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Reviewed Paper

Material Jetting of Suspension System Components.

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Abstract

Material Jetting has demonstrated great promise in being able to produce complex functionalities using multi-material printing. Despite this potential material jetting has struggled to find applications in direct part production. Here we show how material jetting can be used to produce viscoelastic energy absorbers for large displacement applications in harsh environments. We generate printed components to act as the core of a suspension system on a recumbent trike. The 3D printed dampers allowed for improvements of the ride experienced. Through long term exposure studies, we demonstrate that techniques and methods previously applied to the absorption of vibration in indoor power tool applications can be extended to outdoor environments.

Introduction

There has been a growing excitement in academia and industry alike due to the increasing capability of Material Jetting to fabricate parts with intricate designs and diverse material properties [5,4]. With the improvements in speed, and material compatibility, the technology is no longer confined to the realm of prototyping but has forayed into direct digital manufacturing of functional components. Material jetting's capacity to print multi-material and the ability to manufacture parts with complex internal geometries have opened new avenues in sectors such as aerospace, healthcare, and automotive.

In prior research, researchers created a 3D printable viscoelastic energy absorbing material by integrating TangoBlack+, an acrylate polymer with a non-curing liquid – specifically Polyethylene Glycol, typically used as a model cleaning fluid [1]. The devised technique presents the potential for the manufacture of hydraulic components [2] as well as microfluidic devices [3]. Through manipulation of the liquid concentrations, ranging from 0 to 25%, a closed-cell structure can be established. This structure encapsulates the liquid while still being capable of achieving tan deltas between 0.3 and 1 at 1 Hz, exhibiting a power law relationship with frequency. Given these attributes, the material has established itself as an ideal candidate for impact and vibration absorption.

The first known direct application of multi-material parts from the material jetting process was the production of viscoelastic energy absorbers for use on power tools [6]. The systems were designed to absorb low displacement, but high intensity vibrations associated with Hand-arm vibration systems[7]. It showed that material jetting can produce durable and effective vibration protection equipment that reduces vibrations felt by the user by an average of 23% to 45% and can be deployed at a Boeing factory and survive 1 month of usage [6].

Furthering this line of work, we investigated how the materials can be used for larger displacement applications. Viscoelastic materials are often used as components in suspension systems for light weight bikes and other small vehicles. Viscoelastic dampers are widely used for large displacement vibration isolation for these application [8,9,10] In these applications the system experiences externals loads that cause more than 1% strain. We examine the effect that various 3D printed viscoelastic energy absorbers have on these systems. We perform repeated tests on a track to measure the effect of the components and then perform a one-month long durability to determine if the materials degraded under regular usage.

Sample Preparation

Samples were produced on a J750 Digital Material Polyjet system with the research package. We produced a 25% liquid filled, 40A, 60A and 95A durometer scale samples seen in Figure 1. The materials and times for each sample is found in table 1. The liquid filled samples were produced using a mixture of TangoBlack+ and the model cleaning fluid. The liquid filled samples were generated from custom python code which is available upon request. The resulting code generated image stacks which were then processed in the J750 Voxel print mode with the liquid printing enabled. The nonliquid filled samples were printed using the J750s digital materials library of blends of TangoBlack+ and VeroFlexWhite. After the samples were printed, they were cleaned with the pressure washing station and allowed to dry for several weeks before usage to ensure that no water remained in the samples.

Figure 1: Polymer Suspension components. From left to right, 25% liquid, 40A, 60A, and 95A

Sample	Time (H:MM)	VeroFlexWhite (g)	TangoBlack+ (g)	Liquid (g)
25%	2:35	0	29	10
40A	2:35	10	39	0
60A	2:35	13	36	0
95A	2:35	22	28	0

Table 1: Material usage and time for each sample type

Experimental setup

Figure 2: The ICE Trike(A) with the polymer suspension system. The rear suspension is blue in parts B and C. The polymer components are attached to the suspension and compress on the front frame.

