to produce a hardened surface layer on a softer but tougher base metal. These are in three broad categories (Rigney and Glaeser 59):

1. Hardening achieved by surface heat treatment, including flame and induction hardening.

2. Hardening achieved by a change in chemical composition near the surface, including carburising, carbonitriding, cyaniding, gas nitriding, ionitriding and nitriding.

3. Application of a different material on the surface by mechanical or other means, including hardfacing, ion implantation and laser heat treatment.

2.4.6.2.1 CARBONITRIDING.

The carbonitriding process was readily available in N.Z. at a relatively low cost (J.D. McGregor pers.comm. 1981), and was reported to have exhibited a hard, wear resistant case layer (Rigney and Glaeser 59).

Carbonitriding is a case hardening process in which carbon and alloy steels are held at an elevated temperature (typically 722-916°C) in a gaseous atmosphere from which they absorb carbon and nitrogen simultaneously. They are then cooled to room temperature at a rate that will produce desired case and core properties. Full hardness with less distortion can be achieved using oil quenching or gas quenching employing a protective atmosphere as the quenching medium (Rigney and Glaeser 59, Groves 32).

2.4.6.2.2 METALLIC DEPOSITS.

This category includes processes such as chromium plating, soft metal coatings, electroless nickel coatings, plasma spraying, metalliding, Chemical Vapour Deposition, manganese diffusion coatings and hardfacing overlays (Rigney and Glaeser 59).

2.4.6.2.2.1 HARDFACING OVERLAYS.

High wear rates may often be reduced by the use of hardfacing overlays applied by welding (Rigney and Glaeser 59, Gilder 30). Hardfacing materials comprised more than 150 different compositions to provide required combinations of hardness, resistance to shock, corrosion and heat, and other specific properties (Gilder loc cit.).

Selection of wear resistant materials for specific applications depended on true assessment of wear and impact conditions (Richardson 57). For hardfacing materials, base metal composition, availability of welding equipment and required smoothness of application also influenced the choice (Gilder *loc cit.*).

The pattern of overlaid material is also important. Tillage tool specimens showed little evidence of sliding damage to the base material between weld beads applied transverse to the direction of travel (Moore *et al.* 47). This was attributed to disruption of soil flow, probably by formation of stationary soil bodies on the speciman surface, resulting in shortening the abrasive particle contact distance. As weld bead spacing was increased, wear resistance decreased due to the reduced proportion of the tool surface covered by hardfacing material. Optimum spacing was between 12.5 and 16.5mm for transverse weld beads, with highest wear resistance in weak soils with low stone content.

2.4.6.2.2.2 CHROMIUM PLATING.

Commonly called "hard" chromium plating for engineering purposes, this process has been widely used on steel to provide a low friction, wear resistant surface (Rigney and Glaeser 59). Plate has usually been applied directly to the steel surface in contrast to an undercoating of copper or nickel used for decorative chromiun plating. Plate thickness has been in the range 25 to 625 microns. Hardness of the plate could not be accurately determined by the common hardness testers, such as Brinell and Rockwell, but it was estimated to be in the range 850 to 1040 Vickers Hardness. Hardness of the plating was temperature sensitive and began to decrease as temperature rose above approximately 230°C.

3 EXPERIMENTAL MATERIALS AND METHODS.

3.1 INTRODUCTION.

The Massey experimental direct drilling coulter assembly has been reported as biologically successful as a seed/fertiliser placement tool, utilising a non-rolling chisel coulter bisected vertically by a rolling disc component (Baker et al. 9, 11, Choudhary and Baker 20, 21, Mai 44). The vertical portion of the coulter blade, when new, lies at an angle of 9° to the disc allowing scouring and ease of passage for soil around the coulter shank. Sub-surface lateral wings at the base of the shank present a more abrupt angle to maximise soil shattering in a distinct sub-surface zone (Figure 1). As the inner face of the vertical shank becomes worn down, its angle increases up to 15° without any evident adverse effects on soil shattering. Beyond this angle however, a buildup of soil as a wedge on the side and in front of this portion of the blade during operation (with consequent reduction in scouring properties of the shank) leads to greater surface shattering than desired, thereby affecting moisture retention by the seed groove (Baker et al. 11).

The wear problem with the coulter unit is complicated as any fundamental changes to coulter geometry may alter biological functions, and tolerance limits in this respect are not clearly defined. Current cold-stamped mild steel coulter blades wear on the outer shank and lateral wing areas through soil abrasion, and are thought to wear on the inner shank due to metal to metal adhesion. Effective life of these blades is

Figure 1: The Massey University experimental chisel coulter in its operating position.

thought to be approximately 20 hectares (C.J. Baker pers. comm. 1981). By studying the components of coulter wear, it was hoped that improvements to the wear characteristics could be made within the constrictions outlined below.

3.2 CONSTRAINTS.

An investigation into factors affecting wear of this given direct drilling coulter is a complex proposition involving consideration of the following points:

1. The principle function of the chisel coulter is a biological one involving placement of seed and fertiliser into a desirable sub-surface micro-environment. Hence any alterations to assembly geometry must not detract from present reported performance.

2. At present the rolling disc component of the assembly is manufactured from steel which has both tensile strength and abrasion properties determined by the industry to economically meet agricultural requirements and allow for cutting scallops from the disc. Since the non-rolling coulter blades are mild steel, it is the softer blade that beds (wears) in against the disc and is, when worn, easy and inexpensive to replace. The disc itself, although replaceable, has a much slower rate of wear. This is partly due to its action in the soil and partly due to it being manufactured from spring steel.

3. To clear trash effectively the coulter blade is required to contact the plain portion of the disc along the full length of the leading edge of the former. Subsequent bedding-in of the blade appears desirable to exclude trash from between components (Baker et al. 9). The blade is held

against the disc by soil pressure in the lower shank region and by a self-adjusting pressure block at the upper shank region. This block distributes pressure throughout the leading edge of the blade to give more even wear along this edge.

4. Coulter blades have been previously hardfaced in various ways on wearing edges and faces. Treating both sides (or at least the inside) of the entire leading edge of the blade has shown that accurate grinding of this edge was necessary to retain a close relationship between the disc and the blade. This would introduce a much increased cost per unit manufactured. Leading edge treatment has also shown that eventual wear of the softer metal behind and below the hardfacing material can lead to the formation of a hook of hard metal in this area. This hook has presented problems with sub-surface trash clearance and subsequent seed and/or fertiliser delivery tube blockage.

5. It is possible that the current wing width might be wider than optimal to allow a margin for wear during operation. A more wear-resistant material should allow coulter wings to be manufactured closer to the optimum size for biological function, thereby reducing draught requirements. This situation may result in reduced soil-metal wear on wings and/or a smaller wear profile on the inner leading edge of the blade shank.

6. Any improvement to the existing lifespan of components must be expected to withstand the wide range of soil types and conditions that the drilling machine will be

operating in.

7. The drilling machine is at present in the pre-production prototype stage of development. Hence any wear rate improvements must be commercially viable and economically beneficial. This was regarded as one of the foremost constraints on this study.

3.3 INVESTIGATIVE APPROACHES.

It was felt that the wear problem could be approached from two viewpoints:

1. It would be possible to restrict the investigation to fundamental components of wear per. se.

2. The wear problem could be regarded and investigated as a strictly empirical one in which end results are determined with limited scope for identifying fundamental causes in detail.

Within the objectives and limitations outlined above, it was considered that the latter approach was more realistic in this situation.

Three experiments were designed to enable observation of wear mechanisms involved with the experimental chisel coulter assembly design. These were as listed below:

1. Experiment 1: Soil lubrication tests.

2. Experiment 2: Wear pattern tests.

3. Experiment 3: Wear rate tests.

A laboratory test (Experiment 1) was devised to establish whether soil particles were passing between the disc and coulter blades during implement operation. It was considered that if there was soil lubrication between these two components, the main study could include treatments that were harder than the disc material without risk of preferential wear on the more expensive disc. Prior to the setting up of Experiment 1, a pilot study was made to evaluate lateral soil pressure on the blade shank during operation. These results enabled field conditions to be more closely simulated in the laboratory.

A field test (Experiment 2) using a tractor-drawn three row testing rig was undertaken to observe the patterns of wear on both standard untreated and selectively treated coulter blades. This was considered to be necessary in order to determine what linear measurements would best describe the observed wear pattern and also to establish an initial weld bead pattern for subsequent modification.

The main field evaluations (Experiment 3) compared several selected hardening treatments of the blades operating on a prototype multiple row direct drilling machine.

3.4 PILOT TEST.

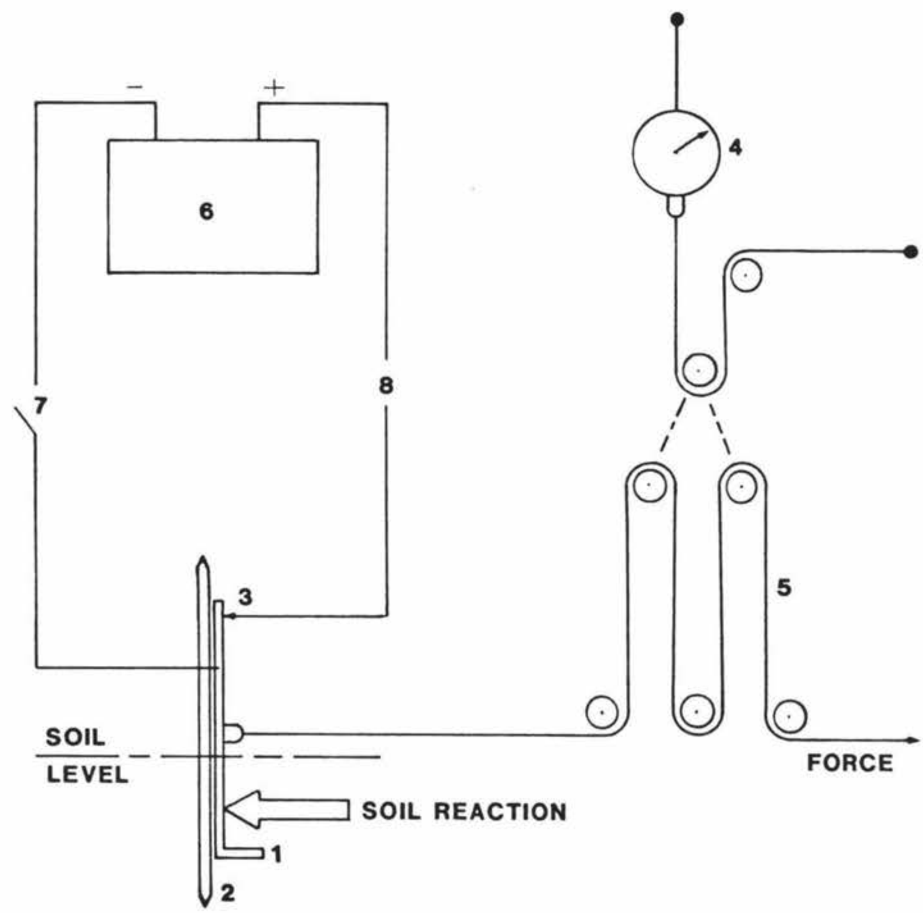
3.4.1 OBJECTIVE.

In order that the forces arising from field conditions could be simulated as nearly as possible during the laboratory test, it was necessary to determine the range of side forces exerted on the coulter shanks by a soil mass when the coulter assembly was in operation.

3.4.2 METHODOLOGY.

Measuring soil side thrust was achieved using a spring balance and pulley system mounted on a tractor-drawn three row test rig equipped with a chisel coulter assembly (Figures 2 to 4). The system was constructed in such a way that the leading edge of the rear-pivoted coulter blade was manually pulled out of contact with the disc using a pulley reduction. This action brought the blade into contact with an electrode, set in close proximity to the leading edge of the blade. An indicator light connected from this electrode to a battery power source thereby detected any slight outward movement of the blade. In operation, the side force required to move the blade away from the disc was applied on the move. This measurement was recorded for several speeds in the range 0.9-6.7 km/hr. and included measurements of static soil side thrust. The recorded force was thus taken as the force application against the blade. Disc-coulter electrical contact was re-established by allowing the disc several revolutions without any cable tension to clean the contacting portions prior to the next run.

Figure 2: Schematic representation of the spring balance and pulley system used to measure the lateral side force on coulter blades in field operation.



Legend
1 Coulter blade
2 Disc
3 Electrode
4 Scales
5 Pulley system
6 Battery
7 On/off switch
8 Indicator light

Figure 3: The electrode mounting showing the proximity to the coulter blade.

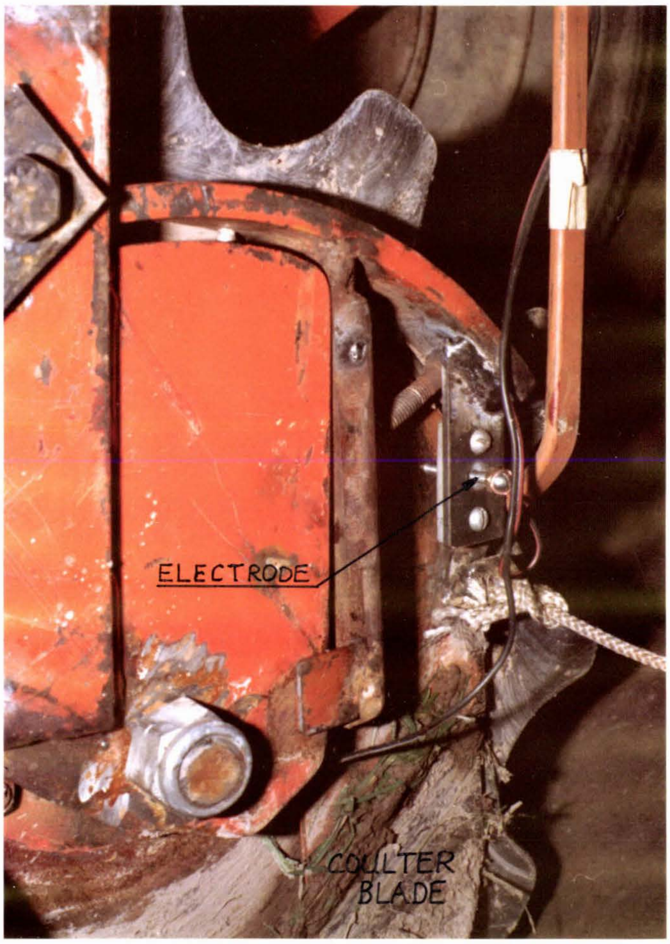


Figure 4: The single coulter assembly on the three row testing rig. The indicator light can be seen at the middle of the right hand side. The pulley reduction is not shown.

3.4.3 EXPERIMENTAL DESIGN.

Although this test was seqentially replicated five times for each operational speed, replication was not strictly randomised. The data were therefore not analysed statistically although means are listed together with their standard errors. This was felt to be adequate as the objective was to gain only a broad spectrum of side forces on the coulter wings which were likely to be incurred in the field.

3.4.4 RESULTS AND DISCUSSION.

Results of lateral soil force at varying speeds are presented in Table 5.

With a nominal sowing depth of 25mm., in a mixed ryegrass-white clover pasture, in a moist plastic silt loam soil and with standard mild steel coulter blades, the average lateral force measurements were essentially constant in the range 14.2-14.8 kg. force for all speeds up to 4.8 km/hr. At 6.7 km/hr., this force appeared to diminish slightly. Although this may have been a true effect, it could also have been the result of difficulty in obtaining accurate measurements because of contour and compaction variations.

TABLE 5.

LATERAL SIDE FORCE MEASUREMENTS ON A DIRECT DRILLING COULTER (KG.) - PILOT TEST.

Nominal Speed (km/hr.)	Replicate Readings 1	2	3	4	5	Average	Standard Error
0.00	6.6	6.4	6.0	6.0	6.4	6.2	0.08
0.92	13.6	14.0	14.6	14.2	14.0	14.2	0.15
1.29	14.8	14.4	14.6	15.2	14.8	14.8	0.21
1.78	14.8	13.6	14.4	15.2	14.0	14.4	0.40
2.50	13.2	13.6	14.4	14.2	15.2	14.2	0.60
3.52	14.4	15.6	15.2	14.4	14.8	14.8	0.28
4.84	14.8	14.4	14.0	15.0	15.2	14.6	0.24
6.68	11.0	11.6	12.8	14.4	13.6	12.6	1.96

3.5 EXPERIMENT 1. (SOIL LUBRICATION TEST.)

3.5.1 OBJECTIVE.

The objective of this test was to investigate possible soil lubrication between the disc and coulter blade components.

3.5.2 METHODOLOGY.

A stationary test rig was constructed to simulate as nearly as possible field operating conditions at the disc-coulter interface.

A complete coulter assembly was mounted in such a way that the leading edges of the coulter blades were almost horizontal, therby enabling free flowing soil to be introduced by gravity at an incident angle similar to that which would be experienced in uninterrupted forward travel in the field. Figure 5 shows the mounting of the coulter assembly. A plain disc was used in this test because the coulter blades contacted only the plain section of the standard scalloped disc.

A lateral soil pressure of 14.6 kg. force was simulated using a calibrated spring tensioner on the leading edge of the blade at the same sowing depth (25mm.) as was used in the pilot test (Figure 6). The soil pressure was assumed to be greatest at the soil surface/coulter blade leading edge interface, hence the tensioner applied that pressure at the nominal sowing depth.

The disc was driven by an A.C. motor with speed

Figure 5: The inclined coulter assembly with the soil return pipe (white).

Figure 6: The calibrated spring tensioner used to simulate the lateral soil pressure measured against the coulter blade in the Pilot Test.

variable in the range 100 to 800 rpm. This gave a theoretical ground speed range of 2.8 to 22.6 km/hr. Tests were carried out at an equivalent ground speed of 5 km/hr.

Recycling the abrasive soil medium was achieved using a collecting hopper below the assembly which was continually unloaded by an inclined auger feeding into a return pipe. The return pipe could be positioned such that soil was continually fed back to the soil engaging portion of the disc-coulter blade interface, thereby completing the cycle. Figure 7 shows the recycling system.

Two test soils were broken up, dried and pre-sieved throught 2 mm. mesh. Samples of the test soils were removed from the auger outlet at zero hours and quarter hourly up to one hour and then at five and ten hours running time. Samples were taken both with and without the disc revolving in order that any grinding influence which may have occurred at the disc-blade interface could be segregated from that caused by the auger itself. With the disc rotating, soil was introduced only to one side of the disc. This was to allow a comparison to be made with and without soil flow on a single disc for one soil type.

Samples taken were dry sieved to identify if soil degradation had occurred. Measurements were recorded of the weight of soil retained on sieves having apertures of 36, 200 and 300 microns after one minute of manual shaking.

Plastic and liquid limit tests were carried out on pre-test soil samples in accordance with N.Z.S. 4402P Part

Figure 7: The soil recycling hopper (red), return pipe (white), and variable speed motor (on the left).

1: 1976 "Methods Of Testing Soils For Civil Engineering Purposes". These results, in conjunction with the Unified Soil Classification System (Tuma 72), allowed the test soils to be identified, thereby giving some indication of soil physical engineering properties. This was considered necessary to enable the observed wear phenomena in this experiment to be discussed in terms of the soil physical properties attributed to the test abrasives. These results are summarised in Table 6.

Photographs (some at 12.5 times magnification) of the inner surface of the coulter blades and of the discs were taken prior to, during, and after operation.

3.5.3 EXPERIMENTAL DESIGN.

Degradation tests on the two sample soil types were not replicated as it was considered that 10 hours disc running time (equivalent to 50 km. linear drilling) would have been sufficient to allow any effects of abrasive particle breakdown to show up. Besides, the experiment was more concerned with whether or not soil breakdown had occurred than with the absolute extent to which the phenomenon might have been present.

TABLE 6.

IDENTIFICATIONS OF TEST SOILS FOR EXPERIMENT 1.

	SOIL 1.	SOIL 2.
Liquid Limit	33	Not Applicable
Plastic Limit	25	81
Plasticity Index	8	Not Applicable
Unified Soil Classification System Identification	ML	SW
Group Attributes	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands and slight plasticity.	Well graded sands, little or no fines.
Engineering Characteristics:		
-shear strength	High	Medium
-compressibility	Very slight	Medium
-permeability	High	Medium
-compaction	good	Good to poor, depending on density and drainage conditions.

3.6 EXPERIMENT 2. (WEAR PATTERN TESTS.)

3.6.1 OBJECTIVE.

The objective of Experiment 2 was to determine patterns of coulter wear.

3.6.2 METHODOLOGY.

A three row field test rig, which had independent hydraulics for macro depth control and a ground driven distance meter, was equipped with chisel coulter assemblies (Figure 8).

Three existing mild steel coulter blades (one left and two right) were used as controls. Three other mild steel coulter blades (two left and one right) were treated by hardfacing the outer leading edges of the shanks and the top of the leading edges of the lateral wings with arc applied Hardcraft 700* welding rod (Figures 9 and 10).

In the field, the machine was driven counterclockwise throughout this test to determine whether there was any shielding effect on the outer coulter blade of each pair caused by the disc during turning.

* Supplied by New Zealand Industrial Gases Ltd., Palmerston North.

Figure 8: The three row rig in field operation. The coulter assemblies have their press wheels removed to show the coulter blades in operation.

Figure 9: The existing mild steel blade used as a control in all experiments.

Figure 10: Typical hardfacing deposit over a mild steel coulter blade.

Blades were removed for measurements every 10 km. travelled, which was indicated by a calibrated meter. After washing the blades in soap and water, metal weight loss and linear dimensions were recorded. These parameters were selected to best depict observed patterns of wear. Figure 11 shows the linear dimensions used. These included measurements of the following regions: Length of inside wing; Rear wing to highest lateral point; Highest lateral width; Rear wing lateral width; Shank measurements taken parallel to the wing at 10mm. intervals up to 50mm. from the wing. Measurements were standardised by using a jig constructed to position a coulter blade accurately for measuring with vernier calipers, and is shown in Figures 12 and 13.

A sample of the field soil was taken to enable identification under the Unified Soil Classification System using calculations of plastic and liquid limit tests as per N.Z.S. 4402P (described in Section 3.5.2). These results are summarised in Table 7.

Closeup photographs were taken of controls and treatments before field work was undertaken. Several photographs were taken of the coulter blades during the initial hectare of work in order that regions of higher stress, evident as shiney areas where the protective anti-oxidisation coating was abraded away from the blade, could be recorded. Further photographs were taken of the wings and the inside edges at every measurement interval.

In this manner the progressive wear patterns on blades were recorded for visual analysis.

3.6.3 EXPERIMENTAL DESIGN.

The six coulter blades (one control and treatment replicated three times) were randomly positioned on the test machine.

A standard Genstat computer programme (see Appendix 9) was used to analyse metal weightloss and linear dimensional changes during blade operation. For each of these changes, comparisons were made between left and right hand blade positioning, coated and uncoated treatments, and lateral assembly and fore/aft blade positioning on the drilling machine.

Figure 11: Diagram showing the linear dimensions taken to describe the wear patterns of coulter blades.

A Inside wing length.
B Rear wing to highest lateral point length.
C Highest lateral point length.
D Rear wing lateral width.
E-I Shank lengths from 10 to 50mm. from the wing.

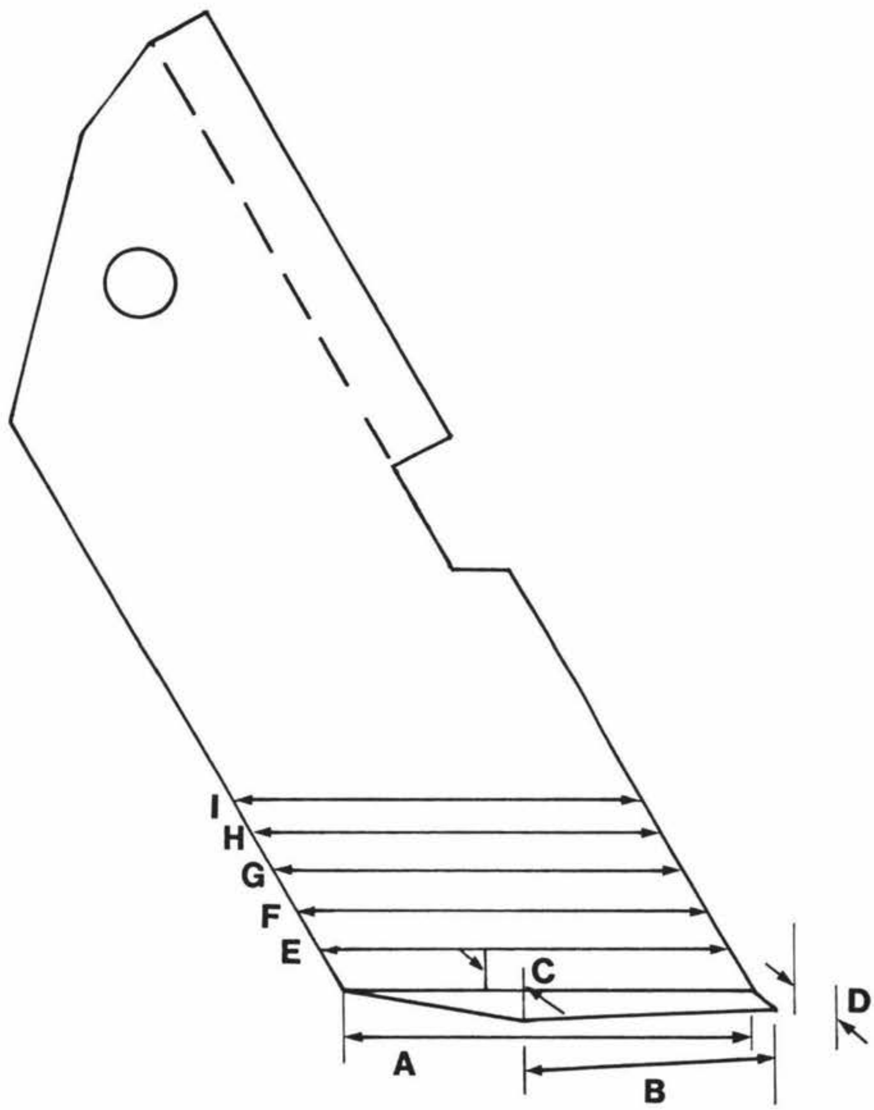


Figure 12: The measurement jig that was used for standardising coulter linear measurements.

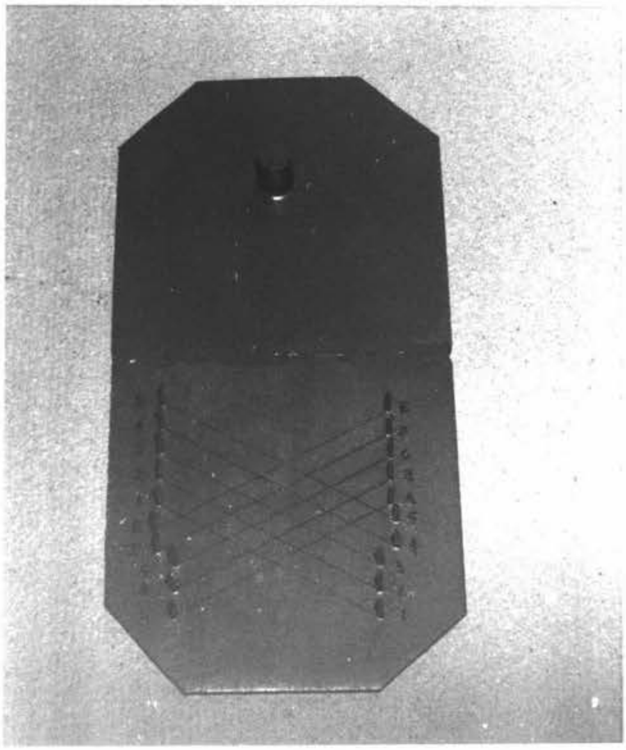
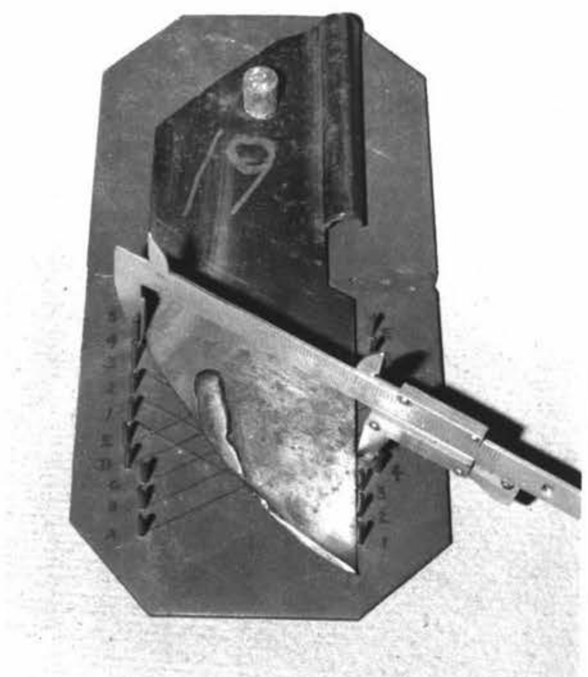


Figure 13: The use of vernier calipers to measure a blade dimension.



3.7 EXPERIMENT 3. (WEAR RATE TESTS.)

3.7.1 OBJECTIVE.

The aim of this test was to monitor wear resistance of selected hardening treatments with coulter blades operating in a normal fashion on a field drill.

3.7.2 METHODOLOGY.

Prototype chisel coulter assemblies on the Massey University prototype direct drill were equipped with a range of treated coulter blades. Treatments were selected within the constraints outlined earlier and from consideration of the technological alternatives listed in Table 8.

Because of the constraints listed in Table 8, surface treatment of existing mild steel blades appeared to be the most promising alternative for the present study.

Field observation of coulter blades in operation indicated that they encountered only minor, if any, impact conditions from stones. This was thought to be because of the small exposed frontal area of blades. Thus it seemed reasonable to place relatively minor importance on material toughness compared with hardness for abrasion resistance.

Weightloss measurements and dimensional measurements in this experiment were the same as those for Experiment 2. The drill was expected to operate in several different soil types during its routine seed-drilling operation in the Manawatu district. This might have been expected to

TABLE 7.

IDENTIFICATION OF THE FIELD SOIL FOR EXPERIMENT 2.

Locality	Walkers Road, Longburn, Manawatu, New Zealand.
Soil Science Classification	Karapoti brown sandy loam.
Testing Dates	17/8/81 to 21/8/81, 30/9/81 to 5/10/81.
Liquid Limit	37
Plastic Limit	31
Plasticity Index	6
Moisture content at test commencement	27.66%
Unified Soil Classification System Identification Group	ML
Group Attributes	Inorganic silts and very fine sands, rockflour, silty or clayey fine sands and slight plasticity.
Engineering Characteristics:	
-shear strength	High
-compressibility	Very slight
-permeability	High
-compaction	Good

TABLE 8.

ALTERNATIVE TECHNOLOGIES FOR ABRASION RESISTANCE.

1.	Surface treatments on existing mild steel blades.	Several hard surfacing, heat, case hardening and plating treatments were considered. The main advantages were retention of linear dimensions, ease of application and availability of materials and technical details.
2.	Alternative steels and alloys for blade fabrication.	There was no other plate available in N.Z. in a suitable thickness. Importation was prohibitively expensive. Even if available, many of the suitable steels would have posed fabrication problems because of their strength and hardness which might have required at least hot pressing and probably also special post-pressing treatment (D. Manning pers. comm. 1981).
3.	Cast irons for blade fabrication.	All materials investigated were considered to be too brittle when cast in thin sections (C. V. Dickinson, A. M. Smale pers. comms. 1981, Anon 2). The use of inserts could be a possibility in future, but these were not available for this study (D. Manning loc cit., A. M. Smale loc cit.) An exception may have been Nickel Spheroidal Graphite Iron (Ductile or Nodular iron) with suitable post-casting heat treatment to acquire desired wear properties, but this was not available for testing (C. V. Dickinson pers. comm. 1981, Anon 3).

4. Cast ceramic materials. These materials were considered to be too brittle when cast in thin sections. Investigations revealed the possibility of using inserts of ZAC 1681 Fusion Cast Alumina but samples of this became available too late to be included in this study (K. Harte pers. comm. 1981).

5. Polymers. Moulded "Lurethane" materials were considered to be too resilient to withstand the wear under pressure on the inner leading edge of the blade (R. Donald pers. comm. 1981).

confuse the wear resistance measurements taken during the several months the drill was in operation, especially since soil moisture conditions varied greatly in that time (see Appendix 1). However, an experimental design was chosen (see below) which obviated problems in this respect.

Treatment blades were considered to be worn out (and were discarded) when any of the following arbitrary conditions arose:

1. Inner lateral wing length was reduced to 30mm. or less.

2. Widest wing width was reduced to 10mm. or less.

3. Trash clearing ability was inhibited.

4. Where loss, damage or mechanical malfunction created other than "normal" operating conditions for any one blade.

Surface Treatments.

1. Surface heat treatments were excluded due to the low carbon content of the base steel (0.19%) which restricted the potential increases in hardness normally associated with steels having a carbon content closer to the eutectic composition (0.77%) (Van Vlack 74).

2. Techniques involving alteration to the chemical composition near the metal surface were restricted to the process of carbonitriding. This technology was readily available in N.Z. at a relatively low cost (J.D. McGregor pers. comm. 1981) and was reported to have exhibited a hard, wear resistant case (Rigney and Glaeser 59).

Boriding the blade surface was also considered. This process was reported as extremely successful in resisting abrasive wear (Von Matuschka 75) having hardness values between 1800 and 2100 kg/mm.^{2} (Anon. 1). The further advantage that blades could be selectively treated in the wing area (Anon. loc cit.) made this process appealing since it was not certain whether or not high hardness on the inner leading edge would alter the function of excluding trash effectively. Unfortunately however, the technology was not available locally (J.D. McGregor loc cit.) and became available overseas (K. Harte pers. comm. 1981) too late to be included in this study.

3. Surface deposition of wear resistant materials offered the widest choice of treatments within the hardfacing overlay category. Hardfacing materials were selected for anticipated maximum abrasion resistance for this situation.

Hard chromium plating was selected as one treatment because this process left a surface layer which was reportedly (Rigney and Glaeser 59) between 850 and 1040 Vickers Hardness. It was anticipated that this treatment would illustrate how critical coulter blade bedding-in was likely to be in effectively excluding trash, since the surface deposit on the inside against the disc was expected to have been harder than the disc surface. The hardness differential may also have caused the disc to wear preferentially, thereby effectively eliminating the treatment.

Two test runs were undertaken to enable the maximum number of alternative surface treatments to be evaluated.

3.7.3 TEST RUN A.

In the first test run, each hardfacing material was applied in two different weld patterns derived from results of Experiment 2 and discussed in Section 4.2. These patterns and the two control treatments are shown in Figures 14a to 14f.

All welding was carried out by a New Zealand Industrial Gases technologist, to maximise the skill available and reduce the variation in manually applied materials. It was also considered that this application would produce treatments as near as possible to those that an automated welder would produce if the process were to be commercialised in the future.

Treatment conditions for the first test run are outlined in Table 9.

3.7.4 TEST RUN B.

In the second test run, the top pattern was retained for each of three different treatments. This was because of the more desirable wear profile that this pattern had given the treated blades in Run A (compared with the under pattern). The pattern was modified slightly by curving the weld beads as shown in Figures 15a to 15c to better match the observed pattern of weld bead loss in the first run. Weld beads were applied as a wider deposit in this instance as it appeared from the first run that some promising

Figure 14a: Run A: Mild steel control blade.

Figure 14b: Run A: Carbonitrided mild steel blade.

Figure 14c: Run A: Toolcraft arc welded over mild steel -top pattern.

Figure 14d: Run A: Toolcraft arc welded over mild steel -bottom pattern.

Figure 14e: Run A: EutecBor gas welded over mild steel -top pattern.

Figure 14f: Run A: EutecBor gas welded over mild steel -bottom pattern.

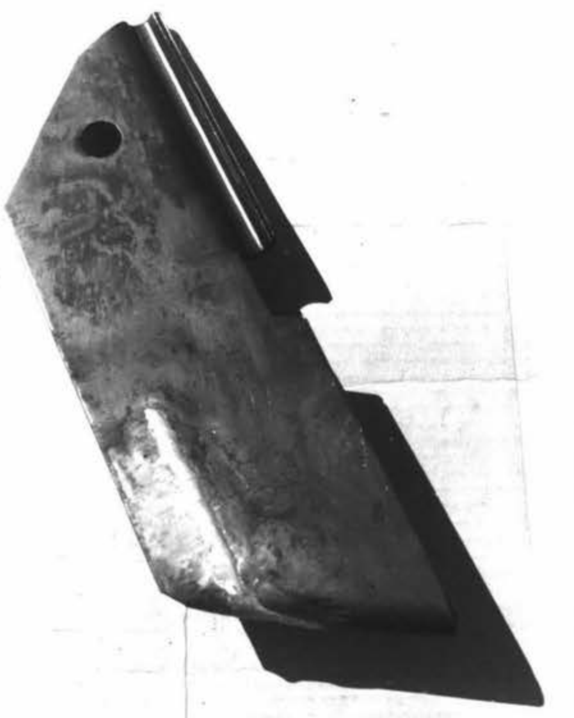


TABLE 9.

TREATMENT CONDITIONS FOR TEST RUN A.

REF	DESCIPTION	CONDITIONS
C1	Control: mild steel base plates. Composition (%): C 0.19 Si 0.15-0.55 Mn 0.5-1.4 P 0.04 S 0.035 Cu 0.2-0.5 Ni 0.5 Cr 0.3-0.6 Mo 0.04	Plates were cleaned before use.
C2	Control: carbonitrided mild steel plates.	Carbonitrided in an atmosphere seal quench furnace at 900°C for 2 hrs giving a claimed case depth of 0.51mm. Then oil quenched at 880°C and tempered at 180°C in a Forced Air Circulating Oven giving a final hardness of Rockwell C-60 (HV=700). The method gives a very hard surface to a depth of 0.51mm and a toughened core. Core not affected by this method. Certain conditions withheld by the processor for commercially protective reasons.
T1 and T2	*Toolcraft over mild steel plates. Claimed hardness: Rc=58-62 (=650-800 HV).	Plates were warmed with a gas torch to reduce stress build-up when applying a hard rod onto a softer basal material. Rods of 3.15mm diameter were applied with a D.C.arc welder at 90 amps. Plates then cooled slowly in a covered steel container to facilitate stress reduction in the finished component.
T3 and T4	*EutecBor over mild steel plates. Claimed hardness: Rc=55-62 (=620-800HV).	Rods of 3.15mm diameter were gas applied and then slowly cooled in a covered container as above.

* Supplied by New Zealand Industrial Gases Ltd.

Figure 15a: Run B: Eutalloy Tungtec gas welded over mild steel.

Figure 15b: Run B: Cobalarc arc welded over mild steel.

Figure 15c: Run B: Ultimium arc welded over mild steel.

Figure 15d: Run B: Chromium plated mild steel.

applications developed prematurely a trash-collecting hook of hardened material. This was due to the thinner weld bead eroding essentially parallel to the leading edges of blade wings. The initial breakthrough-point caused trash to collect because of differential wear of the bead and the softer base material adjacent to it.

Figure 15d shows the chromium plated treatment.

Treatment conditions for the second run are presented in Table 10. Controls 1 and 2 were retained from the first run.

3.7.5 HARDNESS TESTING AND PHOTOMICROGRAPHS.

All treatment materials used in both runs, as well as a sample of the disc component, were tested for hardness in the "as-applied" condition. Tests were carried out with the assistance of the Metallurgical Section, Department of Scientific and Industrial Research, Gracefield, New Zealand. A Leitz Miniload hardness tester was utilised to give Vickers Hardness values (HV) at 60, 200, 500, 1000 and 2000 microns (0.06, 0.2, 0.5, 1.0 and 2.0 mm.) from the weld or blade surface.

Readings taken at 60 microns were as near the surface hardness as could be obtained without distortion of the diamond indentation occurring. This would have resulted in inaccuracy of any measurements taken. These measurements were considered to be the surface hardness in the regression analysis and correlation coefficients calculated.

Micrographs were taken (at 88 times magnification) of

TABLE 10.

TREATMENT CONDITIONS FOR RUN B.

REF	DESCRIPTION	CONDITIONS
T5	*Tungtec 10112 over mild steel plates. Eutalloy powdered alloy with evenly distributed tungsten carbide particles in a nickel base matrix. Claimed hardness: Rc=57-64 (=650-850 HV).	Material was gas applied with a specialised eutectic gas torch.
T6	*Ultimium 112 over mild steel plates. Homogenous solid tungsten carbide. Claimed hardness: RC=65 (=900HV).	Plates pre-heated. Rods of 3.15mm. diameter were arc applied at 90 amps. D.C. Treated plates were cooled in an enclosed steel container to relieve residual stress.
T7	*Cobalarc 1A over mild steel plates. Chromium carbides (25%) in an austenitic matrix. Claimed general hardness: Rc=54 (=650-850 HV). Claimed carbide hardness: Rc=72 (=1400 HV).	Low hydrogen rods were D.C. arc applied as a buttering run under the hardfacing rod in order to reduce residual stress. Hardfacing rods were applied over this at 95 amps and plates were cooled slowly in an enclosed container.
T8	Hard Chromium plating over mild steel plates.	Plates were bead blasted in preparation for electroplating the leading edge and wing areas. Plating applied at 0.31 amps per sq.cm. Post-plating treatment involved stress relieving at 180°C for 4 hrs.

