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Natural frequency modelling to identify material properties of crush damaged corrugated fibreboard

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Introduction

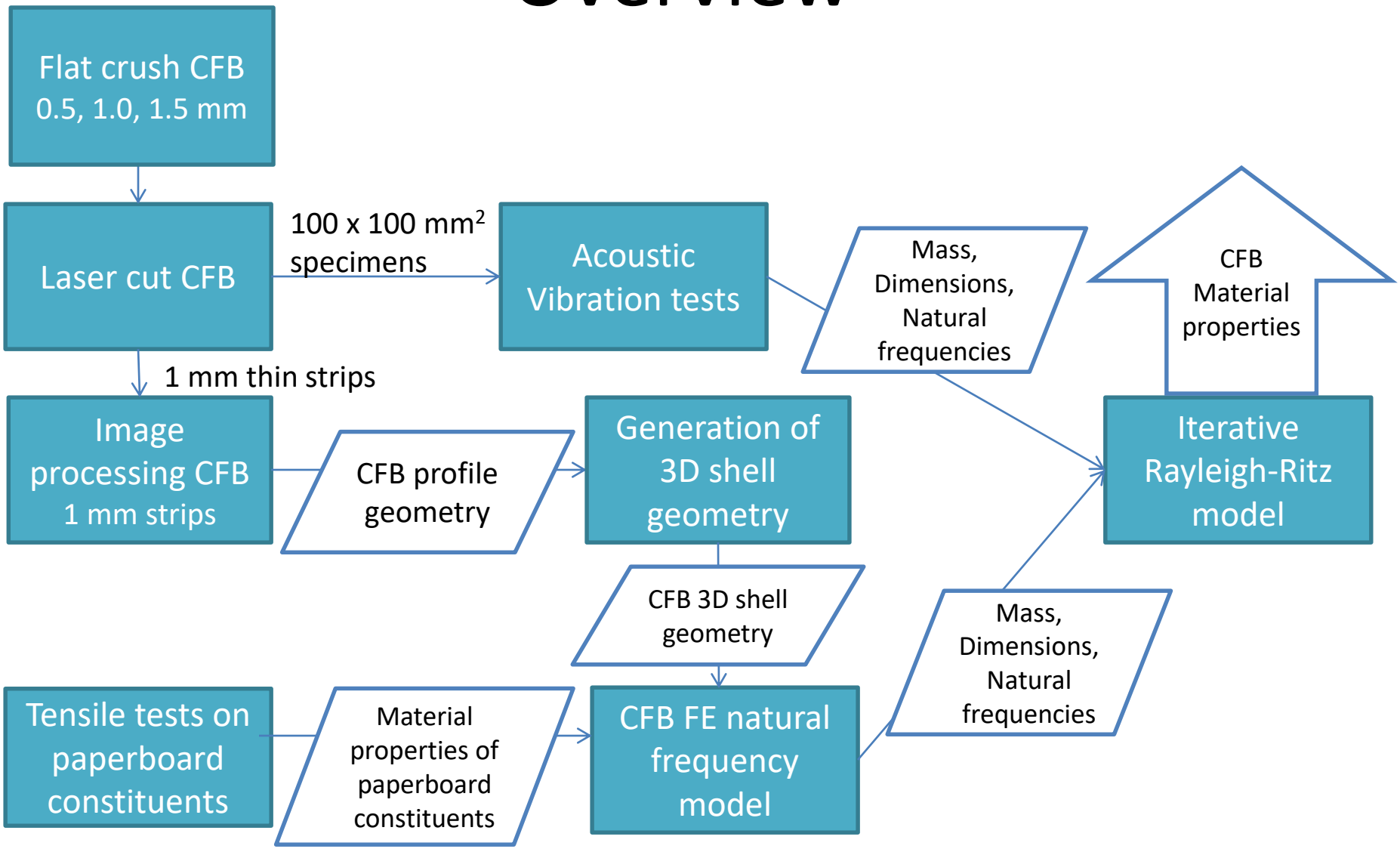
- Part of project on corrugated fibreboard (CFB) packaging with Centre for Postharvest and Refrigeration Research (CPRR) at Massey University
- Particular focus: Modelling to optimise design of packaging for compression loading

