3D Printing Thin Skinned Composites to Achieve the Strength-to-Weight Ratio of Aluminum.

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ABSTRACT

Kevlar and stainless steel mesh reinforcements were added using epoxy to 3D printed ABS-M30 thin skins, thereby making a composite structure with significantly improved mechanical properties over that of the 3D printed plastic alone. These additive manufactured composites have a strength to weight ratio that is comparable to solid aluminum. Flexural 3-point bend tests and Charpy Impact tests were conducted. Experiments were conducted that were designed to characterize the influence of adding Kevlar to the composite structure and also the influence of pre-mixing glass microspheres into the epoxy. These new additive manufactured (AM) composites are an attractive choice to designers attempting to reduce weight because any 3D printed shape can be reinforced in this manner. Additionally, actual production time is less than 3D printing a fully solid component.

Keywords— Composites; strength-to-wieght ratio; additive manufacturing, 3D printing.

INTRODUCTION

The phrases 3D printing and additive mmanufacturing are often used interchangeably even though they have slightly different meanings. Technically speaking, 3D printing is only one type of additive manufacturing (AM) but since these technologies have gone mainstream in public use the phrase 3D printing has been used in a broad sense for all these technologies. Fused deposition modeling (FDM) is the extrusion of a thread of plastic deposited in shapes created from a sliced 3D model. Each shape becomes one layer and successive layers build a 3D plastic component. Most people would refer to FDM as the 3D printing of plastic even though there are many other technologies that 3D print plastic such as selective laser sintering and inject printing. FDM was used in this research and is used synonymously with 3D printing in this paper.

The advantages of 3D printing plastics are extensive and well known to most readers of solid freeform fabrication symposium conference papers. Two key disadvantages are the speed of printing and the fact that plastics are typically not very strong relative to other materials. This research explores and idea that improves upon those two disadvantages.

By 3D printing two thin skins that are designed to interlock, a hollow 3D structure can be printed in less time than if the full 3D structure were printed entirely as a whole. Additionally, by printing thin skins that interlock, reinforcements can be added internally using epoxy. These internal reinforcements can include fiberglass mesh, steel mesh, carbon fiber, aramid fabric (Kevlar), aluminum, titanium. These can be used for external reinforcements as well, and/or integrated between layers. A variety of adhesives can be used although epoxy is likely the most common. The adhesive can contain fiber additives, be manually applied, or vacuum infused. Some authors refer to these technologies as hybrid composites. Figure 1 is a photo of two interlocking thin skins with stainless steel mesh inside, ready for adhesive.

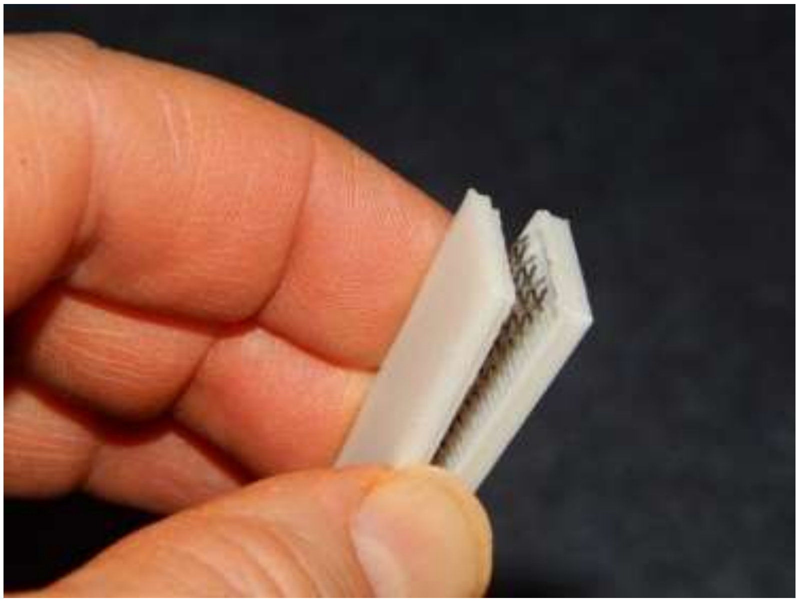

Figure 1 - Interlocking 3D printed thin skins with stainless steel mesh inside.