* Supplied by New Zealand Industrial Gases Ltd.

the cross-sectional structures of all treatments after etching the metal samples with Nitral (2% nitric acid in ethanol). This was carried out to enable observations to be made of the microstructural changes that had occurred during treating processes.

3.7.6 EXPERIMENTAL DESIGN.

The direct drilling machine had 2 sets of 6 coulter assemblies staggered fore and aft, each with a left and right hand coulter blade. Work by Baker and Badger (10), using a different version of the coulter concept, concluded that the tractor wheel tracks (in this case over the outer two seed rows on both sides of the drill) when planting on adjacent runs did not affect the wear rate of coulter blades in those regions. Results from Experiment 2 (Section 4.2) showed some consistant and significant differences between wear rates of blades on the left and right sides of the disc when continually cornering in the same direction. However, it was considered that all 24 positions on the drill could be utilised for these runs to enable a larger number of treatments to be evaluated in each run. Consequently, the experimental design that was used allowed left and right and front and back coulter wear patterns to be compared as a check.

Within a particular run, four blocks of six randomised treatments were used. Within each block, two control treatments were retained to enable comparisons to be made between Runs A and B. One control consisted of the existing mild steel plate (4mm. cold pressed) while the other control consisted of a carbonitrided plate that had performed well in the first run. This effectively provided a separate control at both the lower and upper ends of the scale of wear. The experimental layout is shown in Figures 16 and 17 for Runs A and B respectively.

The randomised block design was considered to be preferable to a latin square design because individual coulter blades could be replaced on the machine after sequential measurements. Even with several interim measurements, coulter blades were able to retain their individual bedded-in wear patterns against their respective disc components. In this way the effect of individual assembly geometry was expected to be reduced as a treatment variable.

Results were analysed using a standard Genstat programme (see Appendix 3) to reflect differences between treatments (coatings), fore and aft assembly geometry, lateral assembly geometry, and left and right side coulter blade positioning.

A further programme (see Appendix 11) graphed ordered treatment means against a normal score to enable differences between means to be seen. Graphs of residual sums of squares were also plotted. These enabled the differences between replicates within a treatment to be assessed.

A further programme (see Appendix 12) provided a regression analysis that fitted hardness, side and coating

COULTER No.	1 2 5 6	9 10	13 14 17 18	21 22	FRONT COULTERS
TREATMENT	C_1 T_1 C_2 T_3	T_3 C_2	T_4 T_3 T_2 C_1	T_3 C_2	
COULTER No.	3 4	7 8 11 12	15 16	19 20 23 24	REAR COULTERS
TREATMENT	T_2 T_4	C_1 T_2 T_1 T_4	C_2 T_1	T_4 C_1 T_2 T_1	

Legend
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

Figure 16: Experimental layout of individual coulters for Run A.

COULTER No.	1 2 5 6	9 10	13 14 17 18	21 22	FRONT COULTERS
TREATMENT	T_5 T_6 T_8 C_1	C_2 T_6	C_1 T_8 T_6 T_7	T_8 C_1	
COULTER No.	3 4	7 8 11 12	15 16	19 20 23 24	REAR COULTERS
TREATMENT	C_2 T_7	C_1 T_8 T_7 T_5	T_5 C_2	T_6 T_5 T_7 C_2	

Legend
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 17: Experimental layout of individual coulters for Run E.

effects to a metal weightloss model.

Correlation coefficients between metal weightloss and hardness were calculated for each measurement interval.

4 RESULTS AND DISCUSSION.

4.1 EXPERIMENT 1. (LABORATORY TEST.)

Weights of soil passing through 36, 200 and 300 mesh sieves for the two different test soils and for both "with" and "without" disc component rotation are presented in Tables 11 (Soil 1) and 12 (Soil 2).

In order to determine whether or not soil degradation had been occurring at the disc/blade interface, changes in the distribution of particle sizes were measured, as these were considered to be the most likely parameter affected.

Comparing "with" and "without" disc rotation data, the only consistant change in degradation was evident for Soil 2 (Table 12) where 36 mesh retention was reduced with time and that for 200 mesh increased with time. This observation implied that soil deformation, if present, had only occurred between the two sieves with larger apertures. Considering that Soil 1 initially had a higher percentage of larger particles compared with Soil 2, a similar difference in particle size distribution would have been expected for Soil 1. Although some differences did occur, these were by no means consistant. Thus the trends in Table 12 are open to some doubt.

Percentages of soil collected on the base plate (less than 300 mesh size) were reduced over time for each soil type. This was surprising as the presence or absence of grinding would have been expected to result in either an increase in fine particles, or at least no change. Perhaps the reason for the recorded loss of fine particles was drift, as considerable

TABLE 11.

EFFECTS OF DISC/BLADE "GRINDING" ON SOIL PARTICLE SIZE.

EXPERIMENT 1: SOIL 1.

TIME (HRS.)		NET % WEIGHT OF SOIL RETAINED (GRAMS) 36 MESH	200 MESH	300 MESH	BASE (<300 MESH)
0	Rotating*	50.3	34.5	11.2	4.0
0	Stationary*	49.3	33.1	14.2	3.4
0.25	Rotating	36.2	33.7	20.5	9.6
0.25	Stationary	27.6	43.9	22.3	6.2
0.50	Rotating	8.5	53.0	29.8	8.7
0.50	Stationary	15.6	55.5	23.3	5.6
0.75	Rotating	6.9	55.9	27.0	10.2
0.75	Stationary	6.1	64.1	26.2	3.6
1.0	Rotating	5.2	60.5	29.7	4.6
1.0	Stationary	12.4	55.9	26.3	5.4
5.0					
5.0	Stationary	14.3	73.4	12.0	0.3
10.0					
10.0	Stationary	15.3	77.5	6.9	0.3

* Disc component.

TABLE 12.

EFFECTS OF DISC/BLADE "GRINDING" ON SOIL PARTICLE SIZE.

EXPERIMENT 1: SOIL 2.

		NET % WEIGHT OF SOIL RETAINED (GRAMS)			
TIME (HRS.)		36 MESH	200 MESH	300 MESH	BASE (<300 MESH)
0	Rotating*	29.1	61.8	4.9	4.2
0	Stationary*	30.0	61.7	4.4	3.9
0.25	Rotating	11.2	64.9	9.3	14.6
0.25	Stationary	8.2	73.2	9.2	9.4
0.50	Rotating	5.4	67.6	11.4	15.6
0.50	Stationary	3.2	74.4	10.0	12.4
0.75	Rotating	2.3	70.6	12.2	14.9
0.75	Stationary	1.1	76.8	11.0	11.1
1.0	Rotating	1.3	74.9	11.6	12.2
1.0	Stationary	0.9	79.6	10.6	8.9
5.0					
5.0	Stationary	1.2	84.4	11.2	3.2
10.0					
10.0	Stationary	1.3	78.2	16.7	3.8

* Disc component.

dust accumulation was observed during machine operation.

From the above observations, there appeared to be no consistant evidence of a soil grinding effect at the disc/coulter shank interface. However, this did not rule out the possibility that soil particles may have passed between the disc and coulter blade without soil particle shattering occurring. Any soil which moved in this manner would have been considered to be a "lubricant" between the disc and the blade.

To clarify the existance of possible soil lubrication at the disc/blade interface, these components were scrutinised and photographed at the conclusion of 10 hours continuous operation (equivalent to 50 kilometers linear drilling). Figures 18 and 19 illustrate the differences in appearance between "soil" and "no soil" introduction (respectively) to the soil engaging portion of the coulter blade in apparent contact with the disc .

Where soil was present, the disc had clearly been abraded (as indicated by the polished and grey band formed by the rotation of the disc in close proximity to the coulter blade). In the absence of soil, the protective coating on the disc appeared to have been barely disturbed during machine operation.

For Soil 1 (silty soil), Figures 20 and 21 show the disc component on the "soil" and "no soil" faces respectively, while Figures 22 and 23 show the corresponding coulter blades. Figures 24 to 27 illustrate the same components for Soil 2

Figure 18: Soil introduction to that portion of the coulter blade/disc interface corresponding to the soil engaging portion in the field situation.

Figure 19: Although 10 hours continuous operation had elapsed, the metal surface of the blade had barely been disturbed where soil had been absent.

(sandy soil).

From the photographs, it seemed evident that both test soils had passed between the rotating disc and the coulter blade. In support of this conclusion, there had been a lower noise and heat level associated with the "soil" side.

Furthermore, the mode of metal wear differed, depending on whether soil was present or absent. Where there was no soil, the disc and coulter blade appeared blotchy and shiney and the surface texture was coarse. Since the blade was impinging directly onto the disc in this situation, the wear mechanism was likely to have been adhesive. Overall wear was much less than that on the soil side.

Where soil was present, components appeared to be evenly scratched, and an opaque grey colour. Without consistant evidence of soil degradation during disc operation, it appeared likely that the presiding wear mechanism had been low stress scratching abrasion.

Thus the possibility of soil "lubrication" between the disc and blades in normal field operation remained strong, thereby removing restrictions in terms of the hardness of coating materials relative to the disc used in subsequent tests (see Section 4.3).

Figure 20: Within the contact width, wear appeared to be predominantly low stress scratching abrasion where the soil had been present, shown by the grey ring area.

Figure 21: In the absence of soil, wear appeared to be adhesive within the contact width, as shown by the blotchey and shiney surface.

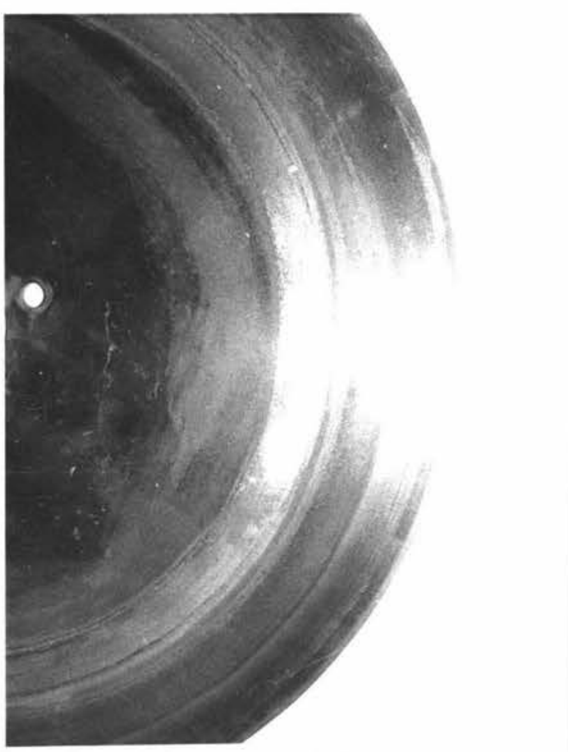


Figure 22: Soil 1: On the soil side, both wear mechanisms were evident throughout the length of the inner blade leading edge. The lower grey area corresponded to the soil contact zone, while the upper portion was not in soil contact.

Figure 23: Soil 1: In the absence of soil, the blade sustained a markedly reduced wear rate compared with the soil situation.

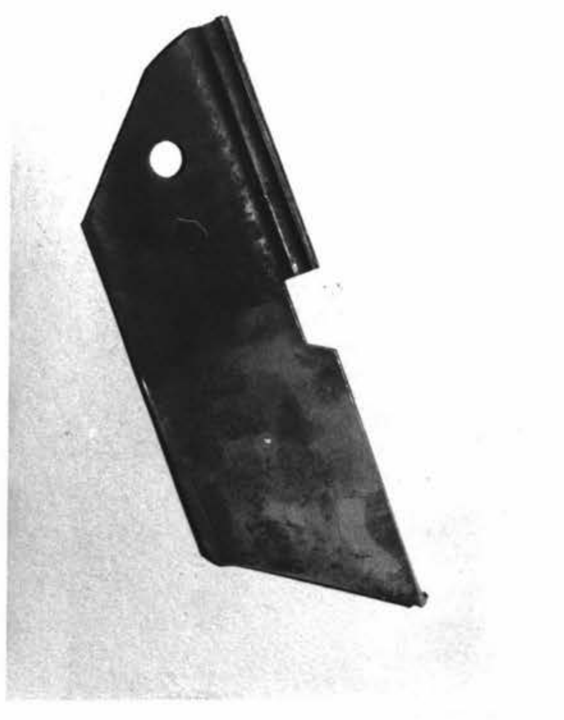


Figure 24: Soil 2: Where soil was present, the two regions of different wear were evident on the disc.

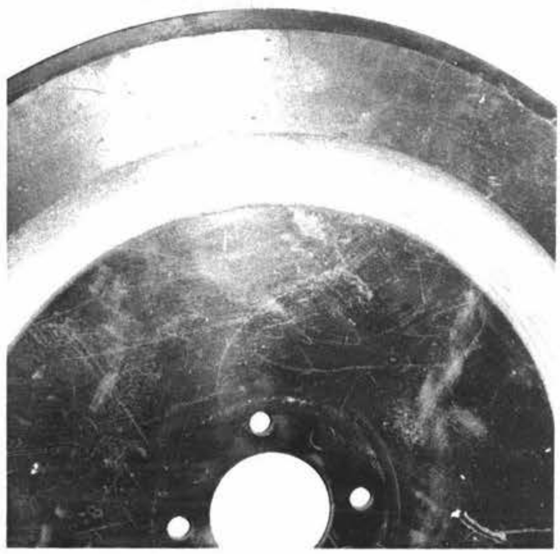


Figure 25: Soil 2: In the absence of soil, the disc surface was barely disturbed after 10 hours of continuous operating.

Figure 26: Soil 2: Where soil was present, the two regions of different wear were evident along the inner leading edge of the blade.

Figure 27: Soil 2: In the absence of soil, wear was markedly reduced compared to both the "soil" situation for Soil 2 and the "no soil" situation for Soil 1.

4.2 EXPERIMENT 2. (WEAR PATTERN TESTS.)

Raw data for Experiment 2 are contained in Appendices 1 and 2.

4.2.1 VARIATION IN METAL WEIGHTLOSS.

Differences in measured weightloss per hectare were expected to be attributable to the effects of surface coatings and physical positioning of the coulter blades on the drilling machine. The latter was determined in terms of left or right side with respect to the disc (labelled "side" effects), fore or aft positioning on short or long drag arms (labelled "position" effects), and the lateral position of coulter assemblies across the machine (labelled "assembly" effects). Table 13 summarises the sources of treatment variation up to 190 km. linear drilling (equivalent to 45.6 ha. drilling with a 2.4 m. width machine). Results throughout the remainder of this study are cited in relation to the distance travelled in kilometers (km.) and the equivalent hectareage (ha.) drilled by a 2.4 meter wide machine.

From these results, coating differences appeared to have been ineffectual, being significant only twice in 13 measurements, and then only in the early stages. Side differences exerted a significant influence on weightloss per hectare for about half the total functional life investigated. Again these differences tended to be most apparent early in the tests. No effects due to either

TABLE 13.

FACTORS INFLUENCING METAL WEIGHTLOSS PER HECTARE

OF A DIRECT DRILLING COULTER.

EXPERIMENT 2.

DISTANCE DRILLED (KM.)	COATING	SIDE	POSITION	ASSEMBLY
20	NS	NS	NS	NS
30	**	**	NS	NS
40	**	*	NS	NS
50	NS	**	NS	NS
60	NS	**	NS	NS
70	NS	**	NS	NS
80	NS	**	NS	NS
90	NS	NS	NS	NS
110	NS	NS	NS	NS
130	NS	NS	NS	NS
150	NS	NS	NS	NS
170	NS	NS	NS	NS
190	NS	NS	NS	NS

* Significant at the 1% level.
** Significant at the 5% level.
NS Not significant.

position or assembly differences were evident.

4.2.1.1 INFLUENCE OF COATINGS.

The mean metal weightloss data for welded and non-welded treatments are presented in Table 14.

While coating showed up statistically on only two (and perhaps three -at a lower order of probability) occasions in these data, the regions on the coulter blade from which the weightloss occurred appeared to be markedly affected by the application of a weld bead in the pattern previously described. This can be seen by comparing Figures 28c and 28f (pages 114 and 115 respectively) which show clearly that the welded coulter blade retained the desirable lower leading edge (and thence the wing) dimensions better than the standard, untreated blade at the completion of the test, even though these two blades recorded no significant differences in weightloss.

A large proportion of metal weightloss appeared to occur at the disc/coulter blade interface as seen in Figure 29. This phenomenon may have contributed to the insensitivity of weightloss measurements in reflecting coating differences, since this wear was likely to be unaffected by the presence of a weld bead on the outer shank, at least until the weld itself contacted the disc further on in blade life.

A further factor that may have contributed to insensitivity of metal weightloss recordings may have been the soil moisture content throughout the test

TABLE 14.

THE EFFECT OF DISTANCE ON MEAN METAL WEIGHTLOSS PER HECTARE (GRAMS) FROM A DIRECT DRILLING COULTER.

EXPERIMENT 2: COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	20	30	40	50	60	70	80
AREA DRILLED (HA.)	4.8	7.2	9.6	12.0	14.4	16.8	19.2
NO COATING	2.25	2.31	2.61	2.20	2.17	2.22	2.10
WELDED	2.83	3.08	3.15	2.65	2.57	2.59	2.45
L.S.D.	1.53	0.49	0.36	0.48	0.60	0.61	0.74
SIGNIFICANCE	NS	*	*	NS	NS	NS	NS

DISTANCE DRILLED (KM.)	90	110	130	150	170	190
AREA DRILLED (HA.)	21.6	26.4	31.2	36.0	40.8	45.6
NO COATING	2.02	1.81	1.63	1.60	1.50	1.41
WELDED	2.31	2.18	2.09	2.00	1.88	1.78
L.S.D.	0.78	1.03	1.36	1.41	1.41	1.41
SIGNIFICANCE	NS	NS	NS	NS	NS	NS

* Significant at the 5% level.
NS Not significant

Figure 29: The action of the disc on the inner leading edge of a coulter blade. Note the presence of a soil film on the lower soil-engaging portion of the blade when the soil was moist enough to adhere to the disc during operation.

period. Soil moisture deficit recordings (Appendix 1) suggested that the field soil was moistened and then dried during the test. When soil passed between the disc and coulter shank, it was likely that soil moisture may have been influencing the lubrication between soil particles and thereby exerted an effect on the abrasive wear in the coulter shank/disc region. A similar effect may have occurred at the wing/soil interface. However, due to the markedly reduced contact area of that region (compared to the shank/disc/soil interface), the magnitude of the effect was likely to have been similarly reduced. The net result of the above was likely to have been reflected in proportionally less wing (and hence coating) wear in relation to shank wear.

4.2.1.2 INFLUENCE OF SIDE POSITIONING.

Metal weightloss means for left and right side positioning of coulter blades are presented in Table 15.

The influence of side positioning on weightloss was significant at the 5% level of probability in six of the thirteen readings. In each case, the weightloss of the left hand coulters was less than that of the right (by an average of 31.6%). It should be noted, however, that in each of the other seven readings, although the differences were not significant, the trend for the left side to have recorded less weightloss than the right side may have continued. Since no seed or fertiliser was drilled in the test, it is difficult to visualise what might have accounted for these weightloss

TABLE 15.

THE EFFECT OF DISTANCE ON MEAN METAL WEIGHTLOSS PER HECTARE (GRAMS) FROM A DIRECT DRILLING COULTER.

EXPERIMENT 2: SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	20	30	40	50	60	70	80
AREA DRILLED (HA.)	4.8	7.2	9.6	12.0	14.4	16.8	19.2
LEFT SIDE	1.93	2.15	2.35	1.92	1.93	1.92	1.85
RIGHT SIDE	3.15	3.24	3.14	2.93	2.81	2.89	2.70
L.S.D.	1.62	0.52	0.38	0.51	0.64	0.64	0.79
SIGNIFICANCE	NS	*	*	*	*	*	*

DISTANCE DRILLED (KM.)	90	110	130	150	170	190
AREA DRILLED (HA.)	21.6	26.4	31.2	36.0	40.8	45.6
LEFT SIDE	1.78	1.62	1.50	1.46	1.38	1.31
RIGHT SIDE	2.55	2.38	2.22	2.13	2.00	1.88
L.S.D.	0.83	1.09	1.45	1.50	1.49	1.49
SIGNIFICANCE	NS	NS	NS	NS	NS	NS

* Significant.
NS Not Significant.

differences as a function of side positioning. Uni-directional machine turning on corners might have been expected to show a side difference. In this case, turning was always to the left hand side. Since there was insufficient data determine conclusively the influence that side positioning had exerted on metal weightloss from blades, this factor was included in Experiment 3 to enable further analyses to be made.

4.2.2 LOCATION OF PRINCIPLE REGIONS OF ABRASION.

Photographs taken in the early life of the coulter blades yielded some insight into the location and magnitude of soil forces acting upon the blades. In Figure 30, the polished areas (where the protective anti-oxidation coating had been worn away) indicated that soil reactions in those regions were higher than those where the coating had been left intact. The principle abraded area was the lower leading edge/wing intersection. Other areas (viz. the shank leading and trailing edges, the outer shank/wing intersection and the leading lower and trailing upper edges of the wing) were also abraded more than the remaining areas.

From these initial observations, it appeared that retention of the lower leading edge/wing corner was likely to be a major determinant of overall coulter life.

4.2.3 VARIATION IN LINEAR DIMENSIONS.

Sources of variation in linear dimensions are presented in Table 16.

Figure 30: After drilling 800 meters (0.19 ha.), regions that were subjected to greater soil stresses were visible as polished areas.

TABLE 16.

FACTORS INFLUENCING LINEAR DIMENSIONS OF A WEARING

DIRECT DRILLING COULTER.

EXPERIMENT 2.

DISTANCE DRILLED (KM.)	DIMENSION	COATING	SIDE	POSITION	ASSEMBLY
20.0	TAIL WING	*	*	*	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	NS	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	**	**	NS	NS
	SHANK -B	**	**	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	**	**	NS	NS
	SHANK -E	NS	NS	NS	NS
30.0	TAIL WING	NS	NS	NS	NS
	MID WING	NS	**	NS	NS
	REAR -MID	NS	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	**	NS	NS
	SHANK -D	**	*	NS	NS
	SHANK -E	NS	NS	NS	NS
40.0	TAIL WING	**	*	**	NS
	MID WING	NS	**	NS	NS
	REAR -MID	NS	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
50.0	TAIL WING	*	*	**	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	**	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS

60.0	TAIL WING	**	*	NS	NS
	MID WING	NS	**	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
70.0	TAIL WING	*	*	*	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	**	**	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	**	NS	NS
	SHANK -E	NS	NS	NS	NS
80.0	TAIL WING	*	*	NS	NS
	MID WING	**	**	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
90.0	TAIL WING	*	*	**	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	*	**	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	**	NS	NS
	SHANK -E	NS	NS	NS	NS
110.0	TAIL WING	*	*	NS	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS

130.0	TAIL WING	*	*	**	NS
	MID WING	NS	**	NS	NS
	REAR -MID	*	**	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
150.0	TAIL WING	**	**	NS	NS
	MID WING	**	**	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	**	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
170.0	TAIL WING	**	**	NS	NS
	MID WING	*	**	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	**	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS
190.0	TAIL WING	**	*	NS	NS
	MID WING	**	**	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	**	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	NS	NS	NS
	SHANK -E	NS	NS	NS	NS

* Significant at the 1% level.
** Significant at the 5% level.
NS Not significant.

Coating differences appeared to influence tail wing length measurements throughout blade life. The rear wing to highest lateral point lengths (Rear -mid) were affected in all but the three initial time intervals. All wing dimensions were affected by coatings in later blade life.

It appeared that side differences affected both tail wing and rear to mid length measurements throughout blade life.

A position effect on tail wing measurements may have been present in early coulter life. The data were not analysed further at this stage since the effect was relatively isolated. However, position was included as a possible source of variation in Experiment 3 so that any true effects due to position could be evaluated if necessary.

4.2.3.1 INFLUENCE OF COATINGS.

Mean linear dimensional data are contained in Tables 17 and 18 for wing and shank recordings respectively.

Tail wing width was significantly affected by coating differences in all but one measurement interval. From 50.0 km. (12 ha.), the rear to mid length remained significantly influenced until the completion of the test. In later coulter life, all wing measurements were significantly affected by coating differences.

In all instances where differences were significant, the welded treatment had resisted wear to a greater extent than the untreated control blades. The

TABLE 17.

MEAN LINEAR WING DIMENSIONS OF A WEARING DIRECT DRILLING COULTER (MM.) - EXPERIMENT 2.

COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREATMENT	TAIL WING	MID WING	REAR -MID	INNER WING
20.0	CONTROL	17.93	23.70	56.37	89.30
	WELDED	18.97	24.53	57.93	91.40
	L.S.D.	0.351	2.001	2.810	0.691
	SIG.	*	NS	NS	NS
30.0	CONTROL	17.60	23.13	54.17	88.57
	WELDED	18.97	24.37	56.97	91.00
	L.S.D.	1.962	1.756	4.006	8.176
	SIG.	NS	NS	NS	NS
40.0	CONTROL	17.50	22.80	52.77	88.07
	WELDED	18.90	24.33	56.30	90.67
	L.S.D.	0.745	1.764	4.639	7.061
	SIG.	*	NS	NS	NS
50.0	CONTROL	17.20	22.77	51.30	88.10
	WELDED	18.77	24.17	56.00	90.30
	L.S.D.	0.527	2.311	3.485	8.821
	SIG.	*	NS	*	NS
60.0	CONTROL	17.07	21.93	50.33	86.40
	WELDED	18.60	23.77	55.63	90.00
	L.S.D.	0.703	2.108	4.557	12.307
	SIG.	*	NS	*	NS
70.0	CONTROL	17.03	21.90	48.37	85.20
	WELDED	18.57	23.87	54.27	89.50
	L.S.D.	0.556	2.285	3.761	9.294
	SIG.	*	NS	*	NS
80.0	CONTROL	17.00	21.80	45.07	82.30
	WELDED	18.47	23.87	54.17	89.70
	L.S.D.	0.633	2.001	6.239	10.284
	SIG.	*	*	*	NS

90.0	CONTROL	17.03	21.73	43.20	82.30
	WELDED	18.37	23.63	53.93	89.00
	L.S.D.	0.248	2.139	2.496	11.661
	SIG.	*	NS	*	NS
110.0	CONTROL	17.13	21.50	42.70	80.00
	WELDED	18.33	23.57	53.10	88.30
	L.S.D.	0.393	2.289	6.089	12.737
	SIG.	*	NS	*	NS
130.0	CONTROL	17.10	21.40	41.93	78.30
	WELDED	18.23	23.27	52.03	87.50
	L.S.D.	0.248	2.108	3.606	12.737
	SIG.	*	NS	*	NS
150.0	CONTROL	17.00	20.83	39.67	74.90
	WELDED	18.30	23.23	51.80	86.90
	L.S.D.	0.724	1.730	5.129	9.725
	SIG.	*	*	*	*
170.0	CONTROL	17.00	20.87	37.70	72.70
	WELDED	18.30	23.03	51.20	86.40
	L.S.D.	0.724	0.878	8.649	9.983
	SIG.	*	*	*	*
190.0	CONTROL	16.47	20.67	36.13	71.63
	WELDED	18.30	23.10	50.10	85.10
	L.S.D.	0.703	1.123	4.871	7.474
	SIG.	*	*	*	*

* Significantly different at the 5% level.
NS Not significantly different.

TABLE 18.

EFFECT OF WEAR ON LINEAR SHANK DIMENSIONAL CHANGES OF A DIRECT DRILLING COULTER (MM.) - EXPERIMENT 2.

COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREAT-MENT	SHANK A	B	C	D	E
20.0	CONTROL	100.97	100.90	100.60	100.47	100.93
	WELDED	100.37	100.33	100.70	101.07	100.90
	L.S.D.	0.393	0.248	1.756	0.176	0.497
	SIG.	*	*	NS	*	NS
30.0	CONTROL	100.80	100.67	100.50	100.53	100.80
	WELDED	100.23	100.57	100.83	100.93	101.03
	L.S.D.	1.618	1.110	0.786	0.176	0.703
	SIG.	NS	NS	NS	*	NS
40.0	CONTROL	100.70	100.60	100.47	100.47	100.80
	WELDED	100.23	100.47	100.60	100.97	100.90
	L.S.D.	1.054	1.278	1.179	1.110	1.618
	SIG.	NS	NS	NS	NS	NS
50.0	CONTROL	100.50	100.60	100.43	100.57	100.67
	WELDED	100.00	100.33	100.60	100.93	100.93
	L.S.D.	0.994	1.764	0.878	1.231	1.579
	SIG.	NS	NS	NS	NS	NS
60.0	CONTROL	100.43	100.53	100.37	100.50	100.73
	WELDED	100.07	100.47	100.63	100.80	100.90
	L.S.D.	1.123	1.244	0.895	1.244	1.579
	SIG.	NS	NS	NS	NS	NS
70.0	CONTROL	100.43	100.53	100.37	100.47	100.80
	WELDED	100.10	100.33	100.60	100.77	100.93
	L.S.D.	0.947	1.054	1.054	0.527	1.153
	SIG.	NS	NS	NS	NS	NS
80.0	CONTROL	100.17	100.50	100.40	100.50	100.80
	WELDED	100.00	100.33	100.60	100.83	100.93
	L.S.D.	1.373	1.110	1.231	0.703	1.278
	SIG.	NS	NS	NS	NS	NS

90.0	CONTROL	100.17	100.33	100.33	100.57	100.80
	WELDED	99.97	100.27	100.43	100.77	100.90
	L.S.D.	1.902	1.730	1.579	0.703	1.338
	SIG.	NS	NS	NS	NS	NS
110.0	CONTROL	98.80	99.83	100.20	100.50	100.67
	WELDED	99.20	99.33	99.77	100.00	100.30
	L.S.D.	3.537	4.686	4.393	4.041	3.343
	SIG.	NS	NS	NS	NS	NS
130.0	CONTROL	97.67	99.47	100.13	100.40	100.70
	WELDED	98.83	99.00	99.57	99.70	99.90
	L.S.D.	4.583	4.337	4.596	5.142	5.271
	SIG.	NS	NS	NS	NS	NS
150.0	CONTROL	94.53	97.83	99.40	100.20	100.43
	WELDED	97.17	98.13	98.97	99.57	99.73
	L.S.D.	6.287	6.287	5.753	4.918	6.171
	SIG.	NS	NS	NS	NS	NS
170.0	CONTROL	93.07	97.17	99.23	100.17	100.43
	WELDED	96.63	97.60	98.70	99.30	99.53
	L.S.D.	6.777	6.536	6.063	5.271	6.872
	SIG.	NS	NS	NS	NS	NS
190.0	CONTROL	91.20	95.90	98.70	100.17	100.43
	WELDED	94.90	96.30	98.30	99.23	99.57
	L.S.D.	12.048	10.628	6.411	5.667	6.510
	SIG.	NS	NS	NS	NS	NS

* Significantly different at the 5% level.
NS Not significantly different.

tail wing length was not directly upheld by weld bead application, consequently wear was expected to be similar to that of the control blades. However, the significant differences that were recorded were likely to have been the result of the weld bead influencing soil flow in early coulter life, such that wear in the wing region was reduced.

In later blade life, significant differences for all wing measurements due to coatings were likely to have been due to the weld bead prolonging the measured dimensions as it was worn away, thereby creating a differential between welded and unwelded treatments.

Shank measurements were significantly infuenced by coatings in early blade life. In the lower shank area, the welded treatments were worn more, whereas in the upper shank area, the control treatments were more affected. The former result might be explained by the heat of welding having conferred an annealled (softened) leading edge to the coulter blades. There appeared to be no obvious explanation for the latter observation.

4.2.3.2 INFLUENCE OF SIDE POSITIONING.

Mean linear dimensional data are contained in Tables 19 and 20 for wing and shank recordings respectively.

Tail wing measurements were significantly influenced by side positioning on 12 out of 13 occasions. Highest lateral point lengths (mid wing)

TABLE 19.

EFFECT OF WEAR ON LINEAR WING DIMENSIONAL CHANGES OF A DIRECT DRILLING COULTER (MM.) - EXPERIMENT 2.

SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	TAIL WING	MID WING	REAR -MID	INNER WING
20.0	LEFT	19.40	25.14	57.70	92.07
	RIGHT	17.50	23.09	56.60	88.62
	L.S.D.	0.373	2.126	2.982	7.096
	SIG.	*	NS	NS	NS
30.0	LEFT	19.25	24.42	56.02	90.92
	RIGHT	17.32	22.57	55.12	88.65
	L.S.D.	2.083	1.863	4.247	8.671
	SIG.	NS	*	NS	NS
40.0	LEFT	19.18	24.70	55.00	90.34
	RIGHT	17.23	22.43	54.07	88.39
	L.S.D.	0.790	1.872	4.918	7.492
	SIG.	*	*	NS	NS
50.0	LEFT	18.95	24.48	54.92	90.10
	RIGHT	17.02	22.45	52.37	88.40
	L.S.D.	0.559	2.453	3.701	9.338
	SIG.	*	NS	NS	NS
60.0	LEFT	18.86	24.02	54.22	88.50
	RIGHT	16.81	21.67	51.75	87.90
	L.S.D.	0.745	2.238	4.832	13.038
	SIG.	*	*	NS	NS
70.0	LEFT	18.83	23.92	53.79	87.50
	RIGHT	16.78	21.85	48.84	87.20
	L.S.D.	0.589	2.423	3.989	9.897
	SIG.	*	NS	*	NS
80.0	LEFT	18.70	23.91	52.43	86.80
	RIGHT	16.77	21.76	46.80	85.20
	L.S.D.	0.672	2.126	6.618	10.887
	SIG.	*	*	NS	NS

90.0	LEFT	18.58	23.73	50.64	86.50
	RIGHT	16.83	21.63	46.49	84.80
	L.S.D.	0.263	2.268	2.646	12.393
	SIG.	*	NS	*	NS
110.0	LEFT	18.60	23.61	49.62	85.70
	RIGHT	16.87	21.46	46.17	82.60
	L.S.D.	0.417	2.431	6.459	13.511
	SIG.	*	NS	NS	NS
130.0	LEFT	18.54	23.48	49.12	83.80
	RIGHT	16.79	21.18	44.85	82.00
	L.S.D.	0.263	2.250	3.821	13.511
	SIG.	*	*	*	NS
150.0	LEFT	18.51	23.12	47.92	82.00
	RIGHT	16.79	20.95	43.55	79.70
	L.S.D.	0.768	1.833	5.443	10.327
	SIG.	*	*	NS	NS
170.0	LEFT	18.51	22.99	46.30	80.90
	RIGHT	16.79	20.91	42.70	78.20
	L.S.D.	0.768	0.934	9.165	10.585
	SIG.	*	*	NS	NS
190.0	LEFT	18.51	22.95	45.35	80.12
	RIGHT	16.76	20.82	40.88	76.62
	L.S.D.	0.745	1.192	5.168	7.926
	SIG.	*	*	NS	NS

* Significantly different at the 5% level.
NS Not significantly different.

TABLE 20.

MEAN LINEAR SHANK DIMENSIONS OF A DIRECT DRILLING COULTER (MM.) - EXPERIMENT 2.

SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	SHANK A	B	C	D	E
20.0	LEFT	100.33	100.74	101.10	100.95	100.94
	RIGHT	101.00	100.49	100.20	100.58	100.89
	L.S.D.	0.417	0.263	1.863	0.186	0.527
	SIG.	*	*	NS	*	NS
30.0	LEFT	100.23	100.92	101.24	101.15	101.12
	RIGHT	100.80	100.32	100.09	100.32	100.72
	L.S.D.	1.717	1.179	0.833	0.186	0.745
	SIG.	NS	NS	*	*	NS
40.0	LEFT	100.22	100.67	101.07	101.17	101.19
	RIGHT	100.72	100.40	100.00	100.27	100.51
	L.S.D.	1.119	1.355	1.248	1.179	1.717
	SIG.	NS	NS	NS	NS	NS
50.0	LEFT	99.95	100.48	101.03	101.26	101.09
	RIGHT	100.55	100.45	100.00	100.24	100.51
	L.S.D.	1.054	1.872	0.934	1.304	1.678
	SIG.	NS	NS	*	NS	NS
60.0	LEFT	99.89	100.55	100.97	101.02	101.10
	RIGHT	100.61	100.45	100.02	100.27	100.53
	L.S.D.	1.192	1.317	0.951	1.317	1.678
	SIG.	NS	NS	NS	NS	NS
70.0	LEFT	99.88	100.43	100.91	100.95	101.10
	RIGHT	100.65	100.43	100.06	100.28	100.63
	L.S.D.	1.003	1.119	1.119	0.559	1.304
	SIG.	NS	NS	NS	*	NS
80.0	LEFT	99.72	100.39	100.91	101.02	101.10
	RIGHT	100.45	100.44	100.09	100.32	100.63
	L.S.D.	1.454	1.179	1.304	0.745	1.355
	SIG.	NS	NS	NS	NS	NS

90.0	LEFT	99.73	100.24	100.72	101.04	101.00
	RIGHT	100.40	100.36	100.05	100.29	100.70
	L.S.D.	2.014	1.833	1.678	0.745	1.420
	SIG.	NS	NS	NS	*	NS
110.0	LEFT	99.04	99.43	100.16	100.21	100.46
	RIGHT	98.96	99.73	99.81	100.29	100.51
	L.S.D.	3.748	4.970	4.660	4.286	3.546
	SIG.	NS	NS	NS	NS	NS
130.0	LEFT	98.72	99.36	100.09	100.01	100.19
	RIGHT	97.77	99.11	99.61	100.09	100.41
	L.S.D.	4.858	4.600	4.875	5.456	5.594
	SIG.	NS	NS	NS	NS	NS
150.0	LEFT	97.25	98.66	99.85	99.98	100.08
	RIGHT	94.45	97.31	98.52	99.78	100.08
	L.S.D.	6.665	6.665	6.102	5.215	6.545
	SIG.	NS	NS	NS	NS	NS
170.0	LEFT	96.56	98.37	99.74	99.90	99.91
	RIGHT	93.14	96.40	98.19	99.57	100.06
	L.S.D.	7.190	6.932	6.433	5.594	7.289
	SIG.	NS	NS	NS	NS	NS
190.0	LEFT	94.10	97.00	99.47	99.87	99.94
	RIGHT	91.80	95.20	97.52	99.52	100.06
	L.S.D.	12.909	11.274	6.799	6.007	6.902
	SIG.	NS	NS	NS	NS	NS

* Significantly different at the 5% level.
NS Not significantly different.

were similarly influenced on 8 out of 13 occasions, most consistantly in later coulter life.

Left side means were greater than right side means in all instances where differences were significant. This was likely to have been explained by the outward movement into undisturbed soil of the rear end of the coulter blade wing operating on the outside of the disc component during continual anti-clockwise machine operation (compared with the rear of the inside blade wing moving into previously disturbed soil) as discussed further in Section 4.3.2.2.

Shank dimensions were essentially unaffected by side positioning except in early blade life. It is difficult to envisage what may have caused these results. Out of eight significant differences, left side means were greater than right side means in seven instances. The right side blades may have been subjected to increased wear forces due to the increased stress imposed by the disc flexing outwards during continual anti-clockwise machine operation.

4.2.4 WEAR PATTERNS.

Figures 28a to 28f demonstrate typical changes that occurred up to 190 km. (45.6 ha.) drilling for both standard and treated blades.

Standard blade wing measurements reduced at a faster rate than those of treated blades. Treated blades essentially retained their leading edge dimensions in

Figure 28a: Field wear of a standard blade after 20 km. (4.8 ha.) drilling.

Figure 28b: Field wear of a standard blade after 90 km. (21.6 ha.) drilling.

Figure 28c: Field wear of a standard blade after 190 km. (45.6 ha.) drilling.

Figure 28d: Field wear of a treated blade after 20 km. (4.8 ha.) drilling.

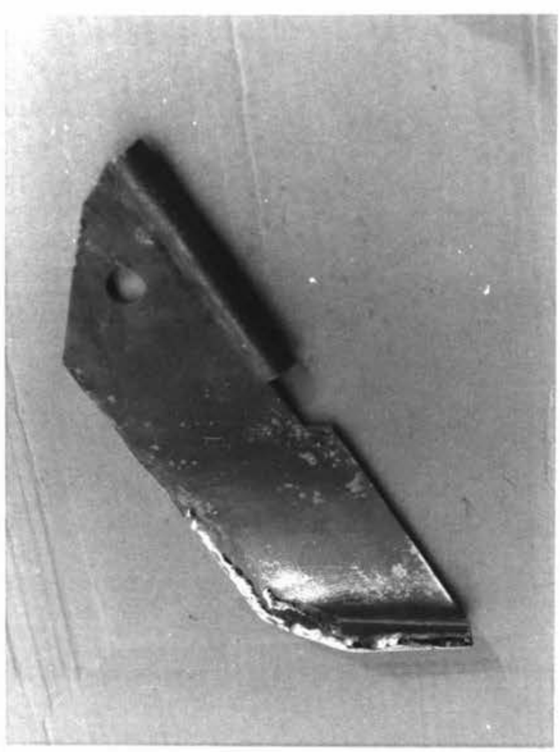


Figure 28e: Field wear of a treated blade after 90 km. (21.6 ha.) drilling.

Figure 28f: Field wear of a treated blade after 190 km. (45.6 ha.) drilling.

contrast to the standard blades which eventually were worn in a curve simulating disc rotation against the inner leading edge. This interaction between the disc and the blade is illustrated in Figures 29 and 32. The disc tended to transport soil over the blade leading edge in a pattern clearly shown in the photographs. The result was that the blade leading edge was worn to the shape of the disc radius, inevitably accelerating wear of the coulter wing in the process.