For this experiment we chose to use the ICE Trike Adventure HD with E-assist with rear suspension. The suspension, seen in Figure 2, consists of two 30.5mm outer diameter, 11.5mm inner diameter, 39mm tall with posts of polymer. They are attached to the rear drive wheel and compress between the rear frame and the front frame of the trike. The E-assist allows the system to be run at a consistent and uniform speed during experiments. We chose the trike frame rather than a bike frame as it provides a stable base for the experiment and for mounting the accelerometer. The Trike was tested on a triangle shaped track that was 90m long. The track has peak to ridge differences of up to 76mm. This was chosen as it provided a consistent surface for testing while allowing for high variations in the surface height.

Vibration reduction

To compare the effectiveness of the printed samples we compared a 25% liquid printed system with various digital material samples. We mounted two samples to the trike as the suspension components. They were then driven around the track at a speed of approximately 3.75m/s 10 times. The acceleration data can be seen in Figure 3. As we see there are large spikes in the accelerations experienced. This are closely associated with the rear tire of the trike hitting a pothole on the track. To analyze the relative effectiveness of the suspension systems, we plot the power spectral density (PSD) of the vibrations. We calculated the PSD using the welch method. As seen in Figure 4, the 40A and 95A samples had higher loading between 0 and 2Hz. The 60A and the 25% Liquid samples were indistinguishable in terms of performance. From this we can conclude that the liquid filled samples provided little improvement over the digital material samples we produced. Therefor we conducted the remainder of the tests with the digital material samples.

