Investigating Compressing Particle Damper Pockets in Beams Manufactured by Laser Powder Bed Fusion Additive Manufacturing

Yanzhou Fu[1], Satme Joud[1], Austin R.J. Downey[1,2], Lang Yuan[1], Tianyu Zhang[1], and Daniel Kiracofe[3]

[1]Department of Mechanical Engineering
University of South Carolina, Columbia, SC 29208

[2]Department of Civil and Environmental Engineering
University of South Carolina, Columbia, SC 29208

[3] Department of Mechanical Engineering
University of Cincinnati, Cincinnati, OH 45221

ABSTRACT

Components manufactured by laser powder bed fusion (LPBF) additive manufacturing can have particle dampers designed into the part by leaving unfused powder inside a defined pocket of the part during manufacturing. These pockets of unfused material have inherent damping capabilities that suppress the vibrations and potentially reduce component wear. Particle dampers have been shown to be a simple and effective way to increase the damping of a structural component manufactured by LPBF; however, the compressing effects of the particle damper pocket inside the beam have not been studied. The amount of unfused powder inside the pocket is difficult to control (or even measure) during manufacturing, therefore, this study reports preliminary investigations on the effects of energy absorption provided by changing the volume of the pocket. In this study, beams are printed with 316L stainless steel powder with single particle dampers. Thereafter, the cover of the pocket is deformed. Decreasing the volume of the pocket. The energy absorption characteristics of the particle damper are quantified. The unfused powder pocket's damping characteristics are assessed by observing the structure's response to various excitation methods. An input-output relationship can be deduced using a reference accelerometer and an accelerometer mounted passed the damper pocket with respect to the fixity. With this relationship established, the magnitude of damping and the phase attributed to it is determined. Studying the damping characteristics of various compressed pocket sizes and powder quantities will provide helpful information to enhance particle dampers' efficiency using LPBF techniques.

Keywords: Laser powder bed fusion, Particle damper, Structural dynamics, Multifunctional materials, Additive manufacturing

INTRODUCTION

Laser powder bed fusion (LPBF), one of the additive manufacturing technologies, has unrivaled strengths due to its design and manufacturing freedom. With the improvement of the LPBF processes and materials, it has been widely applied to engineering, medicine, and aerospace, especially for aerospace, which is a field that needs products with lower weight but good structural integrity [1]. Particle dampers made using LPBF have been proven as an efficient way to increase structure damping, which is made by keeping some un-melted powder inside of the structure on purpose. It works through a combination of non-elastic impact and friction between powder particles and pocket walls. With the unique advantages of no additional mass and space needed, which can reduce unnecessary vibration to prevent high cycle fatigue simultaneously. Interest in particle dampers for aerospace applications has been growing.

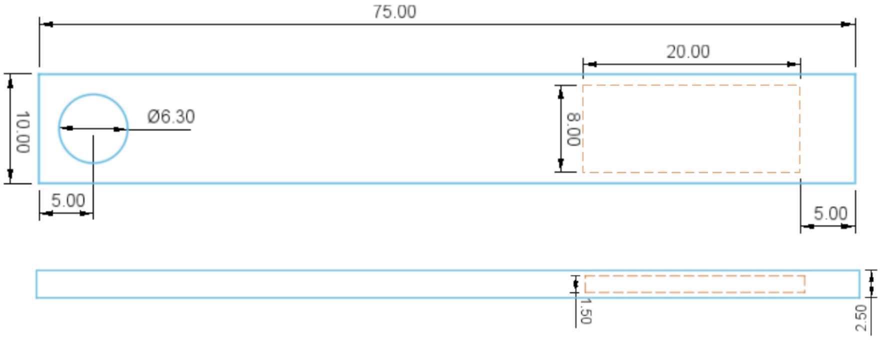


Figure 1: The designed cantilever beam with unfused powder pocket.

