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# EXPERIMENTAL INVESTIGATION OF VIBRATION DAMPING ABILITY FOR DIFFERENT SIMPLE CUBIC PERIODIC LATTICE STRUCTURES MORPHOLOGIES

Mario Soldo & Davorka Šaravanja

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**Abstract**

Lattice structures have been the object of research by an increasing number of scientists in recent years following the rapid development of additive manufacturing. A series of improved mechanical properties have enabled the wide application of lattice structures in the automotive industry, aerospace industry, vibration damping, sports equipment, and medicine. In this paper, the impact of the morphology of additively manufactured PLA periodic Simple Cubic lattice structures on improving mechanical properties during vibration testing is investigated. It has been demonstrated that structures optimizing the morphological distribution of Simple Cubic unit cells offer better mechanical performance in terms of damping of vibration. Vibration testing has shown enhanced damping properties of vibrations with reduction of unit cell height in morphologically optimized lattice structure.

**Keywords:** lattice structures; Simple Cubic unit cell; additive manufacturing; PLA material; morphological distribution; vibration damping.

## 1. Introduction

Lattice structures are considered cellular structures (with honeycomb and foam structures) and were defined as a three-dimensional porous spatial structure formed by unit cells with different topologies that are spatially tessellated. An example of a lattice structure with the components of a unit cell (struts and nodes) is shown in Fig. 1. Depending on the arrangement of the unit cell, lattice structures can be periodic (if they belong to the group of non-stochastic cell structures) or random (if they belong to the group of stochastic cell structures) [1].

The topology of the unit cell refers to the type of unit cell, that is, the spatial position of the nodes that connect the struts. Spatial positions of the unit cell nodes are determined by the type of unit cell. The morphology of the unit cell is characterized by the shape and geometry of the struts and nodes. The morphology of the lattice structure refers to the spatial distribution and orientation of the unit cells within the lattice structure. Relative density is one of the crucial properties of lattice structures and represents the ratio of lattice structure volume to solid volume. The main parameters that generally affect the mechanical properties (therefore the vibration damping properties) of lattice structures at the macro level are:

- topology of the unit cell;
- morphology of the unit cell;
- lattice structure morphology;
- relative density of the lattice structure and
- mechanical properties of the building material [3].

The growth in the use of additive manufacturing for final products has been visible last few years and the best indicator of growth is the increase in the use of additive manufacturing in the creation of patents. Additively obtained structures are widely used in the aviation industry [4]. The possibility of additive manufacturing of high-quality, complex specific components and the possibility of manufacturing components with lattice structures whose stiffness is lower than bone stiffness make lattice structures ideal for medical implants [5]. In recent years, a particularly large application of additively obtained plastic rigid lattice structures is in the production of sport and sports protective equipment [6]. A great potential that could be capitalized in the future is the application of lattice structures for acoustics and vibration damping, but it should be considered that additively obtained products are particularly sensitive to small irregularities during the manufacturing process [7]. The experimental investigation of the vibration damping ability of additively obtained plastic periodic lattice structures with different morphological distributions of unit cells (while the relative density is constant) is the subject of this research.

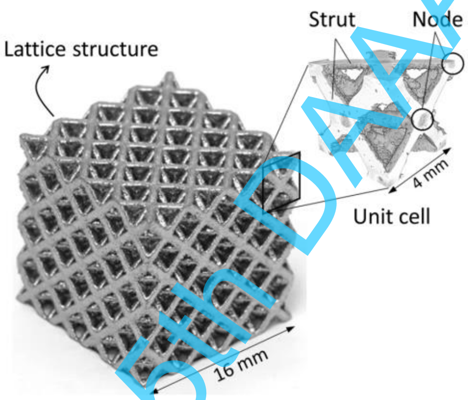


Fig. 1. Lattice structure formed by a repeating arrangement of octet unit cells made up of struts and nodes [2]

## 2. Previous research

In researching the ability of vibration damping of additively obtained lattice structures, several significant studies stand out. In a review paper by Dalela et al. [8], through a series of research papers mentioned, state the positive effect of the mechanical properties of metamaterials for the purpose of vibration control. However, due to the closedness and non-uniformity of the structure of porous materials, it is concluded that it is difficult to accurately predict the absorption of vibration energy and the behavior of oscillations. This is where additive manufacturing comes into play, which enables the production of uniform, periodic, open unit cells, where lattice structures show a good ability to oscillation wave damping and vibration behavior control, with generally good mechanical properties.

