Influence of Reinforcement Volumetric Percentage and Aspect Ratio on Additive Manufactured Multi Material Structure in Uniaxial Loading

Arumaikkannu, G.; Sugavaneswaran, M.; Saravanan, K.

2014

Arumaikkannu, G., Sugavaneswaran, M., & Saravanan, K. (2014). Influence of Reinforcement Volumetric Percentage and Aspect Ratio on Additive Manufactured Multi Material Structure in Uniaxial Loading. Proceedings of the 1st International Conference on Progress in Additive Manufacturing (Pro-AM 2014), 41-46.

<https://hdl.handle.net/10356/84413>

https://doi.org/10.3850/978-981-09-0446-3_138

INFLUENCE OF REINFORCEMENT VOLUMETRIC PERCENTAGE AND ASPECT RATIO ON ADDITIVE MANUFACTURED MULTI MATERIAL STRUCTURE IN UNIAXIAL LOADING

G.ARUMAIKKANNU

*Department of Manufacturing Engineering, Anna University
Chennai, Tamil Nadu 600025, India*

M.SUGAVANESWARAN

*Department of Manufacturing Engineering, Anna University
Chennai, Tamil Nadu 600025, India*

K.SARAVANAN

*Department of Manufacturing Engineering, Anna University
Chennai, Tamil Nadu 600025, India*

ABSTRACT: Additive Manufactured multi material structures have an attractive combination of mechanical and thermal properties and are being increasingly used in engineering applications. To meet this need, additive manufacturing has shown the possibilities of processing multiple material with complex geometry in part fabrication. As a result, AM opens a new opportunity for designers to create multi material structure that were unfeasible to be manufactured in traditional techniques. And also it has been noticed that some products may require positioning and orientation of secondary material in a specific way to achieve desired functional properties. In this study the randomly oriented multi material were modelled based on parameters such as aspect ratio and volumetric percentage of secondary material/reinforcement and the same was fabricated using polyjet 3D printing technique. Influence of the parameters on behaviour of randomly oriented multi material structure under tensile loading was investigated. Experimentation results confirmed that the reinforcement parameter influences macroscopic behaviour of the multi material structure, which depends on the reinforcement intersecting point and the size of multi material structure. Multi material structure with higher aspect ratio has increased tensile modulus, where as with increase in volumetric percentage of reinforcement the tensile modulus get decreases.

INTRODUCTION

Multi material based AM technologies have the potential to become an important resource for the next generation of manufacturing technologies. AM techniques based on material jetting and extrusion have shown very good compatibility with multiple material processing. Jetting and extrusion based systems are able to fabricate components/parts with complex material distribution and Functionally Graded Materials (FGM) with variable properties which have a positive impact on product design and manufacturing. Other than extrusion and material jetting techniques, Weisensel et al (2004) used Laminated Object Manufacturing (LOM) processing multiple materials in order to enhance its process capability and part strength. Recently few researchers have made an attempt to review various AM techniques which are capable of processing multiple materials. Mohammad vaezi et al. (2013) reviewed multi material additive manufacturing techniques which can produce complex geometry parts with different materials. Multi material AM processes have been classified and the principles of the key processes have been reviewed

comprehensively. The advantages and disadvantages of each process, recent progress, bonding interface between materials, process resolutions, material solidification and future trends were discussed. Kumar, S et al. (2009) compared production of composite structure/ multi material structure by main AM techniques. Gibson I et al (2010) discussed and classified AM based upon the way in which multiple material can be implemented and listed out the advantage of incorporating multi material in AM techniques. Some researchers have developed application oriented multi material parts either through use of available AM techniques or by new techniques. Ott. M & Zaeh.M.F (2010) have developed Selective Laser Melting (SLM) with electrostatic charging principle to produce multiple materials (hot work steel and tungsten carbide/cobalt) for to increase the life time of tool insert with abrasive wear. Ryan Wicker et al (2004) modified the construction of existing Stereo lithography process for micro size multi material structure for implantable tissue engineering and functional device manufacturing. Jacob P. Moore et al. (2012) improved fatigue life to 3D printed elastomeric components using reinforced material. In spite of all these development still some of the area related to multi material fabrication in AM techniques such as heterogeneous material representation in 3D modeling, compatibly with range of materials, mechanical property of fabricated components and influence of shape, orientation and volume of secondary material has to be further studied.