This phenomenon was responsible for the failure of a treated blade at 190 km. (45.6 ha.) drilling, resulting in the termination of this test. The blade is shown in Figures 31 and 32. The weld bead resisted wear on the outer shank. Opposing this, the disc rotation, with its accompanying soil, eroded the softer base material from under the weld bead. Without support, the weld bead failed, leaving a chip out of the hardened leading edge that eventually collected trash.

Thus the effective life of coulter blades was likely to have been determined by a balance between the rate of wear at the disc/shank interface and the rate of wear on the wing caused by soil flow. Soil type and condition would also affect both of these wear rates. To prolong coulter life, it appeared necessary to reduce both components of overall wear rate. However, it was clear that emphasis would need to be placed on reduction of the disc action, particularly in the lower leading edge/wing

Figure 31: After drilling 190 km. (45.6 ha.), Experiment 2 was terminated when one treated blade blocked with trash. Blockage was due to a chip out of the hardened material on the lower leading edge.

Figure 32: The rearside of the blade in Figure 31 showing the chip out of the leading edge.

region, thereby reducing consequential wing wear.

Application of welded material to the top edges of the coulter wing may possibly have resulted in the disadvantage of increasing the force required for penetration. This would have been expected as a result of the expansion in cross-section of the near-parabolic leading edge wear profile associated with metal edges wearing in soil (Richardson 57). Figures 28e and 28f show the increased frontal area caused by weld bead application.

4.2.5 SUMMARY OF EXPERIMENT 2.

Metal weightloss measurements appeared to be influenced by differences in side positioning, which was most likely to have occurred during continual anti-clockwise machine operation.

The tail wing dimension was influenced throughout coulter life by coatings and side differences. All wing dimensions were significantly affected by coatings in later blade life, while shank dimensions were influenced by both coatings and side differences in early blade life. All coating effects supported the welded treatment as having resisted dimensional changes to a greater extent than the control blades. Influences from side positioning indicated that the right side had incurred more wear (in terms of larger dimensional changes) than the left side in all but one statistical instance.

Improvement in wear rates by alteration of the weld pattern was envisaged initially by moving the weld bead

25mm. back from the leading edge. It was thought that this might prevent or delay the hardened material being undermined by the disc action, while still attempting to maintain the integrity of the lower leading edge-wing intersection. Figure 33 shows this pattern.

With consideration to the possible increased penetration force due to the upper weld pattern (mentioned above), an alternative pattern applied to the inner side of the shank and underside of the wing was conceived. This weld bead ran parallel to, but 25mm. back from the shank leading edge on the inside shank face. The bead curved around on to the wing and ran parallel to the wing leading edge as illustrated in Figure 34. This pattern was sufficiently removed from the shank leading edge to allow this region to bed-in thoroughly. When erosion of the shank finally resulted in the weld bead contacting the disc, it was likely that the weld would also bed-in since this had occurred when a welded material (HV=700) was tested on the stationary rig used in Experiment 1. This material was similar in hardness to those subsequently used in the first main test run of Experiment 3.

Figure 33: Revised weld bead pattern design for the tops of blades used in Run A of Experiment 3.

Figure 34: Bottom weld bead pattern design for coulter blades used in Run A of Experiment 3.

4.3 EXPERIMENT 3. (WEAR RATE TESTS)

Raw data for Experiment 3 are contained in Appendices 3 and 4 (Run A) and 5 and 6 (Run B).

4.3.1 VARIATION IN METAL WEIGHTLOSS.

Sources of variation in weightloss per hectare are summarised in Tables 21 and 22 for Runs A and B respectively.

Over both runs, the influence exerted by coatings appeared to be responsible for almost all of the variation between treatments for each measurement interval.

4.3.1.1 INFLUENCE OF COATINGS.

Metal weightloss per hectare data are presented for each run in Tables 23 and 24 respectively. These tables were derived from the absolute data shown in Appendices 7 and 8. Least significant differences between treatments were calculated for each measurement interval. Included also is a "control ratio" and the average measurement for the two controls (mild steel and carbonitrided mild steel). The "control ratio" was calculated as the weightloss per hectare for carbonitrided steel divided by the corresponding figure for mild steel. Since this ratio was in the narrow range 0.301 to 0.432 for both runs (with respective averages of 0.379 and 0.366), it was considered that treatments from both runs could be directly compared. This, in fact, had been the intended role of including

TABLE 21.

FACTORS INFLUENCING METAL WEIGHTLOSS PER HECTARE FROM A WEARING DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A.

	DISTANCE DRILLED (KM.)	COATING	SIDE	POSITION	ASSEMBLY
WTLOSS 1	33.5	*	NS	NS	NS
WTLOSS 2	53.5	*	NS	NS	NS
WTLOSS 3	71.0	*	NS	NS	NS
WTLOSS 4	123.0	*	NS	NS	NS
WTLOSS 5	144.0	NA	NA	NA	NA
WTLOSS 6	166.5	NA	NA	NA	NA
WTLOSS 7	216.5	NA	NA	NA	NA

TABLE 22.

FACTORS INFLUENCING METAL WEIGHTLOSS PER HECTARE FROM A WEARING DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B.

	DISTANCE DRILLED (KM.)	COATING	SIDE	POSITION	ASSEMBLY
WTLOSS 1	59.5	*	NS	NS	NS
WTLOSS 2	111.0	*	NS	NS	NS
WTLOSS 3	143.5	*	NS	NS	NS
WTLOSS 4	176.5	*	*	NA	NS

* Significant.
NS Not significant.
NA Not applicable.

TABLE 23.

THE EFFECT OF DISTANCE ON MEAN METAL WEIGHTLOSS PER HECTARE (GRAMS) FROM A WEARING DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A.

	Distance drilled (kilometers).						
	33.5	53.5	71.0	123.0	144.0	166.5	216.5
	Area drilled (hectares).						
	8.0	12.8	17.0	29.5	34.6	40.0	52.0
C1. MS	4.35	6.12	5.42				
C2. CN	1.31	2.47	2.34	2.14	2.16	2.07	1.79
T1. TT	2.94	3.84	3.43	3.28			
T2. TB	3.58	5.19	4.55	3.87			
T3. ET	3.51	5.09	4.47	3.81			
T4. EB	3.55	4.52	3.95	3.56			
L.S.D.	0.89	0.95	0.82	0.74			
CONTROL RATIO CN/MS	0.301	0.403	0.432	AVE=0.379			
AVE	2.83	4.30	3.88				

MS Mild steel.
CN Carbonitrided.
TT Toolcraft -top pattern.
TB Toolcraft -bottom pattern.
ET EutecBor -top pattern.
EB EutecBor -bottom pattern.

TABLE 24.

THE EFFECT OF DISTANCE ON MEAN METAL WEIGHTLOSS PER HECTARE (GRAMS) FROM A WEARING DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B.

	Distance drilled (kilometers).			
	59.5	111.0	143.5	176.5
	Area drilled (hectares).			
	14.3	26.6	34.4	42.4
C1. MS	3.12	2.80	3.61	
C2. CN	1.00	1.11	1.37	2.33
T5. TU	2.49	2.17	2.95	
T6. CO	2.66	2.10	2.62	3.03
T7. UL	3.03	2.42	3.13	
T8. CH	0.72	0.70	1.77	
L.S.D.	0.79	0.44	0.82	0.32
CONTROL RATIO	0.321	0.396	0.380	AVE=0.366
CN/MS AVE	2.06	1.96	2.49	

MS Mild steel.
CN Carbonitrided.
TU Eutalloy Tungtec.
CO Cobalarc.
UL Ultimium.
CH Chromium plated.

controls at either end of the wear range.

Figures 35 and 36 show graphically the information contained in the above tables.

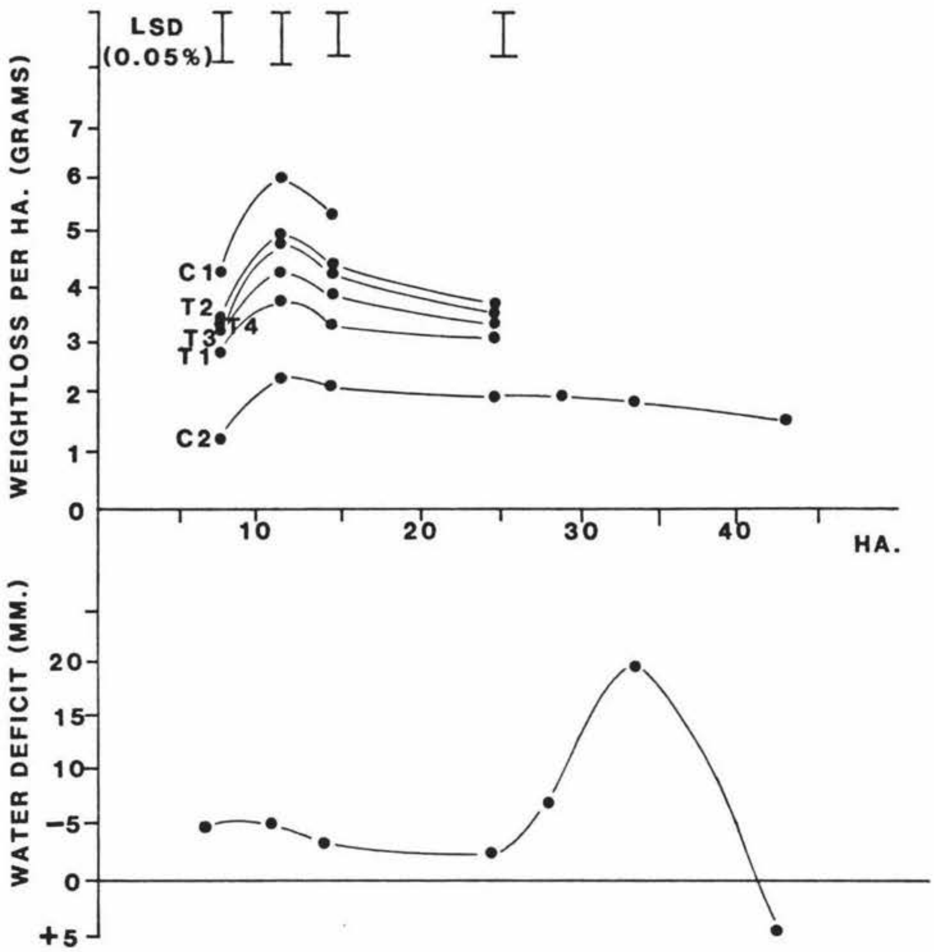
From Figure 35 and Table 23 (Run A), it was apparent that Treatment C2 (carbonitrided) had a significantly lower per hectare wear rate (in terms of metal weightloss) than all other treatments at all measurement intervals for Run A.

From Figure 36 and Table 24 (Run B), Treatments C2 and T8 (carbonitrided and chromium respectively) both exhibited significantly lower per hectare wear rates for all measurement intervals up to 143.5 km. (34.4 hectares). In the interval 111.0 km. (26.6 ha.) to 143.5 km. (34.4 ha.), rates of wear for the chromium treatment accelerated considerably, corresponding to the loss of chromium plating over most of the wing area. However, this was at no time significantly different from Treatment C2. At 143.5 km. (34.4 ha.), this treatment was discarded when a trash collecting hook of hard metal was formed at the shank leading edge/wing intersection.

Treatment T6 (Cobalarc) continued functioning beyond 143.5 km. as did Treatment C2. At the conclusion of this run, however, Treatment C2 had demonstrated significantly lower per hectare wear characteristics compared with Treatment T6.

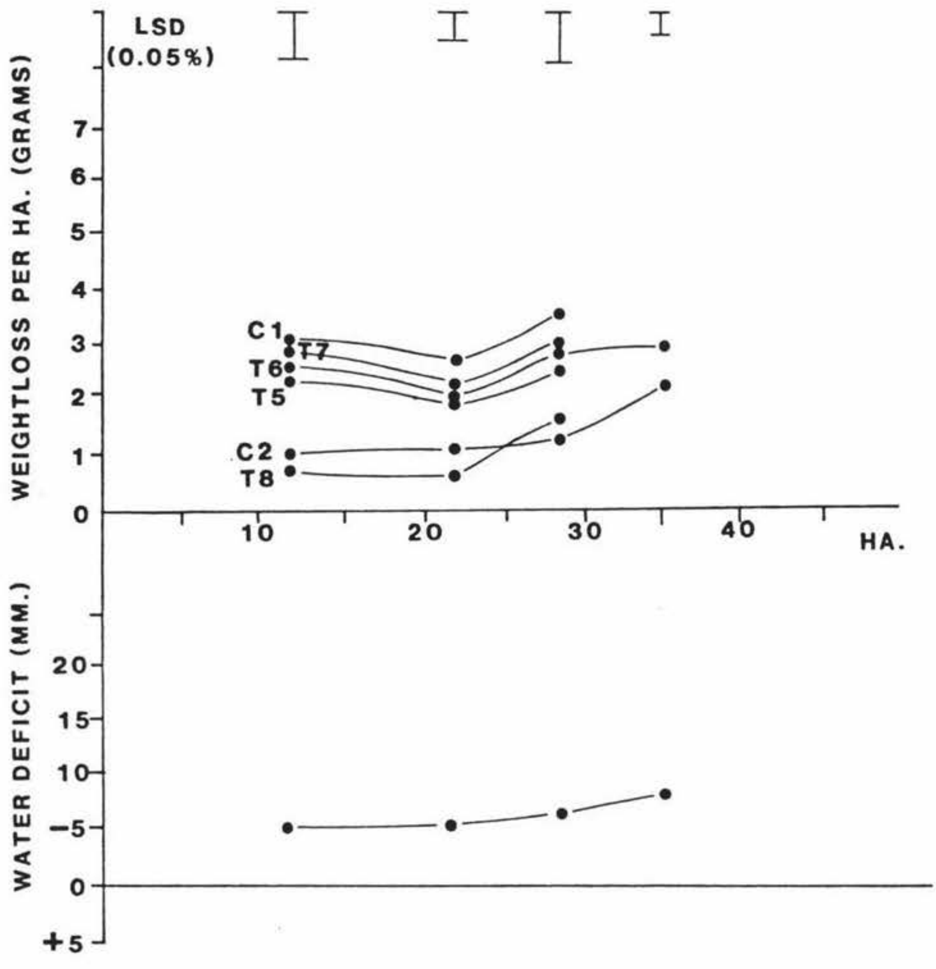
Over both runs, all welded treatments were similar

Figure 35: Graph of metal weightloss per hectare and soil moisture deficit against hectares drilled for Run A of Experiment 3.



Legend
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

Figure 36: Graph of metal weightloss per hectare and soil moisture deficit against hectares drilled for Run B of Experiment 3.



Legend
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

in their patterns of metal weightloss with time, even though material hardnesses and microstructures varied considerably (see Section 4.3.3). Apart from Treatment T6 in Run B (Cobalarc), the patterns of metal weightloss shown in the diagrams (though not necessarily the amount of metal actually lost) paralleled that of the mild steel blades. This suggested that the welded treatments did not offer any large improvement in functional coulter blade life compared with the mild steel base plates. Perhaps this indicates that such welded treatments responded to soil variations in a similar manner to mild steel. Indeed the patterns of weightloss from these treatments appeared to roughly reflect the soil moisture deficit curves shown in Figures 35 and 36 for Runs A and B respectively.

Comparison between runs was made during the first three measurement intervals by calculating "relative wear resistance" of each treatment equivalent to the treatment weightloss per hectare divided by the carbonitrided/mild steel average measurement. This information is shown in Tables 25 and 26.

From Tables 25 and 26, the ordered relative wear resistances were chromium, carbonitrided, Toolcraft-top pattern, EutecBor-bottom pattern, Cobalarc 1A, Eutalloy Tungtec, EutecBor-top pattern, Toolcraft-bottom pattern, Ultimium and mild steel. This ranking does not consider the above-mentioned performances of Cobalarc, chromium

TABLE 25.

RELATIVE WEAR RESISTANCES OF ALTERNATIVE COULTER BLADE

TREATMENTS FOR EXPERIMENT 3.

RUN A.

	Distance drilled (kilometers).			Average
	33.5	53.5	71.0	
C1. MILD STEEL	0.65	0.70	0.72	0.69
C2. CARBONITRIDED	2.16	1.74	1.66	1.85
T1. TOOLCRAFT-TOP	0.96	1.12	1.13	1.07
T2. TOOLCRAFT-BOT	0.79	0.83	0.85	0.82
T3. EUTECBOR -TOP	0.81	0.84	0.87	0.84
T4. EUTECBOR -BOT	0.80	0.95	0.98	0.91

TABLE 26.

RELATIVE WEAR RESISTANCES OF ALTERNATIVE COULTER BLADE

TREATMENTS FOR EXPERIMENT 3.

RUN B.

	Distance drilled (kilometers).			Average
	59.5	111.0	143.5	
C1. MILD STEEL	0.66	0.70	0.69	0.68
C2. CARBONITRIDED	2.06	1.77	1.82	1.88
T5. EUT. TUNGTEC	0.83	0.90	0.84	0.85
T6. COBALARC	0.77	0.93	0.95	0.88
T7. ULTIMIUM	0.68	0.81	0.80	0.76
T8. CHROMIUM	2.86	2.80	1.41	2.36

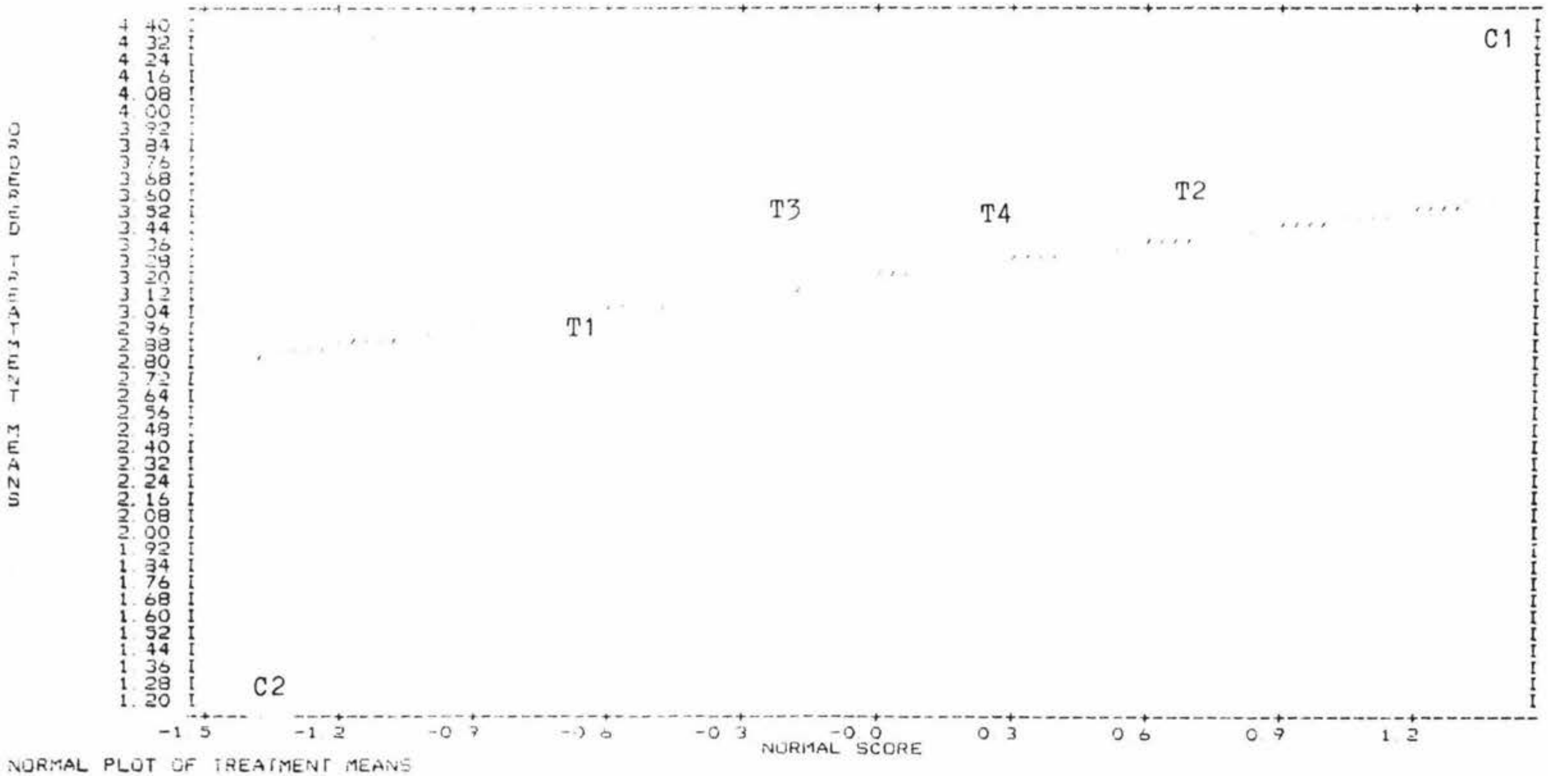
and carbonitrided treatments after the first three measurement intervals, however it may be used to reinforce observations supporting carbonitriding as the most effective wear resistant treatment tested.

Graphs illustrating ordered treatment means for Run A (Figures 37a to 37h) consistantly showed Treatment C2 (carbonitrided) as being different (indicated by separate groupings) from all other treatments up to 71.0 km. (17.0 ha.) drilling. During Run B, both Treatments C2 and T8 (carbonitrided and chromium) were different from the remaining four up to 143.5 km. (34.4 ha.). This visual method of presenting metal weightloss data again took no account of the undesirable trash collecting properties attained by the chromium treatment at 143.5 km. (34.4 ha.), which eventually eliminated this treatment from the wear rate tests.

Plots of residual sums of squares for each of the four replicates of a treatment are shown in Figures 38a to 38h.

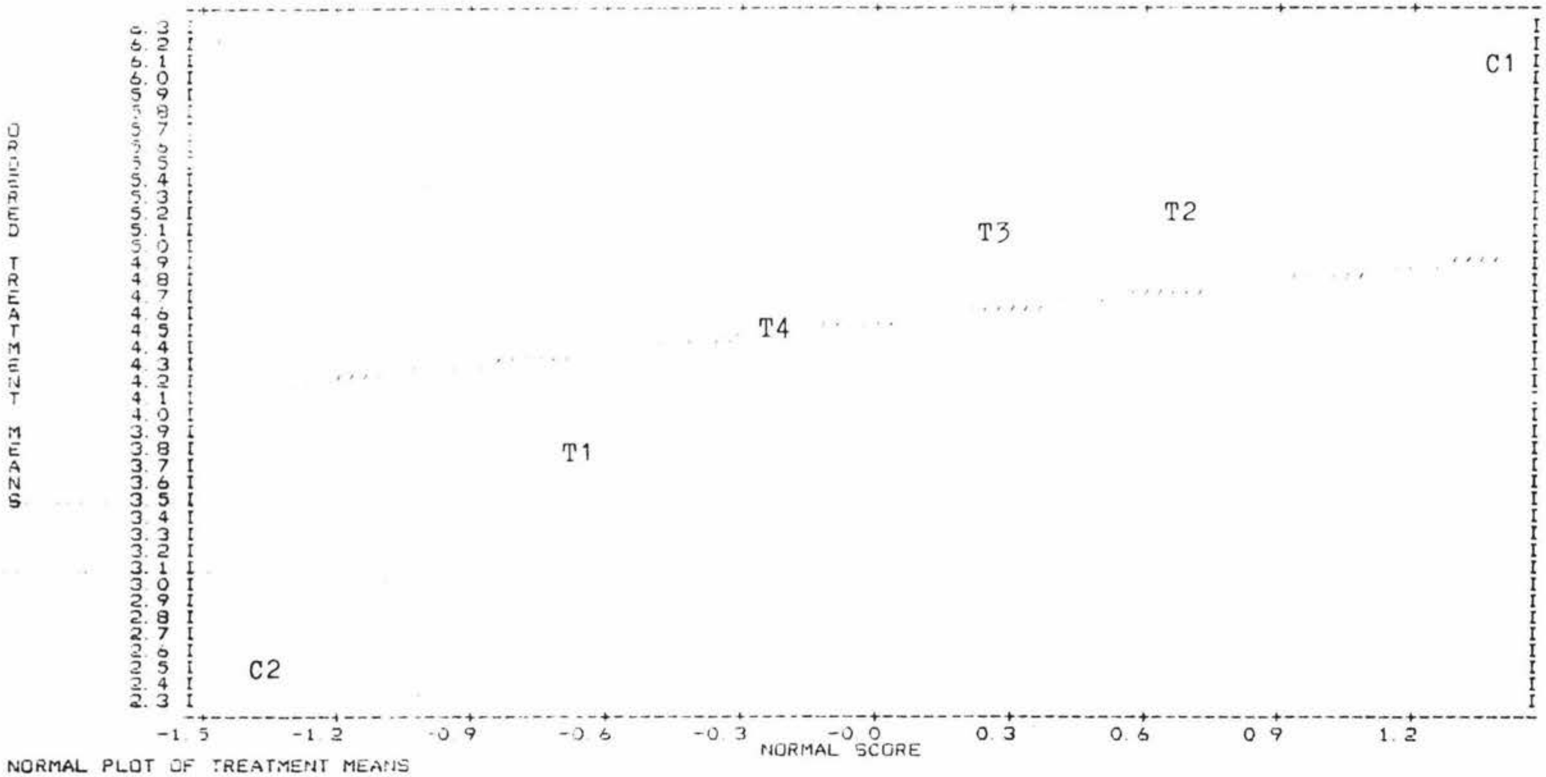
Throughout Run A, Treatments C2 and T4 were consistantly less variable than the other treatments, as indicated by the reduced vertical spread of recordings. For Treatment C2 (carbonitrided), this could be explained by the inherent characteristics of the treatment process involving controlled oven conditions to impart desired properties to batches of base metal plates, thereby ensuring consistancy between production runs. At the other extreme, the remaining treatments

Figure 37a: Run A: Ordered treatment means after 33.5 km. (8.0 ha.) drilling.



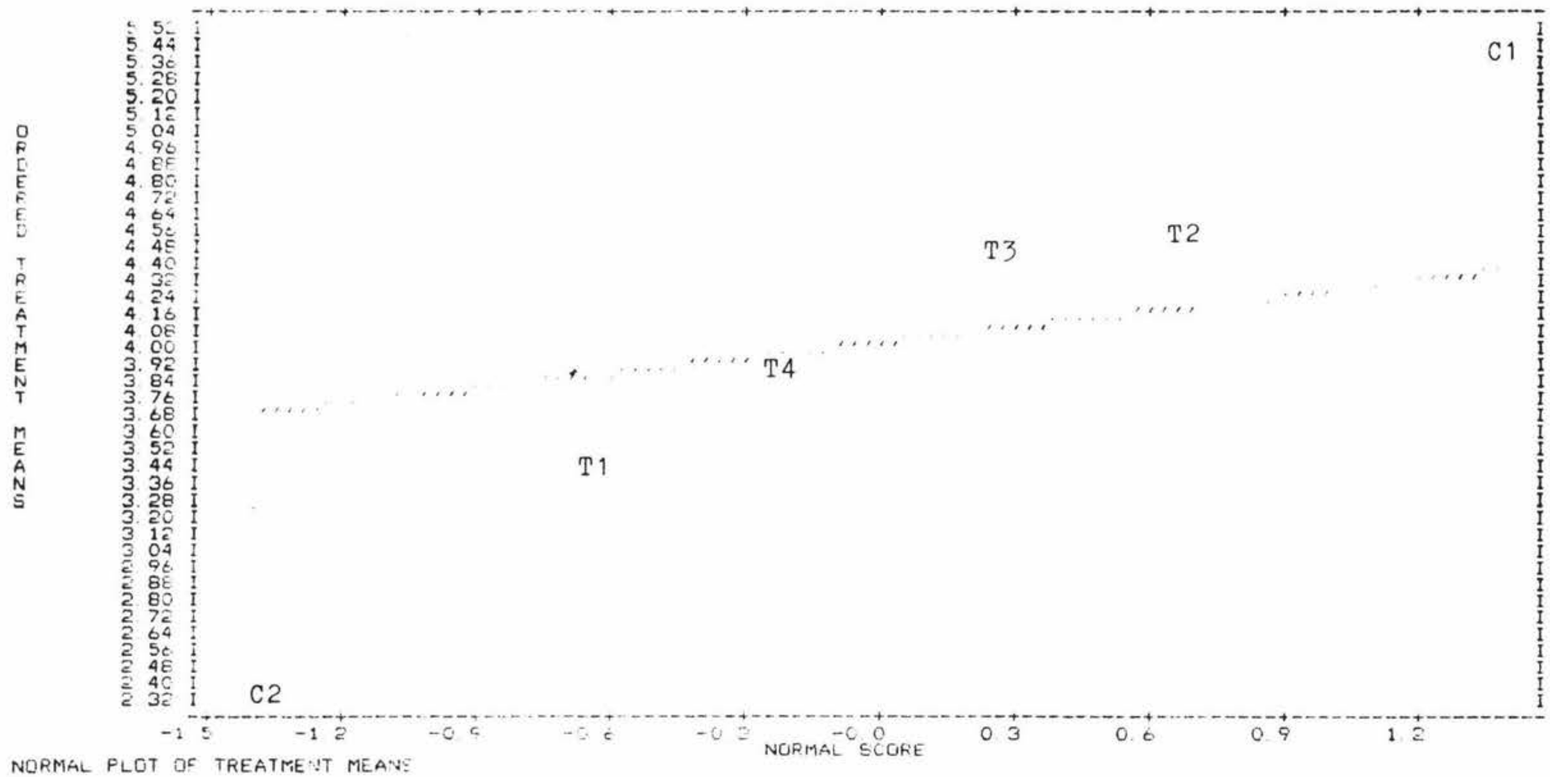
Legend
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

<u>Figure 37b:</u> Run A: Ordered treatment means after 53.5 km. (12.8 ha.) drilling.



<u>Legend</u>

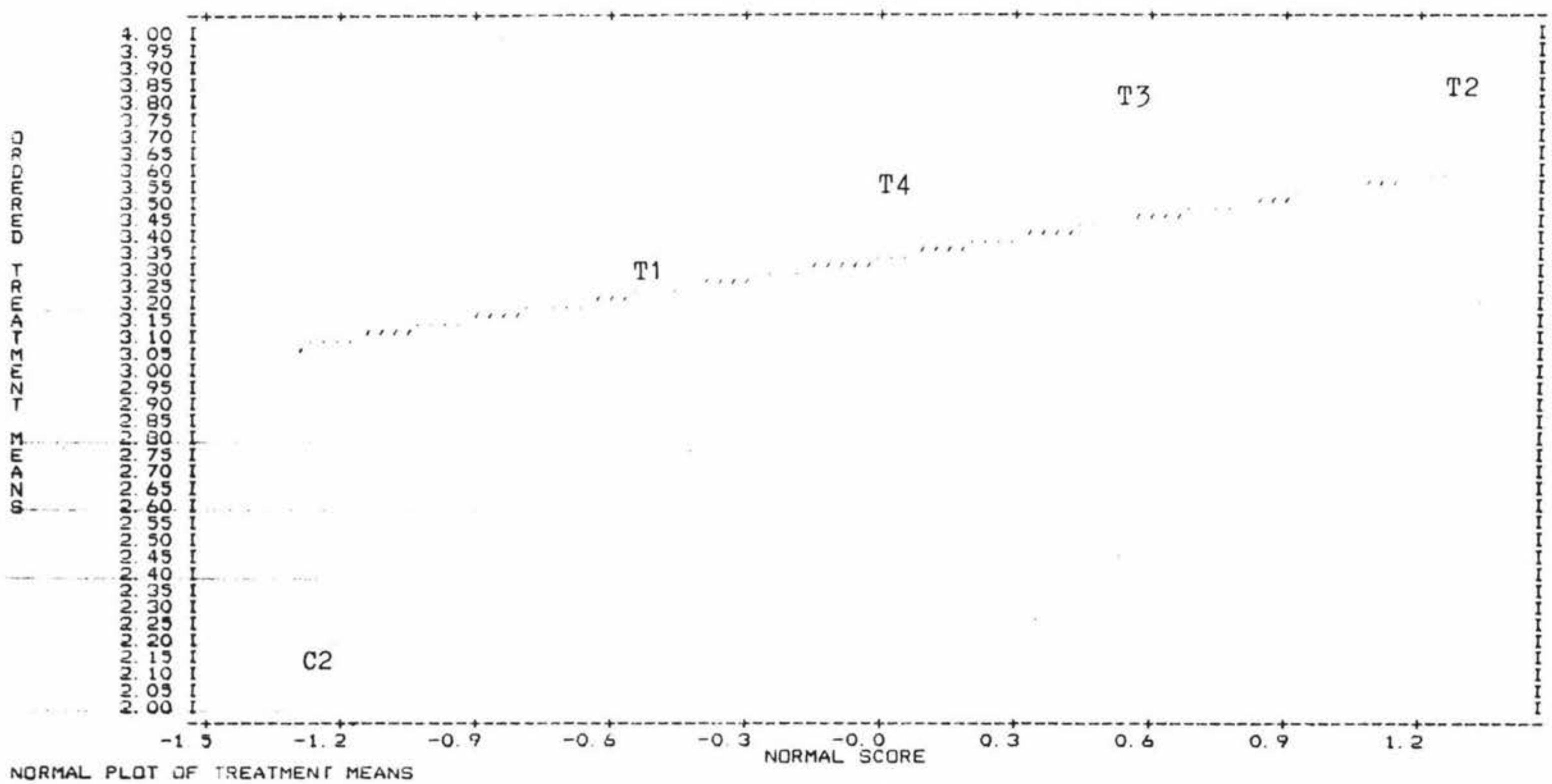
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom



Legend
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

Figure 37c: Run A: Ordered treatment means after 71.0 km. (17.0 ha.) drilling.

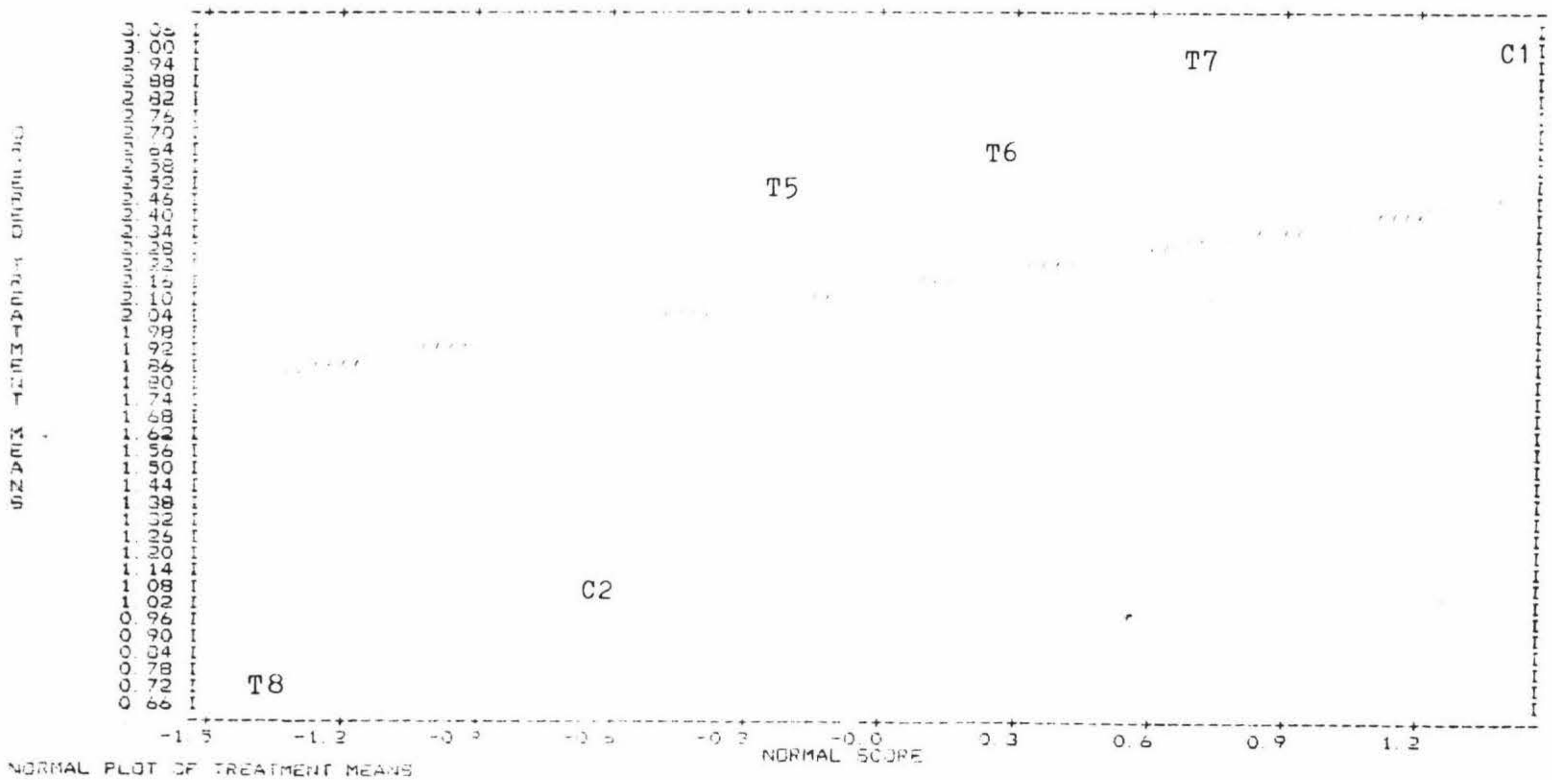
Figure 37d: Run A: Ordered treatment means after 123.0 km. (29.5 ha.) drilling.



Legend

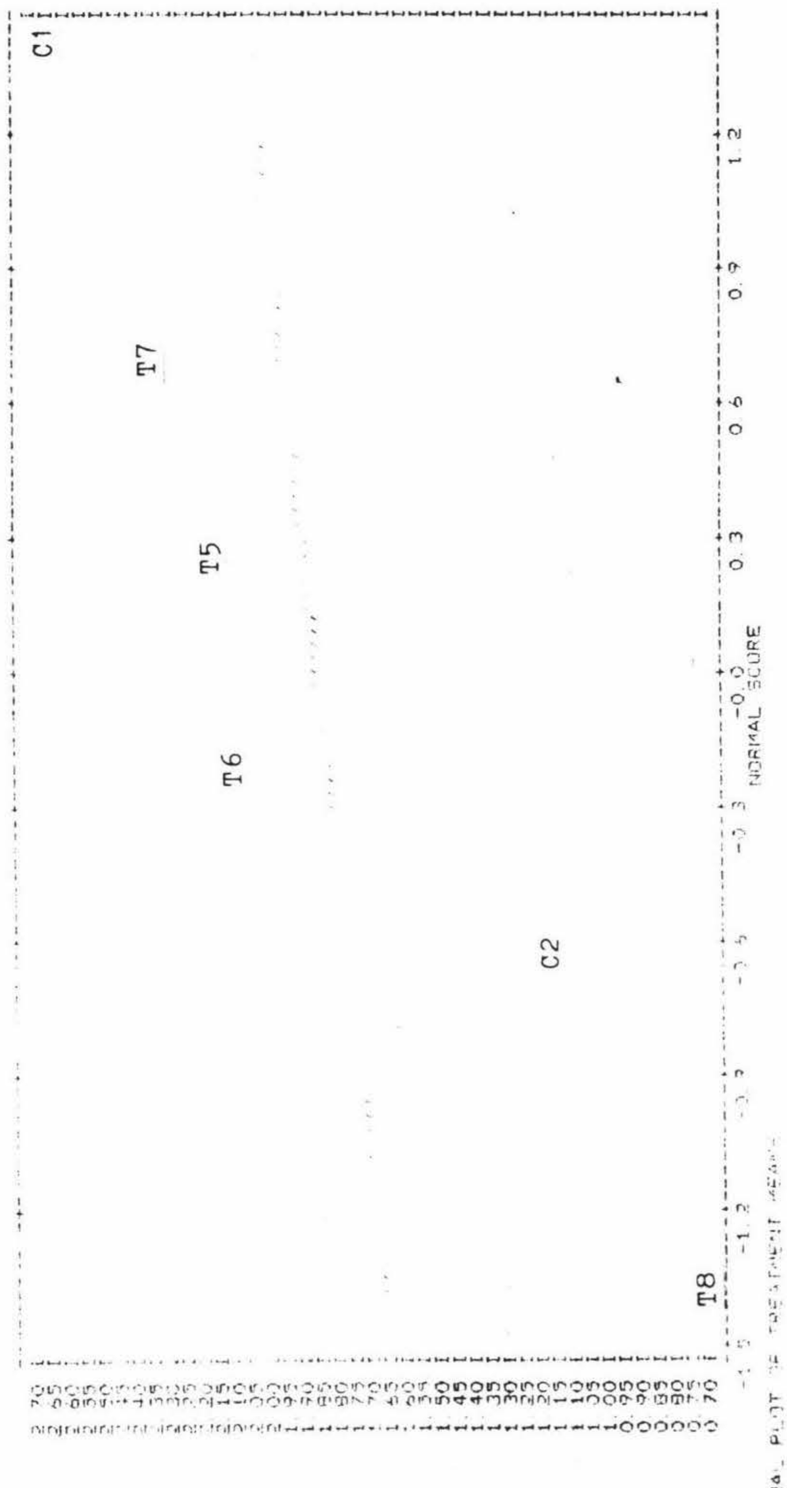
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

<u>Figure 37e</u>: Run B: Ordered treatment means after 59.5 km. (14.3 ha.) drilling.