Chiocca et al. [9] investigate the occurrence of fatigue under displacement control of coated PLA lattice structures with FCC (Face – Centered Cubic) unit cells, obtained by extruding the material, at two different frequencies (3 Hz and 20 Hz). They proved that the coating process increased the fatigue strength for both frequency cases, and interestingly, they managed to model a sample that is suitable for both tensile and compressive testing. Wang et al. [10] examine the natural frequencies of 3D printed plastic samples with homogeneous and variable honeycomb unit cells. They vary the arrangement of the relative density of the test sample from a uniform to an optimized distribution of the relative density of unit cells. They experimentally prove that with this approach to the arrangement of unit cells with different relative densities it is possible to optimize the own frequency of the test samples.

Kayiran and Yaman [11] numerically and experimentally investigate the natural frequency for two different optimization approaches of a beam with cubic unit cells with equal value of volume fraction. The results show that the optimized beam has a 73% higher natural frequency (the first natural frequency is 325.3 Hz) compared to a uniform beam with the same volume fraction of 0.6 (the first natural frequency is 199.6 Hz). They successfully improved the vibration response without disturbing the external appearance (contour) of the beam. Elmadih et al. [12] investigate the influence of the size of the unit cell and the number of layers within the lattice structure (obtained by extrusion of plastic) on the natural frequency results in dynamic analysis. They conclude that the natural frequency of the lattice structure can be reduced by increasing the size of the unit cells and increasing the number of layers in the lattice structure.

Azmi et al. [13] investigate the influence of full and almost full BCC (Body – Centered Cubic) unit cells obtained by the process of extruding plastic material on the vibration characteristics of the struts and conclude that a full cross-section of the struts gives higher natural frequency values, and that the stiffness component of the lattice structure is much more significant compared to the mass component. Syam et al. [14] propose several design parameters (which directly affect stiffness and natural frequency) for the comparison of lattice structures and experimentally analyse natural frequency and compression strength. The main goal of the research was to achieve design parameters of lattice structures that provide high efficiency of vibration isolation along with good ability to withstand external compression loads. Also, they conclude that the defined parameters for the design of lattice structures are only suitable for experimental analysis, while they are not suitable for FE analysis since the simulation calculation is extensive due to the complex lattice structure geometry.

Monkova et al. [15] experimentally investigate the influence of geometrical parameters of BCC unit cells with different relative densities (through changes in BCC cell sizes and strut radius) on vibration damping and compression properties. The results of the experimental test showed that the ability of plastic lattice structures to dampen mechanical vibrations increases with a decrease in the volume ratio and with an increase in the cell size. Some research on periodic lattice structures was devoted to numerical and experimental analysis and showed examples of the application of lattice structures in gears, passenger seats, and as a vibration isolator. When a vibrational wave passes through lattice structures, it is attenuated based on the topology and geometry of the lattice, thus reducing the associated amplitudes. Although there is a large amount of research regarding the influence of lattice structure parameters on vibrations, there is not enough knowledge on how to improve damping efficiency by applying lattice structures based on different topologies, using functionally graded lattice structures, and changing geometric parameters such as cross-sectional area [16]. In this research, vibration damping abilities were tested on the different morphological arrangements of Simpe Cubic unit cells in lattice structures while the relative density of lattice structure was constant.