Lots of research focusing on particle damper performance have been done. For example, Ehlers et al. investigated the particle damping performance on a beam manufactured by LPBF [2]. The damping performance is evaluated under various beam parameter sets. The results show that a particle damper can dramatically reduce the vibration amplitudes for the first to seventh bending mode. Guo et al. explored the particle damper's damping performance with experiment and numerical approaches by attaching the damper to a cantilever beam [3]. Schmitz et al. studied the damping and mode shape modification on a thin wall made by LPBF [4]. The experimental result shows that the damping increases with bigger powder core width. In addition, the mode shape is deformed relative to the solid wall results as the core width is increased and wall thickness is decreased. Scott-Emuakpor et al. evaluated the damping performance sustainment from the endurance, repeatability, and recovery sides on cantilevered beams produced by LPBF [5]. Moreover, the authors investigated the damping performance of LPBF beams with unique internal structures [6]. The results show that with only 1-4% inner volume unfused powder, the four unique beams can provide up to ten times damping compared with the referenced solid beam.

From the literature review above, it can be concluded that the cantilever beam is an easy and effective way to measure the particle damper's damping performance, as demonstrated by prior results. However, the effects changing the volume of the pocket post manufacturing has not been investigated. As the amount of unfused powder inside of the pocket is hard to control during printing, therefore, this study reports preliminary investigations on the effects of energy absorption provided by indenting the volume of the pocket. In this study, a beam is printed by 316L stainless steel powder with a single pre-designed particle damper. Thereafter, the cover of the pocket is deformed. Decreasing the volume of the pocket and the damper's damping performance is quantified. The unfused powder pocket's damping characteristics are assessed by observing the structure's response to impulse excitation. An input-output relationship is established by analyzing the data from accelerometers.

EXPERIMENT SETUP AND METHODOLOGY

In this research, a 75 mm × 10 mm cantilever beam with a 2.5 mm thickness is fabricated with 316L stainless steel powder by an AcontyMIDI LPBF printer, as shown in Figure 1. A 20 mm × 8 mm pocket with 1.5 mm thickness is located 5 mm from the top. The key printing parameters such as power, speed, laser spot, and hatch distance are 200 W, 800 mm/s, 100 µm, and 100 µm. A solid beam with the same dimension and printing parameters is used as a reference.

The excitation for the free vibration test is an impulse generated by the cantilever beams fixed to a structure in free fall hitting a seismic mass. Tests were carried out on a Lansmont P30 shock test system. Two beams are fixed on the testing platform through the pre-designed holes, as shown in Figure 2. Two IEPE accelerometers are attached to the beam to measure the impulse response (Model 352A92, which is from PCB Piezotronics). The test platform is dropped from a height of 76 mm to generate the impulse force. The data is collected at 50000 S/s using an IEPE signal conditioner (NI 9234 from NI). Each test is repeated ten times. The signal obtained during free vibration data is then used to deduce the damping properties of the particle damper.