Aim

- Investigate the detection of crush damage on CFB, using natural frequency analysis to determine changes to material properties relative to undamaged CFB

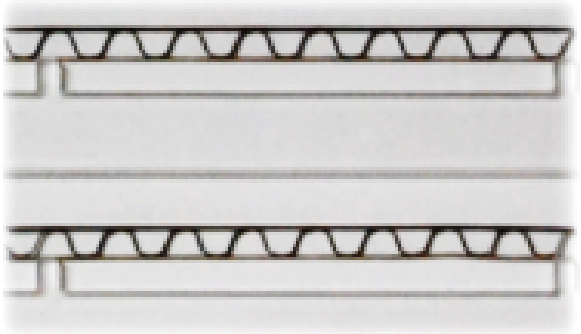
➢ Potential application for quality assurance

Overview


Flat crush CFB
0.5, 1.0, 1.5 mm
Laser cut CFB
100 x 100 mm2 specimens
Acoustic Vibration tests
Mass, Dimensions, Natural frequencies
CFB Material properties
1 mm thin strips
Image processing CFB
1 mm strips
CFB profile geometry
Generation of 3D shell geometry
Iterative Rayleigh-Ritz model
CFB 3D shell geometry
Mass, Dimensions, Natural frequencies
Tensile tests on paperboard constituents
Material properties of paperboard constituents
CFB FE natural frequency model

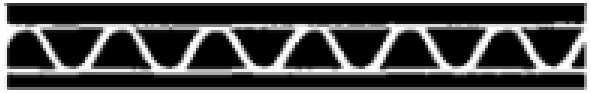
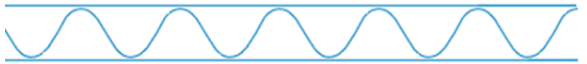
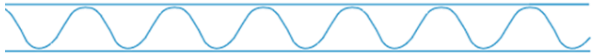
Specimen Preparation

- CFB obtained after box conversion flat crushed to varying levels {0.5, 1.0, 1.5, 2.0} mm
- CFB laser cut 100 x 100 mm^2 vibration specimens and 1 mm thin strips
- CFB thin strips imaged



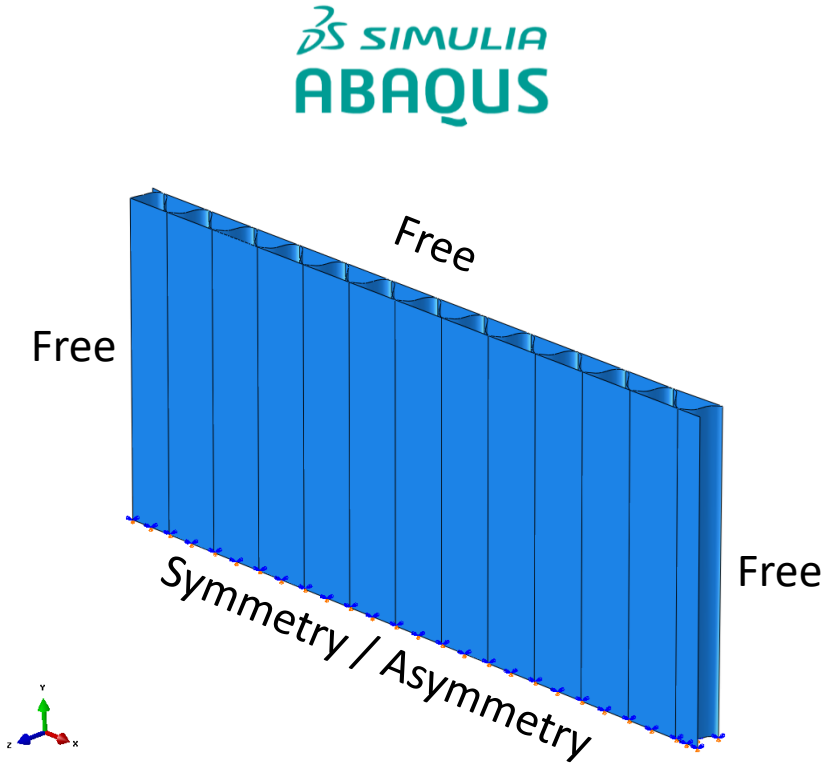
Geometry of Crushed Board

- Image processing of thin strips images in *Matlab* to generate profile of crushed CFB as in Jamsari et al. (2018)
- Profile used to generate CFB 3D shell geometry in *SolidWorks*