### 3. Modeling of different morphologies Simple Cubic periodic lattice structures

To define different morphological distributions of unit cells the lattice structures, the Simple Cubic (SC) unit cell was chosen as a type of unit cell, which is one of the most representative types of unit cells. The wireframe is modeled in the Rhinoceros program, and the dimensions of the volume for the wireframe model are 10 mm x 10 mm x 10 mm. It is an empirical assumption that those dimensions of the volume, in which the unit cell is modeled, are suitable for the material extrusion additive process. The SC unit cell is made with 12 struts, 8 of them are in horizontal position (where 4 struts are spatially parallel to each other) and 4 of them are in vertical position (which are also spatially parallel to each other), as shown in Fig. 2. The length of each SC unit cell strut within the previously defined volume is equal to 10 mm. The place where 3 struts join is called a node. SC unit cell has 8 nodes. By defining the spatial position and orientation of the struts and nodes, the topology (type) of the unit station is defined. By adding the cross section of the struts and nodes (in this case, a circular cross-section with a radius of 1.43 mm), the result is a defined unit cell morphology. When the morphology of the unit cell is defined, it is also possible to determine the relative density or porosity of the unit cell. In this case, the relative density of this SC unit cell with struts radius of 1.43 mm is 0.2, so porosity is 80%.

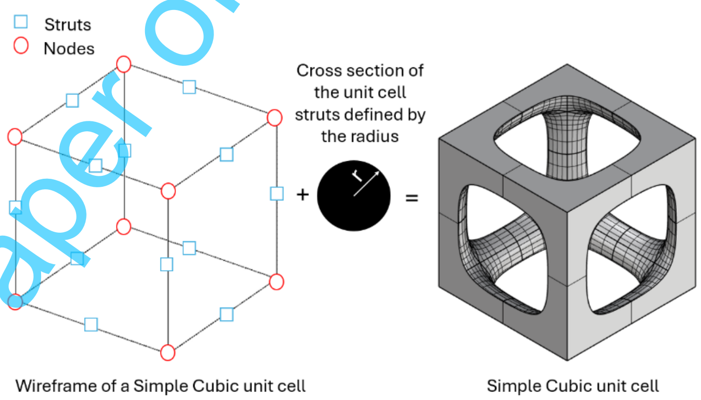


Fig. 2. Wireframe of a Simple Cubic unit cell (left) and Simple Cubic unit cells with defined struts radius (right)

In the Rhinoceros program, with the plug-in Grasshopper, an algorithm is defined for modeling three different morphologies of SC periodic lattice structures that, by changing the value of the radius of the struts and nodes, will have the same value of relative density (0.2), thus maintaining the same consumption of materials during the additive manufacturing process. The first series is designated as SC – A and has a rectangular spatial arrangement of SC unit cells within a lattice structure. The second series is designated as SC – B and has a spatial arrangement of SC unit cells along concave parabolas within a lattice structure. The third series is designated as SC – C and has a spatial arrangement of SC unit cells along convex parabolas within a lattice structure. The SC – B and SC – C series differ, in addition to the parabolic spatial arrangement of the SC unit cells within the lattice structures, by the reduced heights of the unit cells in the zones closer to the place of assembly of the test specimens and the place of measurement of the vibration response of the lattice structures (upper and lower lattice layers), as it is shown on Fig. 3. A relative density of 0.2 was chosen for all three series, and the radii of the struts and nodes were assigned according to the relative density. Dimensions of samples for lattice structures with different morphology distributions of unit cells are 50 mm x 50 mm x 50 mm. The multiplication array of SC unit cell for SC – A series is 5 (length) x 5 (width) x 5 (height) and for SC – B and SC – C series, it is 5 (length) x 5 (width) x 7 (height).

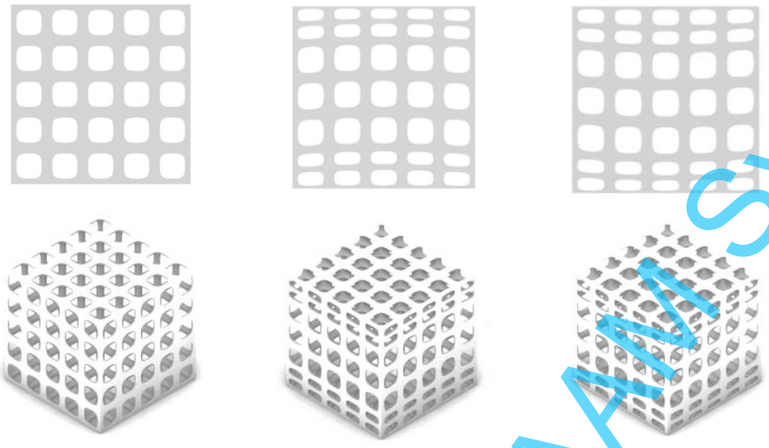

Fig. 3. Front (top) and isometric (bottom) view of models of lattice structures series SC – A (left), SC – B (middle) and SC – C (right)

