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Investigation of the damping capacity of stochastic lattice structures

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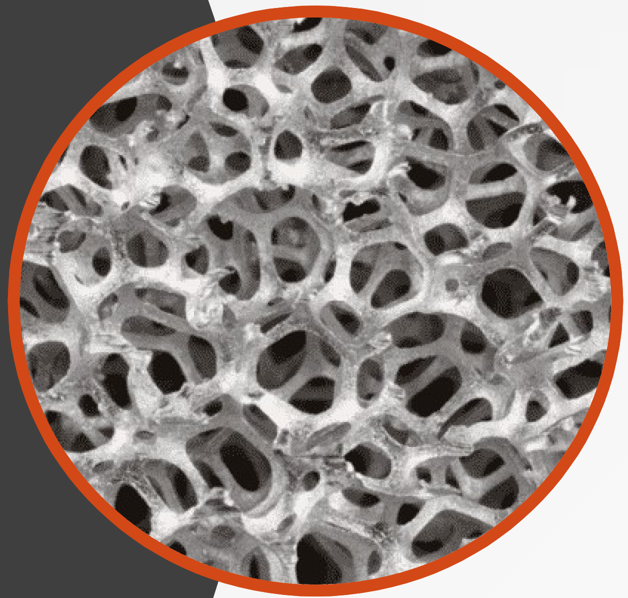
PRESENTATION CONTENTS



1st Part

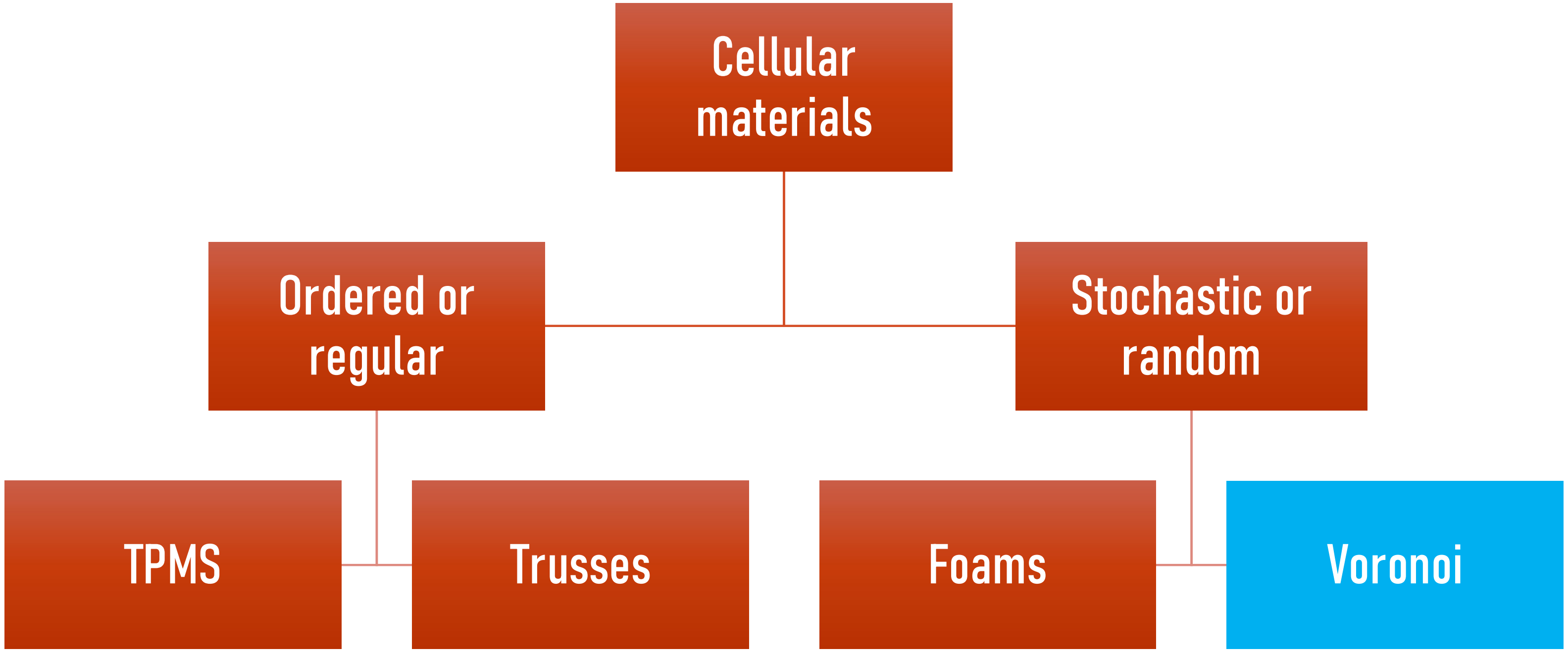
Introduction

Scope

This work presents the design and experimental verification of 3D printed stochastic lattice structures to enhance the mechanical vibration isolation properties of a robotic milling support.