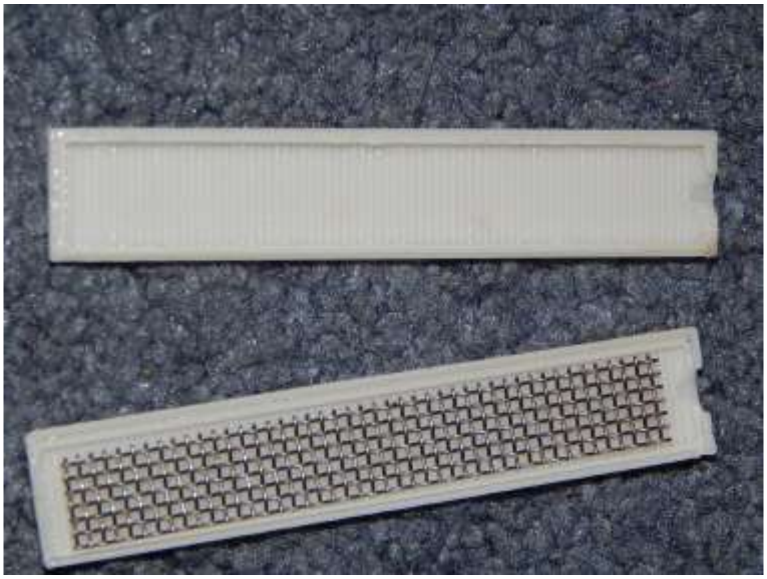

Figure 2 - Interlocking 3D printed thin skins showing the opening on the right side for injecting the adhesive by syringe.

Research Objectives

1. Develop methods for fabricating reinforced composites using 3D printed or FDM thin skins.

2. Compare the strength to weight ratio of reinforced composites to that of solid aluminum.

3. Conduct experiments using Charpy impact testing (to standards of ISO-179) that examine the influence of internal reinforcement and hollow glass microspheres in epoxy.

4. Conduct flexural 3 point bend testing (to standards of ISO-178) on reinforced composites.

Experiments

Three experiments were proposed:

1. ANOVA using impact strength as the response variable to compare internal reinforcements of fiberglass mesh versus stainless steel mesh using hot glue.

2. Blocked ANOVA using impact strength as the response variable to examine epoxy with glass microspheres as additive into the epoxy.

3. ANOVA using flexural strength as the response variable to examine epoxy with various reinforcement types of stainless steel mesh, Kevlar fabric, carbon fiber.

Figure 3 - Specimens being prepared by injecting the adhesive in the first experiment.

RESULTS AND DISCUSSION

Results of the first experiment showed potential, an ANOVA using impact strength as the response variable to compare internal reinforcements of fiberglass mesh versus stainless steel mesh using hot glue. The analysis of variance did yield evidence of significant differences in the reinforcement types, with p-values even lower than 0.0005. This full factorial experiment showed the strongest composite construction to be the combination of fiberglass mesh and stainless steel mesh. Figure 4 is a box plot of the results of the first experiment.