## 4. Lattice structures additive manufacturing

Additive manufacturing of lattice structures was done on a Zortrax M200 Plus printer (material extrusion printer) with the support of the Z-Suite slicer program. The PLA (polylactic acid) material was selected with the printing parameters listed in Table 1. Material and the printer were selected according to earlier research on this topic [17]. Three identical samples of all series were printed at the same time to maximally reduce the influence of external factors on the quality of the test results. Table 2 shows the time spent on printing one series of lattice structures with three samples and the total material consumption (in grams and meters of used raw PLA material). The values from Table 2 proved the same consumption of material for all test sample production, so the accuracy of the defined algorithm in the plugin Grasshopper and program Rhinoceros for determining the same relative density over the radius of the struts and nodes was confirmed. Fig. 4 shows printed samples for experimental testing.

| Selected material | Extruder temperature | Platform temperature | Layer thickness | Extruder diameter | Model infill |
|---|---|---|---|---|---|
| PLA | 210°C | 30°C | 0.19 mm | 0.4 mm | Solid (100%) |

Table 1. Zortrax M200 Plus printing parameters

| Series | Printing time | Material used |
|---|---|---|
| SC – A | 21 h 42 min | 102 g; 35.94 m |
| SC – B | 21 h 45 min | 101 g; 35.54 m |
| SC – C | 21 h 38 min | 101 g; 35.45 m |

Table 2. Printing time and material used for sample production

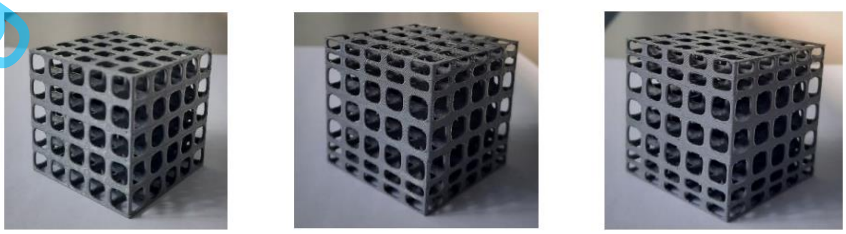

Fig. 4. Printed samples of lattice structures for experimental vibration testing

## 5. Lattice structures vibration damping testing

The vibration testing was performed on a mechanical model adapted for the needs of vibration research on lattice structures. The vibration test, for all three series of morphologically different lattice structures, was carried out in three key steps: mounting the samples on the vibration platform, vibration excitation of the lattice structures via the vibration platform and saving the output data for validation of the experimental results. Vibration testing of additively manufactured lattice structures was performed using excitation and measurement equipment consisting of a vibration platform Model 25 – VP – T, measuring device VIBROSTORE 100 and appropriate program support for processing the results in the form of the ReO program (Report & Route Manager Software B&K Vibro – Brüel & Kjær).

A vibration platform Model 25 – VP – T was used to create vibration excitation in the vertical direction (perpendicular to the printing direction) of the testing samples. During the operation of the vibration platform, the frequency can be changed manually from 5 to 100 Hz (cycles per second CPS = Hz). The power of the electric motor of the vibrating platform is 1 KW. The motor must be adjusted in such a way that the mechanism rotates in a clockwise direction. The selection of the acceleration range is determined by a selector that changes the vibration speed over the selected frequency range automatically or manually. On this way, it is possible to choose the required frequency within the limits of 5 Hz to 100 Hz by applying appropriate limiters that correspond to the lower or upper limit frequency. The samples are tested in the frequency range from 10 Hz to 30 Hz.

