International Journal of Research Publication and Reviews, Vol 4, no 4, pp 1074-1081, April 2023

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Modeling of Multi-Material Structure for Additive Manufacturing

[1]Tirukovalluru Venu Kumar, [2]Dr. G. Kalivarathan

[1]Research scholar, Dept of Mechanical Engineering, CMJ University.
[2]Supervisor, Dept of Mechanical Engineering CMJ University

ABSTRACT

The technology known as Additive Manufacturing (AM) is evolving quickly and is being incorporated into both manufacturing and daily life. Since it first appeared on the market, it has gone by a variety of names, including Three-Dimensional (3D) printing, Rapid Prototyping (RP), Layered Manufacturing (LM), and Solid Free from Fabrication (SFF). The concept behind additive manufacturing (AM) is that it is a process that enables 3D designs to be produced directly from computer-aided design files without the need for tooling or dies that are customized to a given product. AM is seen to be a crucial element of this new trend. “Stereo Lithography (STL)” files are created by converting "Computer-Aided Design (CAD)" files for use in additive manufacturing processes. For the past 30 years, rapid prototyping has been a common application of AM technologies. The initial stages of work involve developing a straightforward algorithm using a Visual Basic (VB) script to simulate MM structures with random distributions of reinforcement. In addition, the algorithm's spatial configuration (position and orientation) and size (dimension) are represented by analytical equations in the algorithm. The CAD modeling system utilized is CATIAv5r18 from Dassault Systems, and the modeling approach employed is detailed. The equipment (AM method) and materials utilized in this study are specifically described in the paper. Its unique capacity to treat various materials is detailed in detail, as well as the construction and operation of the specified AM technique (poly jet 3DP).

Keywords: Additive manufacturing, modeling, multi-material structure, Computer-aided design, visual basic

Introduction

Engineering practice of Multi-Material (MM) structure application stops the spread of cracks and enhances mechanical performance such as improving the structures' stiffness and strength [1]. Recent advancements in Advanced Manufacturing (AM) technology, such as the processing of various materials, have made AM one of the viable manufacturing processes for the construction of MM structures with complex shapes [2].

To make use of such an AM capability method, one needs to create an appropriate CAD model using secondary data. distribution of reinforcement within the main material (matrix) of MM structure. Two CAD-related approaches have been summarized in this paper. Designing an MM structure that will be made using an AM method [3]. The first model for simulating the MM structure using random distribution reinforcement was achieved with a straightforward algorithm and Visual Basic (VB) script developed [4].

This algorithm was created with the AM process in mind capabilities (i.e., precision, number of material processes, layer thickness, and wall thickness). The core 3Diamensional kernel structure of Computed Aided Machine (CAD) software's VB script uses embedded geometric algorithms that were programmed inside as a library for creating reinforcement. In addition, the algorithm's spatial configuration (position and orientation) and size (dimension) are represented by analytical equations in the algorithm. The CAD modeling system utilized is CATIAv5r18 from Dassault Systems [5]. The second methodology was model-led and was based on the CAD modeling software's pre-existing features for modeling directional reinforced (unidirectional and multidirectional) MM structures. This paper describes a technique used to model directional reinforced MM structures.

Related works

The research [6] provided a Simulated Annealing and Monte Carlo (SIMP)-based technique for dealing with topology optimization of the multi-material structure with a graded interface. By combining the densities flattening and projecting method, a more robust two-stage filtering technique is created to characterize the multi-material structure and locate the material interface. The article [7] provided an overview of the research on multi-material structures printed with LPBF, particularly those made of incompatible materials. The work [8] proposed an ordered multi-material Solid Isotropic Material with Penalization (SIMP) interpolation to tackle multi- material topology optimization issues without adding any additional variables. The study [9] introduced two novel and highly productive joining methods and describes these procedures according to their technical characteristics for a particular steel/aluminum material combination. The paper [10] examined current research that created 3D-printed structures to help with the design and use of various articulated and multi-material structures as well as to explain the mechanics of the biological systems they imitate. The paper [11] provided a practical strategy for developing multi-material structures that can withstand interval loading uncertainty. Minimizing the compliance of linear elastic structures is the focus of this research. The study [12] demonstrates that micro-scale processing compatibility between metal and polymer 3D molding may be achieved using the subtractive manufacturing phase inherent in template-assisted techniques. The article [13] provided a powerful technique for optimizing the geometry and topology of multi-material structures while taking into consideration their elusive graded interface features. The [14] work comprehensively explored the stiffness and strength of 3D- printed multi-material interfaces by testing their tensile characteristics. The study [15] proposed an original method of increasing microwave ovens' temperature consistency by using a multi- material turntable construction.