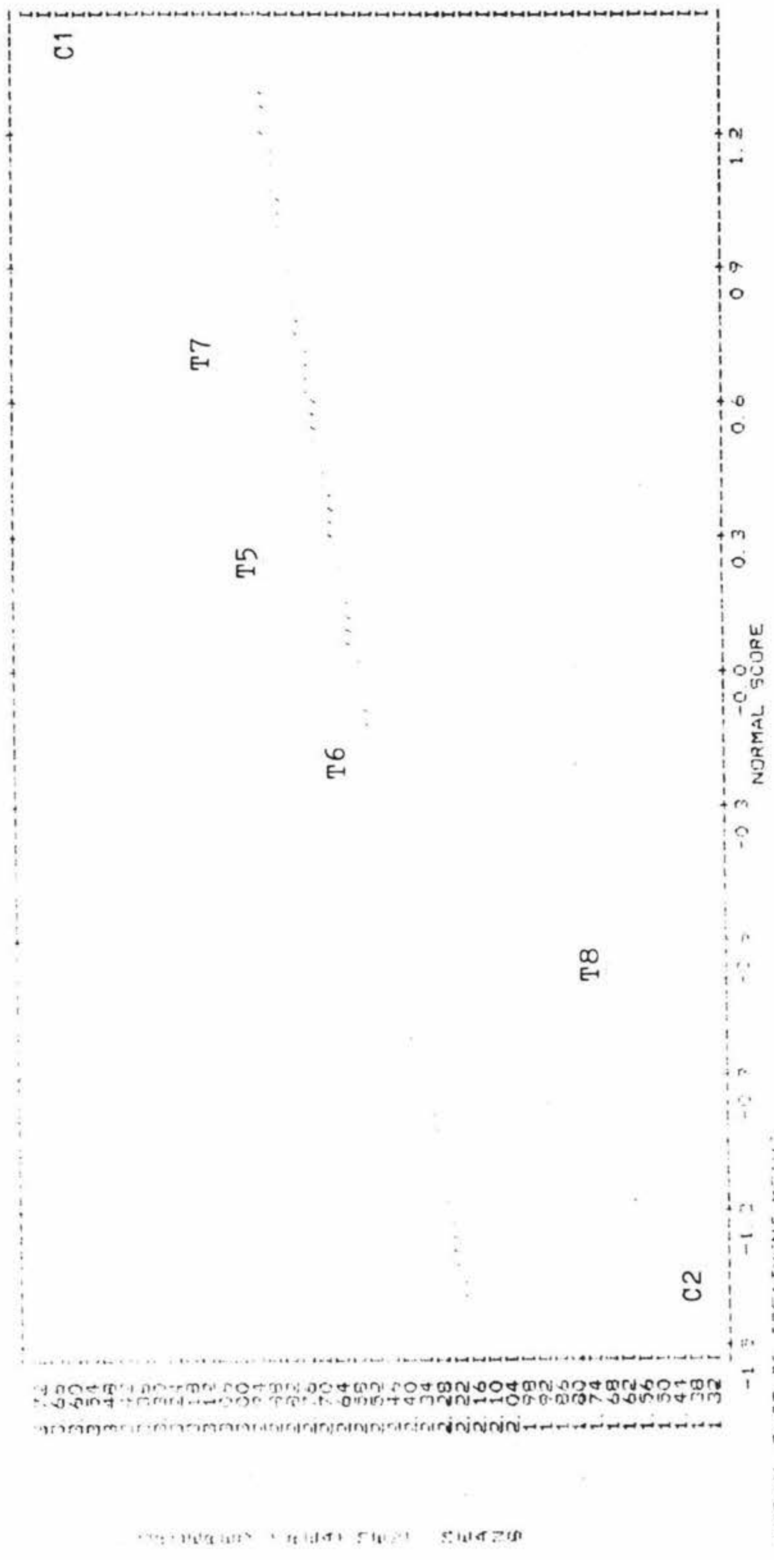
<u>Legend</u>
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 37f: Run B: Ordered treatment means after 111.0 km. (26.6 ha.) drilling.



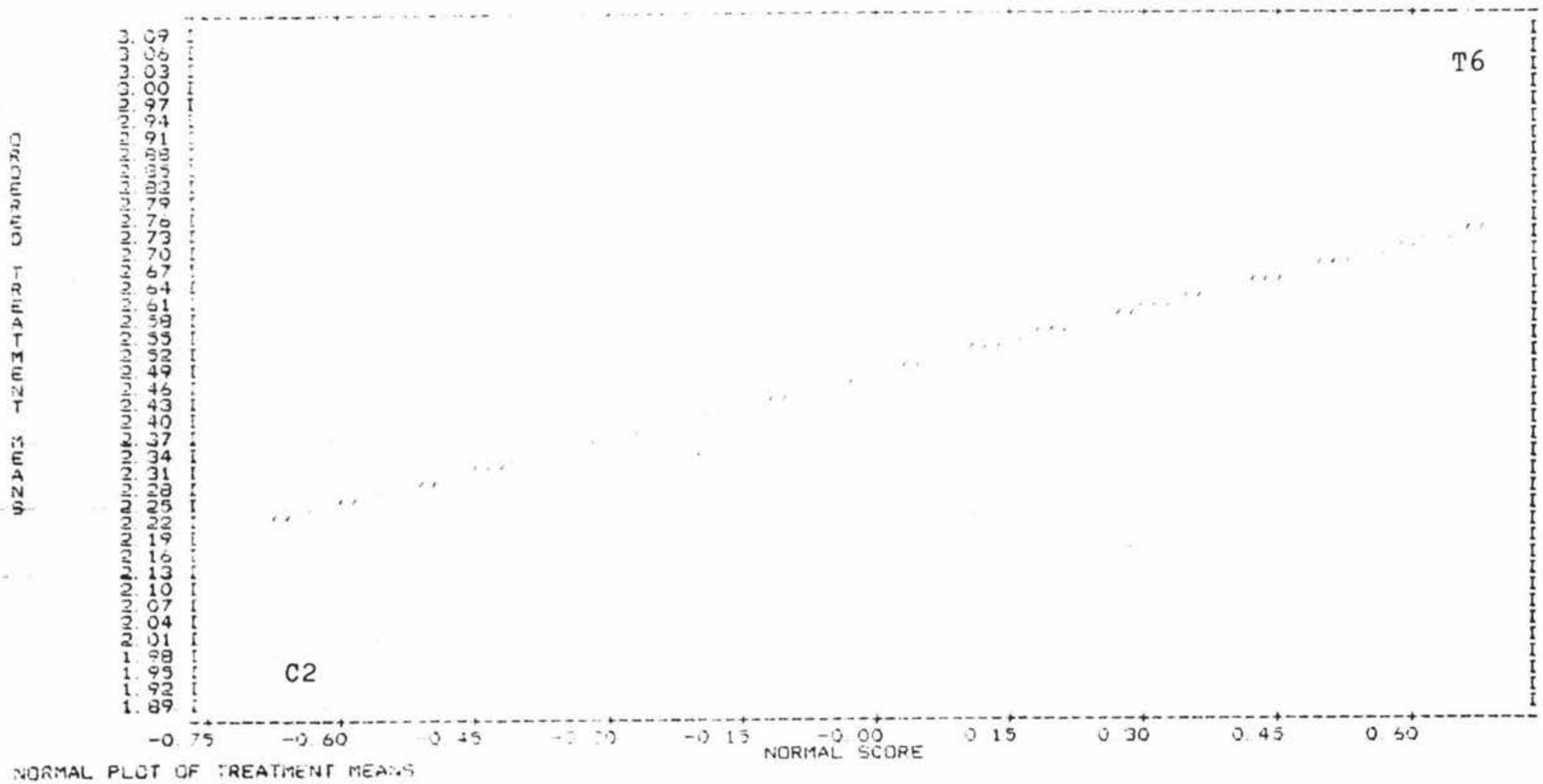
Legend
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

<u>Figure 37g</u>: Run B: Ordered treatment means after 143.5 km. (34.4 ha.) drilling.



<u>Legend</u>
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 37h: Run B: Ordered treatment means after 176.5 km. (42.4 ha.) drilling.



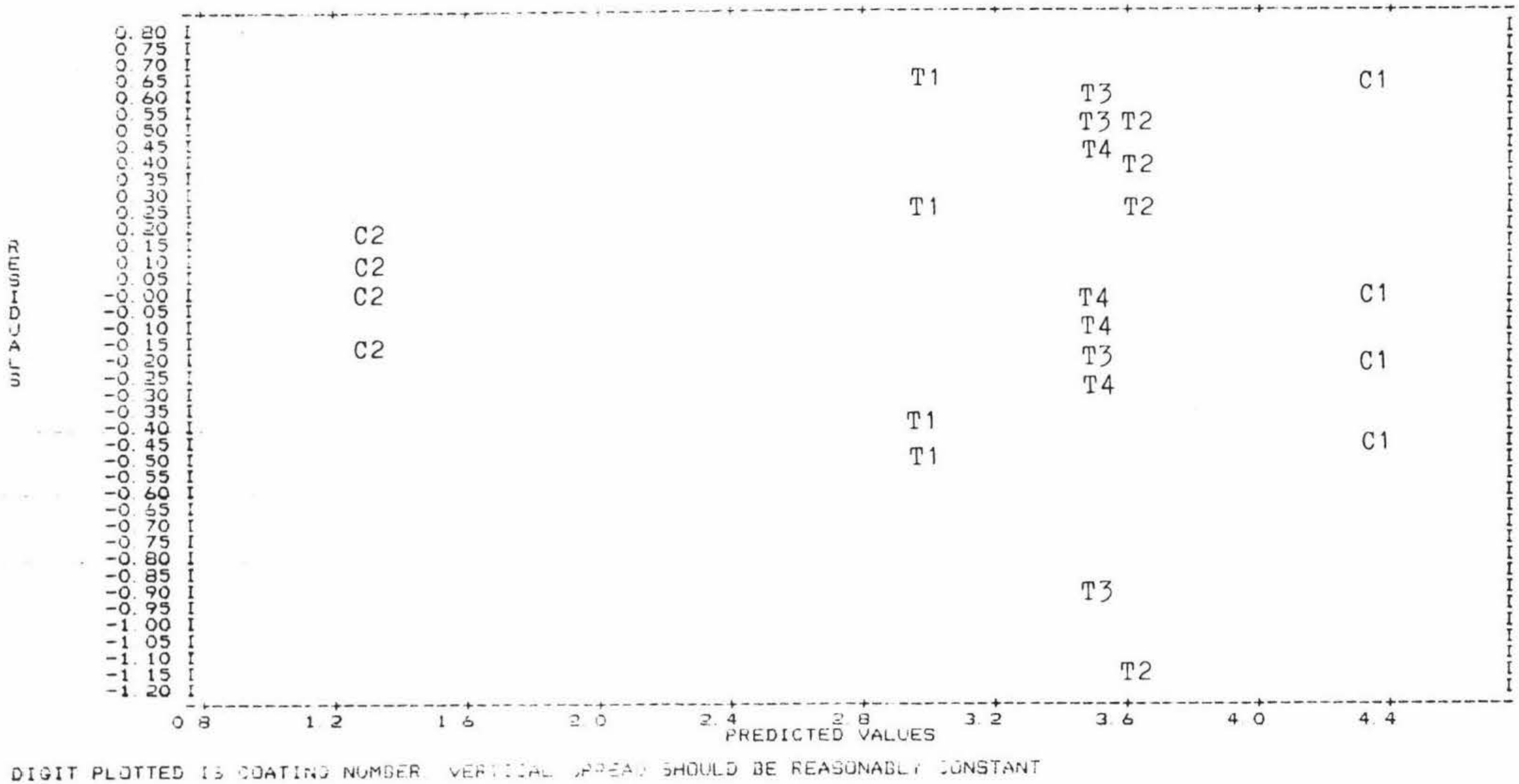
Legend

C2 Carbonitriding
T6 Cobalarc

were all manually welded. Therefore variation between replicates was inevitable. For Treatment T4 (EutecBor-bottom pattern), it is difficult to see a logical explanation for the reduced variation observed, as it too was manually applied. In fact, variation in Treatment T4 was less than that for Treatment C1 (mild steel control blades used as base plates for all treatments) which might have been expected to be relatively consistant because of its mass production, cold stamping fabrication process.

During Run B, Treatments C2 and T8 were again less variable than all other treatments. It is suggested that a similar explanation to that for Run A would apply to Treatment C2. Lack of variation for Treatment T8 (chromium plated) was similarly likely to be explained by the controlled electo-plating conditions operating on a batch system during coulter blade processing. Although welded treatments were more variable than Treatments C2 and T8, the control coulter blades were the most variable of all, again contrary to expectations outlined earlier.

Figure 38a: Run A: Residual sums of squares for replicates after 33.5 km. (8.0 ha.) drilling.



Legend

C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

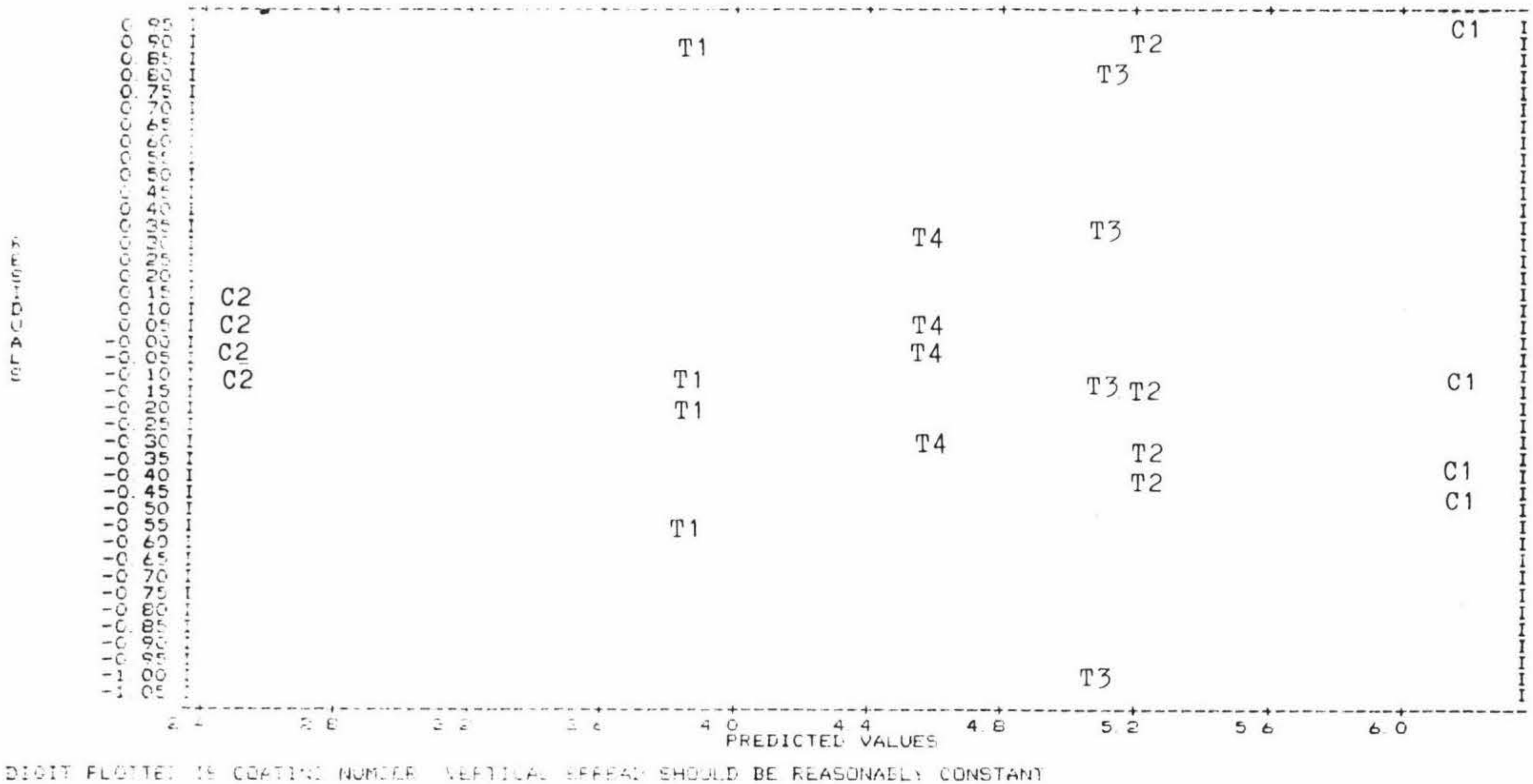
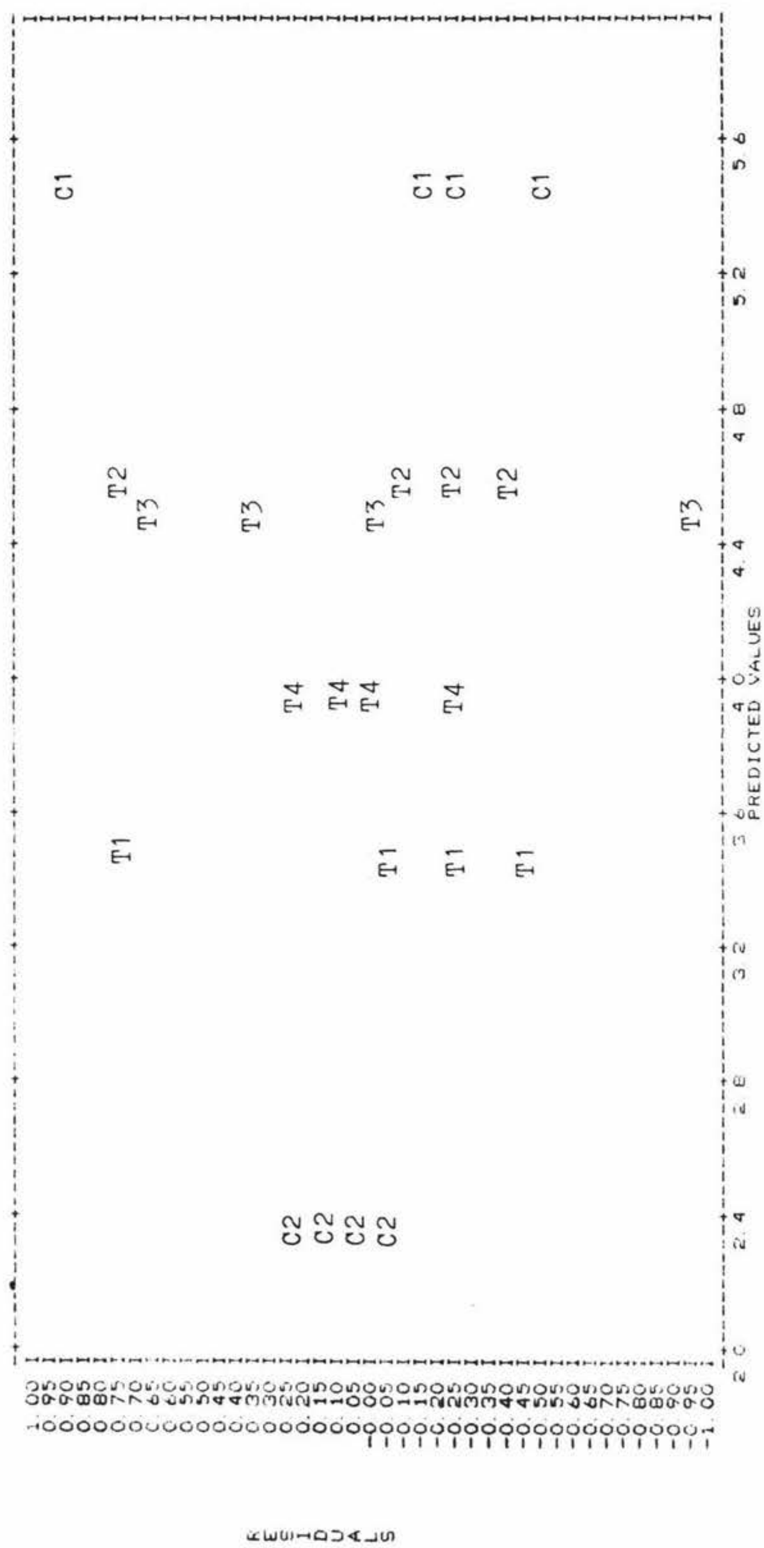


Figure 38b: Run A: Residual sums of squares for replicates after 53.5 km. (12.8 ha.) drilling.

Legend

C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

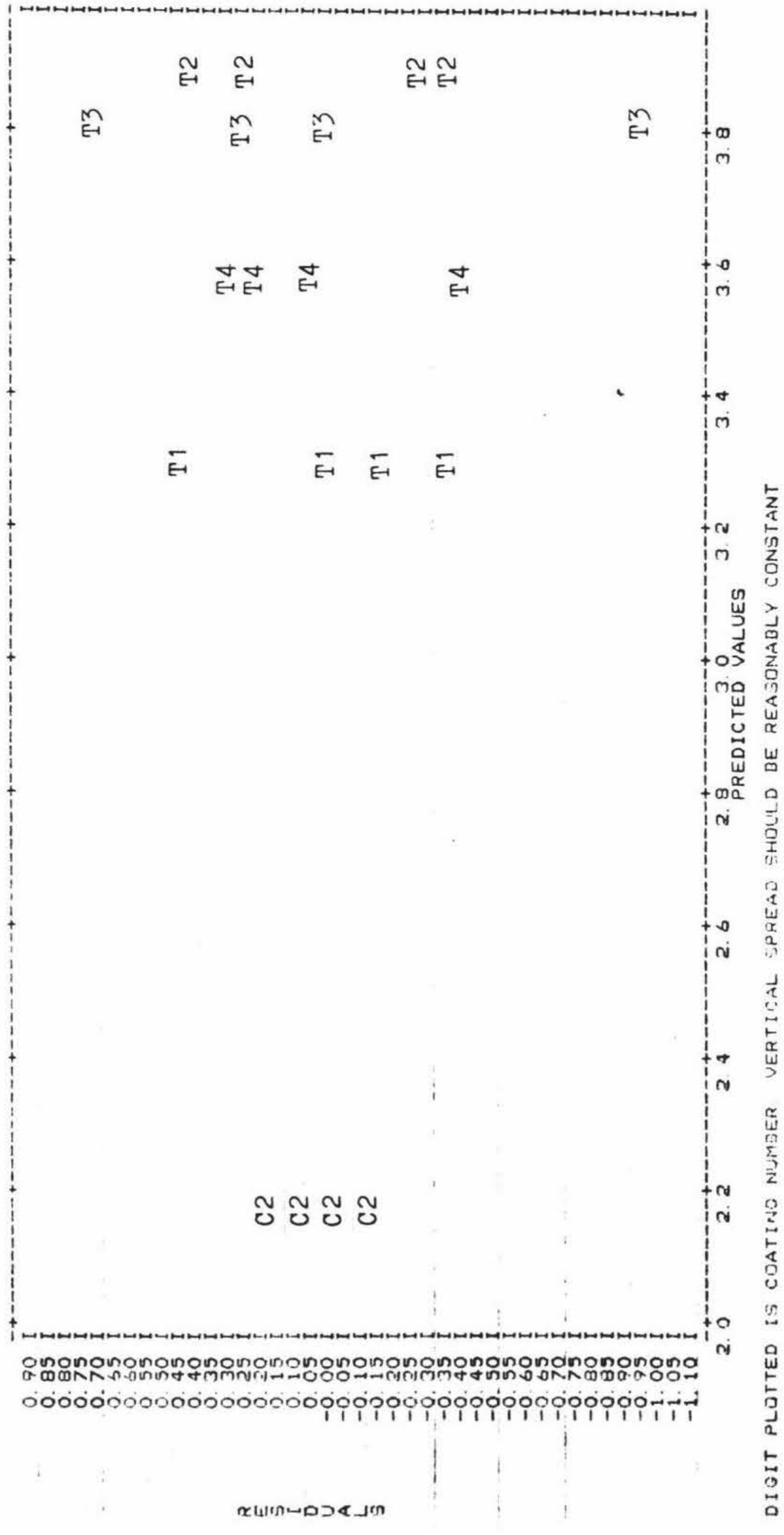
<u>Figure 38c</u>: Run A: Residual sums of squares for replicates after 71.0 km. (17.0 ha.) drilling.



DIGIT PLOTTED IS COATING NUMBER VERTICAL SPREAD SHOULD BE REASONABLY CONSTANT

<u>Legend</u>
C1 Mild steel
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

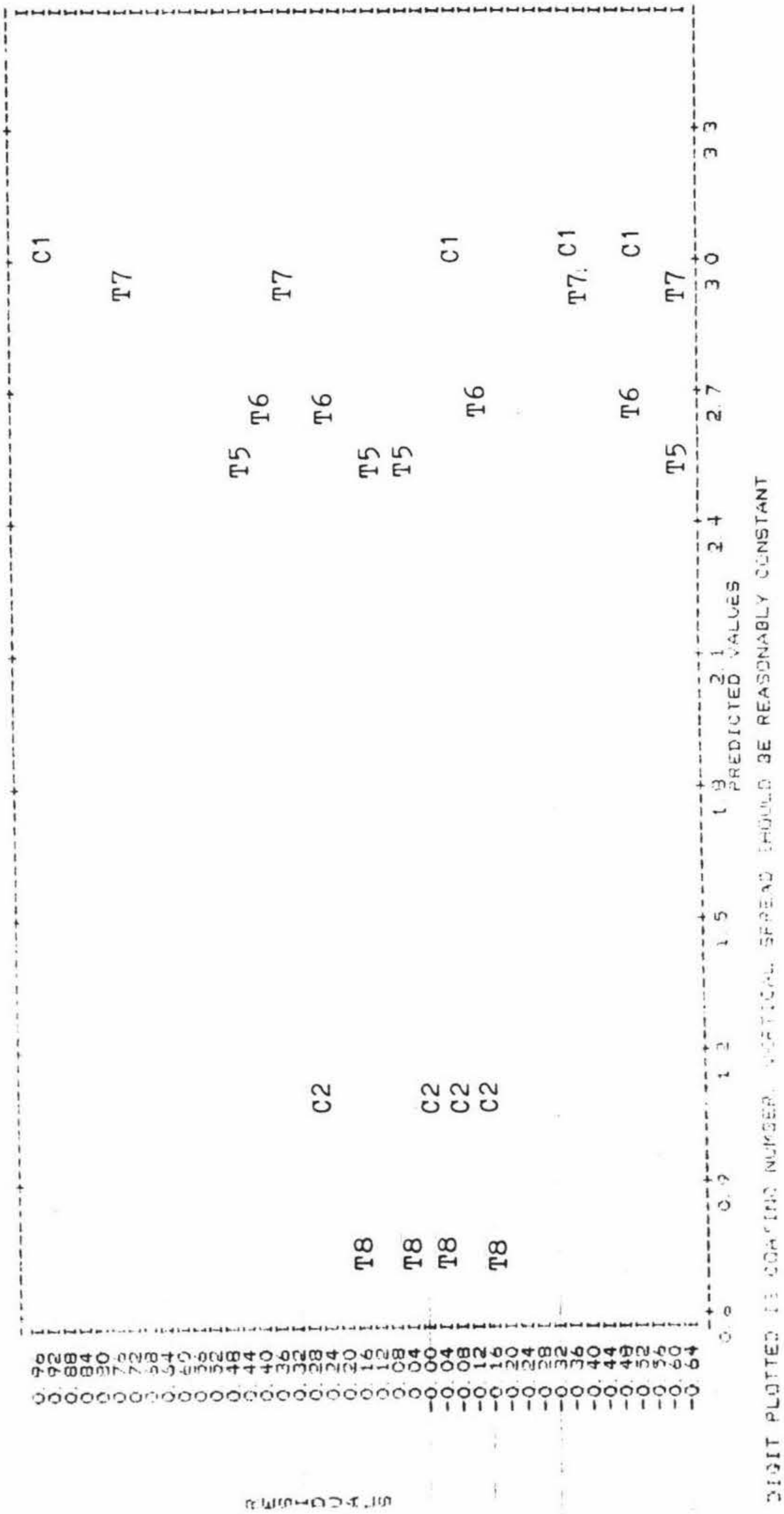
<u>Figure 38d</u>: Run A: Residual sums of squares for replicates after 123.0 km. (29.5 ha.) drilling.



<u>Legend</u>

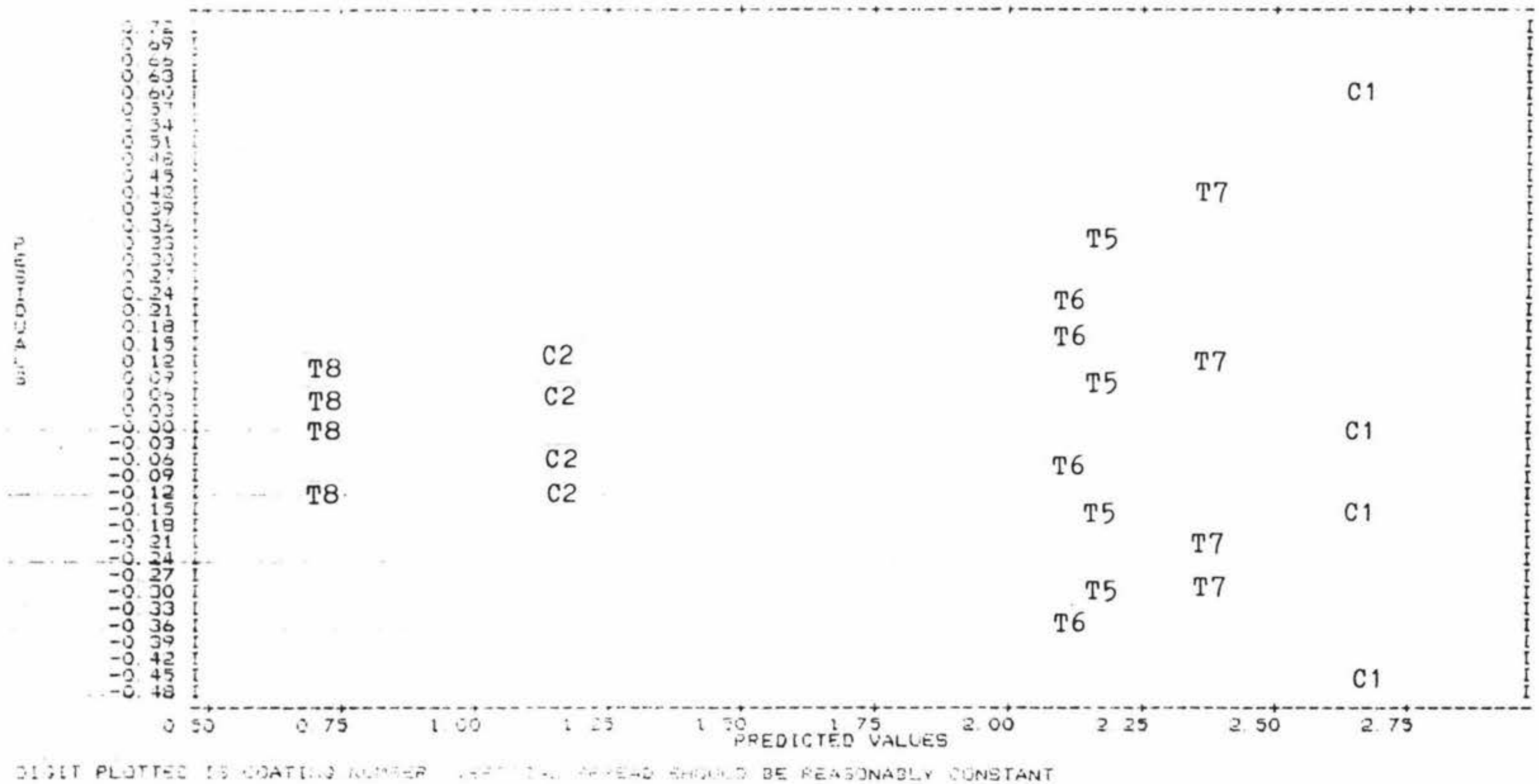
C2 Carbonitriding
T1 Toolcraft -top
T2 Toolcraft -bottom
T3 EutecBor -top
T4 EutecBor -bottom

<u>Figure 38e</u>: Run B: Residual sums of squares for replicates after 59.5 km. (14.3 ha.) drilling.



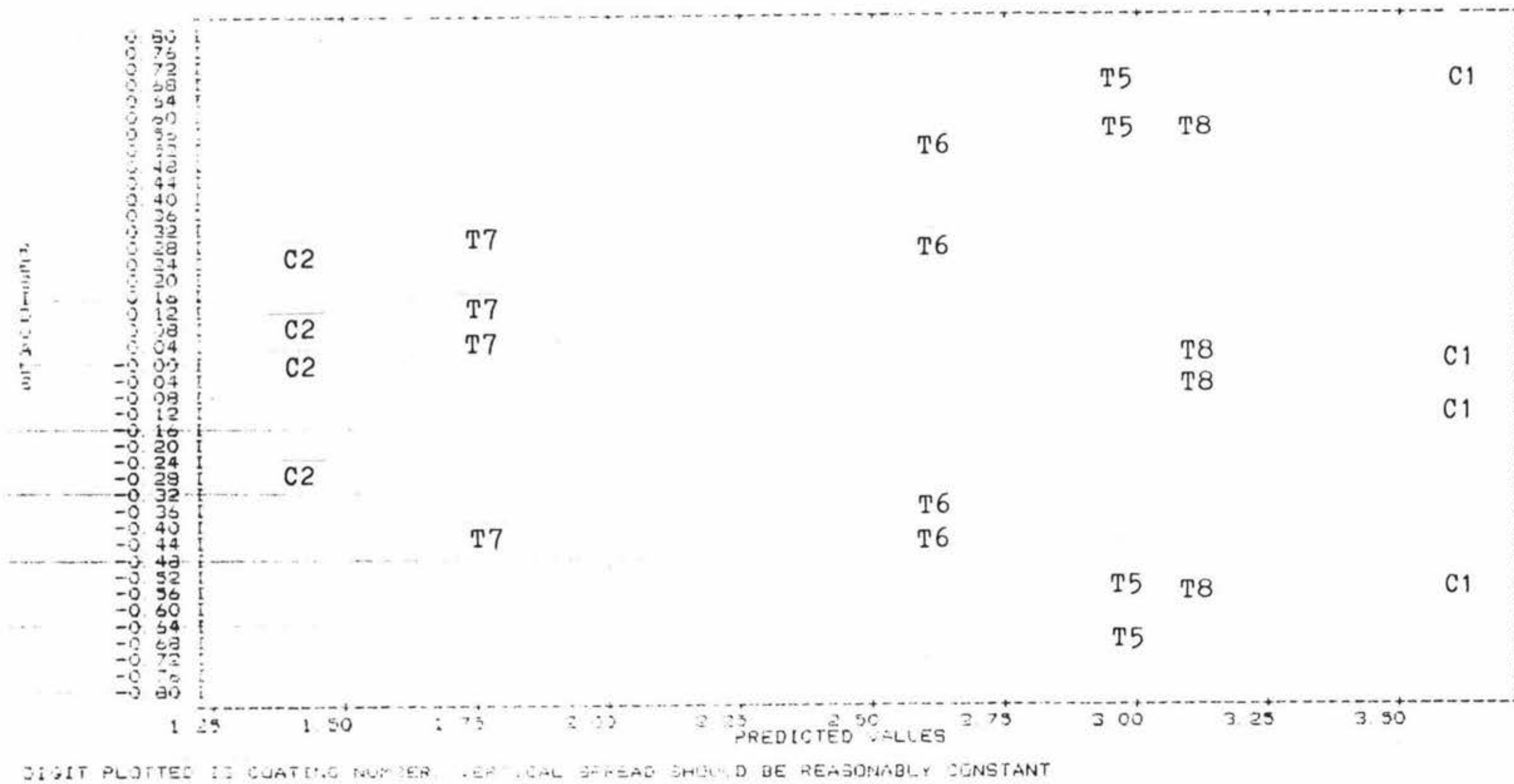
<u>Legend</u>
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 38f: Run B: Residual sums of squares for replicates after 111.0 km. (26.6 ha.) drilling.



Legend
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 38g: Run B: Residual sums of squares for replicates after 143.5 km. (34.4 ha.) drilling.



Legend
C1 Mild steel
C2 Carbonitriding
T5 Tungtec
T6 Cobalarc
T7 Ultimium
T8 Chrome plated

Figure 38h: Run B: Residual sums of squares for replicates after 176.5 km. (42.4 ha.) drilling.

4.3.2 VARIATION IN LINEAR DIMENSIONS.

Tables 27 and 28 summarise sources of variation for the linear dimensions that were measured.

Effects of lateral assembly and fore/aft positioning were insignificant during both runs and for all dimensions.

Coatings had their predominant influence on wing dimensions. Coulter shank dimensions appeared to be affected by side positioning of the blades throughout blade life while wing dimensions were only affected by this parameter in early blade life.

4.3.2.1 INFLUENCE OF COATINGS.

Dimensional data for the range of coating treatments are presented for each run in Tables 29 and 31 for wing dimensions and Tables 30 and 32 for shank dimensions.

The tables show that almost all of the linear wing and shank dimensions for carbonitrided mild steel were equal to or significantly greater than those for all other treatments during both runs and throughout the entire blade life. Mild steel appeared to be the treatment least resistant to dimensional changes. No other clear trends were evident.

The influence of coatings upon mid, rear-to-mid, and inner wing dimensions was not unexpected since these measurements were directly upheld by weld beads, case hardening or electro-plating on all treatments.

TABLE 27.

FACTORS INFLUENCING LINEAR DIMENSIONS OF A WEARING DIRECT DRILLING COULTER. EXPERIMENT 3: RUN A.

DISTANCE DRILLED (KM.)	DIMENSION	COATING	SIDE	POSITION	ASSEMBLY
33.5	TAIL WING	NS	*	NS	NS
	MID WING	*	*	NS	NS
	REAR -MID	*	**	NS	NS
	INNR WING	*	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	**	NS	NS
	SHANK -C	NS	*	NS	NS
	SHANK -D	NS	*	NS	NS
	SHANK -E	NS	**	NS	NS
53.5	TAIL WING	*	*	NS	NS
	MID WING	*	NS	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	*	NS	**	NS
	SHANK -A	**	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	*	NS	NS
	SHANK -D	NS	*	NS	NS
	SHANK -E	NS	*	NS	NS
71.0	TAIL WING	*	*	NS	NS
	MID WING	*	NS	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	*	NS	NS	NS
	SHANK -A	**	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	*	NS	NS
	SHANK -D	NS	*	NS	NS
	SHANK -E	NS	*	NS	NS
123.0	TAIL WING	NS	NS	NS	NS
	MID WING	**	NS	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	NS	NS	NS	NS
	SHANK -A	**	NS	NS	NS
	SHANK -B	**	NS	NS	NS
	SHANK -C	NS	NS	NS	NS
	SHANK -D	NS	**	NS	NS
	SHANK -E	NS	NS	NS	NS

* Significant at the 1% level.
** Significant at the 5% level.
NS Not significant.

TABLE 28.

FACTORS INFLUENCING LINEAR DIMENSIONS OF A WEARING DIRECT DRILLING COULTER. EXPERIMENT 3: RUN A.

DISTANCE DRILLED (KM.)	DIMENSION	COATING	SIDE	POSITION	ASSEMBLY
59.5	TAIL WING	NS	*	NS	NS
	MID WING	*	*	NS	NS
	REAR -MID	**	NS	NS	NS
	INNR WING	*	NS	NS	NS
	SHANK -A	*	NS	NS	NS
	SHANK -B	NS	**	NS	NS
	SHANK -C	NS	*	NS	NS
	SHANK -D	NS	*	NS	NS
	SHANK -E	NS	*	NS	NS
111.0	TAIL WING	*	*	NS	NS
	MID WING	*	**	NS	NS
	REAR -MID	*	NS	NS	NS
	INNR WING	*	NS	NS	NS
	SHANK -A	NS	NS	NS	NS
	SHANK -B	NS	NS	NS	NS
	SHANK -C	NS	*	NS	NS
	SHANK -D	NS	*	NS	NS
	SHANK -E	NS	*	NS	NS
143.5	TAIL WING	**	NS	NS	NS
	MID WING	NS	NS	NS	NS
	REAR -MID	NS	NS	NS	NS
	INNR WING	**	NS	NS	NS
	SHANK -A	**	NS	NS	NS
	SHANK -B	**	NS	NS	NS
	SHANK -C	**	NS	NS	NS
	SHANK -D	NS	**	NS	NS
	SHANK -E	NS	*	NS	NS

* Significant at the 1% level.
** Significant at the 5% level.
NS Not significant.

TABLE 29.