The size of the amplitude and frequency of the vibration platform was determined with appropriate instruments for measuring vibrations (VIBROSTORE 100 with its associated sensors and ReO software). A vibration meter is an electronic device that processes vibration signals that it receives using a sensor that collects vibrations translated into electrical signals. After placing the magnetic part with the vibration sensor at the exact measuring point of the testing samples, the vibrations of the sample are converted into electrical signals that are transmitted to the measuring instrument via a cable. The signal is processed into vibration values that can be read on the screen of the measuring instrument. Acceleration or speed values are displayed on the screen of the vibrating device. It is important to place the magnet with the sensor always in the same location to achieve reparability of the test under the same conditions. For this reason, it is desirable to clean the surface where the magnet will adhere to remove unwanted impurities (oil grease, rust, dust, or residual paint) that can adversely affect the measurement results. The main screen of the VIBROSTORE 100 measuring device shows the state of the test sample in BDU (damage unit) and total g (or rms acceleration). Rms vibration (Root Mean Square Vibration) is one of the practical measures of vibration speed. It is often used to describe the vibration signal and represents the mean power of the measured velocity. It is obtained by measuring the peak amplitudes and multiplying by $1/\sqrt{2}$, which is approximately equal to 0. 707. Logically, dividing the rms value by 0.707 gives the peak amplitude value.

VIBROSTORE 100 can work independently or with Brüel & Kjær software Vibro Report & Route Manager (ReO). Report & Route Manager is a powerful and highly functional vibration analysis editor that results in high quality reports. First, a route with selected names is defined in the ReO software, and the names are loaded into the VIBROSTORE 100. After testing, all recorded data from the VIBROSTORE 100 is loaded into the ReO program. Data in ReO can be displayed in many ways, including vibration frequency spectrums, ISO graphs, and "waterfall" graphs. Also, output reports can be generated automatically or adjusted manually.