The research investigates the possibility of designing stochastic 3D structures employing the Voronoi tessellation technique, which can easily be incorporated in the design of critical components that require vibration damping in a lightweight design.

Cellular materials

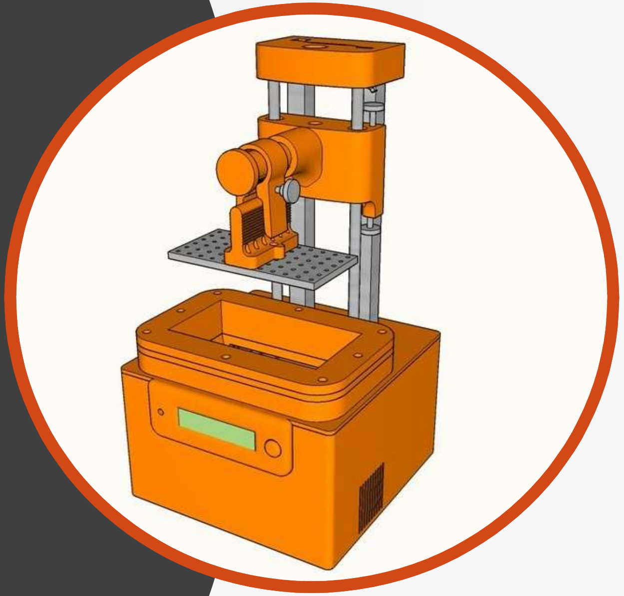


- Cellular materials are characterized by their porous microstructure that is comprised of solid and void networks

Stochastic – Voronoi lattices

- can be optimized for geometric, as well as mechanical requirements by parameter tuning,
- offer a promising approach for vibration and damping applications, providing efficient energy dissipation, broadband damping and adaptability to various scenarios, and
- have a high capacity for energy absorption. Due to their random and disordered structure, they can effectively dissipate energy from vibrations by converting it into heat.

The structures that were fabricated for this research were investigated by focusing on the optimal combination(s) of geometry and material.



2nd Part

Sample preparation and characterization

Design and Porosity

Porosity 0%

Porosity: 70%

Porosity: 75%

Porosity: 80%

- A generative algorithm has been developed, using the add-on Grasshopper of the CAD software Rhinoceros.
- Porosity defines how much space is absent in the overall volume occupied by the cellular material.

Mixtures: ratios

In order to create the mixtures two different types of resins were combined:

- Durable resin: Resione K
- Flexible resin: Resione F69

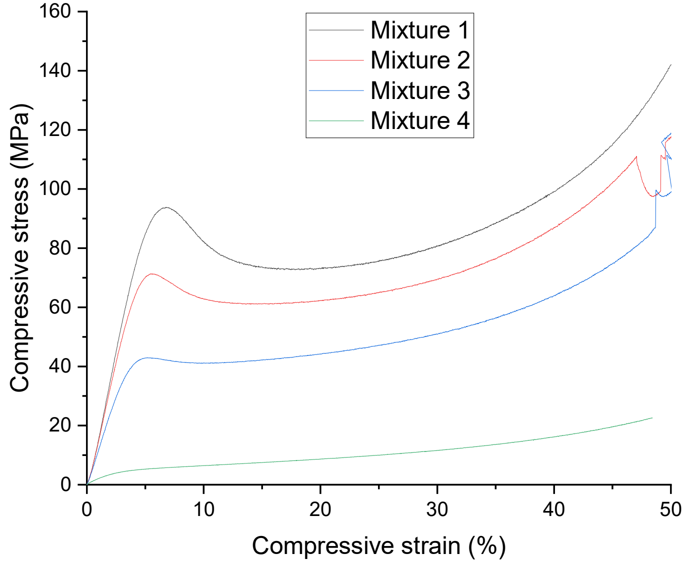
Four different resin mixtures were used:

- First mixture: 100% durable resin,
- Second mixture: 75% durable resin and 25% flexible resin,
- Third mixture: 50% durable resin and 50% flexible resin and
- Fourth mixture: 100% flexible resin.

Characterization

- The scope is to investigate the effect of the concentration of elastic resin in the durable resin.
- It was found that increasing the concentration of the elastic resin in the durable resin resulted in a decrease in the required compressive load to achieve the same deformation.