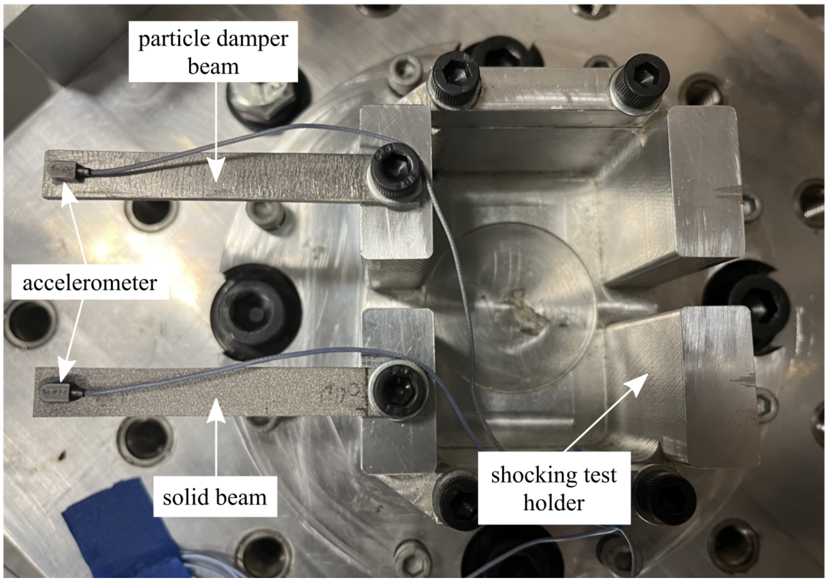
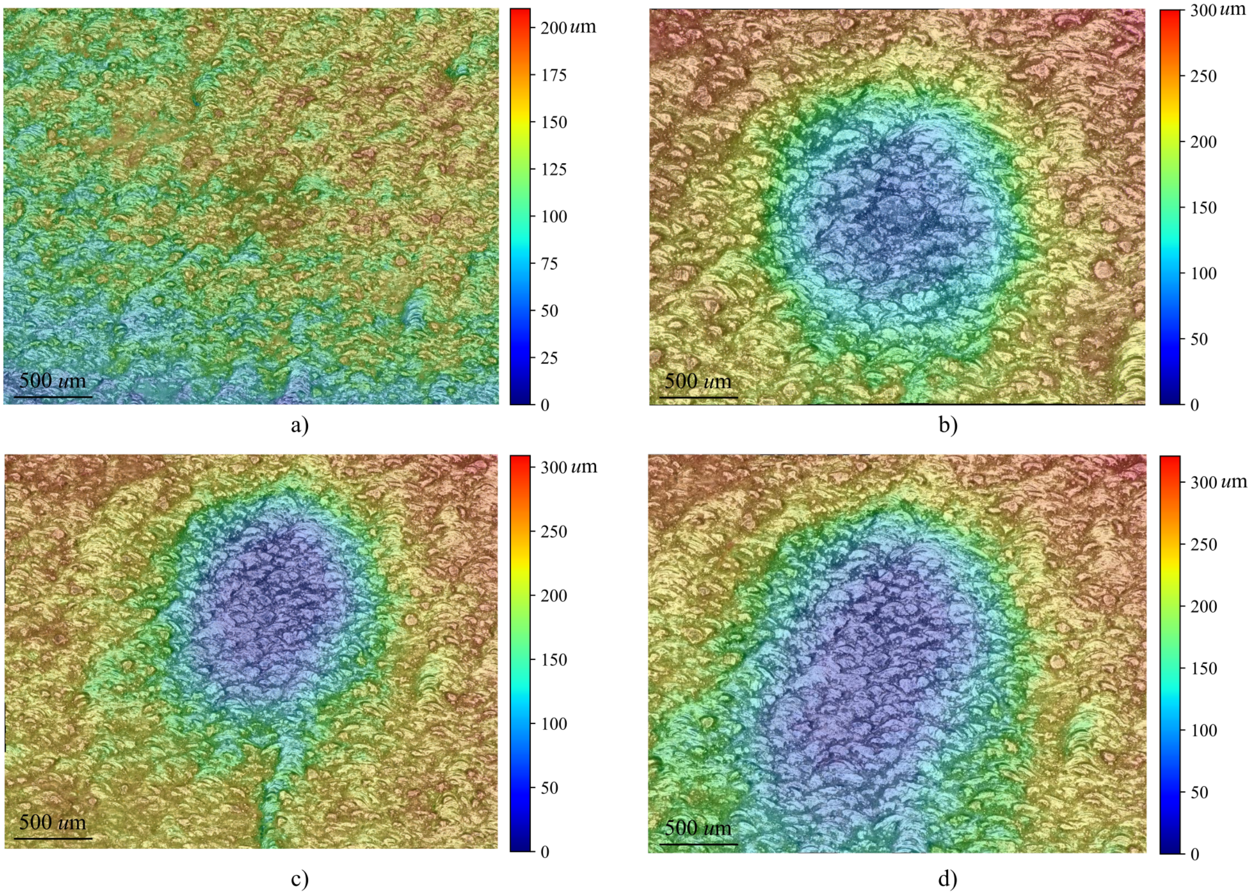


Figure 2: The experiment setup on a shock test machine with a solid beam and particle damper beam.



a)

b)

c)

d)

Figure 3: Microscope topography images, showing the particle damper beam surface topography: a) before indent; b) with a 91 µm indentation; c) with a 99 µm indentation; and d) with a 111 µm indentation.