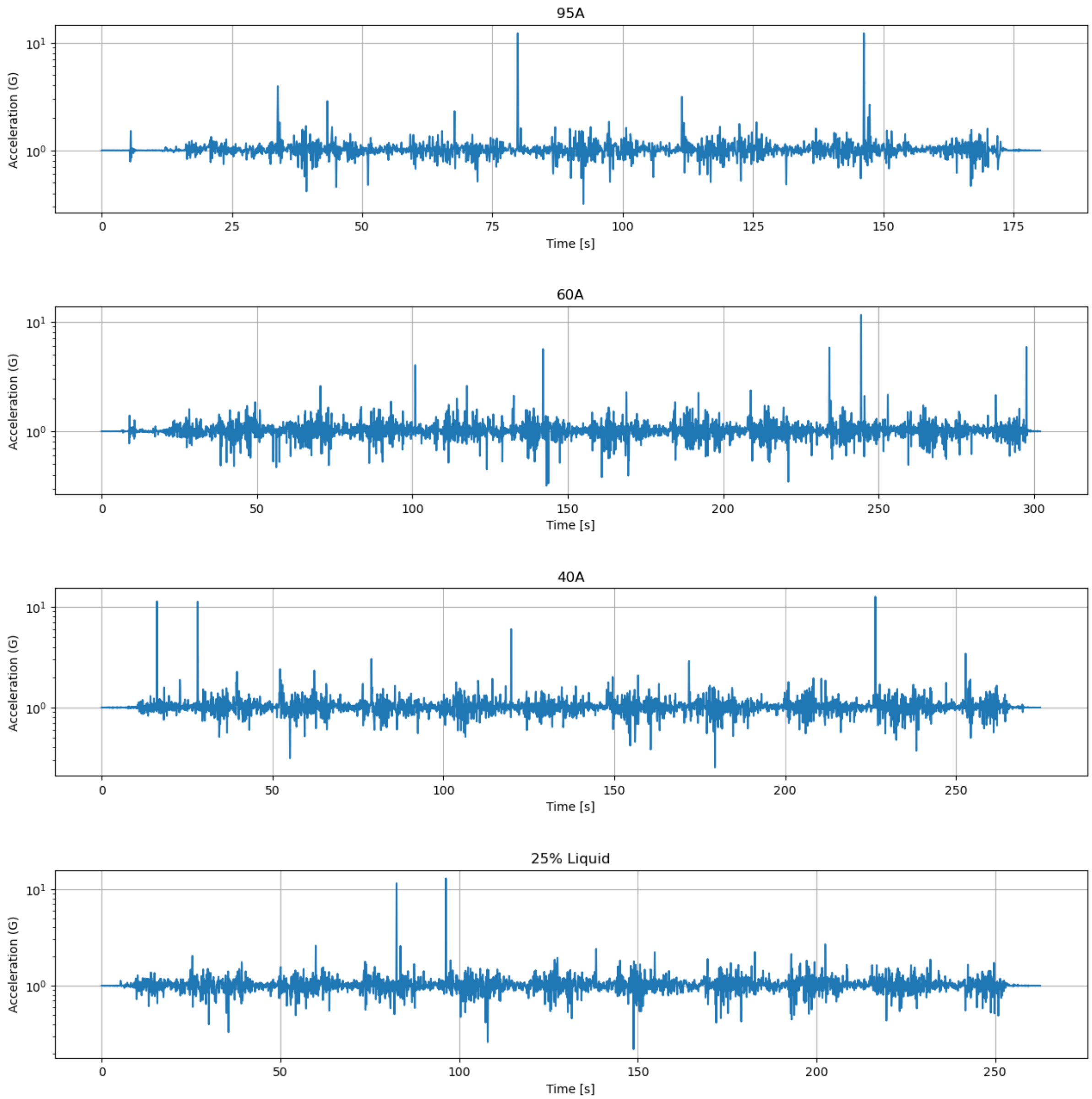

Figure 3, The acceleration on the passenger for various viscoelastic samples. The trike was run around the course 10 times. You can wee the periodic beats in the data as trike went around the track. The high spikes are from the system hitting potholes on the track