EFFECT OF WEAR ON LINEAR WING DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A: COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREATMENT	TAIL WING	MID WING	REAR -MID	INNER WING
33.5	C1. MS	17.25 b	21.27 c	40.67 c	78.40 b
	C2. CN	18.20 a	23.67 b	52.42 a	87.70 a
	T1. TT	17.55 ab	22.95 b	50.30 ab	79.20 b
	T2. TB	17.55 ab	20.95 c	43.07 c	79.37 b
	T3. ET	17.55 ab	27.65 a	47.80 b	79.17 b
	T4. EB	17.05 b	20.60 c	46.22 b	79.95 b
	L.S.D.	0.853	0.825	2.830	2.033
53.5	C1. MS	15.45 c	17.00 d	16.32 d	54.72 e
	C2. CN	17.87 a	21.75 a	38.65 b	80.05 a
	T1. TT	17.17 ab	20.62 ab	46.85 a	74.47 b
	T2. TB	17.00 b	19.75 bc	27.05 c	63.45 d
	T3. ET	17.02 b	19.07 c	32.70 bc	75.05 ab
	T4. EB	16.57 b	19.37 bc	31.62 bc	69.25 c
	L.S.D.	0.780	1.408	7.154	5.050
71.0	C1. MS	15.00 c	16.00 c	9.30 c	42.20 d
	C2. CN	17.87 a	21.75 a	38.65 a	80.05 a
	T1. TT	17.17 ab	20.07 ab	43.20 a	71.00 b
	T2. TB	16.70 b	18.80 b	20.70 bc	56.70 c
	T3. ET	16.87 b	18.75 b	22.90 b	73.00 ab
	T4. EB	16.45 b	18.92 b	23.80 b	66.60 b
	L.S.D.	0.907	1.810	12.334	7.862

123.0	C1. MS	TREATMENT ELIMINATED AT 71.0 KM.			
	C2. CN	17.85 a	19.85 a	18.27 a	61.90 a
	T1. TT	15.42 ab	16.47 ab	12.30 bc	53.20 a
	T2. TB	15.02 ab	15.07 bc	8.85 cd	43.90 a
	T3. ET	12.42 b	12.67 c	4.50 d	36.80 a
	T4. EB	14.37 b	15.32 bc	14.20 ab	56.10 a
	L.S.D.	3.420	3.538	5.768	26.402
144.0	C2. CN	16.95	17.48	9.85	50.85
166.5	C2. CN	16.00	16.18	5.65	44.58
216.5	C2. CN	13.75	3.68	0.75	35.15

NOTE: Unlike letters denote significant differences ($P<0.05$).
MS Mild steel.
CN Carbonitrided.
TT Toolcraft -top pattern.
TB Toolcraft -bottom pattern.
ET EutecBor -top pattern.
EB EutecBor -bottom pattern.

TABLE 30.

EFFECT OF WEAR ON LINEAR SHANK DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A: COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREAT-MENT	SHANK A	B	C	D	E
33.5	C1. MS	100.07ab	100.65a	100.60a	100.68a	101.25a
	C2. CN	100.27a	100.35ab	100.30a	100.40a	100.45b
	T1. TT	99.35 b	99.90 b	100.13a	100.55a	100.68ab
	T2. TB	99.80 ab	100.15ab	100.38a	100.55a	100.70ab
	T3. ET	100.15ab	100.45ab	100.68a	100.85a	101.05ab
	T4. EB	99.80 ab	100.10ab	100.23a	100.43a	100.68ab
	L.S.D.	0.890	0.558	0.646	0.676	0.674
53.5	C1. MS	80.47 c	92.37 b	99.30 a	100.75a	101.03a
	C2. CN	89.07 ab	96.70 a	100.20a	100.35a	100.50a
	T1. TT	91.55 a	97.15 a	99.77 a	100.33a	100.78a
	T2. TB	85.87 abc	94.42 ab	98.92 a	100.18a	100.60a
	T3. ET	84.55 bc	93.47 ab	99.60 a	100.80a	101.08a
	T4. EB	85.25 abc	94.47 ab	98.95 a	100.30a	100.63a
	L.S.D.	6.409	3.821	1.374	0.698	0.667
71.0	C1. MS	79.42 c	91.40 c	98.37 ab	100.70a	100.93a
	C2. CN	88.75 ab	96.22 ab	100.07a	100.37a	100.50a
	T1. TT	90.57 a	96.60 a	99.27 ab	100.20a	100.75a
	T2. TB	83.50 bc	92.05 bc	97.02 b	100.02a	100.53a
	T3. ET	82.67 bc	91.25 c	97.42 b	100.10a	101.03a
	T4. EB	84.45 abc	93.82 abc	98.57 ab	100.30a	100.83a
	L.S.D.	6.893	4.542	2.285	0.801	0.555

123.0	C1. MS	TREATMENT ELIMINATED AT 71.0 KM.				
	C2. CN	82.10 a	93.45 a	99.52 a	100.25a	100.45a
	T1. TT	79.90 ab	90.95 ab	97.55 ab	100.22a	100.77a
	T2. TB	69.60 c	85.52 bc	94.92 b	99.15 a	100.47a
	T3. ET	73.20 bc	83.70 c	94.47 b	99.27 a	100.90a
	T4. EB	75.70 abc	86.17 bc	95.22 b	99.55 a	100.67a
	L.S.D.	7.864	5.590	3.752	1.876	0.740
144.0	C2. CN	81.30	92.63	99.13	100.28	100.45
166.5	C2. CN	80.90	91.95	98.80	100.15	100.40
216.5	C2. CN	78.38	90.20	97.85	100.23	100.40

NOTE: Unlike letters denote significant differences ($P<0.05$).
MS Mild steel.
CN Carbonitrided.
TT Toolcraft -top pattern.
TB Toolcraft -bottom pattern.
ET EutecBor -top pattern.
EB EutecBor -bottom pattern.

TABLE 31.

EFFECT OF WEAR ON LINEAR WING DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B: COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREATMENT	TAIL WING	MID WING	REAR -MID	INNER WING
59.5	C1. MS	17.05 a	21.48 c	42.70 bc	75.37 c
	C2. CN	17.82 a	23.30 a	54.07 a	85.50 a
	T5. TU	17.22 a	22.35 b	49.52 ab	79.97 b
	T6. CO	17.25 a	22.28 b	45.52 bc	74.80 c
	T7. UL	17.52 a	21.98 bc	47.17 bc	75.92 c
	T8. CH	17.75 a	23.68 a	54.25 a	82.87 ab
	L.S.D.	0.793	0.624	6.614	3.979
111.0	C1. MS	16.65 c	20.70 c	32.80 c	69.40 b
	C2. CN	17.83 a	23.05 a	50.17 a	81.50 a
	T5. TU	16.93 c	21.80 b	44.10 ab	77.10 a
	T6. CO	16.93 c	22.17 b	43.45 b	69.20 b
	T7. UL	17.08 bc	21.80 b	44.22 ab	68.82 b
	T8. CH	17.58 ab	23.15 a	47.77 ab	79.77 a
	L.S.D.	0.611	0.838	6.091	4.646
143.5	C1. MS	13.37 c	14.69 b	9.00 b	36.60 c
	C2. CN	17.71 a	21.47 a	35.80 a	71.90 a
	T5. TU	14.30 bc	15.95 b	19.10 ab	49.80 bc
	T6. CO	14.75 bc	17.17 ab	25.50 ab	65.50 ab
	T7. UL	14.02 c	15.05 b	34.40 ab	64.40 ab
	T8. CH	16.70 ab	18.85 ab	17.00 ab	50.90 bc
	L.S.D.	2.502	5.222	25.644	20.587
176.5	C2. CN	15.52	16.27	2.30	18.98
	T6. CO	7.52	7.67	2.75	26.47

NOTE:
- MS Mild steel.
- CN Carbonitrided.
- TU Tungtec.
- CO Cobalarc.
- UL Ultimium.
- CH Chromium plated.

TABLE 32.

EFFECT OF WEAR ON LINEAR SHANK DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B: COATING DIFFERENCES.

DISTANCE DRILLED (KM.)	TREAT-MENT	SHANK A	B	C	D	E
59.5	C1. MS	96.92 b	99.90 a	100.47a	101.00a	101.23a
	C2. CN	100.47a	100.57a	100.50a	100.52a	100.68a
	T5. TU	97.65 b	99.82 a	100.57a	100.82a	101.00a
	T6. CO	97.05 b	100.07a	100.47a	101.17a	101.28a
	T7. UL	97.00 b	99.40 a	100.20a	100.72a	101.15a
	T8. CH	100.72a	100.50a	100.50	100.55a	100.88a
	L.S.D.	2.188	1.212	0.877	0.752	0.633
111.0	C1. MS	96.22 a	99.42 a	100.35a	100.85a	101.03a
	C2. CN	99.37 a	100.40a	100.47a	100.55a	100.63a
	T5. TU	96.37 a	99.52 a	100.25a	100.75a	100.95a
	T6. CO	95.77 a	99.35 a	100.25a	100.82a	101.18a
	T7. UL	95.92 a	99.12 a	100.00a	100.45a	100.90a
	T8. CH	97.05 a	99.12 a	100.47a	100.42a	100.85a
	L.S.D.	5.100	2.380	0.970	0.870	0.654
143.5	C1. MS	61.30 c	78.80 c	90.95 c	97.39 b	100.25a
	C2. CN	86.90 ab	93.80 ab	98.26 a	100.15a	100.75a
	T5. TU	72.80 bc	86.70 bc	95.60 abc	99.32 ab	100.67a
	T6. CO	78.00 ab	87.90 bc	95.90 ab	99.62 ab	100.72a
	T7. UL	75.30 abc	82.80 c	92.38 bc	98.47 ab	100.65a
	T8. CH	88.80 a	97.60 a	100.25a	100.47a	100.70a
	L.S.D.	14.393	9.558	4.808	2.402	0.807
176.5	C2. CN	66.70	85.35	97.52	100.70	101.27
	T6. CO	66.85	84.50	94.42	99.95	100.82

NOTE: MS Mild steel.
CN Carbonitrided.
TU Tungtec.
CO Cobalarc.
UL Ultimium.
CH Chromium plated.

In the field, it appeared that the coulter blade wings were being worn away before the leading edge of the blade shanks had eroded to an extent such that the vertical weld bead on the blade shank became responsible for upholding shank dimensional integrity.

4.3.2.2 INFLUENCE OF SIDE POSITIONING.

Mean dimensional data with respect to the disc component are presented for each run in Tables 33 and 35 for wing dimensions and Tables 34 and 36 for shank dimensions.

Coulter blade positioning appeared to influence the upper shank measurements with distance. Considering the disc interaction in the upper shank region, no side differences were expected due to this phenomenon since it was common to both sides of the disc. This was borne out by Experiment 2. However, no seed or fertiliser was drilled in that experiment. The hypothesis that seed and/or fertiliser had influenced linear dimensions in this region was considered. Over both runs, the left side (fertiliser) mean was greater than the corresponding right side (seed) mean in all 29 instances where side influences on dimensions were statistically significant. The aggregated mean for significant left side dimensions was 76.59mm. compared with 75.48mm. for that of the right side. This represented 1.47% less wear for the left position, over all dimensions measured. The expectation that fertiliser corrosion and/or granule deformation may have been affecting

TABLE 33.

EFFECT OF WEAR ON LINEAR WING DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLIN COULTER.

EXPERIMENT 3: RUN A: SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	TAIL WING	MID WING	REAR -MID	INNER WING
33.5	Left	18.18	22.53	47.74	81.02
	Right	16.87	21.50	45.76	80.24
	L.S.D.	0.505	0.490	1.675	1.203
	SIG.	*	*	*	NS
53.5	Left	17.62	19.94	33.54	70.40
	Right	16.08	19.25	30.86	68.60
	L.S.D.	0.449	0.814	4.130	2.916
	SIG.	*	NS	NS	NS
71.0	Left	17.43	19.51	22.60	65.30
	Right	15.93	18.57	25.30	63.00
	L.S.D.	0.523	1.045	7.128	4.536
	SIG.	*	NS	NS	NS
123.0	Left	15.50	16.21	10.34	51.00
	Right	14.54	15.55	12.91	49.80
	L.S.D.	2.480	2.567	4.184	19.161
	SIG.	NS	NS	NS	NS
144.0	Left	17.85	18.35	10.50	49.65
	Right	16.05	16.60	9.20	52.05
		(CARBONITRIDED TREATMENT ONLY)			
166.5	Left	16.75	16.95	4.55	43.45
	Right	15.25	15.40	6.75	45.70
		(CARBONITRIDED TREATMENT ONLY)			
216.5	Left	14.55	0	0	35.20
	Right	12.95	7.35	1.50	35.10
		(CARBONITRIDED TREATMENT ONLY)			

* Significantly different at the 5% level.

NS Not significantly different.

TABLE 34.

EFFECT OF WEAR ON LINEAR SHANK DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A: SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	SHANK A	B	C	D	E
33.5	Left	99.80	100.44	100.83	101.01	101.02
	Right	100.02	100.09	99.93	100.14	100.54
	L.S.D.	0.527	0.350	0.383	0.401	0.399
	SIG.	NS	*	*	*	*
53.5	Left	85.33	94.78	100.29	100.94	101.03
	Right	86.92	94.75	98.62	99.96	100.51
	L.S.D.	3.700	2.205	0.793	0.404	0.387
	SIG.	NS	NS	*	*	*
71.0	Left	84.34	94.02	99.57	100.80	100.99
	Right	85.45	93.09	97.34	99.77	100.53
	L.S.D.	3.981	2.622	1.320	0.462	0.320
	SIG.	NS	NS	*	*	*
123.0	Left	75.80	88.19	97.51	100.38	100.88
	Right	76.40	87.73	95.17	99.00	100.43
	L.S.D.	5.704	4.055	2.723	0.373	0.537
	SIG.	NS	NS	NS	*	NS
144.0	Left	80.85	93.15	100.20	100.90	100.90
	Right	81.75	92.10	98.05	99.65	100.00
		(CARBONITRIDED TREATMENT ONLY)				
166.5	Left	80.30	91.85	99.70	100.70	100.85
	Right	81.50	92.05	98.90	99.60	99.95
		(CARBONITRIDED TREATMENT ONLY)				
216.5	Left	77.60	90.05	98.80	100.85	100.85
	Right	79.15	90.35	96.90	99.60	99.95
		(CARBONITRIDED TREATMENT ONLY)				

* Significant at the 5% level.
NS Not significant.

TABLE 35.

EFFECT OF WEAR ON LINEAR WING DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B: SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	TAIL WING	MID WING	REAR -MID	INNER WING
59.5	Left	18.06	23.10	49.13	79.08
	Right	16.82	21.92	48.62	79.07
	L.S.D.	0.458	0.361	3.819	2.298
	SIG.	*	*	NS	NS
111.0	Left	17.74	22.43	42.54	74.08
	Right	16.58	21.79	44.97	74.52
	L.S.D.	0.354	0.484	3.516	2.683
	SIG.	*	*	NS	NS
143.5	Left	15.35	17.40	23.20	53.30
	Right	14.94	17.00	23.70	59.70
	L.S.D.	1.444	3.014	14.816	11.875
	SIG.	NS	NS	NS	NS
176.5	Left	13.92	14.07	2.75	33.96
	Right	9.13	9.88	2.30	11.50
		(CARBONITRIDED AND COBALARC TREATMENTS ONLY)			

* Significantly different at the 5% level.
NS Not signficantly different.

TABLE 36.

EFFECT OF WEAR ON LINEAR SHANK DIMENSIONAL CHANGES (MM.)

OF A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B: SIDE DIFFERENCES.

DISTANCE DRILLED (KM.)	SIDE	SHANK A	B	C	D	E
59.5	Left	98.36	100.51	101.23	101.39	101.35
	Right	98.25	99.60	99.67	100.21	100.72
	L.S.D.	1.264	0.700	0.508	0.434	0.365
	SIG.	NS	*	*	*	*
111.0	Left	95.94	99.62	100.97	101.22	101.28
	Right	97.63	99.37	99.62	100.06	100.56
	L.S.D.	2.944	1.376	0.559	0.501	0.378
	SIG.	NS	NS	*	*	*
143.5	Left	74.30	87.30	96.53	100.01	100.97
	Right	80.10	88.70	94.58	98.47	100.28
	L.S.D.	8.310	5.525	2.776	1.386	0.466
	SIG.	NS	NS	NS	*	*
176.5	Left	73.29	88.54	97.97	100.20	101.02
	Right	60.26	81.31	93.98	99.95	101.07

(CARBONITRIDED AND COBALARC TREATMENTS ONLY)

* Significant at the 5% level.
NS Not significant.

readings appeared credible. On the other hand, some influence from seed sowing might not have been unexpected. It has been reported (Sharp 62) that silica (hardness about 1060 $kg.mm^{-2}$, Richardson 57) was incorporated in stiffening networks in many plant structures. This may have been expected to be an important abrasive in these materials, but if this was a factor, it appeared to have been overiden by a lubrication effect of the seeds (including dust, glumes etc.) interacting with the shank/disc interface.

Predominance of left side means over right side means for linear measurements raised the hypothesis that continual drill operation in an anti-clockwise direction (in order to maintain the drive wheel on the outside of corners) might have resulted in each of the coulter blades being subjected to a different proportion of the soil forces contributing to blade wear. Although soil reaction forces have not been quantified, a net reaction to blade movement was likely at incident angles for each disc side as illustrated in Figure 39a. Skewing of the disc when a corner was encountered (Figure 39b) might be expected to result in a larger force resisting both forward and outward movement of the rear of the outer coulter blade. The rear of the inner blade would move outward also, however this translation would be into soil previously disturbed by the leading edge of the same blade. Because of this shading effect, soil

Figure 39a: Diagram illustrating the probable soil reaction forces to coulter assembly travel in a straight line.

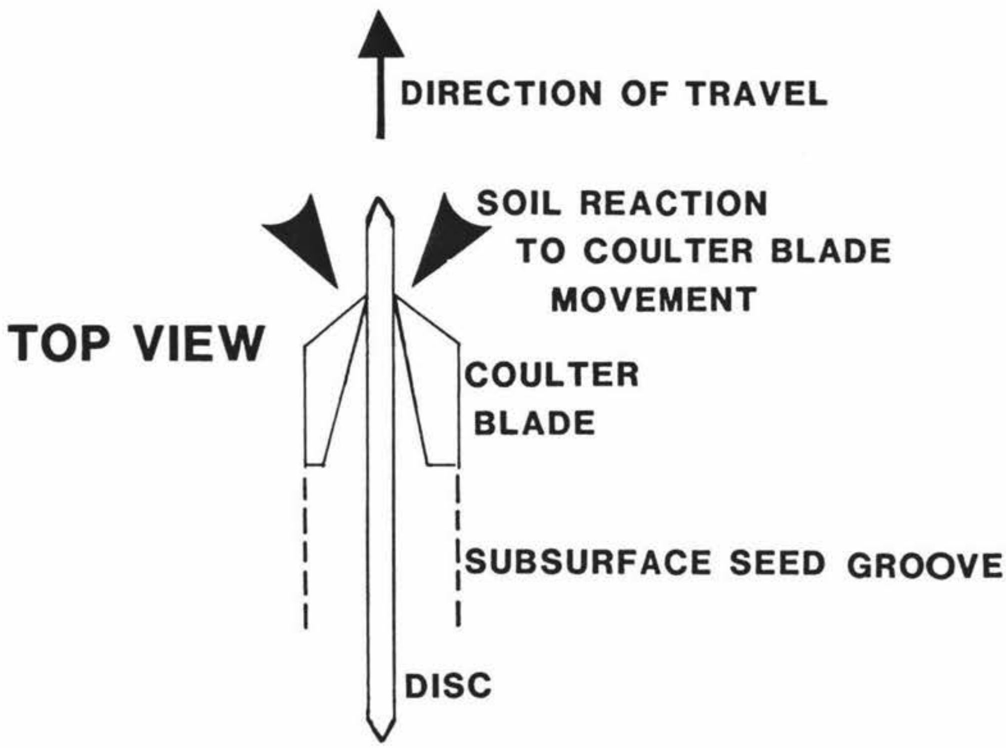
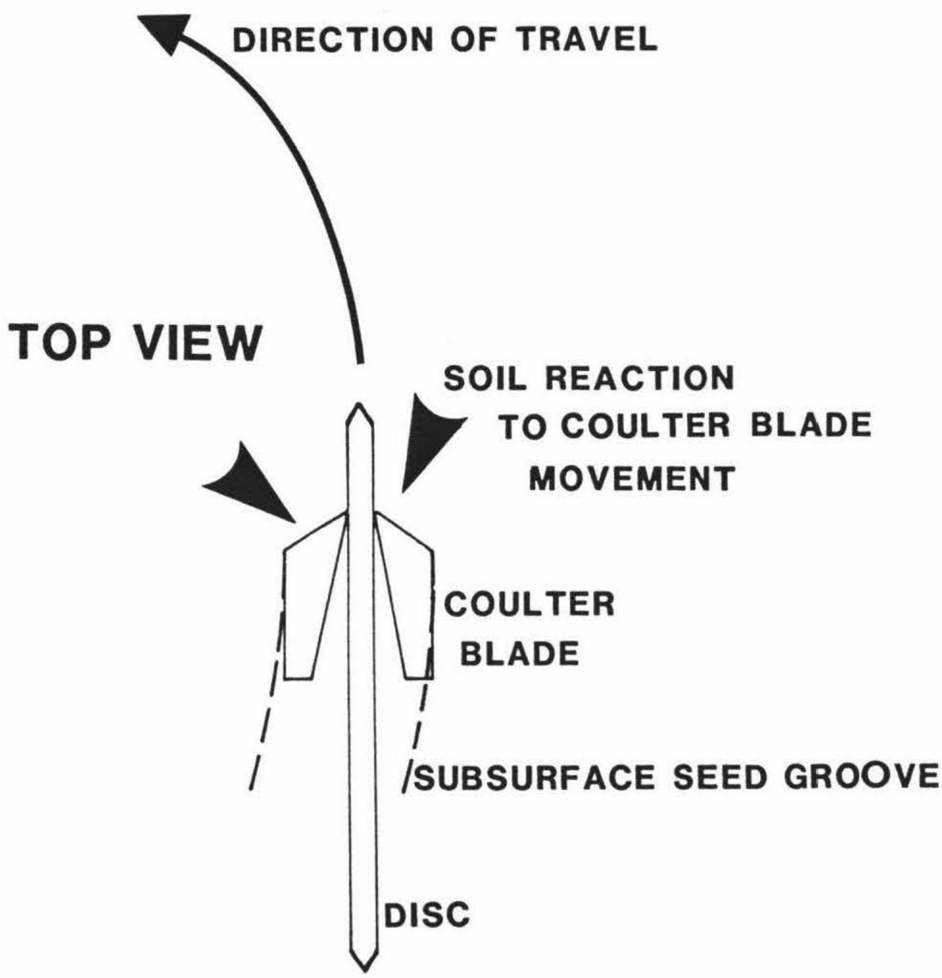


Figure 39b: Diagram illustrating the probable soil reaction forces to coulter assembly travel during cornering.



reaction on the inside of the disc was likely to have been lower than that on the outside. During field operation, increased soil reaction while turning corners was evident as a larger, more shattered seed groove on the outside of the disc.

Effects on wing measurements with respect to side positioning, particularly tail wing width, were restricted to early blade life. There appeared to be no obvious explanation for this phenomenon having occurred at that stage of the test.

The fact that the number of significant differences appearing in wing measurements was not always consistant with the difference between shank measurements within a distance interval might be explained by the presence of soil between the disc and shank components. Higher up the shank, soil was essentially absent, resulting in a similar "unlubricated" disc/coulter blade interaction to that described in Experiment 1. In the disc/lower shank region, passage of soil between components led to a wear mechanism that effectively isolated these components mechanically. From this, it was concluded that the influence of soil appeared to be the only additional factor when comparing the upper and lower shank regions.

4.3.3 INFLUENCE OF HARDNESS AND MICROSTRUCTURE.

Results of microhardness tests made on each treatment have been graphed as hardness profiles from the surface to the middle of the coulter blade cross-section. These graphs are shown in Figures 40a to 40i. These results are discussed in association with the photomicographs that follow.

Figures 41a to 41i illustrate the microstructures of a typical disc sample and the treatments tested. Each sample was etched with Nitral (2% nitric acid in ethanol) and photographed at 88 times magnification. In order to enable the microstructures to be discussed, basic metallurgical changes that are normally exhibited by an iron-carbon solution during moderate heating are outlined below.

Van Vlack (74) described that when an iron-carbon alloy with a carbon content of 0.77% was cooled from within the stable austenitic heat range, complete austenite (gamma iron) decomposition to pearlite (lamellar iron carbide in ferrite, or alpha iron) took place and was called the eutectoid reaction. Insufficient carbon in the alloy resulted in excess ferrite separating from austenite before the commencement of the eutectoid reaction, thereby leaving austenite of eutectoid composition (0.77% carbon, 99.23% iron) to decompose to pearlite and proeutectoid ferrite.

Figure 40: Hardness profiles from the weld or blade surface to the middle of the blade cross-section.

a: Disc component. b: Mild steel. c: Carbonitrided mild steel.

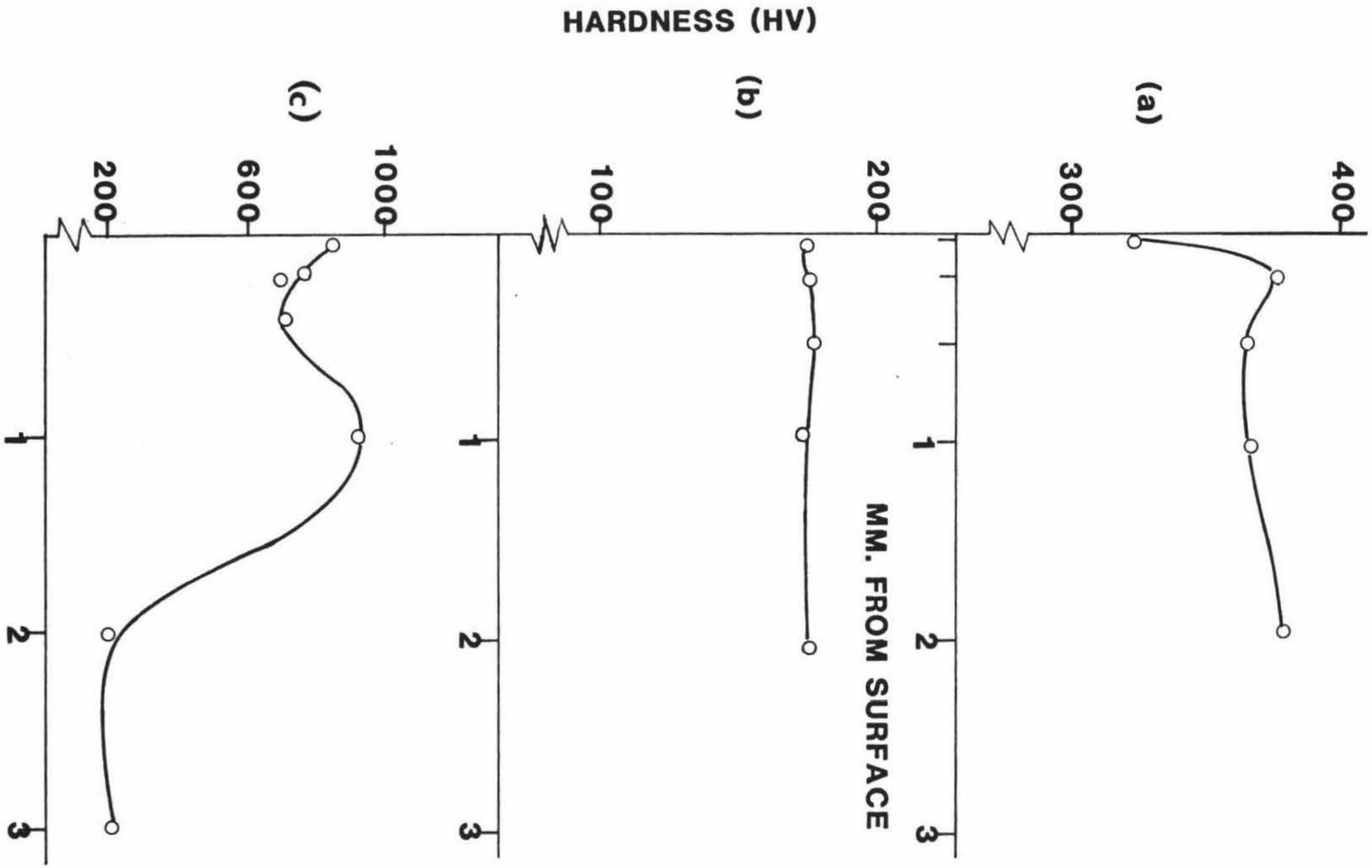


Figure 40: Hardness profiles from the weld or blade surface to the middle of the blade cross-section.
d: Toolcraft. e: EutecBor. f: Eutalloy Tungtec.

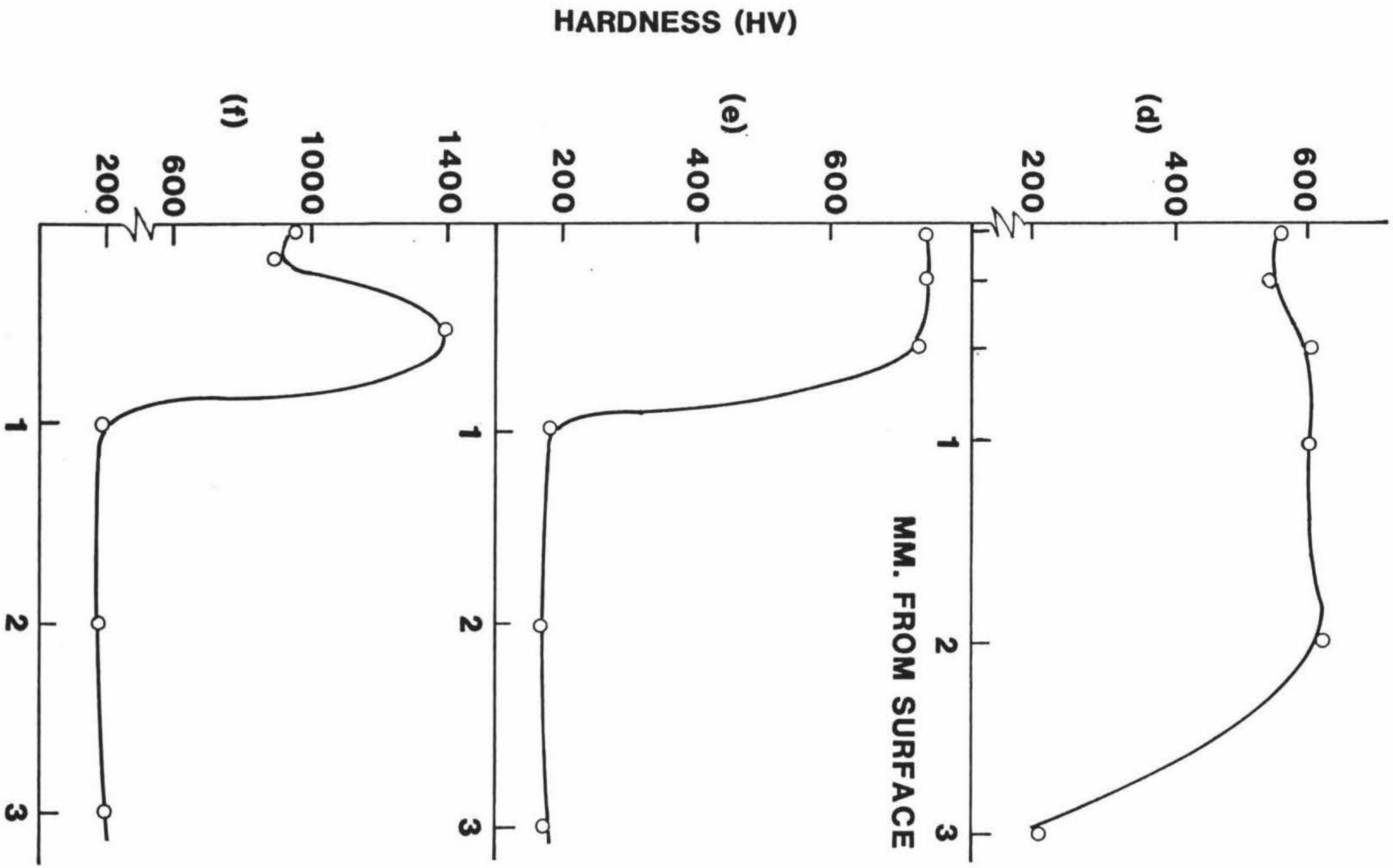
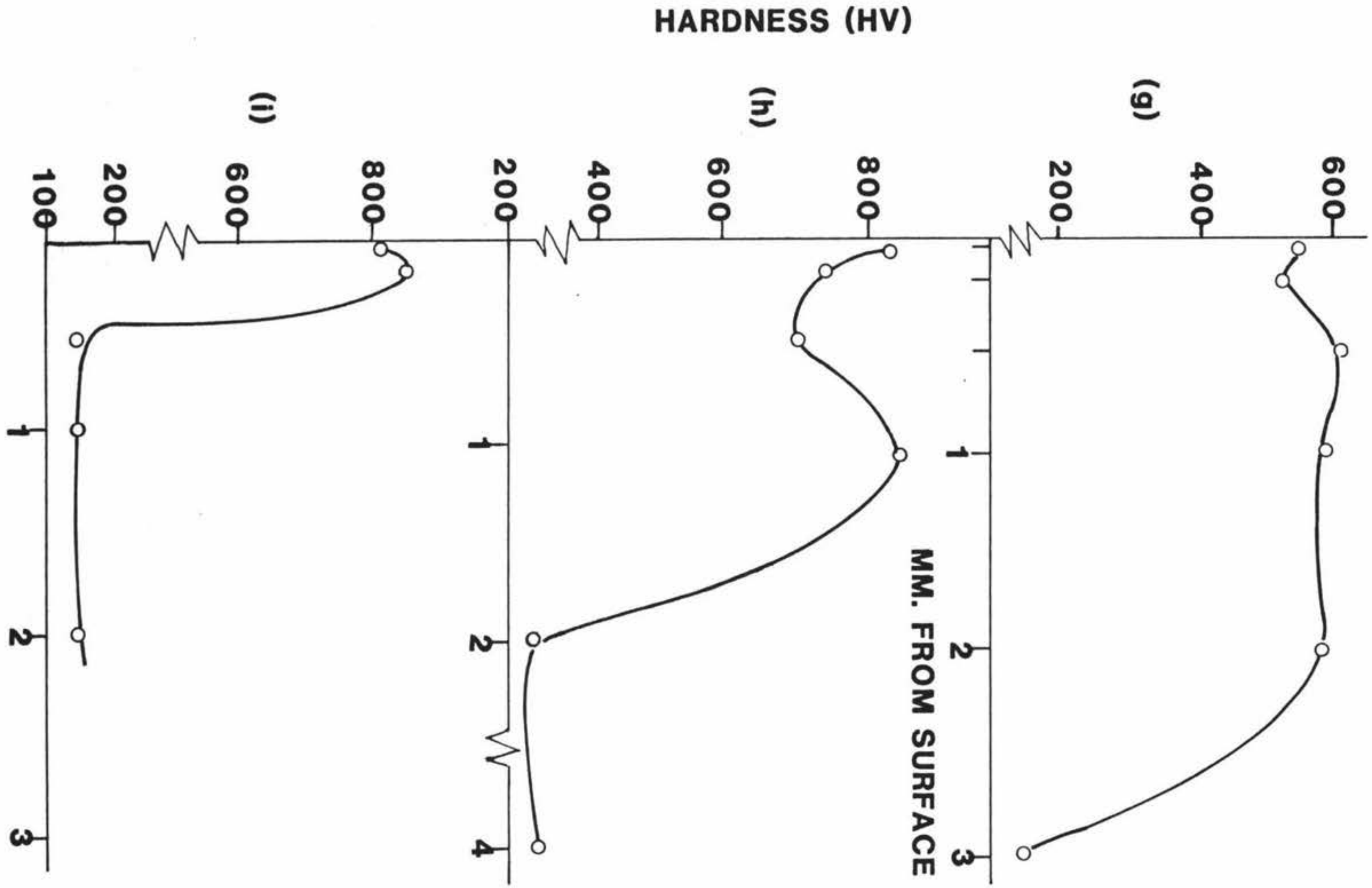


Figure 40: Hardness profiles from the weld or blade surface to the middle of the blade cross-section.
g: Cobalarc. h: Ultimium. i: Chromium plated mild steel.



Excess carbon resulted in proeutectoid carbide in the product microstructure. Very rapid cooling of austenite lead to the formation of a very hard transition phase (martensite) intermediately between austenite and pearlite. When this phase proceeded to the more stable pearlite, carbides formed a very fine dispersion in the ferrite matrix.

Figure 41a illustrates the cross-sectional microstructure of a typical disc component from the coulter assemblies. From the description of Van Vlack (74), it seems likely that the grey areas indicate that the formation of pearlite from austenite had occurred during the disc manufacturing process. Presence of the white regions are likely to be proeutectoid ferrite, indicating that the carbon content of the disc steel was less than 0.77%. The surface layer structure is not visible at this magnification. However, it is most likely to have been pearlitic.

Although heat treatment details for the disc were not available to this study, the hardness profile (Figure 40a) indicates that this steel had been heated, quenched, and then tempered to impart toughness that could withstand impact and abrasion conditions in agricultural soils. Surface hardness was HV=317.

The microstructure for the mild steel base plates used as a foundation for all other treatments is illustrated in Figure 41b. It appears that larger (lighter) areas of

Figure 41a: Disc microstructure from the surface (top) to mid cross-section. (Nitral, 88x)

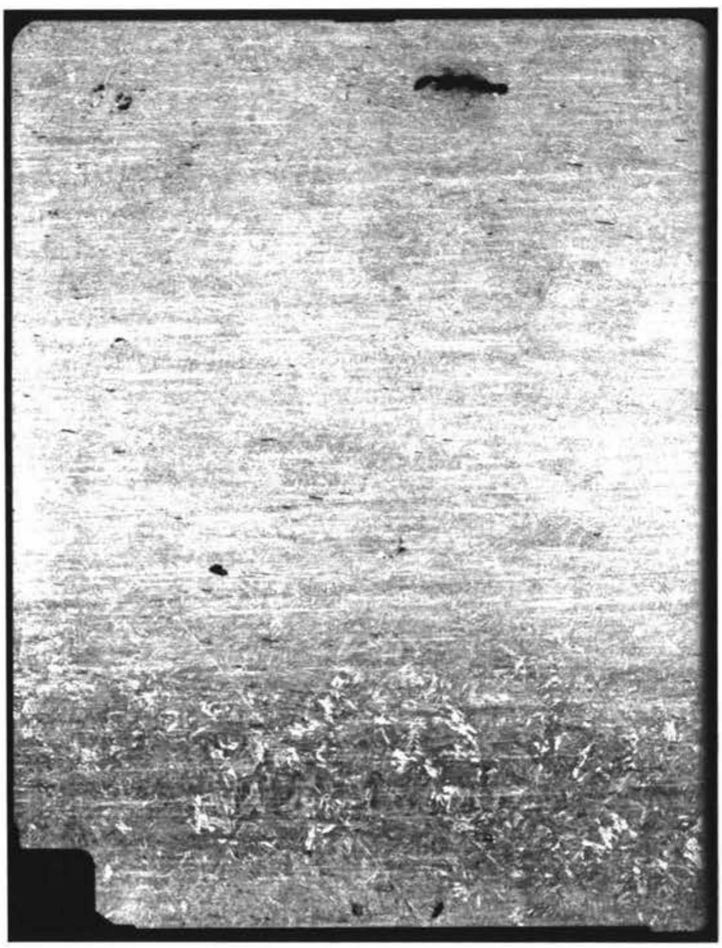
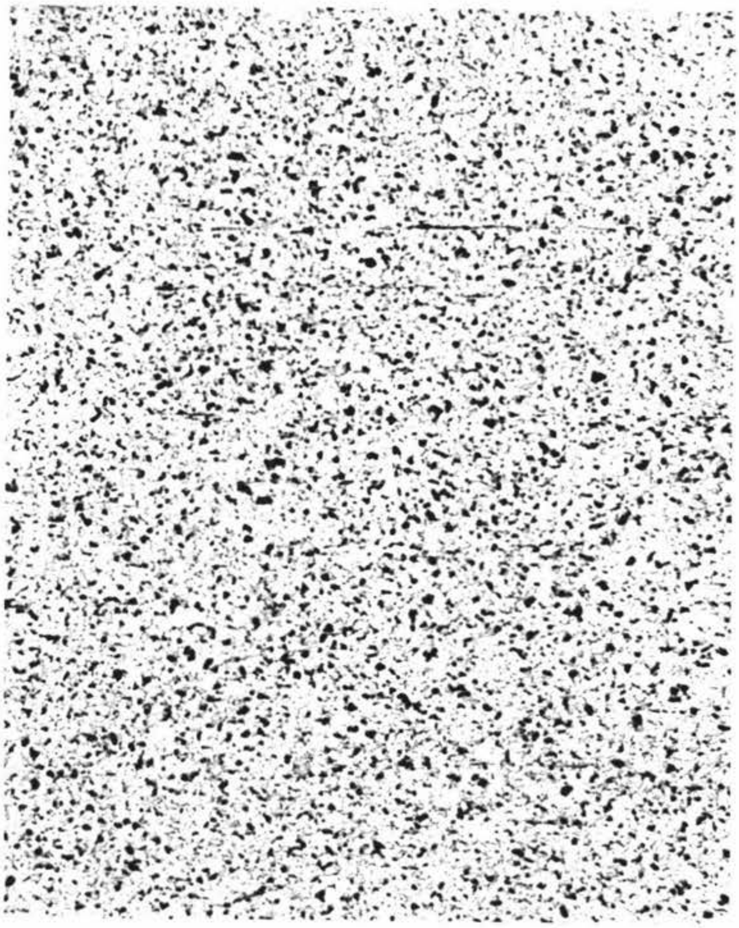


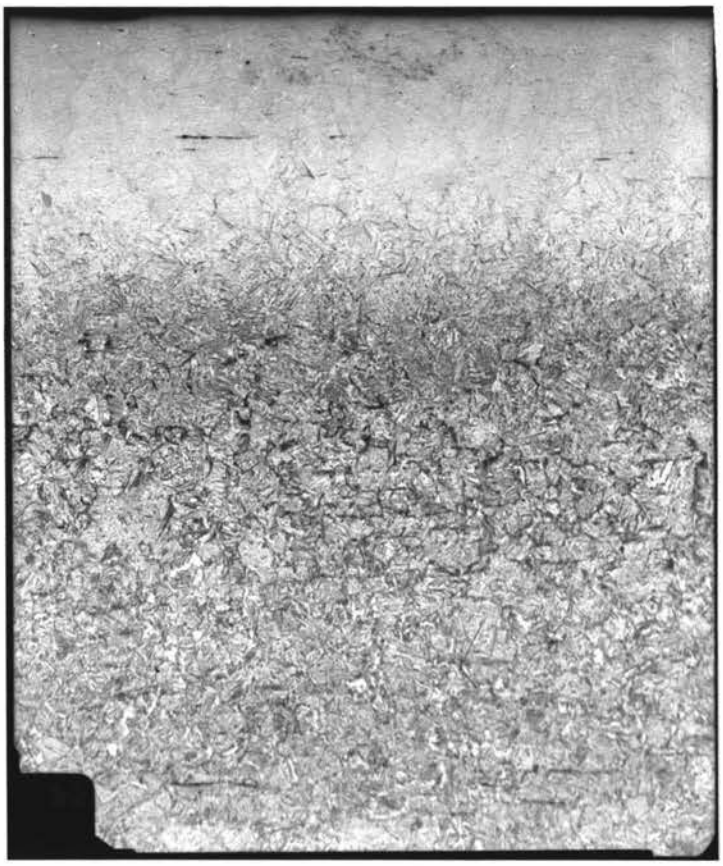
Figure 41b: Microstructure of mild steel. (Nitral, 88x)



ferrite predominate over the pearlitic regions (darker) due to the carbon content of this alloy (0.19%) not being sufficient to have allowed all of the austenite to decompose to pearlite. Pearlite has a fine grained structure in this situation, which suggests that the steel had been normalised during manufacture (air cooled from the austenitic range). Surface hardness was HV=177 (Figure 40b), which was considerably softer than the disc component upon which the coulter blades were impinging.