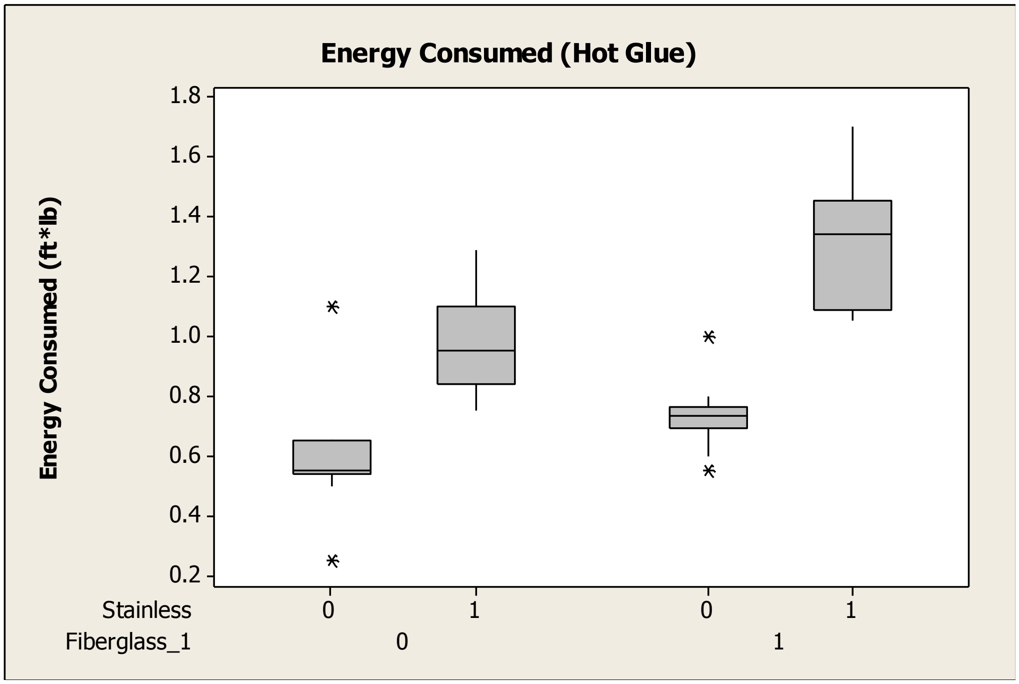

Figure 4 - Box plot of the results of the first experiment.

Variation in these data for each factor level combination was noticeable. It is assumed that much of this variation was the influenced by the presence of internal voids in the adhesive. These voids formed during fabrication in part due to the viscosity of the adhesive and the rate at which the adhesive filled the internal cavity. These internal voids are visible in Figure 5, a photo of the specimens fabricated for the first experiment, prior to the impact tests.

Figure 5 – Specimens fabricated for the first experiment, inconsistent filling of the internal cavity is visible in all factor level combinations.

Results of the first experiment were also compared to similar measurements of the impact strength of 6061-T6 aluminum. The first experiment was conducted to the international standards of ISO-179-1. This is a pendulum impact test that measures the amount of energy consumed by the specimen as a result of the pendulum impacting the specimen. A larger amount of energy consumed indicates a stronger specimen. Aluminum specimens were prepared to the same dimensions as that of the 3D printed specimens (3.1mm x 15mm x 77.5mm). The span of the supports was 62mm. Dividing the impact energy consumed by the weight of the specimen yields a strength to weight ratio. Calculations are as follows:

S/W ratio of a Stainless Steel Mesh with Fiberglass Mesh :
1.75 J / 54.9 Newtons = 0.0318 J/Newton
S/W ratio of 6061-T6 Aluminum :
5.317 J / 88.80 Newtons = 0.0599 J/Newton

One conclusion of the first experiment were that reinforcing 3D printed thin skins has potential and attention needs to be given to the way the adhesive is inserted into the cavity in order to minimize the internal voids. The second conclusion of the first experiment was that 3D printed thin skins reinforced internally might be able to achieve the strength to weight ratio of a strong aluminum. This will depend on the adhesive type, consistency, and reinforcement type. It is noteworthy that carbon fiber was not used in the first experiment and it has good potential for a lightweight material with high strength. Carbon fiber was used in the third experiment of this research.

The second experiment of this research was a blocked ANOVA using impact strength as the response variable to examine epoxy with hollow glass microspheres as additive into the epoxy. The two 3D printed materials used were ABS-M30 and Ultem. The hollow glass microspheres (glass bubbles) were intended to reduce weight without a loss in strength. Unfortunately, the internal voids formed during the first experiment were even more pronounced in the second experiment. These voids prevented meaningful data collection as the specimens would always break at one of the large voids. The voids were so inconsistent that often the impact reading from a test was not even on the scale of the instrument. A decision was made to stop the data collection during the second experiment since it was of no real value.

Viscosity of the epoxy was a factor, and adding the hollow glass microspheres produced a noticeable change to the viscosity of the epoxy. Figure 6 is a photo of the specimens for the second experiment. Figure 7 is an image that reveals the size distribution of the glass microspheres.

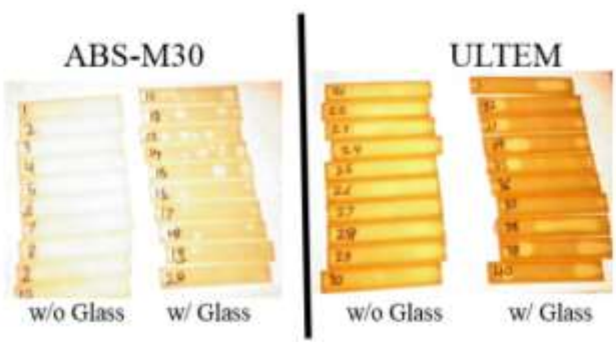

Figure 6 – Specimens fabricated for the second experiment, internal voids are visible.