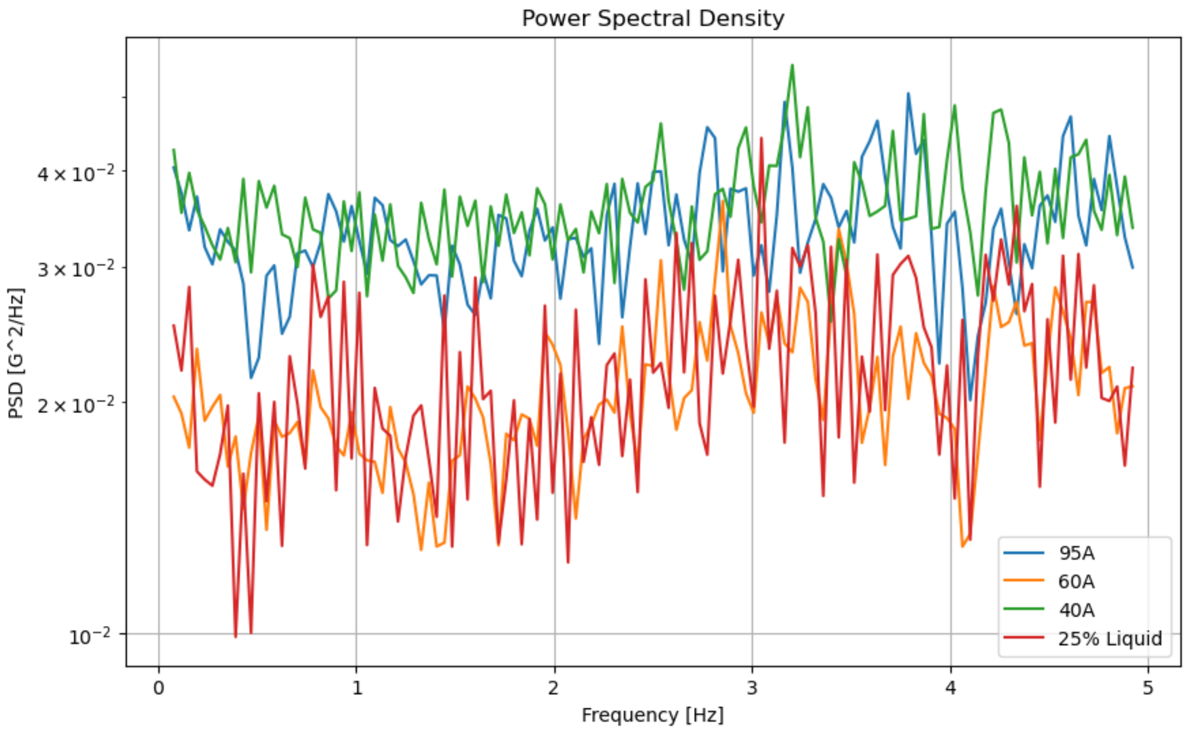

Figure 4: The power spectral density of the low frequency vibrations of the passenger on the trike. The 40A and 95A samples had higher loading between 0 and 2Hz. The 60A and the 25% Liquid samples were indistinguishable in terms of performance.

Performance over time

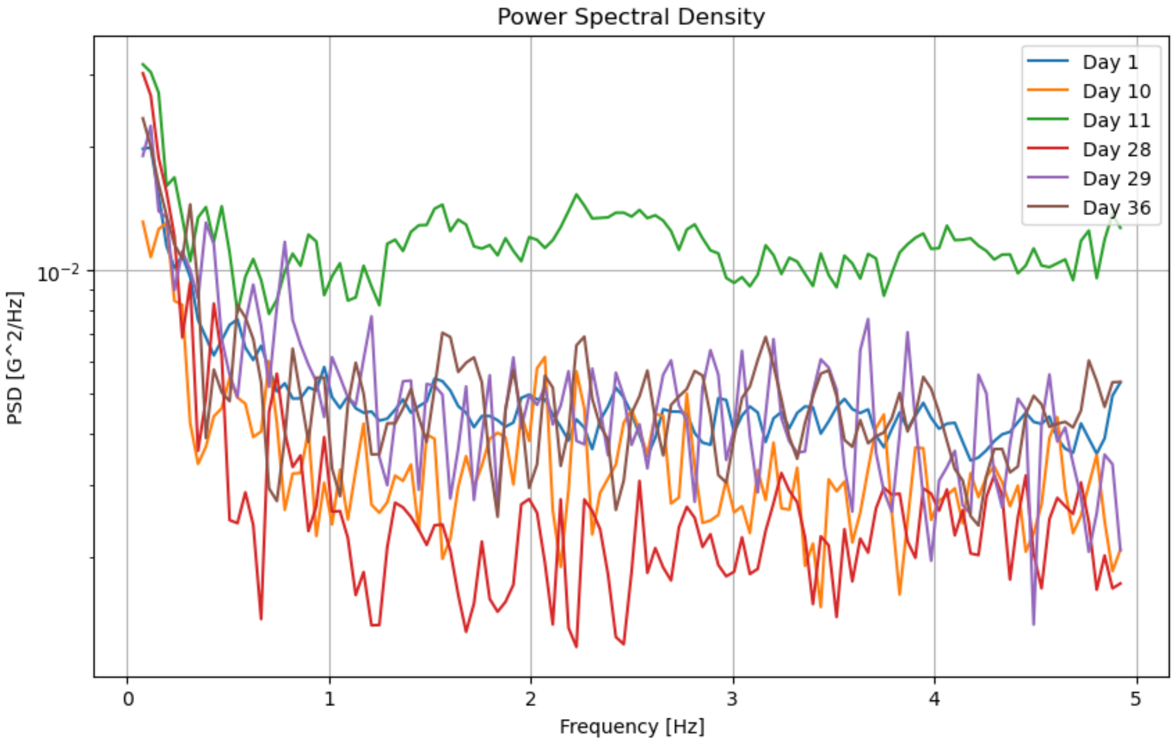

Figure 5: Performance of a 60A sample over time. There is no degradation in performance over the 36 days.