RAND MULTI-MATERIAL STRUCTURE WITH REINFORCEMENT

Many different types of approaches for modeling can simulate MM structure. Lack of control over the reinforcement's size, form, and volume is one of these algorithms' special drawbacks. Additionally, the bulk of these algorithms were developed for modeling the Representative Volumetric Element (RVE) (natural and artificial) of MM structures. These RVE models were produced artificially to do finite element analysis. Typically, one unit (RVE) is repeated to represent the entire MM structure. Additionally, several of these algorithms didn't support converting the developed MM structure to the "de facto" format. Stereo Lithography (STL) in AM processing. Consequently, an algorithm has been created in this thesis using CATIA. Modeling random reinforced MM structure for AM process using VB script. CAD modeling with VB Script generally aids in automating tedious chores. Design processes are expedited, and complex geometries are automatically generated. These benefits have led to the usage of VB SCRIPT in the building of MM structures with random reinforcement orientation. The shapes and direction of the reinforcement are not restricted by the algorithm that was developed. The flowchart for the modeling algorithm is conceptually shown in Figure 1. The following is a description of the methodology used to produce reinforcement in three- dimensional Euclidian space with random orientation and position:

Step 1: The volumetric percentage (vol.%) and aspect ratio (dimension) are first calculated. As input, information about the reinforcement's width (W_r) and length [L_r] is provided. The rationale for choosing cuboid reinforcement and its size is outlined in this section.

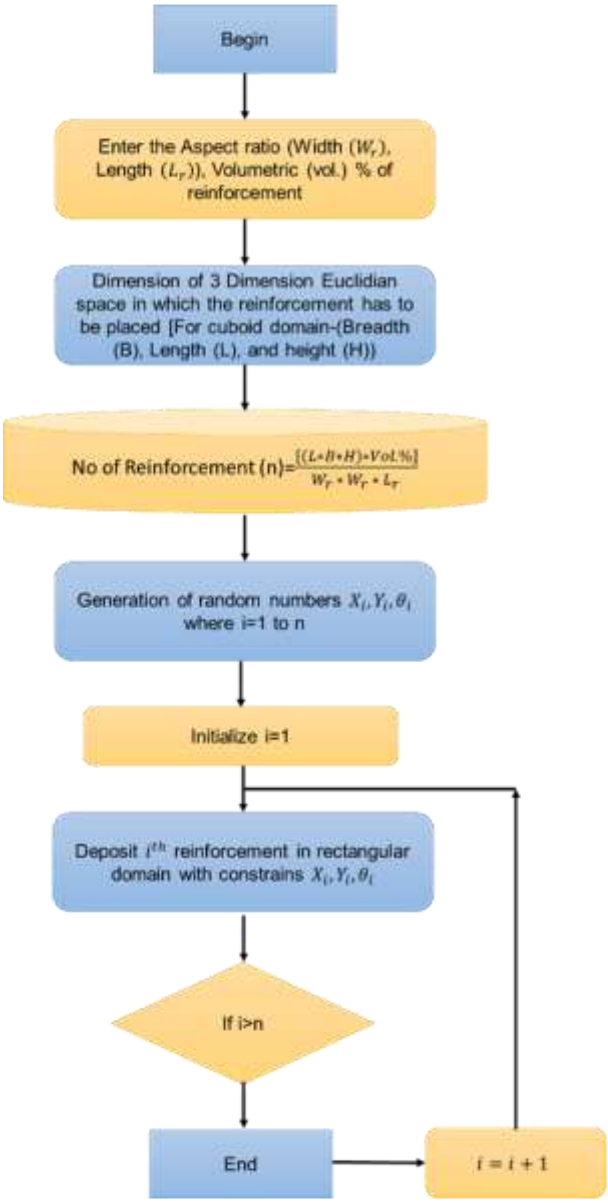

Figure 1: Modeling techniques for multi-material structures randomization of reinforcement orientation