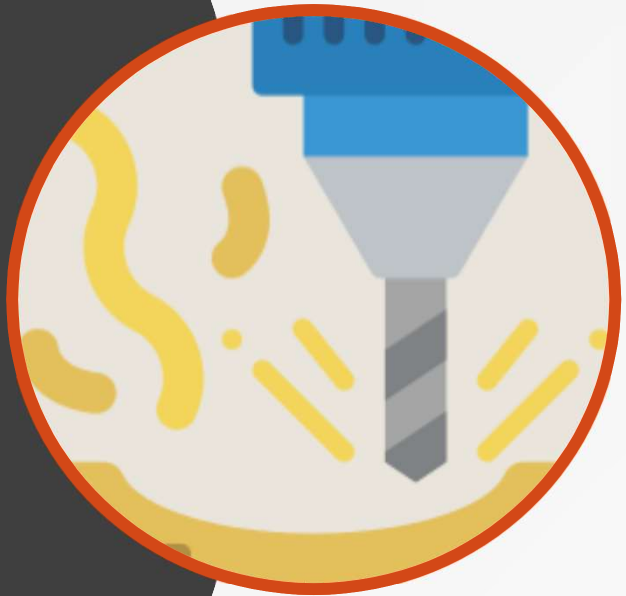
	Elastic modulus E[Mpa]	Yield strength σ[Mpa]
Mixture 1	2800	85
Mixture 2	2550	69
Mixture 3	2200	40
Mixture 4	250	5



Specimens

- The specimens were fabricated via additive manufacturing method.
- A Stereolithography 3D printer was used.
- In total, 16 specimens were created (4 different porosity designs combined with 4 mixtures).

	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Porosity 0%	Mix1-Por0	Mix2-Por0	Mix3-Por0	Mix4-Por0
Porosity 70%	Mix1-Por70	Mix2-Por70	Mix3-Por70	Mix4-Por70
Porosity 75%	Mix1-Por75	Mix2-Por75	Mix3-Por75	Mix4-Por75
Porosity 80%	Mix1-Por80	Mix2-Por80	Mix3-Por80	Mix4-Por80



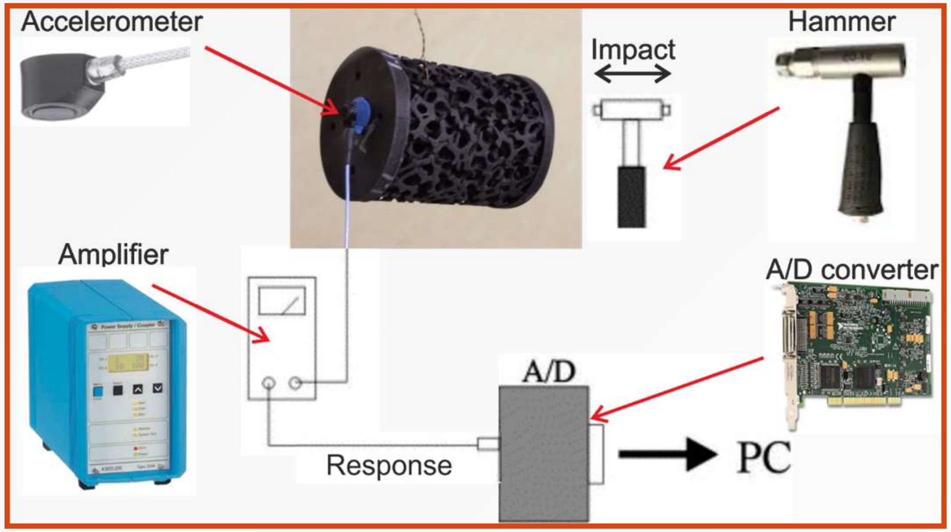
3rd Part

Experimental set-ups

Impact testing set-up

The experimental set-up used to determine the natural frequency and the damping ratio of the samples:

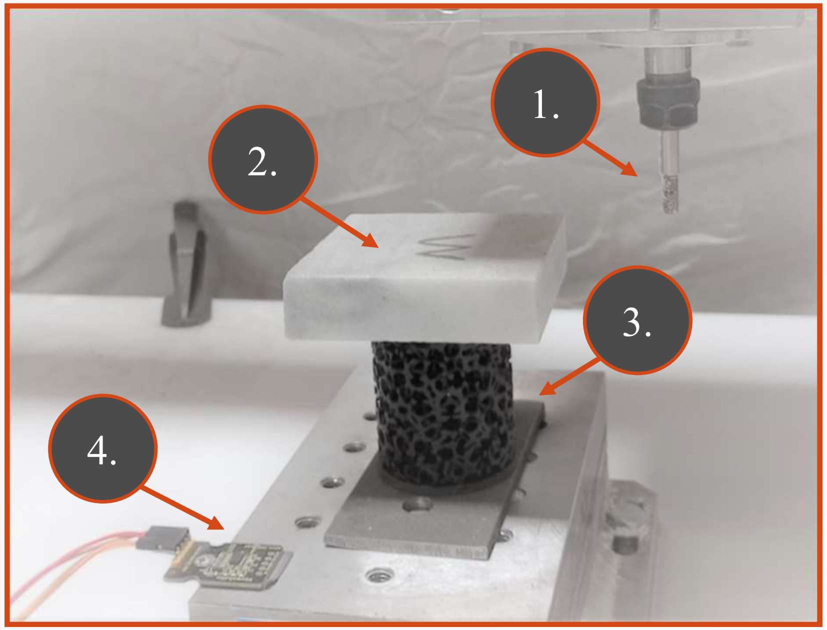
1. Specimen
2. Impact tool (hammer)
3. Accelerometer (1-axis)
4. Signal amplifier
5. Analog/Digital amplifier