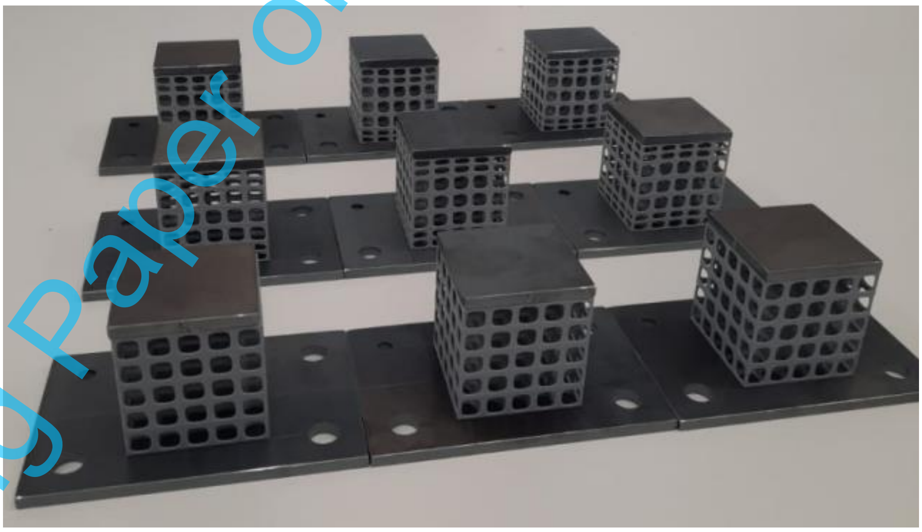

Fig. 5. Samples of series SC – A, SC – B and SC – C glued on steel plates

The vibration test sensor of the VIBROSTORE 100 device can only be stably positioned on samples made of magnetic materials. Since the lattice structures are made of PLA material, it is necessary to connect two steel plates to the lattice structures sufficiently rigidly (one for mounting the lattice structure on the platform, and the other on the lattice structure for sensor positioning). On the lower surface of the lattice structures (the surface that is printed first in the 3D printing process), a larger steel plate is glued. The board has 4 holes drilled in it for proper mounting on the platform of the vibration device. Three of the four holes have a diameter of 11 mm (for the passage of M12 screws), and one hole (upper left) has a diameter of 6.6 mm. The exact values of the distance between the holes are determined according to the distance of the threaded holes on the vibration platform to achieve tight clamping. For all the test samples to be successfully mounted at the same position on the platform, the position of the glued center of the sample is measured on the larger steel plate exactly in the middle of the plate. The longer and shorter sides of the plate are divided in half, and the center of the lower surface of the lattice structure is mounted in the center of the intersection. A smaller plate is rigidly attached to the upper surface of the testing samples (the surface that was printed last in 3D printing). While making smaller and larger plates, the requirements were fine processing to create a solid connection when gluing. Before gluing the plates, the contact surfaces of the plates with the sample, the vibration platform, and the magnetic sensor are cleaned. Testing samples of all three series (SC – A, SC – B and SC – C) of lattice structures with glued steel plates are shown in Fig. 5.

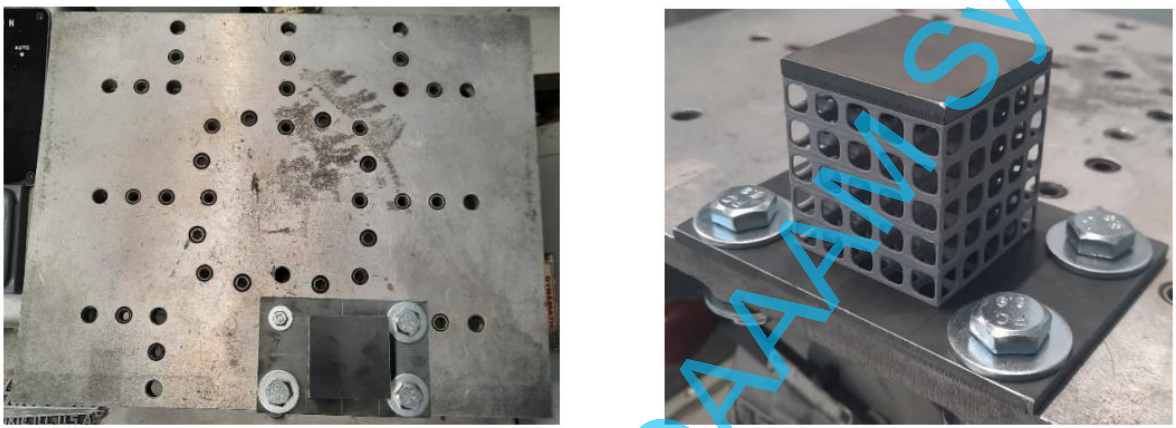

Fig. 6. Position of the test samples on the platform (left) and clamping the samples (right)

Experimental testing of three series of lattice structures with different morphological distributions of SC unit cells was performed at a temperature of 25°C (in one day) to avoid unwanted influence of external factors (temperature change, humidity) on the response of structures subjected to vibration excitation. Each test specimen is mounted in the same place on the vibration platform, as shown in Fig. 6. (left). Each sample is mounted with three M12 screws (ISO 4014) and one M8 screw (ISO 4014) and their corresponding nuts (ISO 4032) and washers (ISO 7091) as shown in Fig. 6. (right). Before the start of the vibration testing, a vibration sensor with a magnet was placed on the upper, smaller plate (exactly in the middle of the plate) and connected by a cable to the VIBROSTORE 100 device, as shown on Fig. 7. (left). Through the routes with the ReO program, each lattice structure of each series and each excitation frequency is assigned a suitable name. The structures were subjected to three different excitation frequencies of 10 Hz, 20 Hz, and 30 Hz via a manually adjusted frequency on the excitation device, as shown in Fig. 7. (right).

