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EXPERIMENTAL STUDY OF ELASTIC WAVE PROPAGATION IN METALLIC MULTIMATERIAL SPECIMENS MADE BY ADDITIVE MANUFACTURING

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Abstract: *Wave propagation in 3D printed metals is an area of research that focuses on the behavior of mechanical waves in metallic materials produced by additive technologies, specifically 3D printing. This process is increasingly being used to produce complex geometric structures that can exhibit different properties compared to traditionally manufactured materials. In this context, the focus is on how the structure of the printing material, the microscopic arrangement of particles, porosity, and anisotropy affect the wave behavior. The aim of the research is to understand how different printing parameters (e.g., layer orientation, material composition) affect wave propagation and how this knowledge can be applied for e.g., defect detection, sound insulation, or structures with optimized mechanical properties. This work focuses on the instrumentation of 3D printed samples with actuators and measurement labels, the creation of an experimental setup and the measurement of initial high frequency mechanical wave propagation experiments.*

Keywords: 3D printing, multimaterial, wave propagation, laser vibrometery

1. Introduction

Over the last decade, there has been remarkable shift from plastic-based to metal printing technology including the possibility of multimaterial (hereafter MM) processing. Although the challenging manufacturing process, MM metallic structures may offer useful properties. This may involve different mechanical, thermal, electrical, and magnetic behaviors of different metals. Properly designed geometry of the MM structures can lead to filtering of the specific frequencies, or guide waves to desired location avoiding damaging of the component behind the structure. Another application may be the efficiency of energy harvesting, or general signal amplification. MM printing suffers from similar problems as conventional printing. The major one is the connection and continuity between the size ranges of the layers, and the quality of the bonding of the heterogeneous materials is related to this (Zhu et al., 2024). MM printing might be increasingly used in different types of applications in the future. The use of biocompatible metals could enable use in medical applications, such as bone substitutes (Putra et al., 2021, 2020). It is not necessarily only the mechanical properties of a given MM construct that are at stake. In terms of wave propagation through the material, it can be a topic filter design, where the absorption of microwaves has already been successfully influenced (Zuo et al., 2020; Gong et al., 2022). The degree of wave absorption can be influenced by many parameters, from the choice of material to the thickness of the individual layers to the gradient properties of the structure. An equally important area are the structures designed for their electrical properties. The combination of printing and metallization can be demonstrated to produce complex 3D objects with electrical properties comparable to those of bulk copper (Ryspayeva et al., 2022).

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2. Experimental setup

To experimentally measure the mechanical waves that pass through the sample, which is made by additive technology, a frame of aluminum profiles was created on which the test sample was suspended by a line. This design was used in order to make the measurement as little affected by external conditions as possible. To excite the voltage waves to mechanical waves, a piezoelectric actuator PL055.31 (Physik Instrumente (PI) SE and Co. KG, Germany), with dimensions 5 x 5 x 2 mm, was used. For more specifications see (Physik Instrumente, n.d.).

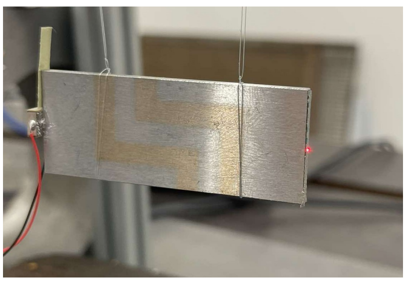
The electrical signal, which the actuator converted into mechanical motion, was generated using a function generator OWON AG4151 (OWON Technology, Canada) of more specifications (OWON, 20103). However, since a piezoelectric actuator needs a higher power supply than the generator is capable of generating, the PiezoDrive PD200x4 Voltage Amplifier (PiezoDrive, Australia), with more specifications (PiezoDrive,2024), was used, where the electrical voltage of the generator was amplified x20.

To measure the vibration velocity of the test specimen, a non-contact measurement using a laser vibrometer based on the Doppler effect was used. The laser vibrometer measurement system consists of a Vibrometer Controller OFV-5000 with a VD-09 measuring card and a Sensor Head OFV-505 (Polytec GmbH., Germany), more specifications (Polytec,2016).

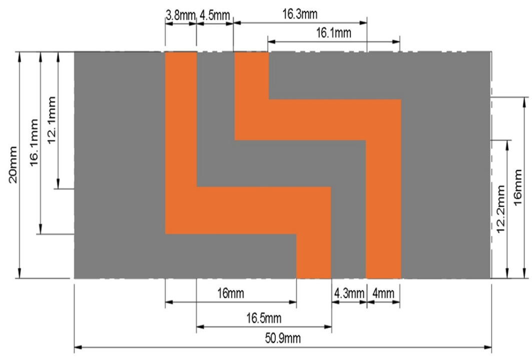
The prepared experimental sample with piezoelectric actuator and laser vibrometer dot can be seen in Figure 1a.

2.1. Experimental sample

The sample used in the experimental measurement was created using powder metal additive technology. The materials used were steel 316L and bronze CuSn10. A geometry was designed, as can be seen in Figure 1a and 1b, where steel represents the major part of the specimen and bronze is used to create a patern to influence the input mechanical waves. The overall dimensions of the sample are 2 x 20 x 50.9 mm. For a more detailed geometry, see Figure 1b.