Vibration testing set-up

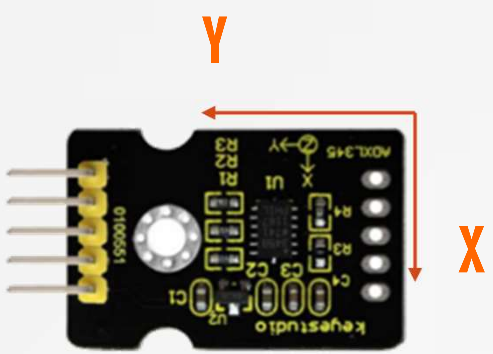
In order to determine the mechanical vibration isolation the following set-up was created:

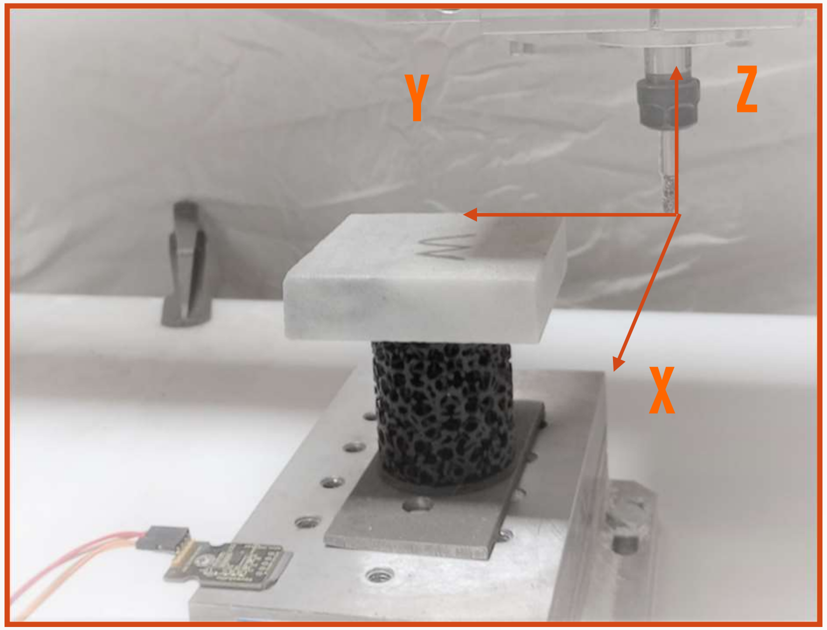
1. Milling tool
2. Marble piece
3. Specimen (vibration dampener)
4. 3-axis accelerometer

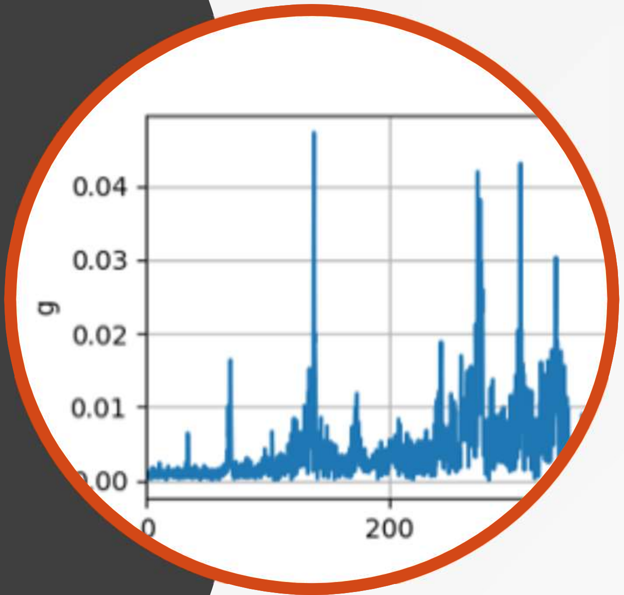


3-axis Acceleration

A 3-axis acceleration module was used to measure the acceleration in each axis.