To determine if the system degraded in performance over time, we monitored the system over a 36-day span. Over that time the system was fitted with two 60A Samples. Each day the trike was driven one mile over paved roads. On days 1, 10, 11, 28, 29 and 36 we recorded the performance of the system. These days were chosen because they were spaced out over the usage of the system and corresponded to times when a closed-circuit loop was available for testing. As seen in Figure 5 and 6, the overall performance remained consistent over the 1 month span. This indicated that on standard light usage equivalent of a small regular commute, the suspensions do not degrade in performance. There was however one day, day 11 when the systems performance degraded significantly. The temperatures outside were consistent during the trial period so we do not think it was a thermal effect. Further investigation is required to determine the sudden change in functionality.

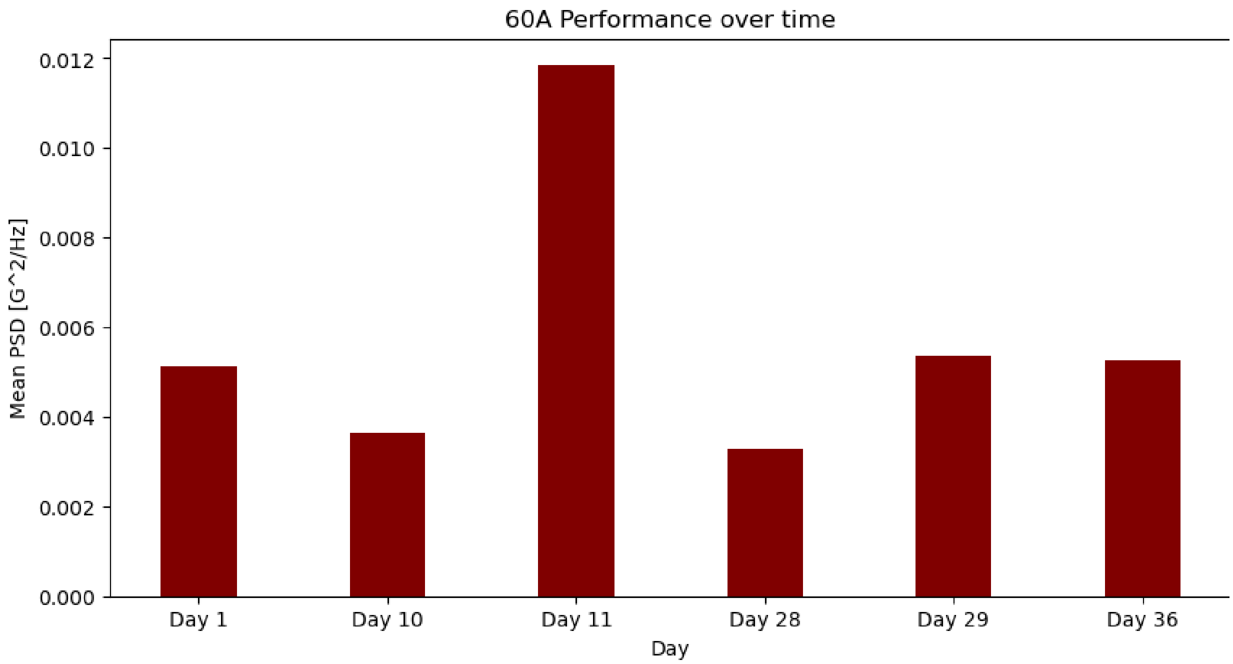

Figure 6: Mean PSD of the sample over time. Lower values indicate better performance. The system had comparable performance over time, with the exception of day 11.

Conclusions:

We have shown that the printed viscoelastic energy absorbers can be used for an extended period of time as the basis of the polymer suspension system. We compared the performance of standard digital materials and liquid filed material system and found that the liquid filled performed comparably to a 60A shore hardness digital material print and that the 60A sample outperformed the 40A and 95A. We believe that this demonstrated the potential for 3D printed material jetted components to be used in high compression and outdoor usage environments.

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