Figure 41c shows the microstructure obtained when mild steel was carbonitrided under the conditions outlined in Table 7, Section 3.7.3. Extra carbon from the treating oven atmosphere is likely to have enabled surface austenite to decompose completely to hard pearlite, visible as the light surface layer without any distinguishing features at this magnification. Further from the surface, the lamellar structure of pearlite can be recognised. As carbon diffusion into the alloy would have been inhibited by the physical distance from the surface, the microstructure displays proportionally more light ferrite regions. Comparing the mid-section microstructure with that of mild steel (Figure 41b) demonstrates that heat treatment during carbonitriding extended throughout the entire cross-section, which was contrary to the manufacturer's claim that the core was unaffected by such processing. This was supported by the hardness profile (Figure 40c) which showed mid-section hardness for carbonitriding well

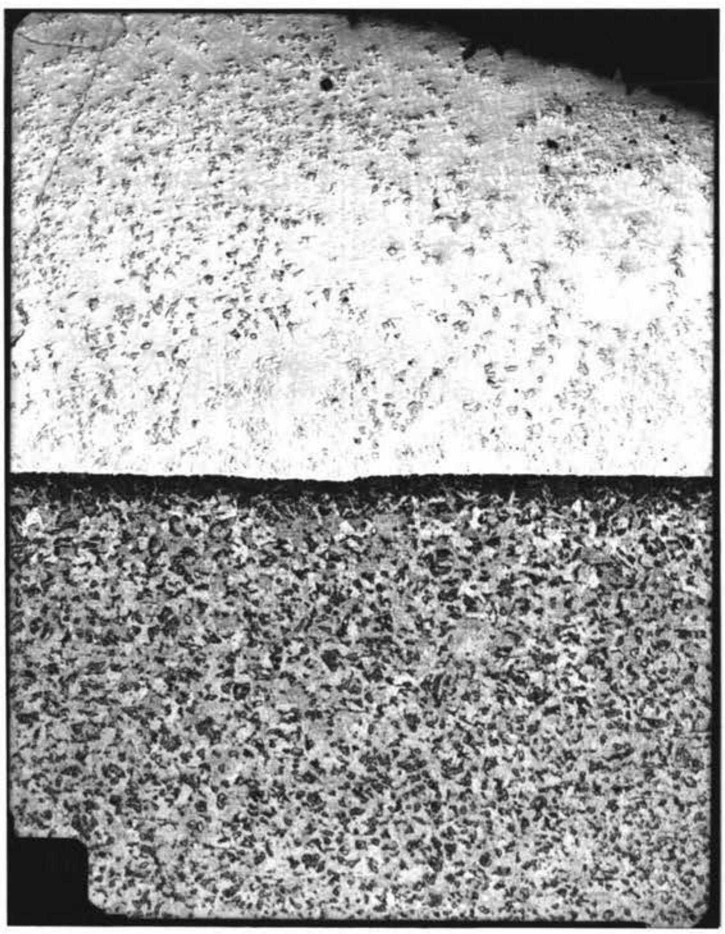
Figure 41c: Microstructure of carbonitrided mild steel from the surface (top) to mid cross-section. (Nitral, 88x)



above that for mild steel. Surface hardness was also higher than claimed (HV=836) and the hardened region extended further (1.00mm.) than the claimed case depth (0.51 mm.).

Figure 41d illustrates the microstructure of gas applied EutecBor 9000. At the time of writing, no information was available regarding material composition. It appears that the weld material was composed of carbides (probably Boron) in an austenitic matrix. Measured hardness (HV=758) was within the range claimed for this material (HV=620 to HV=800).

Figure 41d: Microstructure of gas welded EutecBor from the weld surface (top) to mid cross-section of the base plate. (Nitral, 88x)



The microstructure of arc applied Cobalarc 1A (Figure 41e) was claimed to be composed of chromium carbides (light filaments) evenly distributed throughout an austenitic (darker) matrix. While surface hardness was HV=575, this parameter varied between HV=540 and HV=631 from 0.2 to 1 mm. from the surface. This was lower than the general hardness claimed (HV=650-850) and since the photomicrograph does not show any evidence of material dilution during application, it is difficult to ascertain the cause(s) of the differences observed. Localised welding heat appears to have influenced the microstructure near the mid section of the sample. Coarse pearlite (darker) and ferrite are evident (compared to Figure 41b), indicating that the steel had been fully annealled when the welded plates were cooled slowly in a closed metal container. Annealing is usually associated with lower relative hardness after processing (Van Vlack 74). However, hardness for this treatment was essentially the same as that for the control blades.

Gas applied Eutalloy Tungtec 10112 (Figure 41f) was claimed to have contained massive tungsten carbide particles (lighter) in a nickel based matrix. Welding heat has again resulted in coarse pearlite formation in the base plate, as mentioned above, and hardness at the mid section was actually slightly higher than that of mild steel. It appears that the two measurements of hardness taken closest to the weld surface (HV=990, HV=898, Figure 40f) would have

Figure 41e: Microstructure of arc welded Cobalarc from the weld surface (top) to mid cross-section of the base plate. (Nitral, 88x)

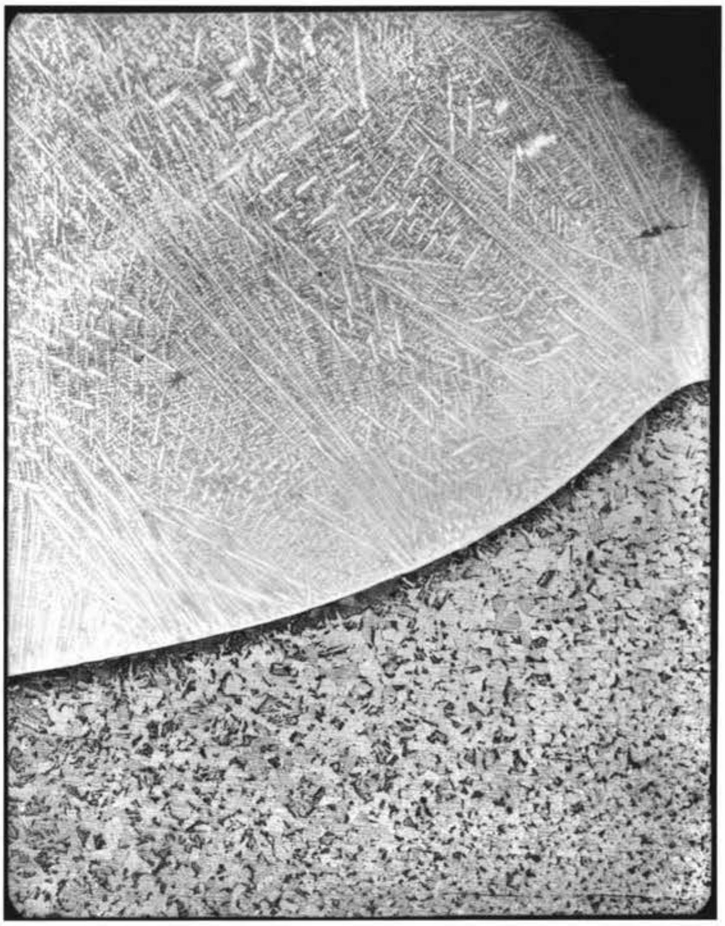
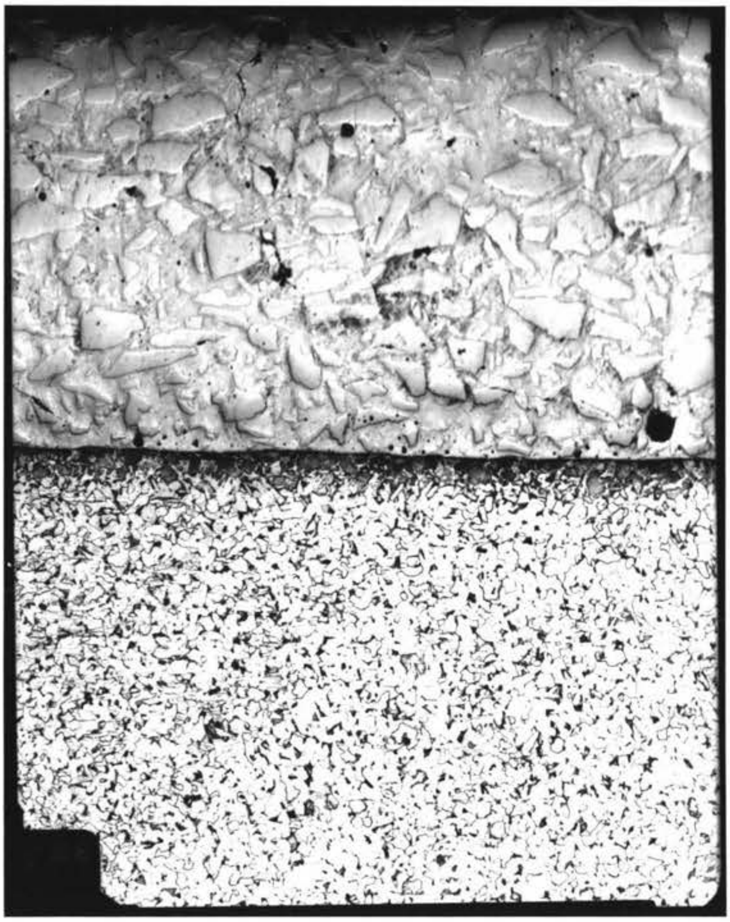


Figure 41f: Microstructure of gas welded Tungtec from the weld surface (top) to mid cross-section of the base plate. (Nitral, 88x)

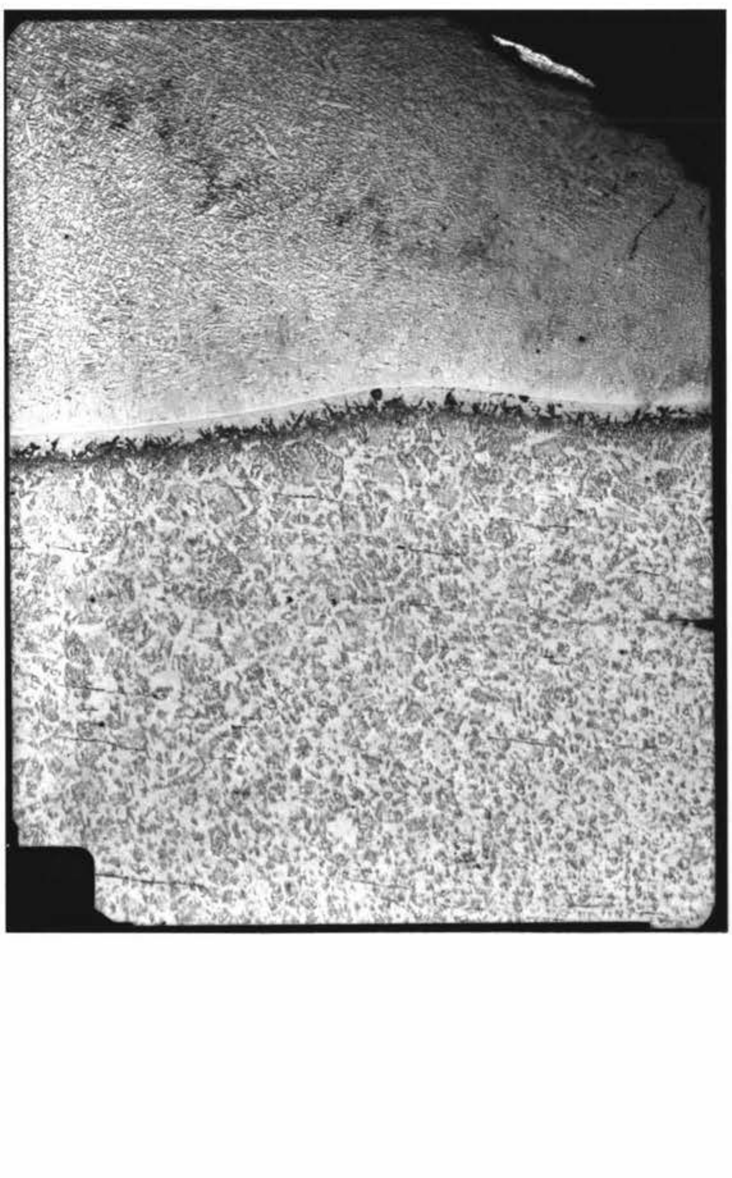


quantified that property of the matrix. The third measurement (HV=1390) is likely to have been the hardness of an individual tungsten carbide particle. Claimed general hardness for this material was HV=650 to HV=850. No explanation is apparent for the measured matrix hardness having been greater than the claimed general hardness.

Due to the property which allowed this material to be applied in very thin overlays (and also to its inherent hardness), it was expected that this treatment would have performed nearest to that of the carbonitrided treatment. This expectation was not realised however. This was primarily attributed to the selective application pattern used (discussed later) in contrast to the complete case property of carbonitrided blades.

Figure 41g illustrates the microstructure for arc applied Ultimium 112. Very finely dispersed particles made this weld essentially a layer of solid tungsten carbide. The surface hardness (Figure 40g) was equivalent to that of of carbonitrided mild steel (HV=836) but this property was maintained to a shallower depth (0.5mm.) than that treatment. The selective application pattern was again most likey to have been responsible for Ultimium not performing as well (in terms of measured wear) as carbonitrided mild steel. Welding heat has produced coarse pearlite (darker) and ferrite in the base plate as explained earlier, and the hardness of the blade mid section was greater than that for mild steel (Figure 40g).

Figure 41g: Microstructure of arc welded Ultimium from the weld surface (top) to mid cross-section of the base plate. (Nitral, 88x)

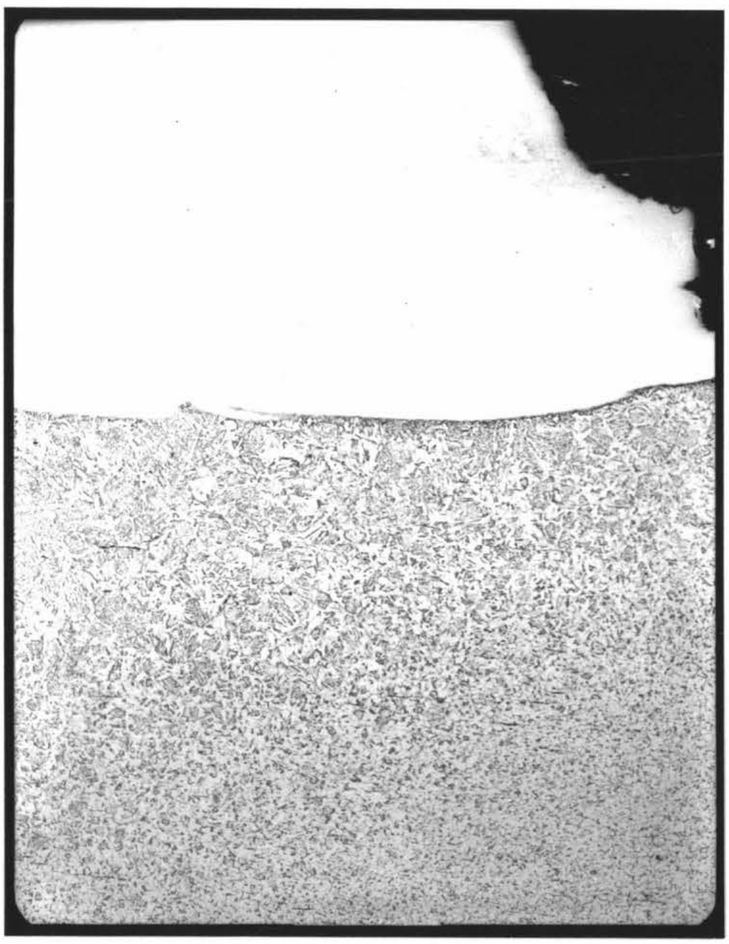


The microstructure of chromium plated mild steel can be seen in Figure 41h. Since only stress relief of the plates was carried out, there was not sufficient heat to transform the base plate microstructure. Electroplating thickness was about 0.1mm. and the hardness measured (Figure 40h) was only at the lower range of that claimed for chromium (HV=850-1040).

Figure 41i shows the microstructure of arc applied Toolcraft. Although not very clear, the weld was claimed to be composed of chromium carbides in a nickel matrix. Weld hardness varied between HV=571 and HV=627. Welding heat has apparently caused a transition from fine to coarse pearlite nearer the weld bead. Fine pearlite (darker) and ferrite are still present (lower portion of the photomicrograph) in contrast to the other welded treatments.

Figure 41h: Microstructure of chromium plated mild steel from the chromium layer (top) to mid cross-section of the base plate. (Nitral, 88x)

Figure 41i: Microstructure of arc welded Toolcraft from the weld surface (top) to mid cross-section of the base plate. (Nitral, 88x)



4.3.4 WEAR PATTERNS.

Figures 42 to 47 and 48 to 53 show the sequential wear patterns for treatments tested in Run A and Run B respectively.

For welded treatments, the pattern of wear was similar to that of the mild steel control blades until the weld beads began exerting an influence on soil flow. As the beads were worn, their influence was reduced accordingly, resulting in the pattern of wear during the later stages of blade life again being similar to that of mild steel.

As can be seen from the photographs, welded treatments almost invariably conferred two less desirable properties on the base plates. Firstly, the near-parabolic leading edges, formed during abrasive wear, were expanded in cross-section where a weld bead was initiating soil penetration. This was likely to have increased the force required for coulter penetration. Secondly, the weld bead tended to form a hook of hardened material where the softer mild steel foundation was eroded from beneath it. This caused trash to collect in the hook (Figure 54) and subsequently was observed to result in undesirable soil shattering towards the surface (Baker et al. 11). The best welded treatment, Cobalarc 1A, was the only material applied over a welded buttering run of interim hardness. This treatment either did not form a trash collecting hook of metal, or it passed through that stage without suffering in performance since there was no evidence of such a hook.

Figure 42: Field wear of mild steel blades in Run A.

a: After 33.5 km. (8.0 ha.) drilling.

b: After 53.5 km. (12.8 ha.) drilling.

c: After 71.0 km. (17.0 ha.) drilling.

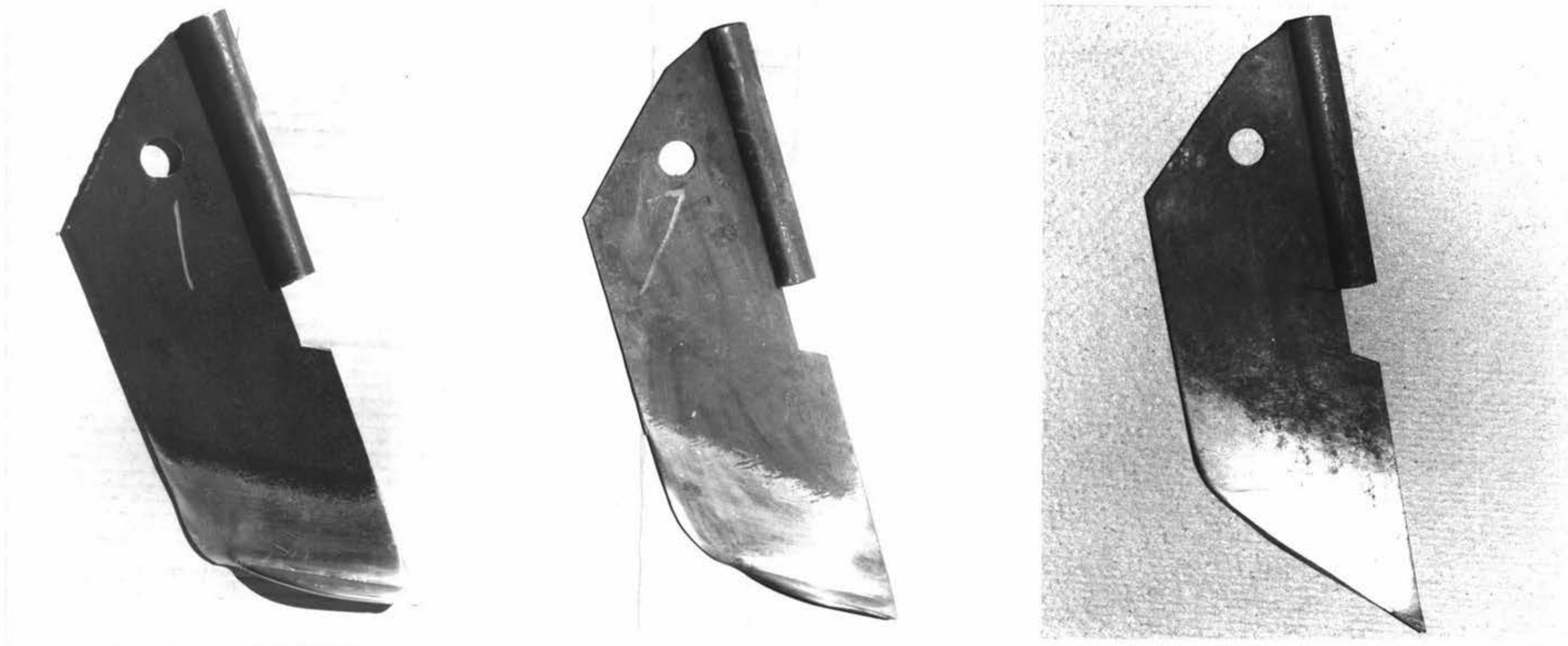
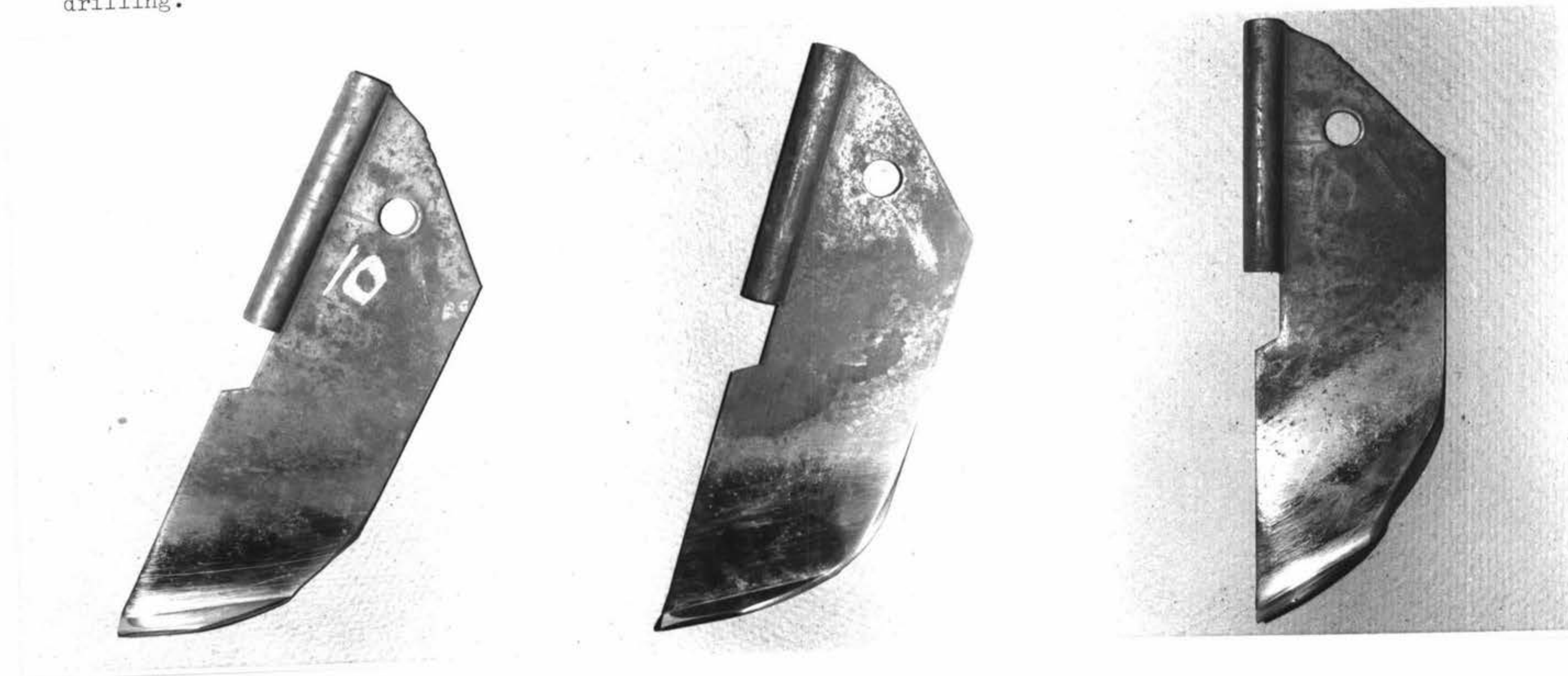


Figure 43: Field wear of carbonitrided mild steel blades in Run A.

a: After 53.5 km. (12.8 ha.) drilling.

b: After 71.0 km. (17.0 ha.) drilling.

c: After 123.0 km. (29.5 ha.) drilling.



<u>Figure 44</u>: Field wear of Toolcraft (-top pattern) welded over mild steel in Run A.

a: After 53.5 km. (12.8 ha.) drilling.

b: After 71.0 km. (17.0 ha.) drilling.

c: After 123.0 km. (29.5 ha.) drilling.

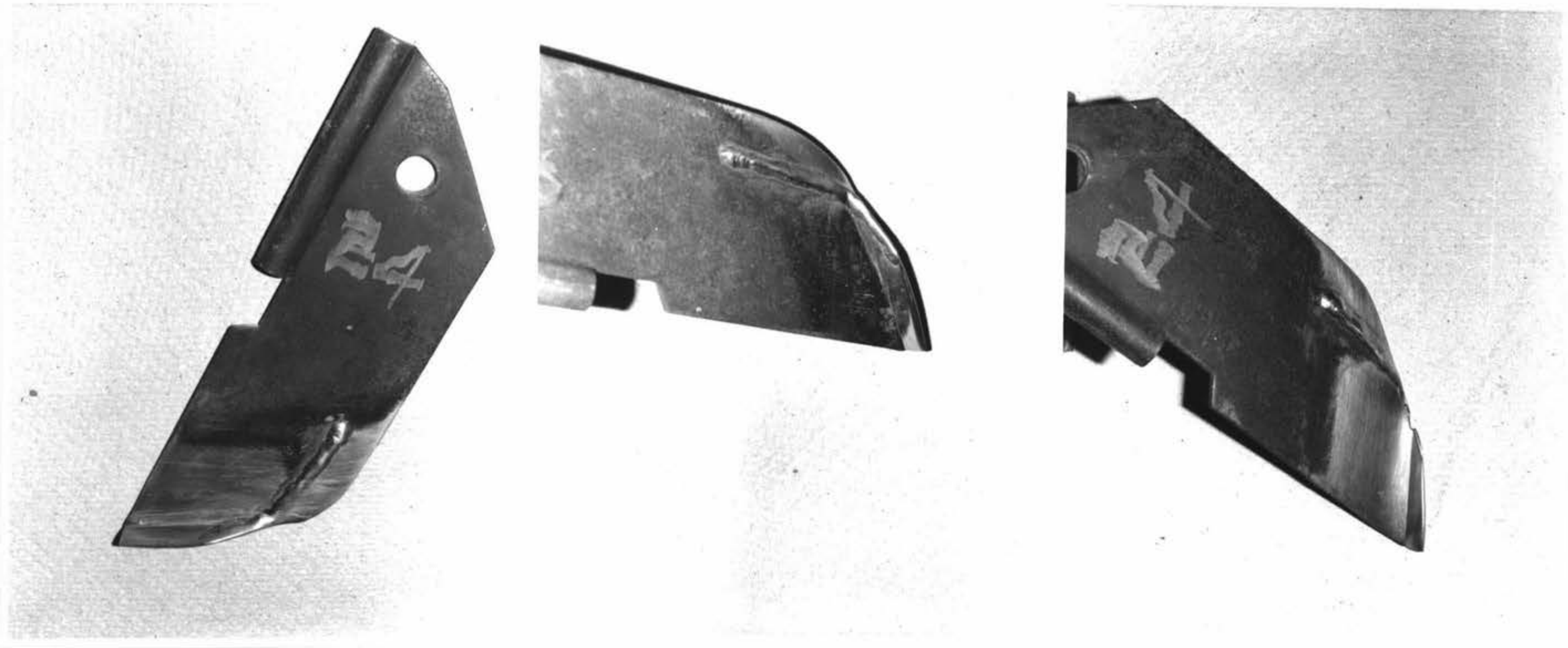


Figure 45: Field wear of Toolcraft (-bottom pattern) welded over mild steel in Run A.

a: After 53.5 km. (12.8 ha.) drilling.

b: After 71.0 km. (17.0 ha.) drilling.

c: After 123.0 km. (29.5 ha.) drilling.

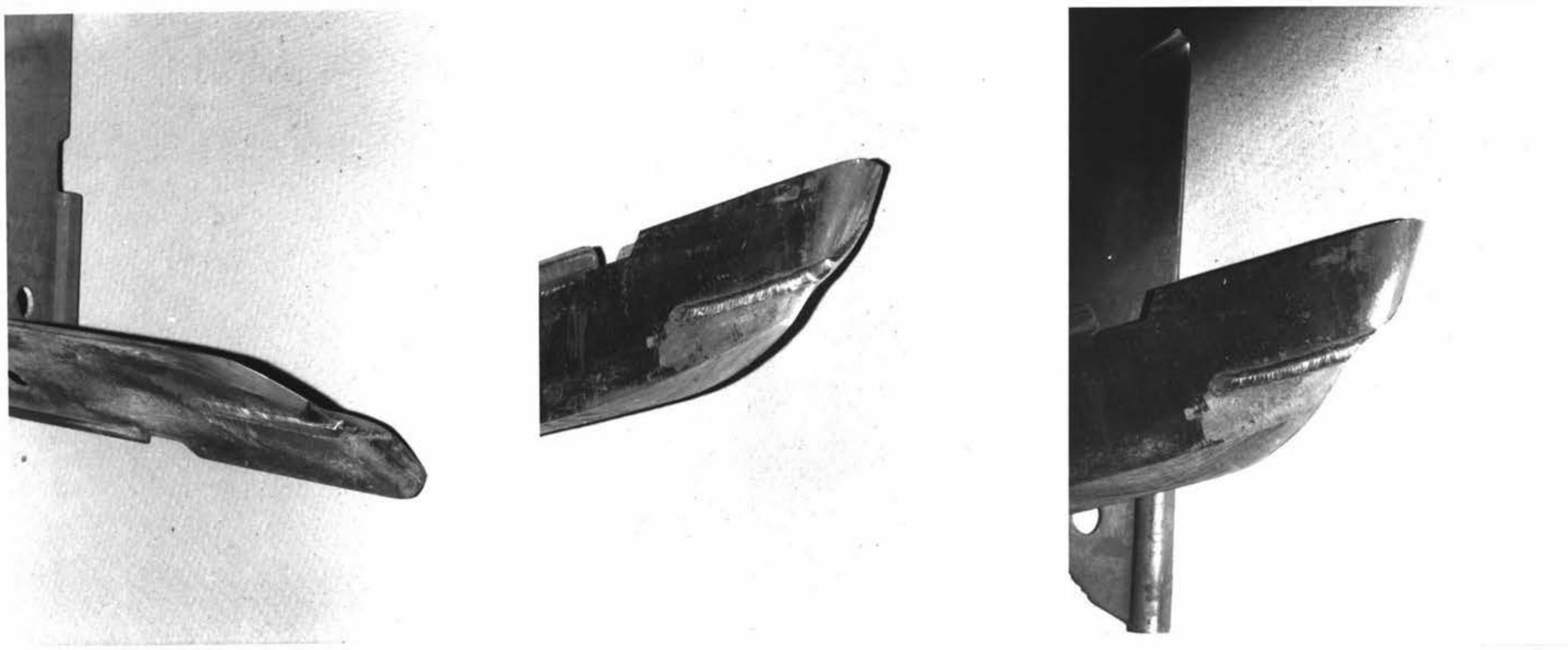


Figure 46: Field wear of EutecBor (-top pattern) welded over mild steel in Run A.

a: After 53.5 km. (12.8 ha.) drilling.

b: After 71.0 km. (17.0 ha.) drilling.

c: After 123.0 km. (29.5 ha.) drilling.

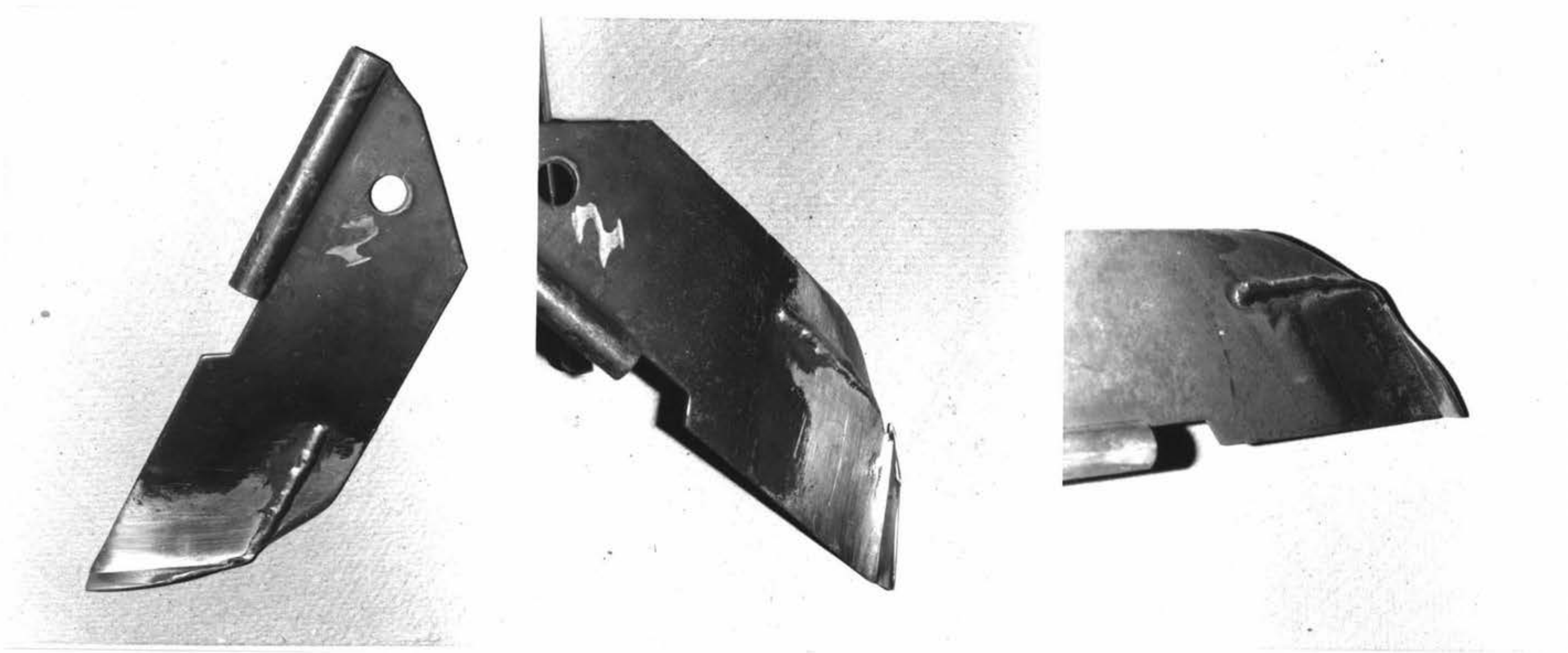


Figure 47: Field wear of EutecBor (-bottom pattern) welded over mild steel in Run A.

a: After 53.5 km. (12.8 ha.) drilling.

b: After 71.0 km. (17.0 ha.) drilling.

c: After 123.0 km. (29.5 ha.) drilling.