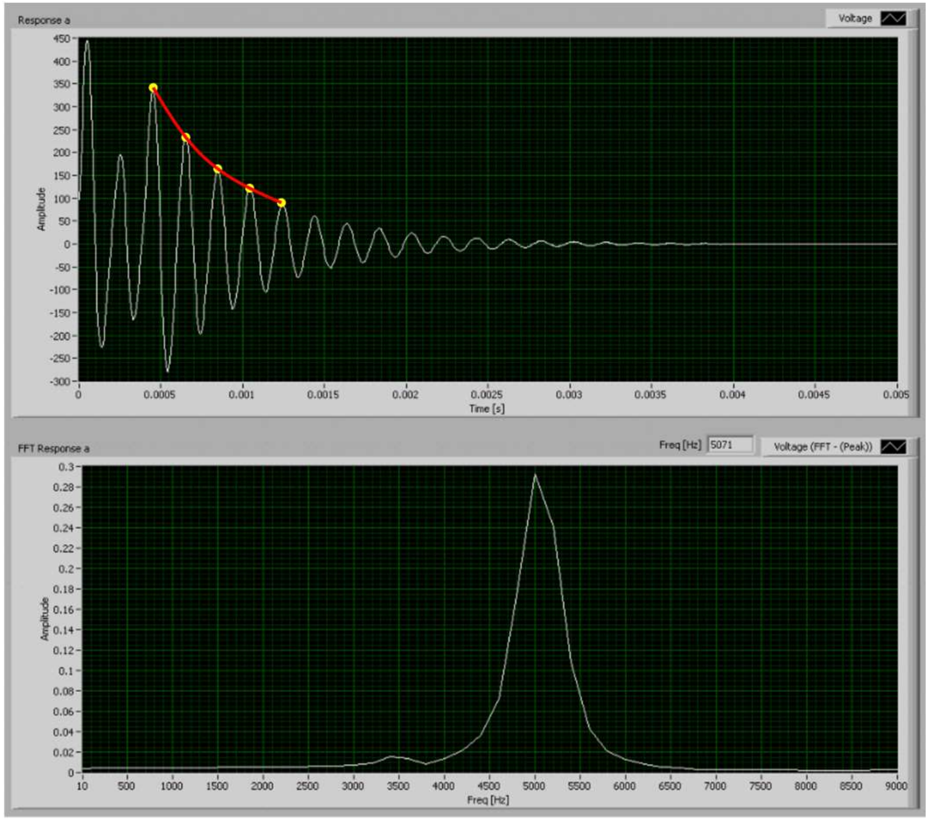




4th Part

Data processing and results

Impact testing results

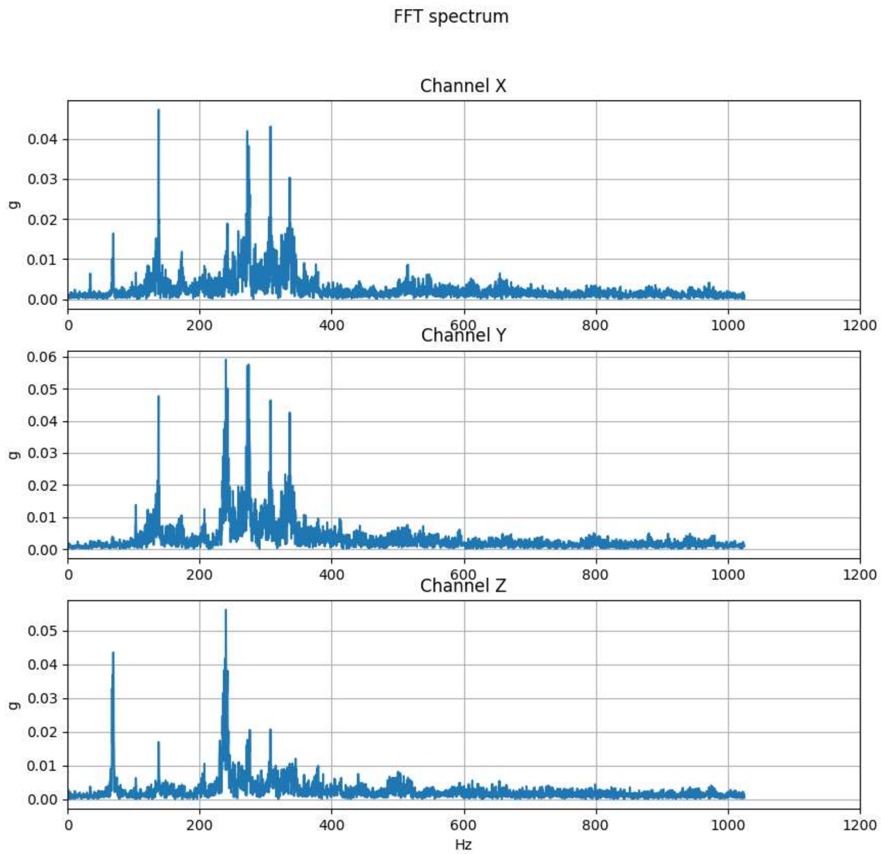


$$x(t) = Ae^{-\delta t}\cos(\omega_d t - \theta)$$

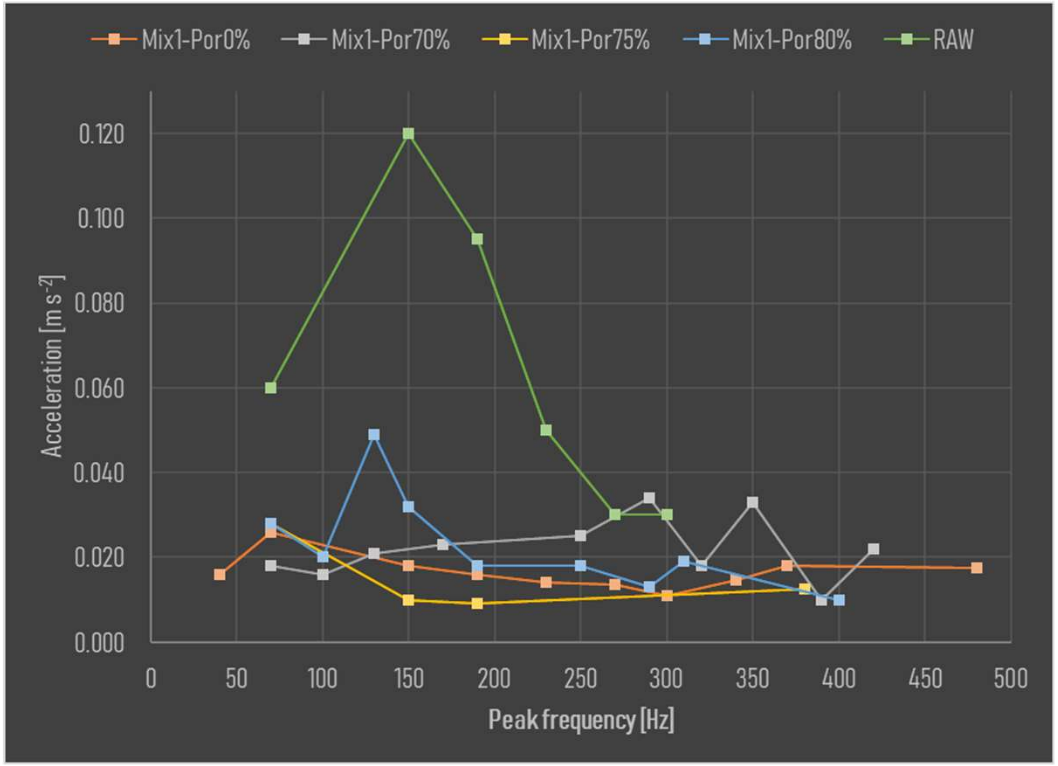
Specimen	1st frequency [Hz]	Damping ratio (ζ)
Mix1-Por70	5071	0.055
Mix1-Por75	5084	0.066
Mix1-Por80	4520	0.070
Mix2-Por70	4269	0.087
Mix2-Por75	4334	0.063
Mix2-Por80	3946	0.120
Mix3-Por70	3303	0.143
Mix3-Por75	3527	0.095
Mix3-Por80	3302	0.091
Mix4-Por70	2112	0.173
Mix4-Por75	2085	0.217
Mix4-Por80	1890	0.239