This paper presents an exploration into additive manufacturing with multiple materials in the form of randomly oriented harder “reinforcement” in the softer “matrix” parts. Two important parameters such as volumetric percentage (Vol. %) and Aspect Ratio (AR) of reinforcement influence on tensile modulus has been investigated. From experimentation it has been reported that the tensile moduli of multi material structure were improved by introducing reinforcement. In addition, these reinforced structures show a 13–30% increase in resistance to deformation, a potentially significant result for AM parts.

MODELING

All AM requires input from 3D solid Computer Aided Design (CAD) model, usually as slices. Therefore first a CAD package has to be used to design the randomly oriented multi materials structure. Based upon algorithm developed by author's (Sugavaneswaran M & Arumaikkannu G (2014)) previous work, randomly oriented multi material structure was modeled. Since it is an preliminary attempt to study the influence of reinforcement in multi material structure, parameters such as Vol. % (10%, 15% & 20%) and AR (10, 15, 20) were given as an input to algorithm. Diameter and volumetric percentage of reinforcement as 10% and 0.5 respectively were assumed for modeling of AR 5, 10, 15 specimens. The developed CAD model as shown in Figure 1. is tessellated and then exported as a .stl file for further processing.

EXPERIMENTATION

Methods and Materials

Polyjet 3D Printing (3DP) process comes under family of 3D inkjet AM technique. This polyjet 3DP has an ability to fabricate multiple materials within a single layer featuring both harder reinforcement and softer matrix. This capability allows for a variety of new design possibilities for additive manufacturing such as living hinges, shock absorbing casings, and integrated gaskets. M. Stanek et al (2012) reported that, polyJet 3DP process provides smooth, fully cured and fine feature size parts. The process works on polymerization of photopolymer materials using UV light.

Figure 1. Methodology for modelling and fabrication of additive manufactured multi material structure.

The materials are deposited in layers thickness of 0.016 mm and then super fine layer with heterogeneous photopolymer and support materials is fully cured as UV heads passed over the multiple materials. Support material is easily separated from the part by either a water jet or hand.

Polyjet 3DP can process wide range of materials ranging from opaque to transparent, rigid plastic to rubber-like materials. By selecting suitable combination of materials, fabricated components will provide new values of mechanical property. Multi material component were fabricated with different Vol. % and AR with the photopolymer material (namely: darus white, vero black). Mechanical properties of photopolymer materials used in this study are listed in Table 1.

Tensile Testing

To determine tensile moduli of multi material component with various Vol. % (10%, 15% and 20%) and AR (10, 15, and 20) of Vero black reinforcement material in Darus white material, tensile test were conducted as per ASTM D638 Type IV standard. The fabricated specimens are shown in Figure 1. The dimension of specimen is shown in Figure 2. Uni axial loading tensile test were conducted on fabricated specimens using Instron-8322 testing machine at a crosshead speed of 5mm/min. Load-displacement curves were recorded. Tensile modulus and failure strain were obtained from associated software.

Table 1. Mechanical properties of polyjet 3DP materials.

S. No.	Properties	Materials	
		Vero white	Darus white
1	Tensile strength (MPa)	50-65	30-40
2	Elongation at break (%)	10-25	40-50
3	Density (g/cm ³)	1.17-1.18	0.905
4	Modulus of elasticity(MPa)	2000-3000	1200-1600

Figure 2. Dimension of ASTM D638 Tensile test specimen.

RESULTS AND DISCUSSIONS

A set of six AM multi material specimens were compared with AM pure matrix and reinforcement specimens and differences in tensile modulus of those specimens were examined. Tensile modulus is a measure of the load needed to induce a given deformation in the material. Figure 3. shows that the tensile modulus decreases as increase in reinforcement volume fraction to 10%. Then rapid reduction in tensile modulus is observed with addition of reinforcement volume fraction from 15% to 20%. It is observed that reinforcement as shown in Figure 7.a. is increasing with increase in vol. % of reinforcement. The possible explanation could be shear stress at the intersecting point between reinforcement results in destruction of network structure of reinforcement due to reinforcement damage or breakage, which has a negative strengthening effect on multi material structure.