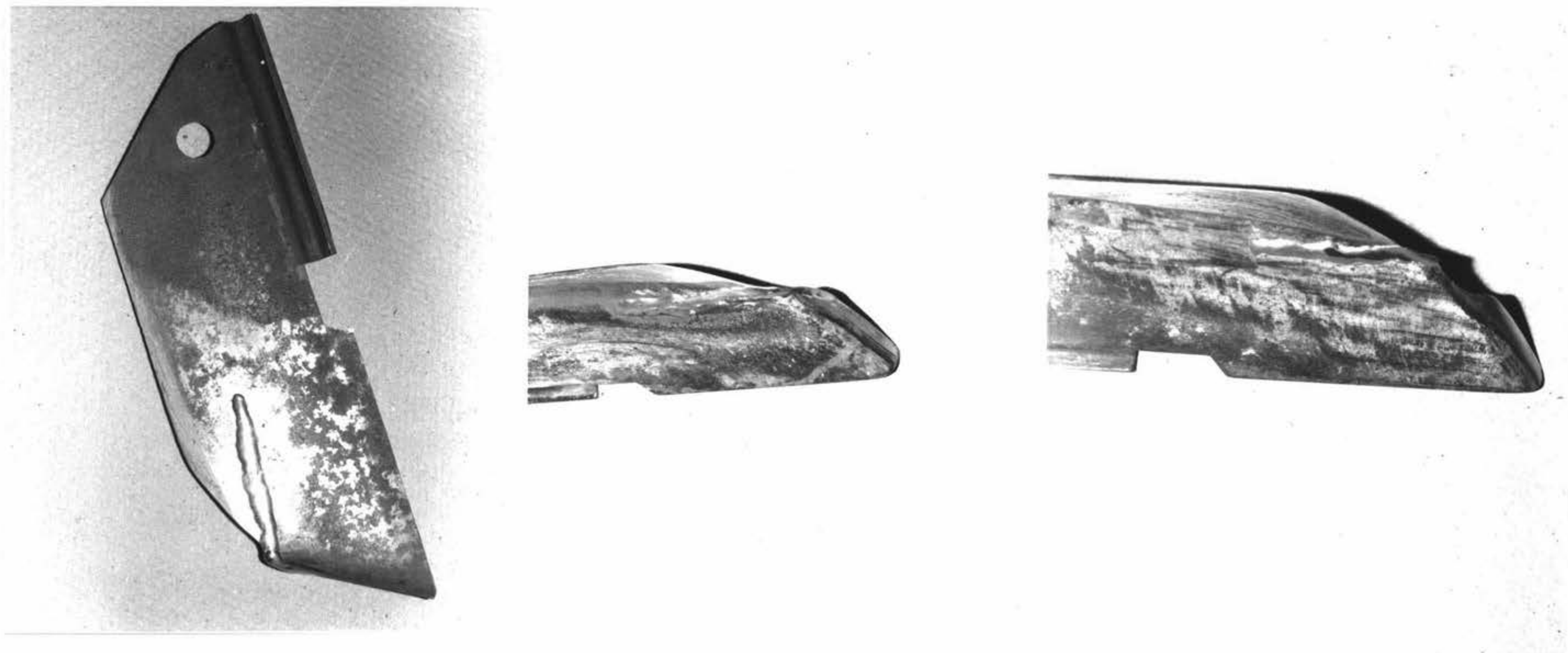


Figure 48: Field wear of mild steel blades in Run B.

a: After 59.5 km. (14.3 ha.) drilling.

b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

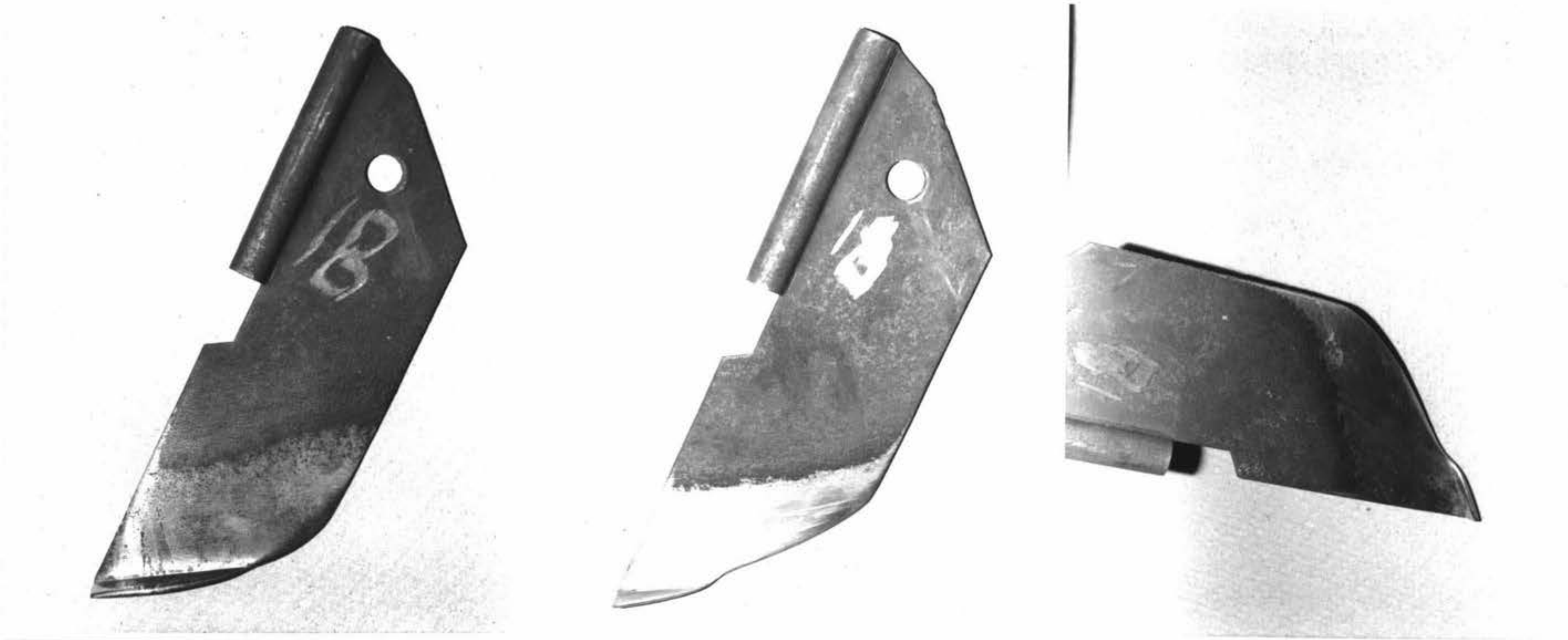


Figure 49: Field wear of carbonitrided mild steel blades in Run B.

a: After 59.5 km. (14.3 ha.) drilling.

b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

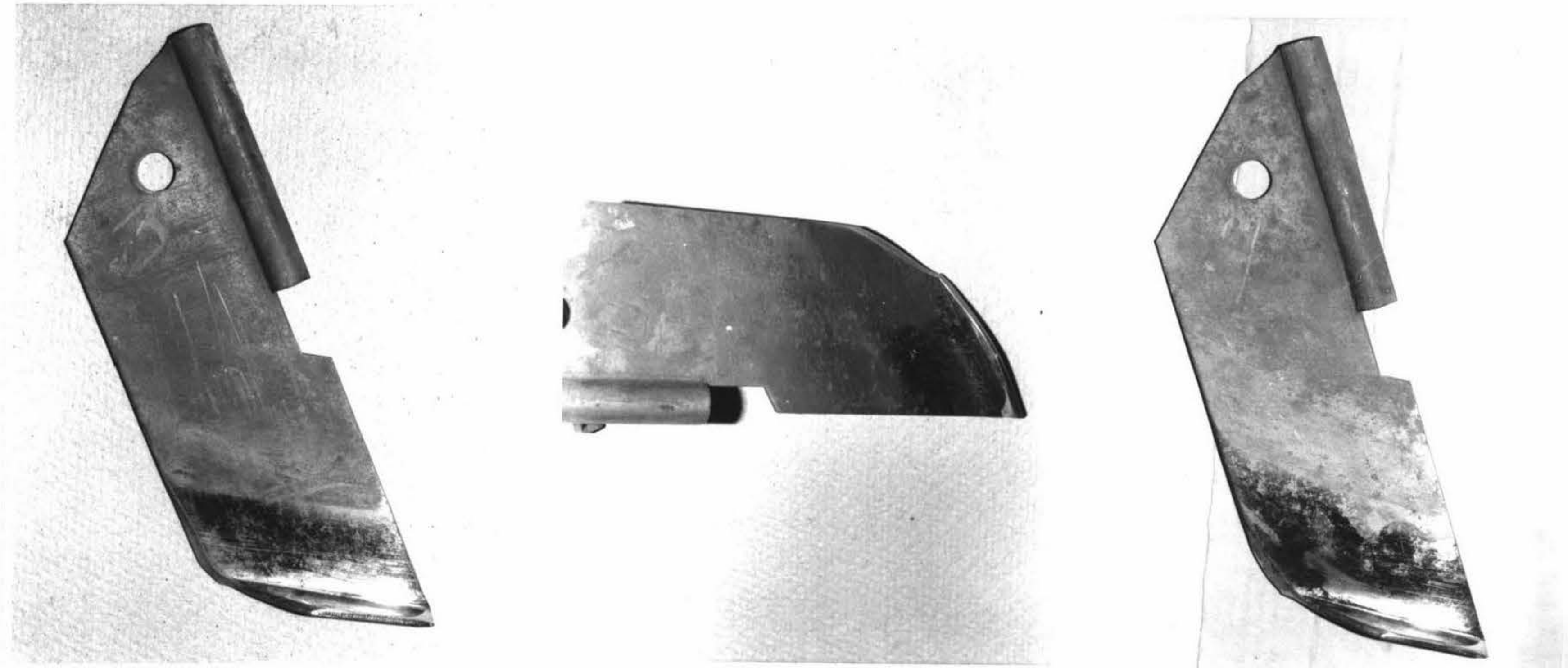


Figure 50: Field wear of Eutalloy Tungtec welded over mild steel in Run B.

a: After 59.5 km. (14.3 ha.) drilling.

b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

Figure 51: Field wear of Cobalarc welded over mild steel in Run B.

a: After 59.5 km. (14.3 ha.) drilling.

b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

Figure 52: Field wear of Ultimium welded over mild steel in Run B.

a: After 59.5 km. (14.3 ha.) drilling.

b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

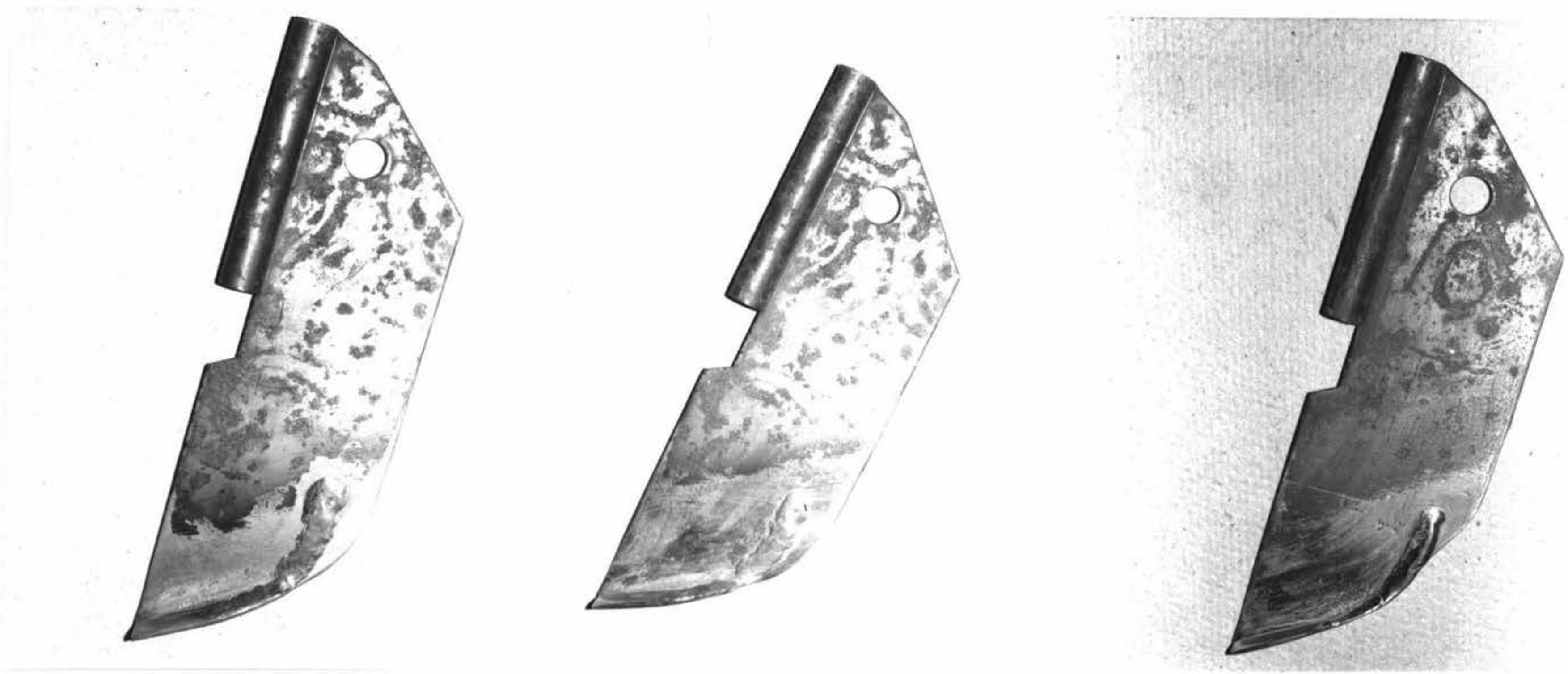
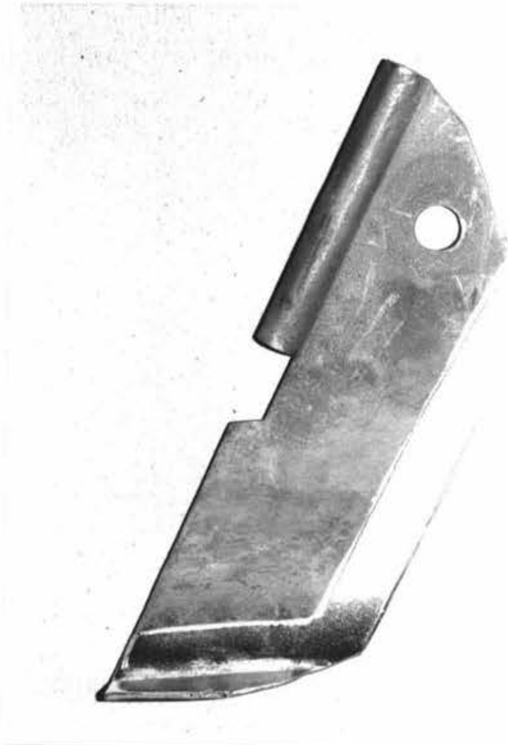


Figure 53: Field wear of chromium plated mild steel in Run B.

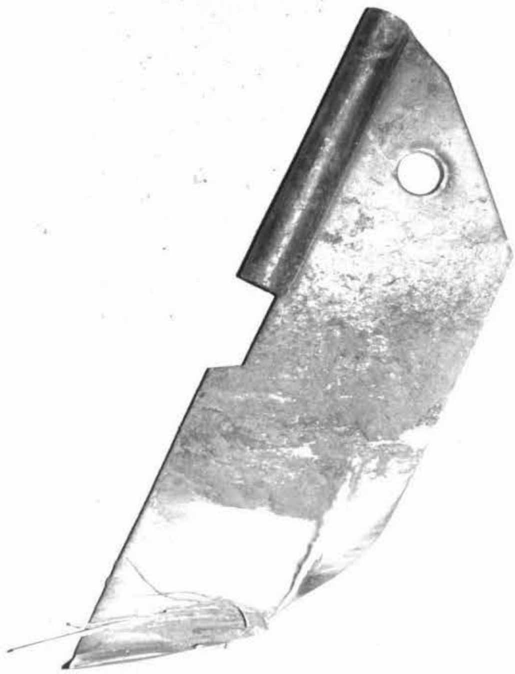
a: After 59.5 km. (14.3 ha.) drilling.



b: After 110.0 km. (26.6 ha.) drilling.

c: After 143.5 km. (34.4 ha.) drilling.

Figure 54: Trash collecting hook of hardened material (EutecBor).



Cobalarc, due to its underlying buttering run, had a weld bead that was physically thicker than other welded treatments. The overall frontal width (up to 8mm. wider than the mild steel control blade) did not appear to cause any excessive soil disruption while operating in the field. This might indicate that perhaps the initial restriction to 4mm. plate thickness (or close to it) for coulter blade fabrication could have been increased, although biological performance of seed grooves formed by welded treatments were not evaluated in any way.

Figure 55 shows the EutecBor material that was worn by contact with the disc. Since the hardness of this material was HV=758 (compared with HV=317 for the disc), the absence of a corresponding worn groove on the disc lended further support to the belief that soil was carried between the disc and coulter blade leading edge and had abraded the weld bead on the inner shank due to the hardness of soil quartz.

Once weld bead wear, that was not associated with disc contact, had been initiated, it was likely that the rate of wear was slowed in these regions, thereby reducing subsequent wing wear due to the effect of disc rotation discussed in Section 2.

Figure 55: EutecBor material worn in by disc rotation.

The chromium plated treatment, due to the selective plating on the leading edge, resulted in a marked reduction in shank wear at the inner leading edge, (Figure 56). The treatment continued to be worn in the wing area however, particularly at the shank/wing intersection, which had been difficult to electroplate correctly. More rapid wear in this region resulted in a hook of metal forming between the shank and wing, thereby effectively eliminating this treatment from contention. During the field trials, there appeared to be no trash problems at the leading edges of the chromium plated coulter blades. Since an increase in wear was not observed on the plain side of the disc component facing the plated blades, further evidence was provided that soil was the dominant component influencing wear from disc/blade grinding. It could be further concluded that the hardness of coulter blade materials need not be less than that of the more expensive disc component.

4.3.5 WEAR MODELS.

A model was tested to determine differences in metal weightloss between top and bottom weld bead patterns evaluated in Run A. The model and its accompanying hypothesis are presented in Appendix 15. There were no significant differences between upper and lower patterns.

Two different models were also tested in an attempt to ascertain the the extent to which coating hardness and side positioning had affected metal weightloss in Runs A and B. These models are outlined in Appendix 12, and a summary of

Figure 56: Typical chromium plated treatment that displayed reduced shank wear at the leading edge compared with mild steel control blades.

relevant data is contained in Tables 37 to 40. Side positioning was grouped with hardness to ensure that the analysis remained statistically balanced. In all instances, addition of side positioning to the hardness model had no significant effect (Tables 37 and 39). This was in agreement with previous analyses of the influence of side positioning on metal weightloss from blades (Section 4.3.1). As can be seen from Tables 38 and 40, over both runs the percentage of variance accounted for by hardness (plus side) differences was in the range 0.8 to 40.2. The addition of coating differences to the model increased the variance range to 63.1 to 85.5. From this it was evident that coatings were influencing metal weightloss due to some property other than their hardnesses (and side positioning). This was supported in part by weak correlation coefficients between metal weightloss and coating hardness, being in the range $r=-0.22$ to $r=-0.55$ (Appendix 14).

Two phenomena offer probable explanations for the influence of coatings. Firstly, since differences in weightloss between top and bottom weld patterns in Run A appeared insignificant, variation between individual coulter blades treated in the same manner (Section 4.3.1.1) was likely to have affected weightloss measurements. Hardness values might be expected to remain more or less consistant between replicates, although no individual measurements were made to verify this. Secondly,

TABLE 37.

THE INTERRELATIONSHIP BETWEEN HARDNESS, SIDE POSITIONING AND COATING DIFFERENCES AS A FUNCTION OF DISTANCE DRILLED BY A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A.

DISTANCE DRILLED (KM.)	MODIFICATIONS TO MODEL +HARDNESS	+SIDE	+COATING
33.5	*	NS	*
53.5	*	NS	*
71.0	*	NS	*
123.0	*	NS	*

TABLE 38.

PERCENTAGE VARIANCE ACCOUNTED FOR BY HARDNESS, SIDE POSITIONING AND COATING DIFFERENCES.

EXPERIMENT 3: RUN A.

HARDNESS+SIDE	HARDNESS+SIDE+COATING
31.1	74.2
37.7	79.8
40.2	78.4
19.7	68.0

* Significant at the 1% level.
NS Not significant.
NA Not applicable.

TABLE 39.

THE INTERRELATIONSHIP BETWEEN HARDNESS, SIDE POSITIONING AND COATING DIFFERENCES AS A FUNCTION OF DISTANCE DRILLED BY A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN B.

DISTANCE DRILLED (KM.)	MODIFICATIONS TO MODEL		
	+HARDNESS	+SIDE	+COATING
59.5	*	NS	*
111.0	*	NS	*
143.0	NS	NS	*

TABLE 40.

PERCENTAGE VARIANCE ACCOUNTED FOR BY HARDNESS, SIDE POSITIONING AND COATING DIFFERENCES.

EXPERIMENT 3: RUN B.

HARDNESS+SIDE	HARDNESS+SIDE+COATING
2.5	85.5
0.8	79.6
NA	63.1

* Significant at the 1% level.
NS Not significant.
NA Not applicable since only two treatments involved.

microstructural differences between treatments were likely to have been the predominating factor affecting wear. Such differences are discussed in Section 4.3.6.

Tables 38 and 40 also show that some variable, other than coating (and side) differences was responsible for residual variation in metal weightloss. This was in the range 14.5 to 36.9% of total variance. It was possible that this residual variation was due to the inherent variation between the cold-stamped base coulter blades. As previously discussed in Section 4.3.1.1, these blades showed a surprising weightloss variance between individuals and were no more consistant in this respect than most welded treatments. When these blades were carbonitrided, variation between individual blades was markedly reduced. When the base blades were treated by welding or chromium plating (which did not substantially alter the base material other than directly under the weld bead), it was likely that individual blade differences might have arisen in the form of residual variation. This may have occurred when the weld bead or plated layer had worn to a point where its influence on wear patterns of the base plate was either reduced or perhaps totally eliminated.

4.3.6 SUMMARY OF EXPERIMENT 3.

Carbonitrided mild steel demonstrated significantly better wear characteristics, in terms of resistance to metal weightloss and dimensional alterations, than all other treatments during field operation. Arc welded Cobalarc appeared to be the best of the remaining treatments.

Side positioning of blades influenced upper shank dimensions throughout coulter life, and wing dimensions in later blade life. Upper shank effects were attributed to seed/fertiliser differences and wing dimensional changes to inside coulter blade shading during cornering.

The superior wearing qualities of carbonitrided mild steel compared with all other treatments was attributed to the continuous resistance to wear over the complete soil engaging region of the coulter blade throughout blade life. Wear resistance was due in part to relatively high surface hardness (attributable to the carbon and nitrogen enriched case) and in part to the predominantly pearlitic microstructure of the cross-section of the blade that resisted wear to a greater extent than mild steel, even when the hard surface case had been eroding away.

Chromium plating was successful as a wear inhibitor only in the early life stages. Difficulty was encountered when plating the shank/wing intersection and this region was the first to abrade away during field drilling. Several chips of chromium were forced out of treatment surfaces, particularly on the blade leading edge, during testing. This was attributed to the combined effects of a brittle plating product and the non-metallurgical bond between mild steel and the electroplated layer.

Welded treatments were disadvantaged by having been applied in selective patterns compared with complete base plate coverage achieved when mild steel was carbonitrided. Microstructurally all welded materials offered what seemed to be a huge potential for wear reduction, but to utilise this potential it would have been necessary to cover the entire wearing regions with hardened material. This was likely to have been biologically unacceptable due to greater soil shattering at the soil surface, and almost certainly would have been economically unacceptable due to high inherent material and labour costs.

5 DISCUSSION AND CONCLUSIONS.

Experiment 1.

Measurements taken of soil degradation with time did not indicate sequential breakdown of soil particles because of passage between the disc and blade components. However, visual observations and photographs of these components illustrated that the presence or absence of soil had markedly influenced the mechanisms of wear observed. Where soil had been present, wear appeared to have been low stress scratching abrasion. Where soil was absent, the mechanism appeared to have been adhesive, since the coulter blade had clearly been in direct contact with the disc in this situation. This evidence, combined with the observation that both noise and heat levels were lower on those sides associated with soil introduction, strengthened the possibility that soil "lubrication" was occurring at the blade/disc interface during normal field drilling, but that this was not leading to soil degradation or breakdown.

Experiment 2.

Side positioning appeared to be the main influence on metal weightloss recordings. This was likely to have been due to continual anti-clockwise machine operation.

Wing dimensions were affected in later blade life by coating differences. Tail wing width was influenced throughout blade life by both coating and side differences. Shank dimensions were influenced by both of these parameters in early blade life.

All coating differences showed the welded treatments to have been more resistant to dimensional changes than the control blades. This was supported by photographic evidence.

Coating differences have been explained by either of the following phenomena:

1. Where the weld bead was isolated from the regions where measurements were taken, the weld bead may have influenced soil flow in a manner that resulted in the measured dimensions (tail wing width, shank dimensions) being less affected than those of the control blades.

2. The weld bead directly upheld some measured dimensions (mid wing length, rear-to-mid length and inner wing length) so that a wear differential was established between welded and control treatments.

All side positioning effects on dimensions indicated that the right side had sustained more dimensional changes than the left side. It appeared that uni-directional cornering was the likely causal factor.

A fore/aft position effect on tail wing width may have been present in this experiment. However, in analyses of all other measurements in Experiment 2 and in all measurements in Experiment 3, this difference was not repeated. Thus some doubt exists as to whether or not a fore/aft factor was involved in blade life.

No effects due to lateral assembly positioning were evident throughout this test.

It could be concluded that welded hardfacing materials offered some improvement to coulter life, in terms of resisting dimensional changes. This resistance was considered to be important in maintaining the reported biological success of the coulter assembly for an extended length of time.

During blade operation, soil abrasion on both the wing and outer shank occurred simultaneously with wear on the inner shank. In the latter case, disc rotation against the coulter blade, with its accompanying soil "lubrication", eventually wore the blade leading edge to the shape of the disc radius. As the blade leading edge/wing intersection was worn away, wear was accelerated in the blade wing region. This same action eroded the softer base metal from beneath weld beads, which eventually resulted in a chip of hardened metal being taken from the blade leading edge. This left a hook that collected trash.

Thus overall wear was likely to have been determined by the two afore-mentioned mechanisms, with individual rates of wear being largely dependent on prevailing soil conditions.

From the above observations, the weld bead pattern used in this test was modified for use in Experiment 3 in an attempt to prevent or delay hook formation as well as maintain the integrity of the blade leading edge/wing intersection. An alternative weld bead pattern was designed to avert the increased penetration force required when hardened weld beads were worn to a wider parabolic leading edge cross-section compared to that of mild steel.

Experiment 3.

In contrast to Experiment 2, coating differences were responsible for almost all the variation in metal weightloss. Carbonitrided mild steel, which averaged 2.72 times the wear resistance of mild steel blades, resisted metal weightloss and dimensional changes to a greater extent than the remaining treatments. This action was attributed to the treated case which covered the entire soil engaging portion of the blade. High surface hardness and a microstructure that was primarily pearlitic could both have contributed to recorded wear resistance.

Arc welded Cobalarc appeared to be the next best treatment. Its success over all other welded treatments was attributed to the welded buttering run (of intermediate hardness between mild steel and Cobalarc) applied beneath the hardfacing material, since other welded materials had both hardness values and microstructures that might have been expected to resist abrasive wear better than Cobalarc.

The effect of side positioning on upper shank measurements throughout blade life was likely to have been due to seed/fertiliser differences. A lubrication effect from seeds on the right hand side together with fertiliser corrosion and/or granule deformation on the opposite side shanks, were likely factors that supported right side blades (on the outside during anti-clockwise cornering) as having worn more than left side blades. Side differences that influenced wing dimensions in later blade life were attributed to the action incurred while cornering.

No effects due to fore/aft or lateral assembly positioning on the seed drill were detected throughout this test.

The most wear resistant welded material, Cobalarc, was disadvantaged with respect to carbonitriding mild steel blades in terms of production costs. Approximate retail costs per blade and associated wear parameters were as follows:

	COBALARC	CARBONITRIDING	MILD STEEL
(a) Base plate	$1.50	$1.50	$1.50
(b) Hardening: Labour, materials, processing (Appendix 17)	2.25	1.00	
TOTAL	$3.75	$2.50	$1.50
(c) Cost ratio: =$treatment/ $mild steel	2.50	1.67	1.00
(d) Mean wear resistance ratio:	0.88	1.87	0.69
(e) Cost benefit = c/d	4.26	1.34	2.17

From the above table, carbonitrided mild steel blades offered, on average, 2.71 times the relative wear resistance (grams metal weightloss per hectare) of mild steel blades for 1.67 times the cost of production. Thus the carbonitrided mild steel treatment was both the most economically beneficial (cost benefit = 1.34) as well as being the treatment most resistant to both metal weightloss and dimensional changes.

Selective application patterns for welded treatments inhibited potential increases in wear resistance that might otherwise have been expected when considering material hardnesses and microstructures.

Improvements to the performance of welded treatments might be attempted by further modifications to the weld bead pattern. However, the costs of application and materials are likely to favour the investigation of processes similar to carbonitriding that offer low cost processing (either due to automation or to low labour requirements) and complete (or near so) coverage of soil engaging portions of coulter blades with a wear resistant layer.

Observations of the action of chromium plated treatments (which were the hardest used in contact with the disc, being 2.5 times that of the disc component) showed two important points. Firstly, trash clearance at the coulter blade leading edge was not dependent on that region of the blade wearing-in to bed against the disc. Secondly, preferential wear of the disc was not apparent, giving further support to the belief that soil had been moved through the blade/disc interface.

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APPENDIX 1.

METAL WEIGHT LOSS FROM A DIRECT DRILLING COULTER .

RAW DATA - PILOT FIELD TEST.

COULTER I.D.	DISTANCE DRILLED (KM.)	WT. LOSS (GRAMS PER HA.)	TEST DATES	MOISTURE DEFICIT (MM.)
1.	20.0	2.80	17/8/81	-2.1
Left side;	30.0	2.77	17/8/81	-2.1
Arc applied	40.0	2.85	17/8/81	-2.1
Hardcraft	50.0	2.41	18/8/81	-0.6
700	60.0	2.45	18/8/81	-0.6
	70.0	2.45	19/8/81	+4.9
	80.0	2.39	20/8/81	+0.3
	90.0	2.30	21/8/81	-1.2
	110.0	2.22	30/9/81	-3.6
	130.0	2.22	1/10/81	-5.0
	150.0	2.17	2/10/81	-3.6
	170.0	2.07	2/10/81	-3.6
	190.0	1.98	5/10/81	-7.6
2.	20.0	2.48	17/8/81	-2.1
Right side;	30.0	2.82	17/8/81	-2.1
Mild steel	40.0	3.10	17/8/81	-2.1
control.	50.0	2.66	18/8/81	-0.6
	60.0	2.52	18/8/81	-0.6
	70.0	2.64	19/8/81	+4.9
	80.0	2.46	20/8/81	+0.3
	90.0	2.33	21/8/81	-1.2
	110.0	2.11	30/9/81	-3.6
	130.0	1.91	1/10/81	-5.0
	150.0	1.85	2/10/81	-3.6
	170.0	1.72	2/10/81	-3.6
	190.0	1.62	5/10/81	-7.6
3.	20.0	1.50	17/8/81	-2.1
Left side;	30.0	1.55	17/8/81	-2.1
Mild steel	40.0	1.83	17/8/81	-2.1
control.	50.0	1.49	18/8/81	-0.6
	60.0	1.57	18/8/81	-0.6
	70.0	1.53	19/8/81	+4.9
	80.0	1.49	20/8/81	+0.3
	90.0	1.46	21/8/81	-1.2
	110.0	1.31	30/9/81	-3.6
	130.0	1.18	1/10/81	-5.0
	150.0	1.16	2/10/81	-3.6
	170.0	1.10	2/10/81	-3.6
	190.0	1.04	5/10/81	-7.6

4. Right side; Arc applied Hardcraft 700	20.0	3.70	17/8/81	-2.1
	30.0	3.77	17/8/81	-2.1
	40.0	3.79	17/8/81	-2.1
	50.0	3.29	18/8/81	-0.6
	60.0	3.13	18/8/81	-0.6
	70.0	3.19	19/8/81	+4.9
	80.0	2.97	20/8/81	+0.3
	90.0	2.78	21/8/81	-1.2
	110.0	2.69	30/9/81	-3.6
	130.0	2.59	1/10/81	-5.0
	150.0	2.45	2/10/81	-3.6
	170.0	2.31	2/10/81	-3.6
	190.0	2.17	5/10/81	-7.6
5. Left side; Arc applied Hardcraft 700	20.0	1.98	17/8/81	-2.1
	30.0	2.70	17/8/81	-2.1
	40.0	2.80	17/8/81	-2.1
	50.0	2.25	18/8/81	-0.6
	60.0	2.12	18/8/81	-0.6
	70.0	2.14	19/8/81	+4.9
	80.0	1.98	20/8/81	+0.3
	90.0	1.86	21/8/81	-1.2
	110.0	1.64	30/9/81	-3.6
	130.0	1.45	1/10/81	-5.0
	150.0	1.37	22/10/81	-3.6
	170.0	1.27	2/10/81	-3.6
	190.0	1.18	5/10/81	-7.6
6. Right side; Mild steel control.	20.0	2.77	17/8/81	-2.1
	30.0	2.55	17/8/81	-2.1
	40.0	2.90	17/8/81	-2.1
	50.0	2.44	18/8/81	-0.6
	60.0	2.43	18/8/81	-0.6
	70.0	2.49	19/8/81	+4.9
	80.0	2.36	20/8/81	+0.3
	90.0	2.26	21/8/81	-1.2
	110.0	2.02	30/9/81	-3.6
	130.0	1.81	1/10/81	-5.0
	150.0	1.78	2/10/81	-3.6
	170.0	1.67	2/10/81	-3.6
	190.0	1.58	5/10/81	-7.6

APPENDIX 2.

LINEAR DIMENSIONAL CHANGES OF A DIRECT DRILLING COULTER.

RAW DATA: PILOT TEST.

TAIL WING	MID WING	REAR -MID	INNR WING	SHNK 10	SHNK 20	SHNK 30	SHNK 40	SHNK 50	DIS. (KM.)
	COULTER 1: ARC APPLIED HARDCRAFT 700								
20.2	26.6	60.3	93.7	100.1	100.3	101.2	101.2	101.3	0
20.0	25.8	58.8	94.7	100.0	100.3	100.4	101.2	100.8	20.0
19.7	25.8	57.3	94.6	99.6	100.4	101.0	101.2	101.0	30.0
19.7	25.8	57.6	94.0	99.6	100.1	100.6	101.0	100.7	40.0
19.5	25.7	57.5	94.0	99.4	99.7	100.6	100.9	100.7	50.0
19.3	25.3	56.7	92.5	99.4	100.0	100.6	100.7	100.7	60.0
19.3	25.3	56.7	92.5	99.4	99.9	100.5	100.8	100.8	70.0
19.1	25.2	56.6	93.0	99.3	99.9	100.5	100.8	100.8	80.0
19.0	25.0	55.9	92.7	99.1	99.6	100.1	100.8	100.7	90.0
18.9	25.0	55.2	91.7	98.2	97.5	98.4	98.7	99.3	110.0
18.9	24.7	54.1	90.7	97.7	97.5	98.2	98.0	98.2	130.0
18.9	24.5	54.1	89.6	96.2	96.3	97.5	98.0	97.8	150.0
18.9	24.0	54.0	89.0	95.7	95.9	97.3	97.7	97.3	170.0
19.0	24.1	52.0	87.6	90.5	93.0	96.8	97.5	97.3	190.0
	COULTER 2: MILD STEEL CONTROL								
18.2	23.9	60.3	90.5	101.4	100.0	100.6	100.6	101.1	0
17.8	22.8	55.7	88.9	101.2	100.7	100.2	100.4	101.0	20.0
17.8	22.3	52.5	88.7	101.2	100.5	100.0	100.3	100.7	30.0
17.3	22.2	51.6	88.3	100.7	100.5	100.2	100.3	100.7	40.0
16.8	22.2	49.7	88.4	100.3	100.5	100.0	100.2	100.5	50.0
16.6	21.3	48.9	86.6	100.3	100.4	99.9	100.3	100.6	60.0
16.5	21.3	46.0	85.4	100.4	100.4	100.0	100.2	100.7	70.0
16.4	21.0	44.3	81.0	100.0	100.3	100.1	100.2	100.6	80.0
16.5	21.0	41.4	80.9	99.9	100.0	100.0	100.3	100.6	90.0
16.6	20.8	40.1	76.2	97.3	99.2	99.8	100.4	100.6	110.0
16.6	20.5	39.7	75.2	95.5	98.5	99.6	100.0	100.6	130.0
16.3	20.0	37.0	72.2	90.9	95.9	98.3	99.9	100.1	150.0
16.3	20.1	34.6	69.5	89.2	94.8	98.2	99.8	100.1	170.0
16.3	19.8	33.2	69.0	87.8	93.5	97.4	99.6	100.2	190.0

COULTER 3: MILD STEEL CONTROL

18.3	24.7	60.0	91.8	100.9	101.3	101.4	100.3	101.0	0
18.2	24.6	57.7	91.0	100.7	101.2	101.4	100.6	101.0	20.0
18.2	24.2	55.3	89.0	100.7	101.2	101.3	101.0	101.0	30.0
18.2	23.9	53.0	88.0	100.7	101.0	101.3	101.0	101.0	40.0
18.0	23.7	53.2	88.0	100.5	100.9	101.3	101.3	101.0	50.0
18.0	23.2	52.0	86.1	100.3	100.9	101.2	101.0	101.0	60.0
18.0	23.1	51.8	84.9	100.3	100.8	101.1	101.0	101.0	70.0
18.0	23.1	49.6	83.6	100.0	100.7	101.0	101.1	101.0	80.0
18.0	23.0	45.7	83.6	100.1	100.6	101.0	101.1	100.9	90.0
18.1	22.8	45.0	83.0	100.0	100.5	100.9	100.7	100.7	110.0
18.0	22.7	44.9	80.1	99.8	100.5	100.9	100.8	100.8	130.0
18.0	22.1	42.7	77.1	98.6	100.1	100.9	100.8	100.8	150.0
18.0	22.1	40.0	75.6	97.5	100.0	100.7	100.8	100.8	170.0
17.9	22.0	39.5	75.2	96.0	99.0	100.7	100.9	100.7	190.0

COULTER 4: ARC APPLIED HARDCRAFT 700

17.8	23.9	60.2	88.6	101.1	100.8	100.3	100.7	101.6	0
16.7	22.7	57.8	88.5	101.0	100.3	100.3	100.7	100.9	20.0
17.0	22.3	56.9	88.4	100.9	100.3	100.1	100.3	100.7	30.0
17.0	22.4	55.3	88.0	100.9	100.5	100.0	100.3	100.4	40.0
17.0	22.4	54.5	89.0	100.8	100.6	100.1	100.3	100.5	50.0
16.8	21.9	54.0	89.0	100.9	100.7	100.2	100.3	100.4	60.0
16.8	22.3	51.1	88.9	101.0	100.6	100.2	100.4	100.5	70.0
16.9	22.3	51.2	88.9	100.8	100.6	100.1	100.5	100.5	80.0
17.0	22.1	50.9	88.1	100.8	100.7	100.2	100.3	100.6	90.0
17.0	22.0	50.8	87.2	100.3	100.4	100.0	100.3	100.4	110.0
16.8	21.5	48.3	86.9	99.7	99.7	99.7	100.2	100.3	130.0
17.0	21.6	49.0	86.0	97.5	98.6	98.7	99.9	100.1	150.0
17.0	21.5	48.7	85.7	96.5	97.8	98.1	99.5	100.1	170.0
16.9	21.6	47.5	84.0	96.4	97.0	97.7	99.5	100.0	190.0

COULTER 5: ARC APPLIED HARDCRAFT 700

20.3	25.4	60.2	92.8	100.2	100.2	101.6	101.1	101.2	0
20.2	25.1	57.2	91.0	100.1	100.4	101.4	101.3	101.0	20.0
20.2	25.0	56.7	90.0	100.2	101.0	101.4	101.3	101.4	30.0
20.0	24.8	56.0	90.0	100.2	100.8	101.2	101.6	101.6	40.0
19.8	24.4	56.0	89.0	99.8	100.7	101.1	101.6	101.6	50.0
19.7	24.1	55.3	87.0	99.9	100.7	101.1	101.4	101.6	60.0
19.6	24.0	55.0	87.2	99.9	100.5	101.1	101.3	101.5	70.0
19.4	24.1	54.7	87.3	99.9	100.5	101.2	101.2	101.5	80.0
19.1	23.8	55.0	86.2	100.0	100.5	101.0	101.2	101.4	90.0
19.1	23.7	53.3	86.0	99.1	100.1	100.9	101.0	101.2	110.0
19.0	23.6	52.7	85.0	99.1	99.8	100.8	100.9	101.2	130.0
19.0	23.6	52.3	85.0	97.8	99.5	100.7	100.8	101.3	150.0
19.0	23.6	51.0	84.6	97.7	99.1	100.7	100.7	101.2	170.0
19.0	23.6	50.8	83.7	97.1	98.8	100.4	100.7	101.2	190.0

COULTER 6: MILD STEEL CONTROL

18.0	24.0	60.3	90.0	101.0	101.0	100.2	100.8	100.8	0
17.8	23.7	55.7	88.0	101.0	100.8	100.2	100.4	100.8	20.0
16.8	22.9	54.7	88.0	100.5	100.3	100.2	100.3	100.7	30.0
17.0	22.3	53.7	87.9	100.7	100.3	99.9	100.1	100.5	40.0
16.8	22.4	51.0	88.0	100.7	100.4	100.0	100.2	100.5	50.0
16.6	21.3	50.1	86.5	100.7	100.3	100.0	100.2	100.6	60.0
16.6	21.3	47.3	85.3	100.6	100.4	100.0	100.2	100.7	70.0
16.6	21.3	41.3	82.3	100.5	100.5	100.1	100.2	100.8	80.0
16.6	21.2	42.5	82.3	100.5	100.4	100.0	100.3	100.9	90.0
16.7	20.9	43.0	80.7	99.1	99.8	99.9	100.4	100.7	110.0
16.7	21.0	41.2	79.7	97.7	99.4	99.9	100.4	100.7	130.0
16.7	20.4	39.3	75.3	94.1	97.5	99.0	99.9	100.4	150.0
16.7	20.4	38.5	73.1	92.5	96.7	98.8	99.9	100.4	170.0
16.7	20.2	35.7	70.7	89.9	95.2	98.0	100.0	100.4	190.0

APPENDIX 3.

METAL WEIGHTLOSS FROM A DIRECT DRILLING COULTER.

RAW DATA: RUN A.

COULTER I.D.	DISTANCE DRILLED (KM.)	WT.LOSS (GRAMS) PER HA.)	TEST COMMENTS
1. Left side; Mild steel control.	33.5 53.5 71.0	4.15 5.74 5.21	Treatment eliminated due to coulter No. 18 wearing out. Blade dimensions still acceptable at the completion of the test.
2. Right side; Gas applied EutecBor; Top pattern.	33.5 53.5 71.0 123.0	2.60 4.07 3.54 2.86	Treatment eliminated due to coulter Nos. 14 and 21 wearing out. Dimensions still good at test completion.
3. Left side; Arc applied Toolcraft; Bottom pattern.	33.5 53.5 71.0 123.0	2.43 3.65 3.20 2.94	Treatment eliminated due to coulter No.16 collecting trash when a hook of hard material was formed. Dimensions still good at test completion.
4. Right side; Gas applied EutecBor; Bottom pattern.	33.5 53.5 71.0 123.0	3.51 4.51 3.95 3.74	Treatment eliminated due to the formation of a trash collecting hook on this blade. Dimensions still good at test completion.
5. Left side; Carbo-nitrided.	33.5 53.5 71.0 123.0 144.0 166.5 216.5	1.40 2.58 2.42 2.15 2.18 2.10 1.84	Treatment eliminated due to this blade wearing out.
6. Right side; Arc applied Toolcraft; Bottom pattern.	33.5 53.5 71.0 123.0	3.99 6.10 5.29 4.29	Treatment eliminated due to the formation of a trash collecting hook on this blade.
7. Left side; Mild steel control.	33.5 53.5 71.0	3.91 5.66 4.94	As for coulter No. 1. Dimensions still good at test completion.