Fig.7. Vibration sensor positioning (left) and manually adjusted excitation frequency (right)

During the test, rms values from the VIBROSTORE 100 measuring device were recorded for three different excitation vibration values. The obtained rms values (expressed in mm/s) of all test samples of lattice structures (SC – A, SC – B and SC – C) for all excitation frequency of 10 Hz, 20 Hz and 30 Hz are shown in Table 3.

| Excitation frequency 10 Hz | | Excitation frequency 20 Hz | | Excitation frequency 30 Hz | |
|---|---|---|---|---|---|
| **Sample** | **rms value** | **Sample** | **rms value** | **Sample** | **rms value** |
| SC – A – 1 – 10 | 14.76 mm/s | SC – A – 1 – 20 | 28.66 mm/s | SC – A – 1 – 30 | 43.06 mm/s |
| SC – A – 2 – 10 | 14.18 mm/s | SC – A – 2 – 20 | 27.80 mm/s | SC – A – 2 – 30 | 41.59 mm/s |
| SC – A – 3 – 10 | 13.88 mm/s | SC – A – 3 – 20 | 28.13 mm/s | SC – A – 3 – 30 | 41.87 mm/s |
| SC – B – 1 – 10 | 14.36 mm/s | SC – B – 1 – 20 | 27.78 mm/s | SC – B – 1 – 30 | 42.04 mm/s |
| SC – B – 2 – 10 | 14.76 mm/s | SC – B – 2 – 20 | 27.90 mm/s | SC – B – 2 – 30 | 42.01 mm/s |
| SC – B – 3 – 10 | 14.44 mm/s | SC – B – 3 – 20 | 28.13 mm/s | SC – B – 3 – 30 | 42.47 mm/s |
| SC – C – 1 – 10 | 14.39 mm/s | SC – C – 1 – 20 | 27.52 mm/s | SC – C – 1 – 30 | 42.18 mm/s |
| SC – C – 2 – 10 | 14.73 mm/s | SC – C – 2 – 20 | 27.43 mm/s | SC – C – 2 – 30 | 41.68 mm/s |
| SC – C – 3 – 10 | 14.57 mm/s | SC – C – 3 – 20 | 27.79 mm/s | SC – C – 3 – 30 | 41.94 mm/s |

Table 3. Measured rms values for three different series and three different excitation frequencies

## 6. Experimental results validation

In Table 4, average rms value and standard deviation of three different series (SC – A, SC – B and SC – C) for three different excitation frequencies (10 Hz, 20 Hz and 30 Hz) are listed.

| Sample | average rms value | standard deviation |
|---|---|---|
| SC – A for 10 Hz excitation frequency | 14.27 mm/s | 0.37 |
| SC – B for 10 Hz excitation frequency | 14.42 mm/s | 0.27 |
| SC – C for 10 Hz excitation frequency | 14.56 mm/s | 0.14 |
| SC – A for 20 Hz excitation frequency | 28.20 mm/s | 0.35 |
| SC – B for 20 Hz excitation frequency | 27.94 mm/s | 0.15 |
| SC – C for 20 Hz excitation frequency | 27.58 mm/s | 0.15 |
| SC – A for 30 Hz excitation frequency | 42.17 mm/s | 0.64 |
| SC – B for 30 Hz excitation frequency | 42.17 mm/s | 0.21 |
| SC – C for 30 Hz excitation frequency | 41.93 mm/s | 0.20 |

Table 4. The average rms value and standard deviation of three different series for three different excitation frequencies

Series SC – A is taken as reference for comparing the results, since there are no morphological changes in the spatial arrangement of SC unit cells in lattice structures. At an excitation frequency of 10 Hz, the SC – A series gives an average value of rms response of the lattice structure of 14.27 mm/s. The SC – B series, at the excitation of 10 Hz gives a rms response of 14.52 mm/s, which is 1.7% higher than the rms value for the SC – A series. The SC – C series at the excitation frequency of 10 Hz gives rms response of 14.56 mm/s, which is 2% higher than the rms value for the SC – A series.

The value of the standard deviation, i.e., the deviation from the mean rms values of the test samples, shows that the smallest deviations among the samples are in the SC – C series with a deviation of 0.14, while the deviations in the SC – B series (0.27) and SC – A (0.37) higher. It can be concluded that at a low excitation frequency of 10 Hz, the SC – A series gives the lowest rms value, which makes it a better vibration dampener than the other two series, while at the same time, the SC – A series is the one that gives the worst results in terms of uniformity of results among the test samples. The best uniformity of results is shown by the SC – C series. The reason for this may lie in the stiffness of the SC – A series, which has large unit cells (10 mm), so even the smallest irregularity during printing can harm the quality of the test sample (also stiffness) and the unevenness of the vibration test results. According to the obtained average rms values, it can be concluded that at a low excitation frequency of 10 Hz, the defined morphological distribution of SC unit cells within the lattice structure gives a worse vibration response and lower damping ability than the rectangular spatial distribution of SC unit cells, but higher repeatability of the results.