(a) Piezoelectric actuator (left), dot from the laser vibrometer (right)



(b) Sample geometry (grey - steel, orange - bronze)

Fig. 1: The investigated MM sample

3. Measurement

As mentioned above, a piezoelectric actuator was used to induce the mechanical waves and a laser vibrometer was used to measure the velocity of the waves. The piezoelectric actuator was glued symmetrically to the edge of the specimen using tensor adhesive, so that the centre of the piezoelectric actuator was at a height of 10 mm on a 20 mm high edge, see Figure 1a. Using a function generator, the frequency and amplitude of the input waves could be adjusted. For the experimental study, a mechanical sine wave with a frequency of 500 kHz was considered, and the magnitude of the amplitude was chosen as high as possible to allow the wave to pass through the entire sample, before it attenuates.

3.1. Input wave

Although a sine wave was fed into the actuator, after several measurements, it was found that the actuator's response is much more complex. It was found that the actuator would not be able to settle to the input waveform at this frequency, it would need a longer signal. Although the input wave does not look like an input electric signal, we verified by fast Fourier analysis, that the signal consists mainly of frequency of 500 kHz, so we have further considered the input waveform that was measured using a vibrometer directly on the actuator.

3.2. Input-output comparison, frequency analysis

After the problem with the input wave was identified, the output wave was measured as it passed through the MM sample. Due to the weak output signal compared to the noise, ten measurements were taken, from which statistics were then made. A comparison of the mean input and output waveforms can be seen in Figure 2. The laser vibrometer was aimed at the centre of the piezoelectric actuator on the input edge and the output edge was measured at the same height as the centre of the piezoelectric actuator, i.e. 10mm on a 20mm high edge, see Figure 1a.

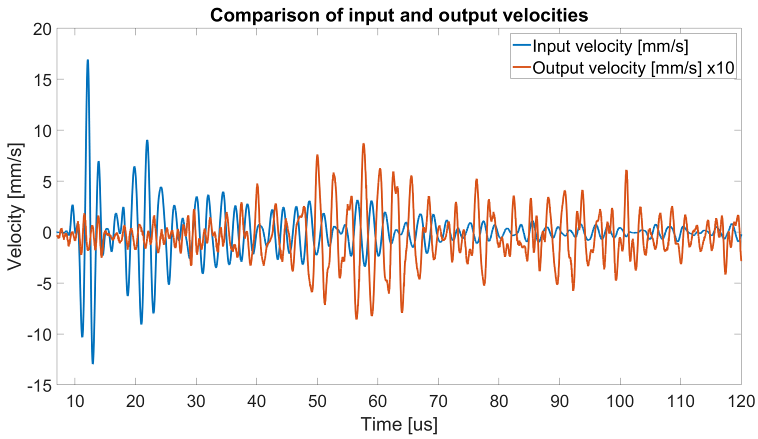


Fig. 2: Input mechanical wave (blue), Output mechanical wave (orange)

As can be seen, the wave passed and was measured with a appropriate delay. In addition, the output wave was measured with significantly lower amplitude, indicating spreading the waves from the "point" source and attenuation as a result of propagation in the sample. The time domain plot of the input and output signal amplitudes tells us only information about the possible attenuation of the wave and outlines general influence of the MM structure on propagating waves. More interesting is a look at the frequency spectrum of each signal, which can be seen in Figure 3.

In this spectrum, it can be seen that the input signal (blue) measured on the actuator has a dominant frequency of 500 kHz and another harmonic of 400 kHz. The curve that takes the frequency spectrum of the output (orange) no longer contains the 500 kHz frequency, and only the 400 kHz frequency is dominant in this signal. It can therefore be concluded that the 500 kHz frequency that was present at the input has been attenuated due to the structure.

4. Conclusions

An experimental setup and experimental method was developed and proved to be sufficient to generate and measure waves propagating through MM specimen in controable manner. The piezoelectric actuator can be used to excite a high-frequency mechanical wave and can be easily controlled by a function generator. This method could be applied to other fabricated samples that have a different MM structure.

The 500 kHz input signal, has a wavelength of 12mm and the bronze strip is 4mm wide, so the bronze structure will not affect the input signal as much as if the input signal wavelength was smaller and would fit at least twice into the bronze strip. Hence frequency of 500 kHz is only starting point for our research. We expect higher frequencies (up to 10 MHz) to be more affected by the multi-material structure.

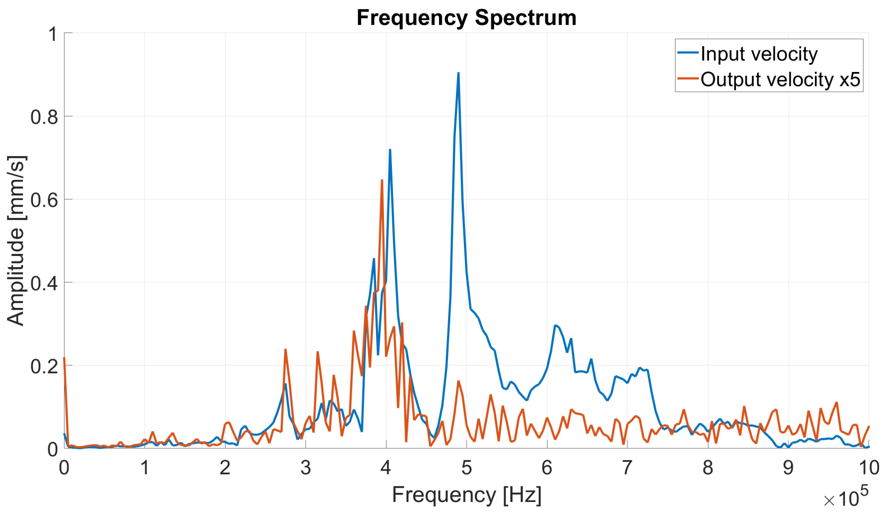


Fig. 3: Input mechanical wave (blue), Output mechanical wave (orange)

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