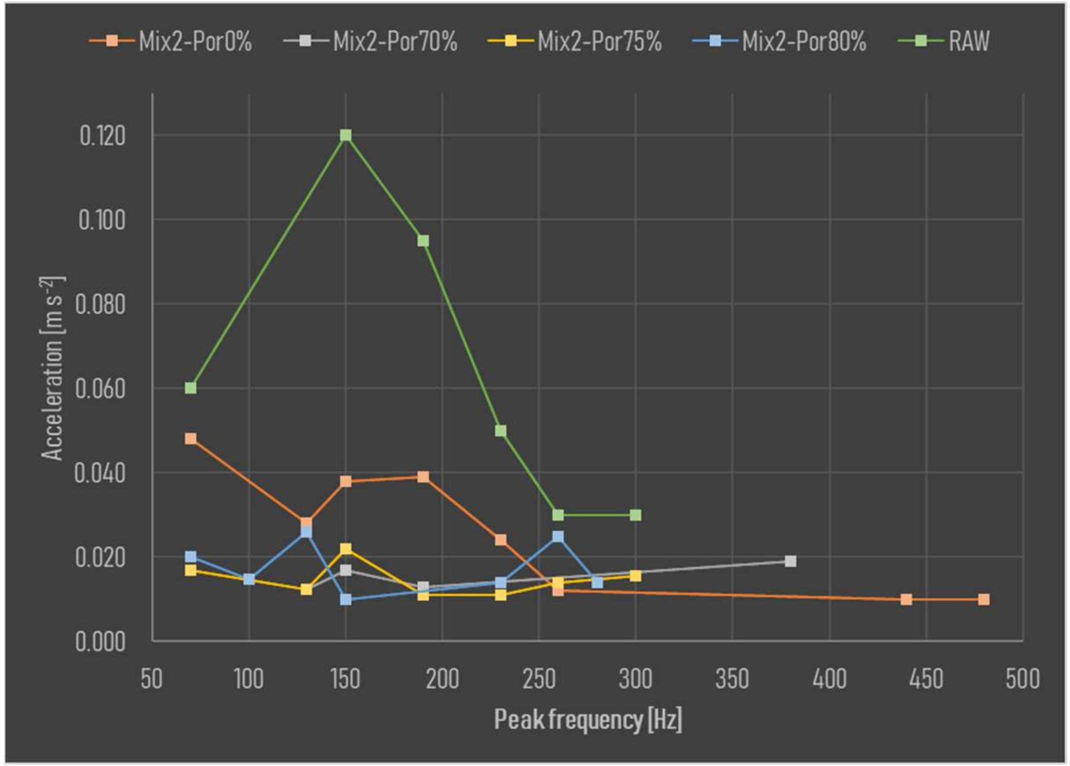
Data processing of vibration results

- For each of the samples, an acceleration-frequency diagram was developed through the use of the aforementioned setup.
- The accelerometer module measured and outputted the acceleration and frequency values over each axis in a separate channel.



Acceleration-frequency diagrams: x-axis 2200 RPM





X-axis maximum acceleration results

x @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.026	70	10	0.048	70	8	0.038	100	6
3500	0.045	340	7	0.029	170	11	0.03	170	11
5000	0.033	270	5	0.17	70	5	0.11	70	9

x @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.034	290	11	0.019	190	4	0.038	100	3
3500	0.075	800	7	0.015	170	5	0.02	170	5
5000	0.051	270	7	0.034	400	6	0.076	400	4

x @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.028	70	4	0.022	150	7	0.01	170	2
3500	0.018	160	5	0.025	260	6	0.014	170	3
5000	0.028	70	4	0.022	150	7	0.052	230	5

x @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.049	130	9	0.026	130	7	0.062	70	8
3500	0.026	160	4	0.018	170	3	0.028	170	4
5000	0.03	400	8	0.033	400	7	0.025	170	3

	x - Raw		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n
2200	0.12	150	6
3500	0.63	120	4
5000	0.84	160	4

X-axis maximum acceleration reductions

x @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	78%	70	10	60%	70	8	68%	100	6
3500	63%	340	7	76%	170	11	75%	170	11
5000	73%	270	5	-42%	70	5	8%	70	9

x @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	72%	290	11	84%	190	4	68%	100	3
3500	38%	800	7	88%	170	5	83%	170	5
5000	58%	270	7	72%	400	6	37%	400	4

x @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	77%	70	4	82%	150	7	92%	170	2
3500	85%	160	5	79%	260	6	88%	170	3
5000	77%	70	4	82%	150	7	57%	230	5

x @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	59%	130	9	78%	130	7	48%	70	8
3500	78%	160	4	85%	170	3	77%	170	4
5000	75%	400	8	73%	400	7	79%	170	3

	x - Raw		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n
2200	0.12	150	6
3500	0.63	120	4
5000	0.84	160	4

Y-axis maximum acceleration results

y @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.033	370	13	0.038	130	11	0.028	170	6
3500	0.08	340	6	0.059	170	9	0.087	170	10
5000	0.035	340	4	0.13	170	5	0.12	170	9

y @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.087	170	10	0.025	680	10	0.019	170	6
3500	0.05	400	8	0.048	440	7	0.09	210	12
5000	0.078	160	6	0.08	400	6	0.078	400	6

y @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.023	130	4	0.019	380	9	0.021	410	5
3500	0.078	500	4	0.041	440	8	0.03	440	7
5000	0.079	500	6	0.05	170	9	0.078	400	5

y @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n	g [m s^{-2}]	f [Hz]	n
2200	0.049	130	9	0.024	130	7	0.043	230	10
3500	0.078	500	4	0.04	500	5	0.034	170	6
5000	0.1	400	6	0.042	170	6	0.03	400	5

	y - Raw		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n
2200	0.86	150	8
3500	0.25	130	8
5000	0.89	170	5