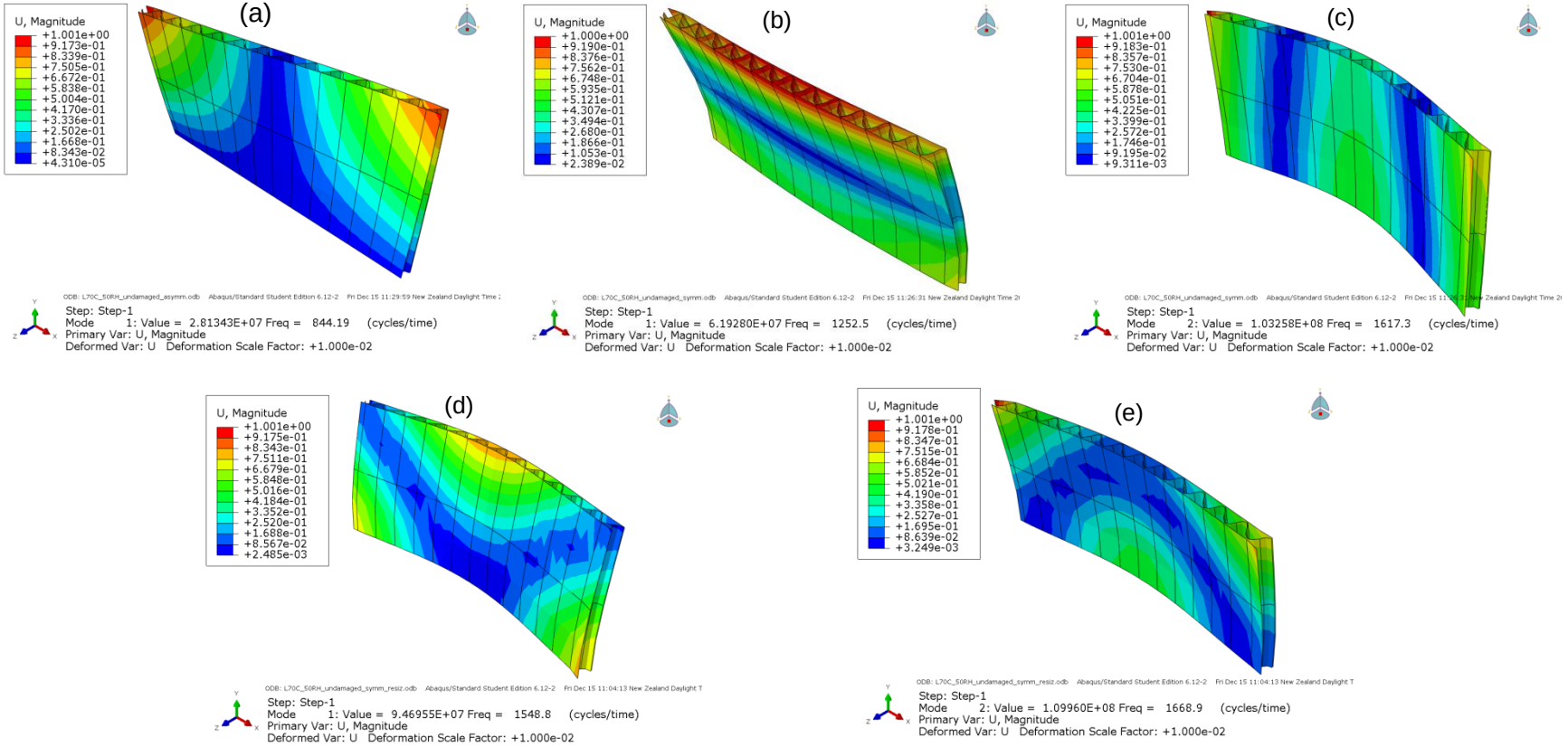
Crushing Level	Thin Strip image	Middle Surface Profile	Calliper
0.0 mm			4.31 mm
0.5 mm			4.21 mm
1.0 mm			4.02 mm
1.5 mm			3.91 mm