8. Right side; Arc applied Toolcraft; Bottom pattern.	33.5 53.5 71.0 123.0	3.81 5.04 4.46 4.12	As for coulter No. 6. Dimensions still good at test completion.
9. Left side; Gas applied EutecBor; Top pattern.	33.5 53.5 71.0 123.0	4.02 5.44 4.81 4.06	As for coulter No.2. Dimensions still good at test completion.
10. Right side; Carbo- nitrided.	33.5 53.5 71.0 123.0 144.0 166.5 216.5	1.34 2.51 2.37 2.14 2.14 2.03 1.78	As for coulter No.5. Dimensions acceptable at test completion.
11. Left side; Arc applied Toolcraft; Top pattern.	33.5 53.5 71.0 123.0	3.61 4.72 4.19 3.73	As for coulter No.3. Dimensions acceptable at test completion.
12. Right side; Gas applied EutecBor; Bottom pattern.	33.5 53.5 71.0 123.0	3.46 4.20 3.70 3.17	As for coulter No.4. Dimensions still good at test completion.
13. Left side; Gas applied EutecBor; Bottom pattern.	33.5 53.5 71.0 123.0	3.25 4.55 3.99 3.59	As for coulter No.4. Dimensions still good at test completion.
14. Right side; Gas applied EutecBor; Top pattern.	33.5 53.5 71.0 123.0	4.12 5.94 5.16 4.53	As for coulter No.2.
15. Left side; Carbo- nitrided.	33.5 53.5 71.0 123.0 144.0 166.5 216.5	1.16 2.36 2.27 2.08 2.08 2.00 1.73	As for coulter No.5.

16. Right side; Arc applied Toolcraft; Top pattern.	33.5 53.5 71.0 123.0	2.54 3.28 2.96 3.15	As for coulter No.3.
17. Left side; Arc applied Toolcraft; Bottom pattern.	33.5 53.5 71.0 123.0	4.06 4.78 4.14 3.56	As for coulter No.6. Dimensions still good at test completion.
18. Right side; Mild steel control.	33.5 53.5 71.0	4.34 7.06 6.30	As for coulter No.1. New control on at 71.0km. New control on at 166.5km.
19. Left side; Gas applied EutecBor; Bottom pattern.	33.5 53.5 71.0 123.0	3.99 4.84 4.16 3.75	As for coulter No.4. Dimensions still good at test completion.
20. Right side; Mild steel control.	33.5 53.5 71.0	4.99 6.04 5.23	As for coulter No.1. Dimensions acceptable at test completion.
21. Left side; Gas applied EutecBor; Top pattern.	33.5 53.5 71.0 123.0	3.30 4.92 4.39 3.81	As for coulter No.2.
22. Right side, Carbo-nitrided.	33.5 53.5 71.0 123.0 144.0 166.5 216.5	1.33 2.44 2.29 2.20 2.22 2.14 1.81	As for coulter No.5.
23. Left side; Arc applied Toolcraft; Bottom pattern.	33.5 53.5 71.0 123.0	2.45 4.86 4.32 3.52	As for coulter No.6. Dimensions still good at test completion.
24. Right side; Arc applied Toolcraft; Top pattern.	33.5 53.5 71.0 123.0	3.19 3.72 3.36 3.29	As for coulter No.3. Dimensions still good at test completion.

APPENDIX 4.

LINEAR DIMENSIONAL CHANGES OF A DIRECT DRILLING COULTER.

RAW DATA: RUN A.

COULTER I.D.	TAIL WING	MID WING	REAR -MID	INNR WING	SHNK 10	SHNK 20	SHNK 30	SHNK 40	SHNK 50	DIST. (KM.)
1.	17.3	21.4	40.7	78.0	99.5	100.8	101.0	101.2	101.3	33.5
MILDST.	15.8	17.0	16.4	55.5	81.8	94.3	100.9	101.4	101.0	53.5
CONTROL	15.6	15.8	8.8	45.7	80.4	92.5	100.0	101.5	101.2	71.0
2.	17.0	21.9	44.8	79.6	100.2	100.3	100.2	100.4	100.6	33.5
EUTECB.	16.7	20.4	41.8	75.7	85.7	94.0	99.5	100.4	100.6	53.5
-TOP	16.7	20.4	41.2	74.4	84.4	92.0	97.0	99.8	100.6	71.0
	16.0	16.7	9.8	69.1	77.4	87.7	95.7	99.4	100.5	123.0
3.	19.0	24.0	51.4	77.8	99.0	99.7	100.0	100.2	100.2	33.5
TOOLCR.	18.5	22.0	48.9	76.5	89.4	95.9	99.7	100.0	100.4	53.5
-TOP	18.5	21.5	28.6	71.9	89.3	95.8	99.0	100.0	100.5	71.0
	17.7	19.2	18.1	54.5	81.5	92.2	97.7	100.1	100.6	123.0
4.	16.4	20.5	47.9	78.9	100.0	100.0	99.8	100.3	100.8	33.5
EUTECB.	15.8	19.0	27.2	71.6	84.8	93.2	97.3	99.9	100.9	53.5
-BOTTOM	15.6	18.4	23.8	69.3	83.8	91.8	96.4	100.0	100.8	71.0
	13.5	14.8	13.9	60.3	74.9	87.3	95.3	99.9	100.6	123.0
5.	17.8	23.9	52.8	87.5	100.2	100.7	101.0	101.1	101.0	33.5
CarboN.	18.0	22.2	41.0	79.5	86.4	95.4	101.2	101.2	101.2	53.5
	18.0	22.2	36.6	75.0	86.0	94.8	101.0	101.1	101.1	71.0
	18.0	21.2	22.4	61.0	80.4	92.7	100.5	101.0	101.1	123.0
	18.0	18.8	9.2	48.0	79.5	92.5	100.0	101.1	101.1	144.0
	17.0	17.2	5.5	42.1	79.1	90.9	99.6	100.8	101.0	166.5
	15.2	15.2	0	34.5	76.7	89.0	98.1	101.0	101.0	216.5
6.	16.8	21.8	40.7	78.0	99.3	99.5	99.5	99.7	100.2	33.5
TOOLCR.	16.0	19.0	27.8	58.5	80.0	90.2	96.8	99.4	100.0	53.5
-BOTTOM	15.9	17.0	16.5	51.0	75.2	84.9	92.7	98.8	100.1	71.0
	13.3	13.8	5.7	33.7	59.5	79.6	90.8	96.9	99.8	123.0
7.	18.7	22.6	44.0	80.7	100.2	101.0	101.3	101.4	101.5	33.5
MILDST.	17.3	19.0	21.6	64.0	85.5	94.2	100.0	101.1	101.4	53.5
CONTROL	17.0	18.4	15.5	52.2	84.6	93.7	99.3	100.9	100.9	71.0
8.	16.7	20.1	41.6	79.3	100.0	100.0	99.8	100.0	100.3	33.5
TOOLCR.	16.4	20.0	24.9	66.6	88.9	95.5	98.2	99.3	100.1	53.5
-BOTTOM	16.1	19.4	23.9	56.0	88.7	93.9	97.2	99.6	100.1	71.0
	15.0	14.7	11.6	47.1	69.8	86.3	94.0	99.1	100.1	123.0

9.	18.5	23.5	51.2	81.5	100.0	101.0	101.5	101.3	101.3	33.5
EUTECB.	18.0	19.3	39.4	77.0	83.8	93.2	100.1	101.5	101.5	53.5
-TOP	17.8	19.3	26.0	76.8	82.7	92.3	99.0	100.5	101.5	71.0
	15.0	15.3	8.2	48.2	72.8	84.7	96.5	100.6	101.5	123.0
10.	17.6	23.2	53.0	86.8	100.2	100.0	99.8	99.8	100.0	33.5
CarboN.	17.5	21.5	37.9	79.4	89.2	95.9	99.3	99.9	100.0	53.5
	17.5	21.4	33.9	74.7	88.7	95.0	99.1	100.0	100.1	71.0
	17.5	19.5	20.9	62.0	81.8	92.5	97.8	99.7	100.0	123.0
	17.1	17.8	9.2	52.6	81.7	91.1	97.0	99.7	100.0	144.0
	16.6	16.8	6.9	45.8	81.5	91.0	96.8	99.6	100.1	166.5
	14.2	14.7	3.0	36.6	77.5	88.7	95.5	99.6	100.1	216.5
11.	17.2	23.7	51.8	79.5	100.0	100.4	100.8	101.1	101.3	33.5
TOOLCR.	17.0	19.5	50.0	75.0	84.3	94.2	99.9	100.9	101.0	53.5
-TOP	17.0	19.3	24.0	71.3	84.0	94.2	99.9	100.9	101.0	71.0
	14.5	14.8	6.6	34.1	74.6	89.1	98.8	101.0	101.0	123.0
12.	16.1	20.3	47.0	80.4	100.8	100.7	100.7	100.5	100.9	33.5
EUTECB.	15.7	18.7	33.1	71.0	90.9	98.0	99.7	100.5	100.5	53.5
-BOTTOM	15.7	18.3	24.0	74.5	90.1	97.6	99.7	100.5	101.0	71.0
	13.7	15.2	18.1	64.8	78.9	89.8	96.8	99.8	100.8	123.0
13.	17.6	21.0	44.2	78.5	99.4	100.0	100.2	100.4	100.5	33.5
EUTECB.	17.2	19.3	30.7	66.8	80.8	90.4	98.7	100.4	100.5	53.5
-BOTTOM	17.0	19.0	22.8	64.5	80.2	90.1	98.0	100.3	100.7	71.0
	15.4	15.8	12.5	51.8	76.7	82.7	94.1	99.3	100.7	123.0
14.	16.8	21.8	46.2	77.7	100.2	100.3	100.0	100.0	100.9	33.5
EUTECB.	16.0	18.3	25.0	74.3	85.1	93.0	97.9	99.8	100.9	53.5
-TOP	16.0	17.7	15.0	69.6	81.4	88.6	94.2	98.7	100.5	71.0
	8.6	8.6	0	9.1	70.1	78.8	88.9	96.2	100.2	123.0
15.	19.4	24.4	52.0	88.7	100.2	100.7	100.8	100.8	100.9	33.5
CarboN.	19.0	22.2	38.9	81.0	89.3	97.8	100.8	100.8	100.8	53.5
	19.0	22.2	31.9	76.8	88.9	97.6	100.8	100.8	100.8	71.0
	18.8	20.4	15.5	63.0	82.9	94.9	100.6	100.7	100.7	123.0
	17.7	17.9	11.8	51.3	82.2	93.8	100.4	100.7	100.7	144.0
	16.5	16.7	3.6	44.8	81.5	92.8	99.8	100.6	100.7	166.5
	13.9	13.9	0	35.9	78.5	91.1	99.5	100.7	100.7	216.5
16.	17.0	22.1	50.2	81.3	98.1	99.3	99.5	100.0	100.0	33.5
TOOLCR.	16.7	20.8	45.5	73.9	95.0	98.8	99.2	100.0	100.2	53.5
-TOP	16.7	20.2	44.1	71.7	92.2	96.8	98.7	99.7	100.3	71.0
	14.7	15.9	13.8	61.3	85.7	93.0	97.0	99.7	100.3	123.0
17.	18.0	21.0	42.0	79.5	100.0	100.3	100.9	101.0	101.0	33.5
TOOLCR.	17.8	20.3	29.5	65.7	87.7	96.5	100.7	100.8	100.9	53.5
-BOTTOM	17.2	19.6	20.9	55.0	87.0	96.4	100.2	100.8	100.9	71.0
	16.1	16.1	9.7	49.8	77.8	88.7	97.2	99.8	100.9	123.0

18.	16.5	20.5	39.0	76.3	100.4	100.5	100.1	100.1	101.0	33.5
MILDST.	14.2	15.0	8.9	43.6	71.8	87.0	97.2	100.1	101.0	53.5
CONTROL	12.9	13.0	3.5	28.0	70.9	86.3	96.0	100.2	100.8	71.0
19.	18.1	20.6	45.8	82.0	99.0	99.7	100.2	100.5	100.5	33.5
EUTECB.	17.6	20.5	35.5	67.6	84.5	96.3	100.1	100.4	100.6	53.5
-BOTTOM	17.5	20.0	24.8	58.1	83.7	95.8	100.2	100.4	100.8	71.0
	14.9	15.5	12.3	47.5	72.3	84.8	94.7	99.2	100.6	123.0
20.	16.5	20.6	39.0	78.6	100.2	100.3	100.0	100.0	100.7	33.5
MILDST.	14.5	17.0	18.4	55.8	82.8	94.0	99.1	100.4	100.7	53.5
CONTROL	14.5	16.8	9.5	42.8	81.8	93.1	98.2	100.2	100.8	71.0
21.	17.9	23.4	49.0	77.9	100.2	100.7	101.5	101.5	101.4	33.5
EUTECB.	17.4	18.3	24.6	73.2	83.6	93.7	100.9	101.5	101.4	53.5
-TOP	17.0	17.6	9.6	71.1	82.2	92.1	99.5	101.4	101.5	71.0
	10.1	10.1	0	21.0	72.5	83.6	96.8	100.9	101.4	123.0
22.	18.0	23.2	51.9	87.8	100.5	100.0	99.6	99.9	99.9	33.5
CarboN.	17.0	21.1	36.8	80.3	91.4	97.7	99.5	99.5	100.0	53.5
	17.1	20.9	28.0	75.1	91.4	97.5	99.4	99.6	100.0	71.0
	17.1	18.3	14.3	61.5	83.3	93.7	99.2	99.6	100.0	123.0
	15.0	15.4	9.2	51.5	81.8	93.1	99.1	99.6	100.0	144.0
	13.9	14.0	6.6	45.6	81.5	93.1	99.0	99.6	99.8	166.5
	11.7	11.7	0	33.6	80.8	92.0	98.3	99.6	99.8	216.5
23.	18.7	20.9	48.0	80.7	99.9	100.8	101.3	101.5	101.3	33.5
TOOLCR.	17.8	19.7	26.0	63.0	86.9	95.5	100.0	101.2	101.4	53.5
-BOTTOM	17.6	19.2	21.5	54.7	83.1	93.0	98.0	100.9	101.0	71.0
	15.7	15.7	8.4	45.0	71.4	87.5	97.7	100.8	101.1	123.0
24.	17.0	22.0	47.8	78.2	100.3	100.2	100.2	101.0	101.2	33.5
TOOLCR.	16.5	20.2	43.0	72.5	97.5	99.7	99.8	100.3	101.3	53.5
-TOP	16.5	19.3	40.3	69.1	96.8	99.6	99.5	100.1	101.2	71.0
	14.8	16.0	10.7	63.0	77.8	89.5	96.7	100.1	101.2	123.0

APPENDIX 5.

METAL WEIGHTLOSS FROM A DIRECT DRILLING COULTER.

RAW DATA: RUN B.

COULTER I.D.	DISTANCE DRILLED (HA.)	WT. LOSS (GRAMS) PER HA.)	TEST COMMENTS
1.	59.5	2.95	Treatment eliminated due
Left side;	110.0	2.51	to this and coulter No.15
Gas applied	143.5	3.64	wearing out.
Eutalloy Tungtec.			
2.	59.5	2.15	Treatment eliminated due
Right side;	110.0	1.76	to coulter Nos.10, 17
Arc applied	143.5	2.21	and 19 wearing out.
Cobalarc 1A.	176.5	2.31	Dimensions still good at test completion.
3.	59.5	1.07	Treatment eliminated due
Left side;	110.0	1.22	to coulter No.9 wearing
Carbo-	143.5	1.62	out. Dimensions still
nitrided.	176.5	2.26	good at test completion.
4.	59.5	3.67	Treatment eliminated due
Right side;	110.0	2.77	to the formation of
Arc applied	143.5	3.67	trash collecting hooks
Ultimium 112.			on all replicates.
5.	59.5	0.76	Treatment eliminated due
Left side;	110.0	0.71	to the formation of
Hard chromium	143.5	1.80	trash collecting hooks
plating.			on all replicates. Blades were left on the machine, resulting in them wearing out.
6.	59.5	3.94	Treatment eliminated due
Right side;	110.0	3.24	to this coulter wearing
Mild steel	143.5	4.24	out.
control.			
7.	59.5	2.50	As for coulter No.6.
Left side;	110.0	2.48	Dimensions still good at
Mild steel	143.5	3.02	test completion.
control.			
8.	59.5	0.54	As for coulter No.5.
Right side;	110.0	0.59	
Hard chromium	143.5	1.34	
plating.			

9. Left side; Carbo-nitrided.	59.5 110.0 143.5 176.5	0.97 1.11 1.46 2.46	As for coulter No.3.
10. Right side; Arc applied Cobalarc 1A.	59.5 110.0 143.5 176.5	2.90 2.27 2.91 3.84	As for coulter No.2.
11. Left side; Arc applied Ultimium 112.	59.5 110.0 143.5	2.31 2.05 2.55	As for coulter No.4. Dimensions still good at test completion.
12. Right side; Gas applied Eutalloy Tungtec.	59.5 110.0 143.5	2.61 2.02 2.25	As for coulter No.1. Dimensions still good at test completion.
13. Left side; Mild steel control.	59.5 110.0 125.0	2.66 2.19 FAILED	Blade broken at 125 km.
14. Right side; Hard chromium plating.	59.5 110.0 143.5	0.69 0.73 1.88	As for coulter No.5.
15. Left side; Gas applied Eutalloy Tungtec.	59.5 110.0 143.5	2.55 2.26 3.51	As for coulter No.1.
16. Right side; Carbo-nitrided.	59.5 110.0 143.5 168.0	1.01 1.06 1.10 LOST	Blade lost at 168.0 km.
17. Left side; Arc applied Cobalarc 1A.	59.5 110.0 143.5 176.5	2.54 2.05 2.22 2.41	As for coulter No.2.
18. Right side; Arc applied Ultimium 112.	59.5 110.0 143.5	3.24 2.48 3.06	As for coulter No.4. Dimensions still good at test completion.
19. Left side; Arc applied Cobalarc 1A.	59.5 110.0 143.5 176.5	3.05 2.30 3.16 3.54	As for coulter No.2.

20. Right side; Gas applied Eutalloy Tungtec.	59.5 110.0 143.5	1.87 1.87 2.39	As for coulter No.1. Dimensions still good at test completion.
21. Left side; Hard chromium plating.	59.5 110.0 143.5	0.89 0.78 2.05	As for coulter No.5.
22. Right side; Mild steel control.	59.5 110.0 143.5	2.91 2.64 3.47	As for coulter No.6. Dimensions still good at test completion.
23. Left side; Arc applied Ultimium 112.	59.5 110.0 131.0	2.53 2.14 FAILED	As for coulter No.4. Blade broken at 131.0 km.
24. Right side; Carbo-nitrided.	59.5 110.0 135.5	1.32 1.30 FAILED	As for coulter No.3. Blade broken at 135.5 km.

APPENDIX 6.

LINEAR DIMENSIONAL CHANGES OF A DIRECT DRILLING COULTER.

RAW DATA: RUN B.

COULTER I.D.	TAIL WING	MID WING	REAR -MID	INNR WING	SHNK 10	SHNK 20	SHNK 30	SHNK 40	SHNK 50	DIST. (KM.)
1.	17.7	22.5	49.8	81.3	94.9	99.2	101.2	101.4	101.2	59.5
EUT.	17.0	21.3	36.2	79.2	92.2	98.3	100.5	101.0	101.2	110.0
TUNGTEC	12.7	12.7	0	36.4	55.0	81.5	95.0	99.8	101.1	143.5
2.	16.3	21.8	49.7	74.6	97.8	99.6	99.7	100.4	101.0	59.5
COBAL-	15.9	21.7	47.8	72.0	97.3	99.6	99.6	100.2	101.0	110.0
ARC	14.3	17.0	16.4	68.5	82.8	93.5	98.0	100.0	100.5	143.5
	14.0	14.6	11.0	63.5	81.5	92.5	97.7	100.0	100.5	176.5
3.	18.0	23.5	55.0	86.2	100.8	101.2	101.4	101.3	101.3	59.5
CarboN.	18.0	23.2	51.8	82.3	100.2	101.0	101.2	101.2	101.2	110.0
	17.6	21.5	36.5	69.4	78.7	90.2	97.8	100.8	100.9	143.5
	17.2	19.0	10.1	33.5	68.3	86.1	96.8	101.0	101.0	176.5
4.	17.7	21.3	46.6	79.0	97.5	99.6	99.8	100.7	101.1	59.5
ULTIM-	16.7	21.3	46.5	65.2	97.4	99.6	99.8	100.1	100.5	110.0
IUM	13.9	11.0	19.8	63.9	76.0	81.6	90.3	97.7	100.6	143.5
5.	18.6	23.9	54.1	81.0	101.0	101.1	101.2	101.2	101.0	59.5
CHROME	18.5	23.8	50.0	74.0	101.0	101.1	101.3	101.3	101.2	110.0
	18.1	19.8	11.2	37.1	86.2	101.0	101.4	101.1	101.1	143.5
6.	16.3	20.6	42.0	71.3	95.9	99.5	99.9	100.8	101.4	59.5
MILDST.	15.9	20.4	31.1	67.0	95.0	98.5	99.9	100.5	100.8	110.0
CONTROL	11.8	11.8	0	30.5	54.5	72.0	85.0	93.9	99.3	143.5
7.	17.2	22.2	45.3	78.5	97.7	100.9	101.4	101.7	101.7	59.5
MILDST.	16.9	21.0	36.0	71.4	96.9	100.4	101.2	101.7	101.8	110.0
CONTROL	15.5	17.5	17.7	48.2	72.1	86.4	96.2	100.2	101.0	143.5
8.	17.5	23.8	55.8	86.0	99.3	98.5	98.4	99.0	100.0	59.5
CHROME	17.4	23.8	53.1	79.0	98.9	98.5	98.4	98.5	99.6	110.0
	17.8	20.3	18.5	53.5	98.7	98.5	98.5	98.6	99.5	143.5
9.	19.0	24.0	53.2	85.0	100.0	100.7	101.0	100.9	100.7	59.5
CarboN.	19.0	23.5	49.0	81.7	98.5	100.7	101.1	101.0	100.8	110.0
	19.0	22.1	29.1	71.0	82.5	92.3	99.7	101.0	101.0	143.5
	12.8	12.8	0	15.0	67.0	88.6	99.3	101.0	101.0	176.5

10.	16.2	21.0	46.8	75.8	97.2	99.7	99.7	100.8	101.0	59.5
COBAL-	16.1	21.0	43.8	74.1	96.1	99.5	99.8	100.4	100.7	110.0
ARC	13.3	14.4	15.0	72.0	79.9	85.5	94.6	99.6	100.5	143.5
	0	0	0	0	54.1	80.5	92.2	99.5	100.6	176.5
11.	17.7	22.5	49.1	74.7	98.8	100.2	101.5	101.9	101.8	59.5
ULTIM-	17.4	22.2	45.5	71.1	97.3	100.3	101.3	101.7	101.7	110.0
IUM	15.0	17.8	44.1	69.8	77.7	86.0	96.4	100.5	101.1	143.5
12.	16.7	22.2	47.1	81.1	98.7	99.7	100.0	100.2	100.8	59.5
EUT.	16.5	22.0	47.0	78.6	98.6	100.0	100.0	100.6	101.0	110.0
TUNGTEC	16.0	19.2	40.3	67.5	92.3	97.8	99.4	100.5	100.9	143.5
13.	18.3	22.5	43.9	76.7	96.8	99.5	100.8	101.0	100.9	59.5
MILDST.	17.8	21.4	31.6	69.1	96.2	99.4	100.6	101.0	100.9	110.0
CONTROL		BLADE SHANK FATIGUED AT 125.0 KM.								
14.	17.2	23.0	54.8	84.0	101.5	101.0	100.6	100.4	100.9	59.5
CHROME	17.2	22.8	46.5	76.1	101.5	101.0	100.6	100.4	101.0	110.0
	15.8	17.7	12.8	46.5	76.5	95.8	99.8	100.5	100.7	143.5
15.	18.0	22.6	48.0	77.8	97.8	100.4	101.1	101.4	101.2	59.5
EUT.	17.8	21.8	44.1	73.9	95.9	100.1	100.8	101.1	101.1	110.0
TUNGTEC	12.5	12.5	0	33.0	66.5	82.1	95.2	99.2	100.5	143.5
16.	16.8	22.6	54.1	86.6	100.7	100.4	100.0	100.1	100.7	59.5
CarboN.	16.8	22.5	51.0	81.2	100.1	100.2	100.0	100.2	100.5	110.0
	16.7	21.0	39.0	75.8	95.9	99.5	99.9	100.0	100.6	143.5
		COULTER BLADE LOST AT 168.0 KM.								
17.	18.5	23.1	49.1	76.8	96.8	100.4	101.2	101.8	101.8	59.5
COBAL-	18.0	23.0	46.2	67.7	94.9	99.7	101.0	101.5	101.6	110.0
ARC	16.8	20.3	39.8	64.1	82.0	92.8	99.2	100.9	101.0	143.5
	16.1	16.1	0	42.4	72.3	92.0	98.8	101.0	101.2	176.5
18.	16.7	20.9	39.7	71.5	93.5	97.5	98.6	99.5	100.4	59.5
ULTIM-	16.6	20.9	39.6	66.4	92.0	96.7	98.4	99.5	100.5	110.0
IUM	12.9	16.1	36.7	66.4	74.2	83.0	91.1	97.0	99.8	143.5
19.	18.0	23.2	36.5	72.0	96.4	100.6	101.3	101.7	101.7	59.5
COBAL-	17.7	23.0	36.0	63.0	94.8	98.6	100.6	101.2	101.4	110.0
ARC	14.6	17.0	30.8	57.4	67.5	80.0	91.8	98.0	100.9	143.5
	0	0	0	0	59.5	73.0	89.0	97.3	101.0	176.5
20.	16.5	22.1	53.2	79.7	99.2	100.0	100.0	100.3	100.8	59.5
EUT.	16.4	22.1	49.1	76.7	98.8	99.7	99.7	100.3	100.5	110.0
TUNGTEC	16.0	19.4	36.0	62.3	77.4	85.5	92.8	97.8	100.2	143.5
21.	17.7	24.0	52.3	80.5	101.1	101.6	101.8	101.6	101.6	59.5
CHROME	17.7	23.8	47.8	77.5	101.0	101.6	101.7	101.6	101.6	110.0
	15.2	15.2	0	28.5	94.1	101.5	101.7	101.7	101.5	143.5

22.	16.4	20.6	39.6	75.0	97.3	99.7	99.8	100.5	100.9	59.5
MILDST.	16.0	20.0	32.5	70.1	96.8	99.4	99.7	100.2	100.6	110.0
CONTROL	13.2	14.8	11.0	38.5	62.8	78.1	89.9	97.2	100.2	143.5
23.	18.0	23.2	53.3	78.5	98.2	100.3	100.9	100.8	101.3	59.5
ULTIM-IUM	17.6	22.8	45.3	72.6	97.0	99.9	100.5	100.5	100.9	110.0
		COULTER SKANK FATIGUED AT 131.0 KM.								
24.	17.5	23.1	54.0	84.2	100.4	100.0	99.6	99.8	100.0	59.5
CarboN.	17.5	23.0	48.9	80.8	98.7	99.7	99.6	99.8	100.0	110.0
		COULTER SHANK FATIGUED AT 135.5 KM.								

APPENDIX 7.

THE EFFECT OF DISTANCE ON ABSOLUTE METAL WEIGHTLOSS (GRAMS) FROM A DIRECT DRILLING COULTER.

EXPERIMENT 3: RUN A.

	Distance drilled (kilometers).						
	33.5	53.5	71.0	123.0	144.0	166.5	216.5
C1. MS	29.15	65.48	76.96				
C2. CN	8.78	26.43	33.23	52.64	62.21	68.93	77.51
T1. TT	19.70	41.09	54.53	80.69			
T2. TB	23.99	55.53	64.61	95.20			
T3. ET	23.52	54.46	63.47	93.73			
T4. EB	23.79	48.36	56.09	87.58			
L.S.D.	5.96	10.17	11.64	18.20			

NOTE: MS Mild steel.
CN Carbonitrided.
TT Toolcraft -top pattern.
TB Toolcraft -bottom pattern.
ET EutecBor -top pattern.
EB EutecBor -bottom pattern.

APPENDIX 8.

THE EFFECT OF DISTANCE ON ABSOLUTE METAL WEIGHTLOSS

(GRAMS) FROM A DIRECT DRILLING COULTER.

	Distance drilled (kilometers).			
	59.5	111.0	143.5	176.5
C1. MS	37.17	62.16	103.61	
C2. CN	11.9	24.64	39.32	82.25
T5. TU	29.63	48.17	84.67	
T6. CO	31.65	46.62	75.19	106.96
T7. UL	30.06	53.72	89.83	
T8. CH	8.57	15.54	50.80	
L.S.D.	9.40	9.77	23.53	11.30

NOTE: MS Mild steel.
CN Carbonitrided.
TU Tungtec.
CO Cobalarc.
UL Ultimium.
CH Chromium plated.

APPENDIX 9.

GENSTAT COMPUTER PROGRAMME FOR ANALYSING A RANDOMISED BLOCK DESIGN IN EXPERIMENT 2.

```
'REFE' RANDBLOC
''ANALYSIS OF A RANDOMISED BLOCK DESIGN.
  WEAR TRIAL ON CHISEL COULTER BLADES - PILOT FIELD TEST.
  THERE WERE TWO REPLICATIONS IN RANDOMISED BLOCKS, EACH
  CONTAINING THREE TREATMENTS.
''
'UNITS' $ 6
'FACT' BLOCKS $ 1=6(1)
   :   SIDE $ 2=(1,2)3
   :   ASSY $ 3=2(1...3)
   :   COATING $ 2
   :   POSITION $ 2=1,1,2,2,1,1
'SCAL' NVAR = 1
'READ' TAILW,MIDW,RTOM,INNERW,SHNKA,SHNKB,SHNKC,SHNKD,COATING
'TREAT' COATING+SIDE+POSITION
'BLOCKS' BLOCKS
'ANOVA' TAILW,MIDW,RTOM,INNERW,SHNKA,SHNKB,SHNKC,SHNKD
'RUN'
''  Data are listed here.
''
'EOD'
'CLOSE'
'STOP'

''NOTE: To determine the effects of assembly differences, the
         'TREAT'ment statement was altered to read 'TREAT' ASSY
         and the 'BLOCKS' statement was deleted.
         Dimensional variables in the 'READ' and 'ANOVA' state-
         ments were changed to weightloss variables when these
         were analysed.
''
```

APPENDIX 10.

GENSTAT COMPUTER PROGRAMME FOR ANALYSING A RANDOMISED BLOCK DESIGN IN EXPERIMENT 3.

```
'REFE' RANDBLOC
''ANALYSIS OF A RANDOMISED BLOCK DESIGN.
  WEAR TRIAL ON CHISEL COULTER BLADES - RUN A.
  THERE WERE FOUR REPLICATIONS IN RANDOMISED BLOCKS, EACH
  CONTAINING THREE TREATMENTS.
''
'UNITS' $ 24
'FACT' BLOCKS $ 4=6(1...4)
   :    SIDE $ 2=(1,2)12
   :    ASSY $ 12=2(1...12)
   :    COATING $ 6
   :    POSITION $ 2=2(1,2)6
'SCAL' NVAR = 1
'READ' TAILW,MIDW,RTOM,INNERW,SHNKA,SHNKB,SHNKC,SHNKD,COATING
'TREAT' COATING+SIDE+POSITION
'BLOCKS' BLOCKS
'ANOVA' TAILW,MIDW,RTOM,INNERW,SHNKA,SHNKB,SHNKC,SHNKD
'RUN'
''  Data are listed here.
''
'EOD'
'CLOSE'
'STOP'

''NOTE: To determine the effects of assembly differences, the
          'TREAT'ment statement was altered to read 'TREAT' ASSY
          and the 'BLOCKS' statement was deleted.
          Dimensional variables in the 'READ' and 'ANOVA' state-
          ments were changed to weightloss variables when these
          were analysed.
''
```

APPENDIX 11.

GENSTAT COMPUTER PROGRAMME FOR GRAPHING ORDERED TREATMENT MEANS AND RESIDUAL SUMS OF SQUARES IN EXPERIMENT 3.

```
'REFER' GRAPHS
''THIS PROGRAMME PLOTS A GRAPH TO PERMIT DIFFERENCES BETWEEN
  MEANS TO BE SEEN.  A FURTHER GRAPH TO ASSESS THE UNIFORM-
  ITY OF RESIDUALS IS ALSO PLOTTED.
''
'UNITS' $ 24
'FACT' BLOCKS $ 4=6(1...4)
   :   SIDE $ 2=(1,2)12
   :   ASSY $ 12=2(1...12)
   :   COATING $ 6
''COATING IS TO BE READ IN AS THE FINAL COLUMN OF DATA''
   :   POSITION $ 2=2(1,2)6
'SET' DATA = WTLOSS1,WTLOSS2
''WRITING 'DATA' IS NOW EQUIVALENT TO WRITING THE ABOVE LIST''
'READ' DATA,COATING
''BLOCK STATEMENT CAN BE INSERTED HERE''
'TREAT' COATING ''ANY TREAT CAN BE USED SO LONG AS COATING
IS INCLUDED''
''
NOW FOLLOWS THE DECLARATION OF STRUCTURES REQUIRED FOR THE
CALCULATING OF GRAPHS
''
'HEAD'  HLP=''LP''
:        R  =''RESIDUALS''
:        P  =''PREDICTED VALUES''
:        OTM=''ORDERED TREATMENT MEANS''
:        NS =''NORMAL SCORE''
'VARIATE'  COAT_MNS,O_TRTMNS,E_TRTMNS ,REPS ,O_DIGITS ,NSI $ 6
:      DIGITS=1...6
'FACTOR' TRT_NO$6,6
'CALC' NSI = NED((DIGITS-0.5)/6)
''
 THE VALUE 6 IS THE NUMBER OF COATINGS, AND MUST BE CHANGED
IF ONE IS DELETED
''
```

```
'FOR' Y=DATA
''THIS DOES A SEPARATE ANALYSIS FOR EACH COLUMN OF DATA''
'ANOVA' Y ; RES=RESIDUALS ; FVAL = PREDICT ; OUT = OUTPUT
'EXTRACT' OUTPUT; COATING $ MEAN = TBL_MNS ; REP = COAT_REP ;
VAR = RES_MSQ
'EQUATE' COAT_MNS = TBL_MNS
  :      REPS = COAT_REPS
'CALC' E_TRTMNS = MEAN(COAT_MNS)+SQRT(RES_MSQ/REPS)*NSI
 :          O_TRTMNS,O_DIGITS = ORDER(COAT_MNS,DIGITS;COAT_MNS)
'GROUPS' TRT_NO = INTPT(O_DIGITS)
'GRAPH/ATY=OTM,ATX=NS' E_TRTMNS,O_TRTMNS;NSI $ HLP;*,TRT_NO
'CAPTION' ''NORMAL PLOT OF TREATMENT MEANS''
'GRAPH/ATY=R,ATX=P' RESIDUALS; PREDICT $; COATING

'CAPTION' ''
DIGIT PLOTTED IS COATING NUMBER. VERTICAL SPREAD SHOULD BE
REASONABLY CONSTANT''
'REPEAT'
'RUN'
''  Data are listed here.
''
'EOD'
'CLOSE'
'STOP'
```

APPENDIX 12.

GENSTAT COMPUTER PROGRAMME FOR CONSTRUCTING A REGRESSION MODEL FOR HARDNESS, SIDE AND COATING EFFECTS IN EXPERIMENT 3.

```
'REFE' RANDBLOC
''ANALYSIS OF A RANDOMISED BLOCK DESIGN.
  WEAR TRIAL ON CHISEL COULTER BLADES - RUN A.
  THERE WERE FOUR REPLICATIONS IN RANDOMISED BLOCKS, EACH
  CONTAINING SIX TREATMENTS.
''
'UNITS' $ 24
'FACT' BLOCKS $ 4=6(1...4)
   :   SIDE $ 2=(1,2)12
   :   ASSY $ 12=2(1...12)
   :   COATING $ 6
   :   POSITION $ 2=2(1,2)6
'SCAL' NVAR = 1
'READ' WTLOSS,COATING,HARDNESS
'TERMS' WTLOSS+COATING+HARDNESS+SIDE
'Y' WTLOSS
'FIT/ANDEV=I' HARDNESS+SIDE
'ADD/ANDEV=T' COATING
'RUN'
''  Data are listed here.
''
'EOD'
'CLOSE'
'STOP'
```

APPENDIX 13.

SOIL MOISTURE DEFICIT (MM.) AND DRILLING SITES

FOR EXPERIMENT 3.

RUN A.

DATE	AREA DRILLED (HA.)	SOIL MOISTURE DEFICIT (MM.)	DRILLING SITE SOIL TYPE
30/10/81	3.0	-4.9	Karapoti brown sandy loam.
30/10/81	3.0	-4.9	Ohakea silt loam.
3/11/81	4.5	-5.0	Ohakea silt loam.
6/11/81	3.7	-3.7	Manawatu fine sandy loam.
12/11/81	6.5	-2.2	Milson silt loam.
17/11/81	4.2	-7.9	Kairanga fine sandy loam.
23/11/81	4.5	-20.1	Carnarvon black - Foxton association sandy soil.
9/12/81	7.8	+4.4	Marton silt loam.
9/12/81	2.2	+4.4	Marton silt loam.

RUN B.

DATE	AREA DRILLED (HA.)	SOIL MOISTURE DEFICIT (MM.)	DRILLING SITE SOIL TYPES
14/12/81	11.9	-5.7	Pukepuke - Motuiti association sandy soil.
19/12/81	10.3	-5.7	Kairanga fine sandy loam.
12/1/82	2.8	-6.3	Kairanga fine sandy loam.
1/2/82	7.5	-7.7	Tokomaru silt loam.
1/2/82	6.6	-7.7	Karapoti sandy loam.

APPENDIX 14.

CORRELATION BETWEEN HARDNESS AND METAL WEIGHTLOSS FROM A DIRECT DRILLING COULTER IN EXPERIMENT 3.

RUN A

Distance drilled	r=
33.5 km.	-0.22
53.5 km.	-0.24
71.0 km.	-0.25
123.0 km.	-0.55

RUN B

Distance drilled	r=
59.5 km.	-0.34
110.0 km.	-0.39
143.0 km.	-0.38

APPENDIX 15.

MODEL TO TEST DIFFERENCES IN METAL WEIGHTLOSS BETWEEN TOP AND BOTTOM WELD BEAD PATTERNS IN RUN A OF EXPERIMENT 3.

When:

Mild steel		1
Carbonitriding		2
Toolcraft	-top	3
Toolcraft	-bottom	4
EutecBor	-top	5
EutecBor	-bottom	6

Then, at every measurement interval:

$$\text{Variance of } \sum C_i \bar{y}_i = \sum C_i^2 (\sigma^2/n)$$
$$= 1/2(\bar{y}3 + \bar{y}5) - 1/2(\bar{y}4 + \bar{y}6)$$

$$\text{Variance} = 1/4(\sigma^2/n + \sigma^2/n) + 1/4(\sigma^2/n + \sigma^2/n)$$
$$= \sigma^2/n$$

where σ^2 = residual (error) mean squares, and
n = number of replicates.
$\bar{y}$ = mean of y
C = constant

$$\text{Standard deviation} = \sqrt{\sigma^2/n}$$

$$\text{T test} = \frac{\sigma^2/n}{\text{Standard deviation}}$$

at 13 degrees of freedom.

If calculated T < T(0.05) from statistical tables, there are no significant differences between top and bottom weld patterns in terms of metal weightloss.

DISTANCE DRILLED (KM.)	VARIANCE	STD.DEV.	T TEST	SIGNIFICANT
33.5	0.0850	0.2915	-1.66	NS
53.5	0.0957	0.3094	-1.26	NS
71.0	0.0716	0.2675	-1.12	NS

APPENDIX 16.

VICKERS MICROHARDNESS RESULTS FOR TREATMENTS

IN EXPERIMENT 3.

SAMPLE	DISTANCE FROM SURFACE (MM.)					
	0.06	0.20	0.50	1.00	2.00	EXTRA
DISC	317	377	366	365	387	
MS	177	177	179	169	168	
CN	836	746	694	869	203	207 (3MM.)
TC	586	571	622	627	643	216 (3MM.)
EU	758	763	763	182	170	176 (3MM.)
TU	990	898	1390	183	187	187 (3MM.)
CO	575	540	631	606	598	170 (4MM.)
UL	836	746	694	869	203	207 (3MM.)
CH	810	848	162	158	159	

NOTE: MS Mild steel.
CN Carbonitrided mild steel.
TC Toolcraft.
EU EutecBor.
TU Tungtec.
CO Cobalarc.
UL Ultimium.
CH Chromium plated mild steel.

APPENDIX 17.

APPROXIMATE RETAIL COSTS FOR PROCESSING COBALARC AND CARBONITRIDED TREATMENTS AS AT 30 MARCH 1982.

Cobalarc Treatment:

Materials: For 5mm. welding rod at $17.70/kg., this was $0.80 per rod. Rod consumption was 0.26 per plate welded, thereby representing $0.208 per welded plate. For 3.15 mm. low hydrogen welding rod (buttering run) at $4.19/kg., this was $0.15 per rod. At the same consumption as for Cobalarc 1A, cost per welded plate was $0.039.

Labour: Assumed skilled labour at $12.00 per hour. At six blades processed per hour (including pre-grinding and welding), labour cost per blade was $2.00.

TOTAL COST OF HARDENING: $2.25 per blade.

Carbonitrided Treatment:

Batch processing at $1.00 per blade included all costs (atmospheric gases, labour, furnace power) except the cost of the base plate.

TOTAL COST OF HARDENING: $1.00 per blade.