Y-axis maximum acceleration reduction

y @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	96%	370	13	96%	130	11	97%	170	6
3500	91%	340	6	93%	170	9	90%	170	10
5000	59%	340	4	85%	170	5	86%	170	9

y @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	90%	170	10	97%	680	10	98%	170	6
3500	94%	400	8	94%	440	7	90%	210	12
5000	91%	160	6	91%	400	6	91%	400	6

y @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	97%	130	4	98%	380	9	98%	410	5
3500	91%	500	4	95%	440	8	97%	440	7
5000	91%	500	6	94%	170	9	91%	400	5

y @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	94%	130	9	97%	130	7	95%	230	10
3500	91%	500	4	95%	500	5	96%	170	6
5000	88%	400	6	95%	170	6	97%	400	5

	y - Raw		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n
2200	0.86	150	8
3500	0.25	130	8
5000	0.89	170	5

Z-axis maximum acceleration results

z @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n
2200	0.058	70	5	0.06	70	7	0.053	100	9
3500	0.078	70	6	0.092	40	3	0.062	170	9
5000	0.058	160	4	0.23	70	4	0.15	170	7

z @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n
2200	0.09	170	6	0.024	70	6	0.096	70	4
3500	0.025	400	6	0.04	40	7	0.068	40	9
5000	0.085	160	5	0.098	170	6	0.18	230	5

	z - Raw		
RPM [min^{-1}]	g [$m\ s^{-2}$]	f [Hz]	n
2200	0.128	70	6
3500	0.68	130	4
5000	0.13	170	3

z @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n
2200	0.068	70	2	0.018	70	7	0.041	70	4
3500	0.034	70	6	0.03	230	6	0.062	40	6
5000	0.058	230	4	0.126	70	6	0.098	170	3

z @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n	g [$m\ s^{-2}$]	f [Hz]	n
2200	0.052	70	8	0.05	70	7	0.03	170	4
3500	0.068	120	8	0.05	40	5	0.034	170	2
5000	0.031	160	4	0.06	70	8	0.043	170	3

Z-axis maximum acceleration reduction

z @ 0%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	55%	70	5	53%	70	7	59%	100	9
3500	39%	70	6	28%	40	3	52%	170	9
5000	55%	160	4	-80%	70	4	-17%	170	7

z @ 70%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	30%	170	6	81%	70	6	25%	70	4
3500	80%	400	6	69%	40	7	47%	40	9
5000	34%	160	5	23%	170	6	-41%	230	5

z @ 75%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	47%	70	2	86%	70	7	68%	70	4
3500	73%	70	6	77%	230	6	52%	40	6
5000	55%	230	4	2%	70	6	23%	170	3

z @ 80%	Mix1			Mix2			Mix3		
RPM [min^{-1}]	g	f [Hz]	n	g	f [Hz]	n	g	f [Hz]	n
2200	59%	70	8	61%	70	7	77%	170	4
3500	47%	120	8	61%	40	5	73%	170	2
5000	76%	160	4	53%	70	8	66%	170	3

	z - Raw		
RPM [min^{-1}]	g [m s^{-2}]	f [Hz]	n
2200	0.128	70	6
3500	0.68	130	4
5000	0.13	170	3

5th Part

Discussion

Discussion

- Regardless of the specimens' properties, all 16 specimens reduced the acceleration values, when compared to milling without a dampener.
- The damping ratio showed an ascending trend due to the increase of flexible resin in the mixture.
- The acceleration values were reduced most at the y-axis. This axis had the highest acceleration values without the use of dampeners (this is the movement axis of the milling tool).

Discussion

- Mixture 4 was too elastic and produced no results due to specimen bending.
- While mixture 4 was not usable as a specimen, a percentage of the flexible resin in the durable one raised the vibration reduction beyond that of the mixture 1.
- Mixture 2 showed the best overall performance, especially combined with porosities 75% and 80%.
- Mixture 3 showed reduced performance on the z-axis, due to its slight deformation which resulted in a different direction of the applied force.

6th Part

Conclusions

Conclusions

- The results showed enhanced damping characteristics, which varied according to the structure geometry and the used materials.
- Based on these results, lightweight vibration damping structures can be incorporated into the mechanical fixtures of robotic milling.
- The best overall damping performance was achieved from mixture 2, with an optimal porosity value of 75%, followed closely by 80%.
- Light-weight specimens showed reduced acceleration values. As light-weight objects are preferred due to lower demand of material, these results show that the light-weight specimens are clearly advantageous over the bulky ones.

THANK YOU FOR
YOUR ATTENDANCE!
ANY QUESTIONS?