Figure 3. Tensile modulus of multi material component as a function of reinforcement vol. %.

Figure. 4 Tensile modulus of multi material component as a function of reinforcement aspect ratio.

Figure 4. shows that tensile modulus of the multi material component increases with increase in aspect ratio. Reinforced specimens with AR 10 and 15 had higher tensile modulus than pure matrix specimens. This strengthening effect may be due to presence of high elastic modulus reinforcement and number of intersecting reinforcement at increase in AR is less compared to increase in volumetric percentage. Figure 7.b. shows the enlarged view of fractured surface of multi material specimen. Prorogation of fature across reinforcement shows that the bonding between reinforcement and matrix good enough to transfer the crack from matrix to reinforcement.

Behavior of failure strain with respect to increase in vol. % and AR of reinforcement is shown in Figure 5. & 6. As failure strain is inversely proportional to tensile modulus, the same behavior was observed in AM multi material specimen. All the multi material specimens failed at the mid of it as similar to plastic failure.

Figure 5. Tensile failure strain of multi material component as a function of reinforcement vol. %.

Figure 6. Tensile failure strain of multi material component as a function of reinforcement vol. %.

Figure 7. Enlarged view of a). Intersecting reinforcement b). Fracture surface of multi material specimen.

CONCLUSIONS

Additive manufactured multi materials are very interesting materials with high potential for use in a large number of engineering applications. Research works presented here highlighted the real possibility to produce tailor-made multi material structure by AM technique, which can be further enhanced by optimizing the reinforcement parameters. The following conclusions were drawn based upon the fabrication and tensile testing of additive manufactured multilateral specimen.

- ✓ At Aspect Ratio of 15, reinforced specimen's tensile modulus is 18.6% higher than the pure matrix specimen.
- ✓ The reduction in tensile modulus of the multi material structure is much lower than pure material as contrast to traditional composite structure, is attributed to the development and presence intersecting reinforcement which act as barriers to the propagation of crack.
- ✓ The use of reinforcement material resulted in significant change in macroscopic behaviour of AM multi material structure in uniaxial loading.
- ✓ With the help of this multi material building strategy, additive manufactured component with enhanced mechanical properties and additional functionality at specific region can be fabricated.

ACKNOWLEDGEMENT

The work described in this paper was supported by Grants (INSPIRE Fellowship Reg. No. IF120710) from the Department of Science and Technology, Ministry of Science and Technology, Government of India. The financial contribution is gratefully acknowledged.

REFERENCES

- Weisensel, L., Travitzky, N., & Greil, P. (2004). *Advanced Laminated Object Manufacturing (LOM) of SiSiC Ceramics*, 15th Solid Freeform Fabrication Symposium 2004, Austin, TX, 257-267.
- Mohammad Vaezi, Srisit Chianrabutra, Brian Mellor & Shoufeng Yang (2013). "Multiple material additive manufacturing Part 1: a review", *Virtual and Physical Prototyping*, 8(1), 19 -50.
- Kumar, S. & Kruth, J.P. (2010). "Composites by rapid prototyping technology", *Materials and Design*, 31,850–856.
- Gibson, I., Rosen, D.W. & Stucker, B. (2010). *The use of multiple materials in Additive Manufacturing*, Additive Manufacturing Technologies, Springer, 436-449.
- Ott, M. & Zaeh, M.F. (2010). "Multi-Material Processing in Additive Manufacturing", *Institute for Machine Tools and Industrial Management*, Technische Universitaet Muenchen, 195-203.
- Ryan Wicker, Francisco Medina, & Chris Elkins, (2004). "Multiple Material Micro-Fabrications: Extending Stereolithography to Tissue Engineering and Other Novel Applications, 754-764.
- Sugavaneswaran, M. & Arumaikkanu, G. (2014). "Modelling for randomly oriented multi material additive manufacturing component and its fabrication", *Materials and Design*, 54,779-785.
- Stanek, M., Manas, D., Manas, M., Navratil, J., Kyas, K., Senkerik, V. & Skrobak, A. (2012). "Comparison of Different Rapid Prototyping Methods", *International Journal of Mathematics and Computers in Simulation*, 6 (6), 550-557.