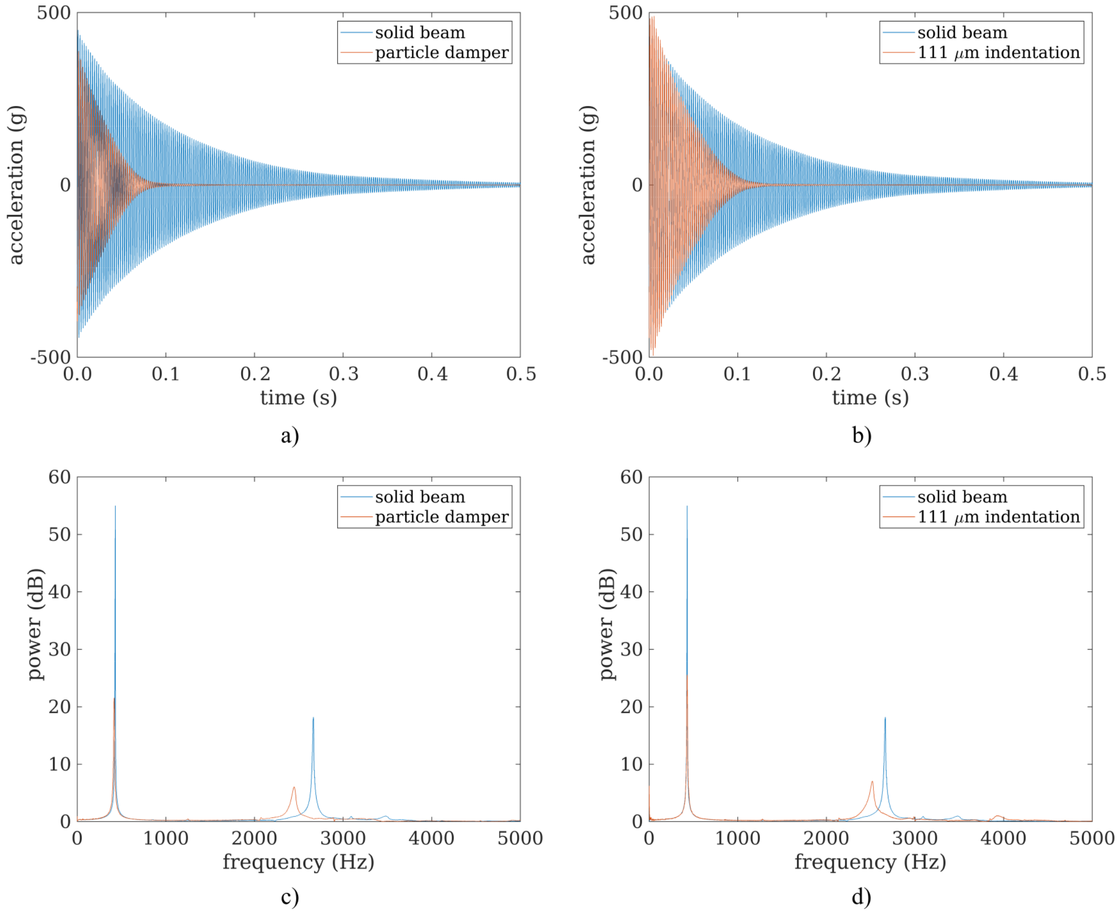
As stated before, this work investigates the effects of pocket volume change. A particle damper beam with different levels of

Table 1: Surface height change of the particle damper beam.

particle damper beam	min-height (µm)	max-height (µm)	surface height change (µm)
before indent	37.44	210.70	0
after first indent	0	301.77	91.07
after second indent	0	310.56	99.86
after third indent	3.93	322.08	111.38

the indent is tested on the shock test system. The indentation process is implemented by an MTS Exceed E43 electromechanical load frame on the particle damper beam: the first indent is applied with 2000 N force on the particle pocket's top surface while the second and third are loaded with 1000 N force. The microscope topography images of the beam before and after the indent are shown in Figure 3. These surface topography measurements are captured by a Keyence VHX 700 digital microscope. The min-to-max surface heights obtained from the surface topography measurements are reported in Table 1.

RESULTS AND DISCUSSION



a) b) c) d)

Figure 4: The vibration curves and fast Fourier transform (FFT) analysis: a) the vibration for the solid beam and particle damper beam before indent; b) the vibration for the solid beam and particle damper beam with a 111 µm indentation; c) FFT analysis for the solid beam and particle damper beam before the indent; and d) FFT analysis for the solid beam and particle damper beam with a 111 µm indentation.