FE Natural Frequency Model

- CFB shell geometry
- Elastic lamina input material properties based on constituent paperboard tensile tests
- Half model
- Mesh: quadratic quadrilateral elements type S8R



Natural Frequency Modes



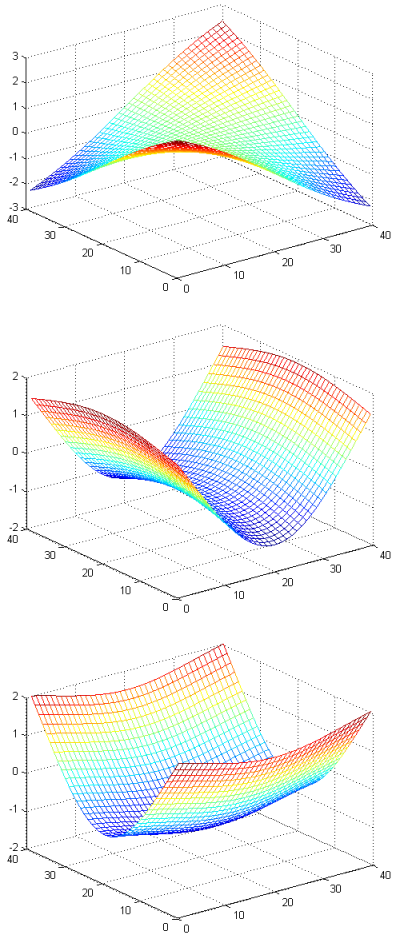
Half model natural vibration modes (a) '+' twist, (b) bending in cross–direction (CD), (c) bending in machine-direction (MD), (d) 'X' mode and (e) ring mode

Results - Natural Frequencies

	Model Natural Frequencies				
	f_+ Twist mode (Hz)	f_{b1} Bending mode in CD (Hz)	f_{b2} Bending mode in MD (Hz)	f_x X mode (Hz)	f_o Ring mode (Hz)
Uncrushed	820.5	1248.0	1572.9	1528.0	1653.3
Crushed 0.5 mm	798.1	1237.2	1470.5	1458.8	1594.1
Crushed 1.0 mm	747.7	1187.7	1296.9	1262.2	1364.1
Crushed 1.5 mm	703.5	1195.2	1127.4	1161.2	1237.9

Rayleigh-Ritz Iterative program

- Developed by McIntyre & Woodhouse (1988) for orthotropic materials, later used by Sato, Hutchings, & Woodhouse (2008) for CFB
- Input specimen mass, dimensions and natural frequencies
- Approximate bending stiffness, Young's modulus and shear modulus obtained from input, used to calculate eigen-frequencies
- Trial function $w(x,y) = \sum_{n=1}^{N} \sum_{m=1}^{M} a_{nm} x^n y^m$
- Iterations minimise the difference between predicted and measured frequencies