While observing the rms value corresponding to the mentioned three series for an excitation frequency of 20 Hz, the following results are obtained. SC – A gives rms response of 28.2 mm/s, while for the SC – B series the rms response is 27.94 mm/s, which is 1% lower than the rms value of the SC – A series. For the SC – C series, the value rms is even lower than the SC – A series, by 2.2% and it is 27.58 mm/s. It can be concluded that the defined morphological distribution of SC unit cells within the lattice structure for excitation frequencies of 20 Hz gives a better vibration response and enables greater damping of excitation vibrations. Densification and reduction of unit cells in places close to mounting and testing lattice structures, resulting in dispersion of excitation vibrations from the excitation point to the measurement point. Thus, reducing the size of a SC unit cell has a positive effect on vibration damping at a higher excitation frequency of 20 Hz.

Standard deviation in the testing samples for an excitation frequency of 20 Hz, again, the SC – A series gives higher deviations among the results (on average 0.35), which makes the SC – B and SC – C series with a standard deviation of 0.15 more uniform. So, at frequencies of 20 Hz, the conclusion can be that the SC – C series provides the best damping of vibrations measured vertically relative to the excitation, and the SC – C series is the one that gives the highest repeatability in results, with an average standard deviation of 0.15.

For an excitation frequency of 30 Hz, the following rms values are obtained: SC – A 42.17 mm/s, SC – B value is equal to 42.17 mm/s, while for the SC – C series the average value is 41.93 mm /s. It is obvious that series SC – A and SC – B give the same rms value. If the standard deviations for the mentioned two series (0.64 and 0.21) are observed, it can be concluded that the SC – B series is the one that gives more uniform results during the vibration test. SC – A has higher deviations in the results. The lowest rms value and, at the same time, the most uniform test results are given by the SC – C series, which makes it optimal for use at excitation frequencies of 30 Hz.

The influence on the uniformity of the results and the reduction of the rms value is again influenced by the defined morphological distribution (by parabolas) of SC unit cells within lattice structures.

## 7. Conclusion and future research

This paper presents the modeling procedure of different morphologies of the SC periodic lattice structure that keep the same relative density of 0.2, the additive production of PLA lattice structures, and the examination of vibration damping ability of lattice structures through comparative rms values for excitation frequencies of 10 Hz, 20 Hz and 30 Hz. Experimental tests have shown that changing the morphological arrangement of SC unit cells within lattice structures gives different responses in terms of vibration damping in vertically excitation of lattice structures. The rms values obtained experimentally showed that at increased values of the excitation frequencies of 20 Hz and 30 Hz, the parabolic distribution of SC unit cells within lattice structures gives better possibilities of damping excitation vibrations. The reason for this lies in the height reduction of unit cells in the areas that are near the place of mounting the lattice structure and the place of measuring the rms response of the lattice structure. For a lower excitation frequency of 10 Hz, it is good to leave the morphological distribution of SC unit cells in the lattice structure in a rectangular distribution. Parabolic morphological distribution of SC unit cells in lattice structure for the specified frequency of 10 Hz does not give an optimal rms response.

Since the dimensions of the SC unit cell within the lattice structure are relatively small, the differences in the measured rms values are also reduced, but they are significant, and they should not be ignored. Future research could refer to the larger dimensions of the unit cells within the test samples of lattice structures. Furthermore, in this research, the shapes of the horizontal struts (straight or curved) were only changed, so that future research can also refer to the change in the morphological arrangement of the unit cells, which will affect the change of the vertical struts as well. Also, since there is not a large amount of research on the numerical analysis of vibration damping of lattice structures, it would be desirable to develop a model that will enable the numerical prediction of the behavior of plastic periodic lattice structures with different morphologies as vibration dampers.

## 8. Acknowledgments

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