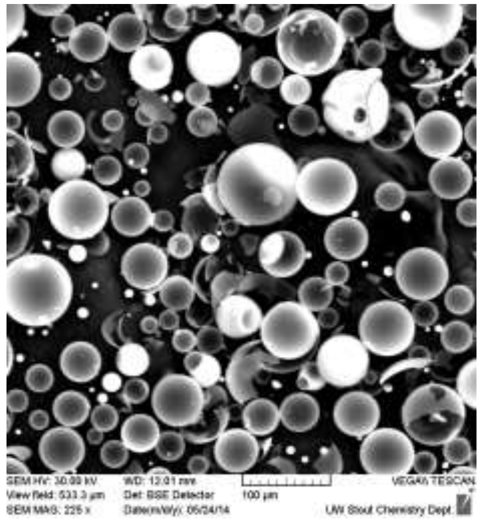

Figure 7 – Image shows the size distribution of the glass microspheres.

The third experiment of this research was an ANOVA using flexural strength (as per ISO-178) to examine the influence of three reinforcement types when fixed in position with epoxy only. The three reinforcement types were stainless steel mesh, aramid fabric (Kevlar), and carbon fiber. As with the previous experiments, internal voids were visible in the specimens and the data indicated a corresponding variation in the data. In this third experiment, full data was collected but the variation was too large to make meaningful conclusions from these results. These inconclusive data are summarized in Figure 8.

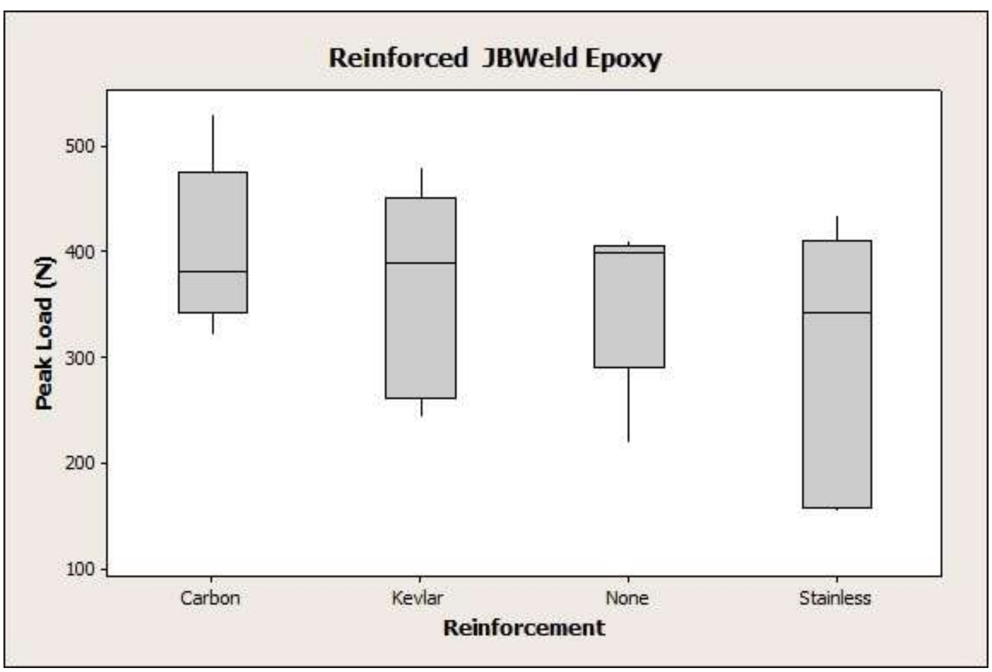

Figure 8 – Results of the third experiment produced inconclusive comparisons.

Summary and Conclusion

3D printing thin skins to reinforce them as hybrid composites was shown to be feasible. Preliminary data have achieved approximately half the strength to weight ratio of 6061-T6 aluminum and those specimens did not use carbon fiber. Three experiments were planned and two of those yielded data. Internal voids in the adhesive were an ongoing problem that produced unacceptably large variations in data measurements for both impact and flexural strength. Visible differences in the viscosity of the adhesive seem to strongly influence the formation of internal voids.

Future research has begun which will 3D print thin skins with louvers. A thickened epoxy will be used such that during fabrication, the adhesive over fills the thin skins in a way that allows the adhesive to extrude outward through the louvers. This shows promise for the ability to fabricate these hybrid composites with minimal internal void formation.

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