Table 2: Shock test result for the solid and particle damper beam

test sample	max frequency (Hz)	damping ratio	Q factor	Q factor standard deviation
solid beam	428.7	0.00287	174.8	1.89
particle beam	416.0	0.00430	116.7	4.88
91 µm indentation	425.7	0.00420	119.4	4.52
99 µm indentation	425.8	0.00408	122.8	4.48
111 µm indentation	428.7	0.00401	124.6	4.17

The beams' time domain and frequency response after processing is shown in Figure 4. Figure 4 a) and b) display the vibration of the solid beam and particle damper beam before the indent and with a 111 µm indentation after the third indent. From the figure, it can be concluded that the vibration of the solid beam lasts much longer than the beam with a particle damper. Compared with the particle damper beam without the indent, the damper beam with a 111 µm indentation after the third indent has a higher density, which reduces the damping and increases the beam vibration. In Figure 4 c) and d), the frequency response for different beams is presented. From Figure 4 c) and d), it can be deduced that the particle damper beam before and after the indent has a lower magnitude, which indicates the beam with a particle damper has higher damping than the solid beam.

Due to particle dampers' nonlinear nature, a consistent metric to calculate the Q factor was put in place. A set window of free decay cycles was used for all test iterations, where the initial transient at the beginning and the low signal-to-noise ratio at the end of the data sets were disregarded. Table 2 shows the shock test result for the solid and particle damper beam. The results are an average of ten tests that make up the dataset. The particle damper before the indent has the largest damping. After the indent, the damping approaches the solid one. The Q factor is a dimensionless parameter that describes how underdamped an oscillator or resonator is. A high Q factor means low damping, which causes the system to vibrate longer. As shown in Table 2, the beam with a particle damper has a much lower Q factor compared with the solid beam, which means the particle damper has good damping qualities. The Q factor of the particle damper beam increases with a higher magnitude of the indent. It indicates that a high powder density cuts the beams damping performance down.

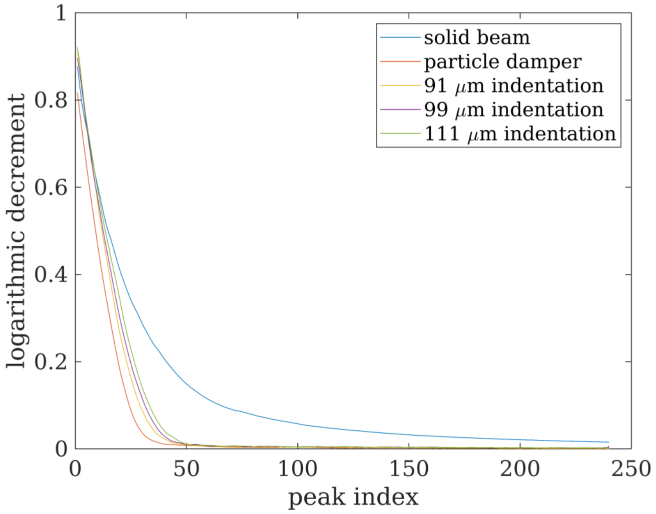


Figure 5: Decay rates for the solid beam and particle damper beam.

The beams' decay rate is displayed in Figure 5. A quickly changing logarithmic decrement implies a highly non-linear damping behavior [2]. From the figure, we can see that the solid beam has the lowest decay rate that matches the free vibration curve. With the increasing indentation, the particle damper's decay rate increases. The gap between the solid beam and the beam with particle damper becomes smaller and smaller. However, even with a higher magnitude of the indent, the particle damper beam still has better damping performance than the solid one.

CONCLUSION

This paper presented an investigation into changing the volume of particle damper's post-manufacturing. A cantilever beam with an unfused powder pocket manufactured by laser powder bed fusion is used. To measure the effect of a pocket volume change on energy absorption, the beam with particle damper is indented three times to study the effect of indenting (i.e., compressing) the damper pocket. The beam damping performances are tested before and after the indent with a solid beam as a reference. The experiment results show the particle damper inside of the beam can dramatically reduce the beam vibration. With compressing the pocket volume, the particle damper density increases, which cuts down the unconsolidated powders' energy absorption capacity. However, the vibration of the beam with an indented particle damper still decays faster than the solid beam. Future work will focus on the quantification of precise powder density before and after the indent and then evaluate its effect on damping performance for a wider range of inputs and over multiple modes. With the relationship established between powder density and damping performance, particle dampers' efficiency in the Laser powder bed fusion (LPBF) techniques can be enhanced.

ACKNOWLEDGEMENTS

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