Results – CFB Material Properties

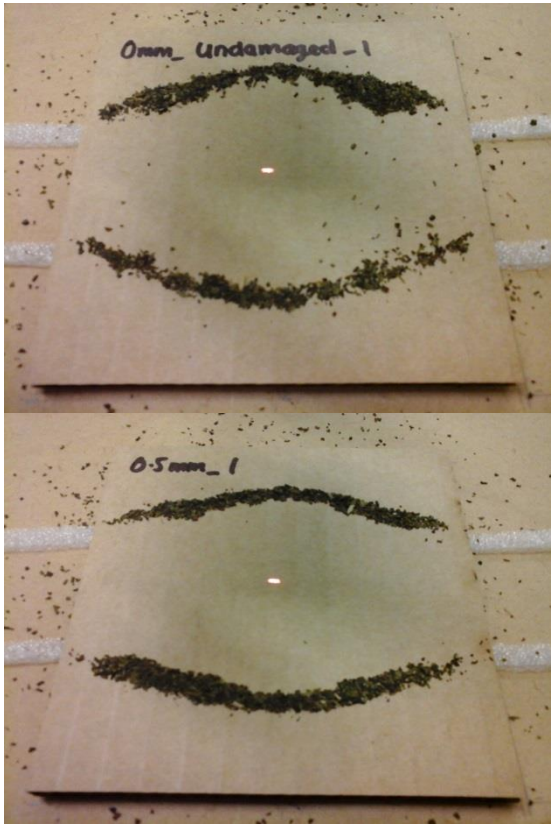
Material Properties	Uncrushed	Crushed 0.5 mm	Crushed 1.0 mm	Crushed 1.5 mm
D_{11} (Nm)	13.21	11.42	8.67	7.61
D_{12} (Nm)	2.46	2.70	1.91	1.35
D_{22} (Nm)	8.56	8.56	8.03	6.97
D_{66} (Nm)	14.00	13.25	11.66	10.34
E_{MD} (GPa)	1.87	1.70	1.52	1.48
E_{CD} (GPa)	1.21	1.27	1.41	1.35
G_{12} (GPa)	2.10	2.13	2.15	2.08

For comparison, static testing on uncrushed CFB:

Four-point bending D_{11} = 16.2±0.6 Nm; D_{22} = 7.9±0.3 Nm

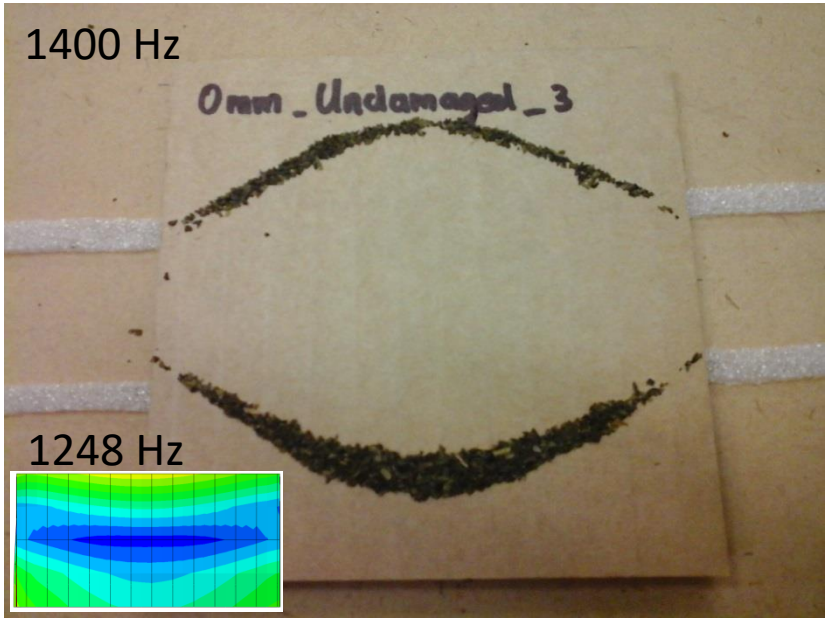
Edge compression testing (ECT) E_{CD} = 1.09±0.07 GPa

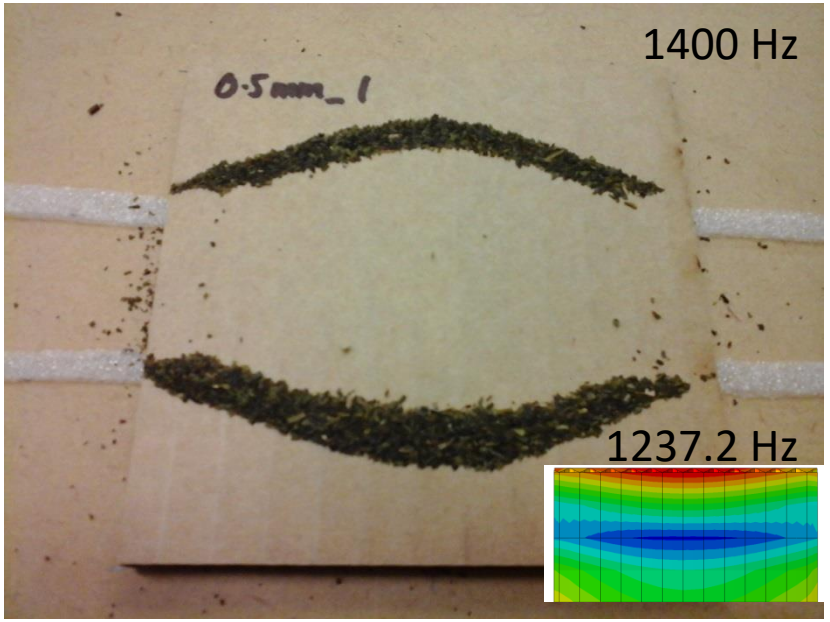
Vibration Testing

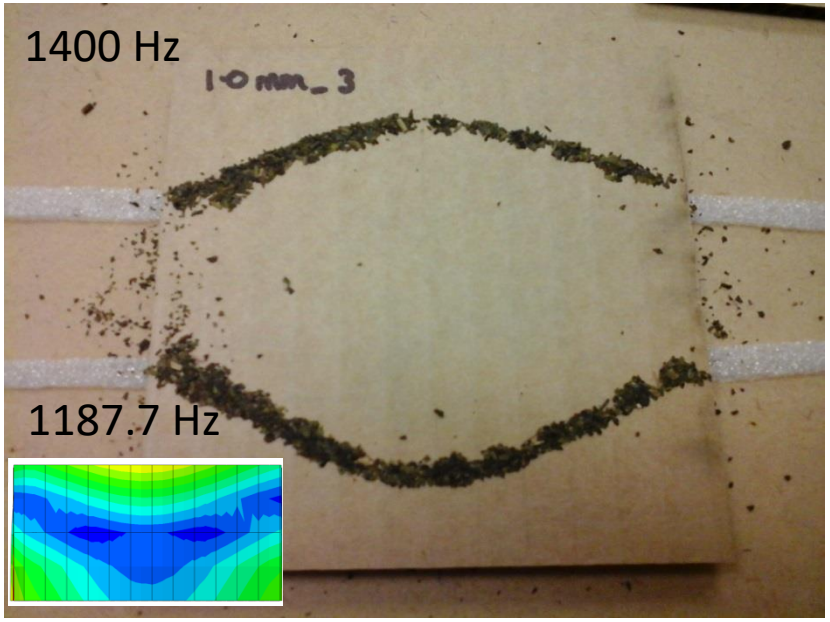


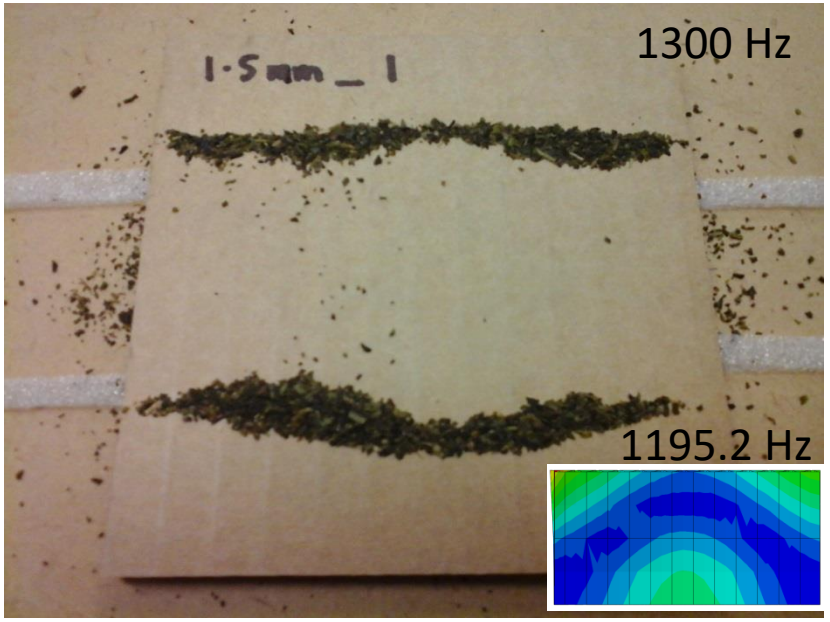
Uncrushed

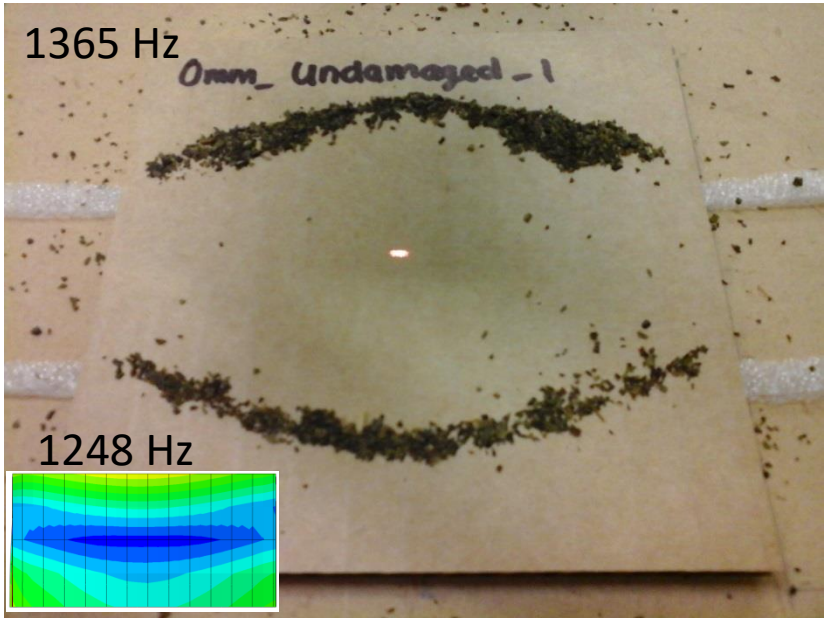
Crushed 0.5 mm

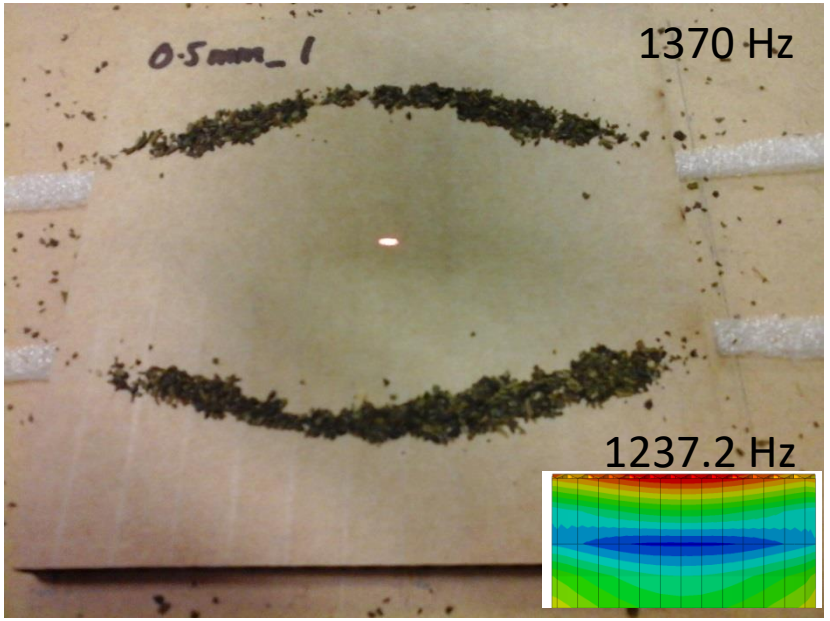

1400 Hz
0mm_Undamaged_3
1248 Hz

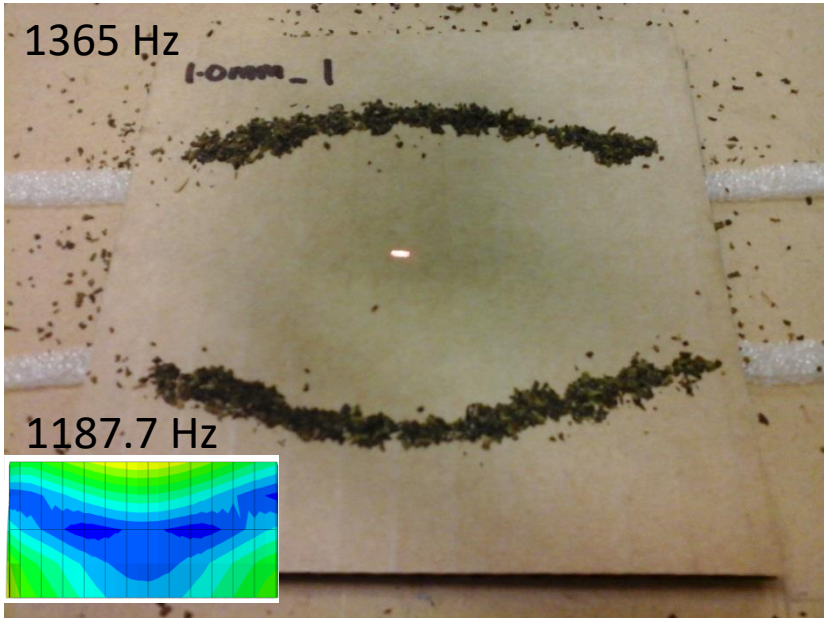

1400 Hz
0.5mm_1
1237.2 Hz

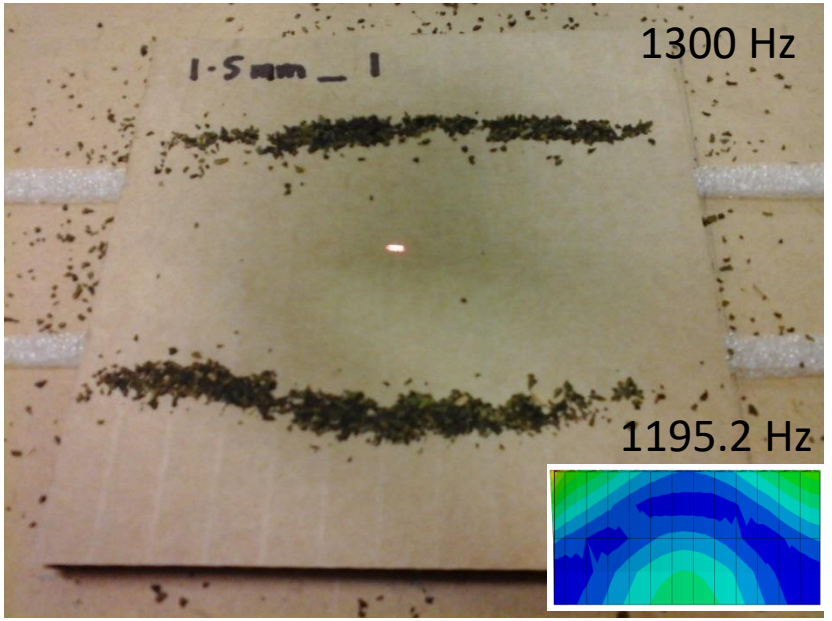

1400 Hz
1.0mm_3
1187.7 Hz


1300 Hz
1.5mm_1
1195.2 Hz


1365 Hz
0mm_ undamaged _1
1248 Hz


0.5mm_1
1370 Hz
1237.2 Hz


1365 Hz
1.0mm_1
1187.7 Hz


1.5mm_1
1300 Hz
1195.2 Hz

Future Directions

- Further vibration tests finding other modes
- Compare material properties of CFB obtained from natural frequencies with static tests – edge crush and bending tests
- Investigate the expected difference between static and dynamic material properties as paper is a viscoelastic material

Conclusion

- Modelling of crush damage CFB using FE to find natural frequencies was achieved
- Natural frequencies used to predict change in material properties using Rayleigh-Ritz iterative model
- Further vibration tests to be carried out

Acknowledgements

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References

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