Step 2: The volume of the Euclidian space that must accommodate reinforcements is defined as created. The cuboid domain is taken into account in this thesis study. Thus, input parameters like height (H), length (L), and width (W) are provided to specify the cuboid domain's volume. Because the majority of ASTM standard specimens were symmetrical and had constant thickness, the cuboid domain is taken into consideration in this case. A similar approach can be applied to AM MM structures with changing cross-sections, albeit this may necessitate more computation.

Step 3: Considering the volumetric percentage of reinforcement needed inside a volume of the domain as determined in step 2, the required number of reinforcements (n), utilizing the formula shown in the flow chart, will be generated is computed.

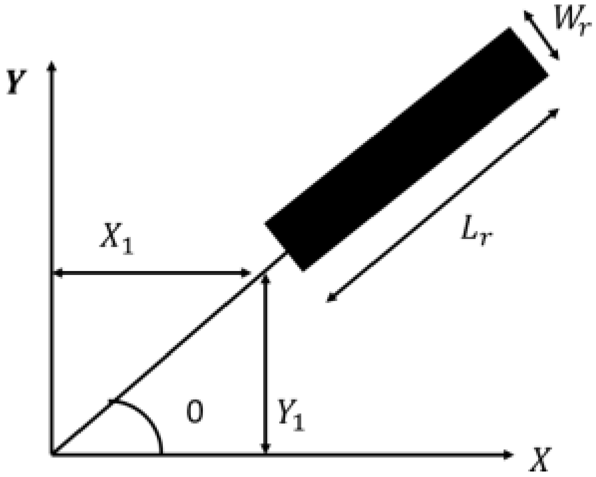

Figure 2: 2D space placement restrictions for reinforcement

Step 4: After determining the necessary number of reinforcements (n), every place and orient the reinforcement in 2D space as illustrated in Figure 2, reinforcement parameters like x, y, and must be defined. Due to the requirement that reinforcement is placed and orientated at random, the input parameters (X_i, L_r $Yi, and\ \theta$)for each reinforcement are given random values by the "r and" sub-function in the CATIA VB SCRIPT. Here, the width and length of the domain serve as the basis for the X_i and Y_I co-ordinate values intended to position the reinforcement, respectively, and the angular coordinated (θ) value is generated between the intervals of $[\theta^{\circ} - 360^{\circ}]$ for orientation of the reinforcement.

If the amount of reinforcement produced (i) equals the number to reach the requisite volumetric %, reinforcements (n) are necessary. If step 3's calculations are correct, the programmer stops; if not, step 4 is repeated until the number of reinforcements is generated by reinforcement i. Figure 3 depicts a reinforcement domain with randomly generated reinforcement orientation.

The production of reinforcement in a random location and positioning in two- dimensional space are described in steps 1 through 5 (see Figure 2, where only X and Y coordinates are mentioned, and the Z value depends on the plane in the previous step that the reinforcement is formed in). The aforementioned technique is continued layer by layer while increasing the Z-coordinate value to model MM structures with numerous layers.

A dog-bone-shaped tensile specimen made by ASTM D638 about the domain, horizontal, inclination, and vertical orientation (3D Euclidian Modeled as seen in Figure 3, it is constructed using the additive manufacturing process. is used for testing tensile to verify that reinforcement is distributed randomly throughout a domain. These three MM structures are described in this paper. Designated as Inclined Orientation (IO), Horizontal Orientation (HO), and an example of an AM/MM construction that is vertically oriented. Aside from that, the mechanical characteristics of random reinforced AM MM structures are predicted to be influenced by the volumetric percentage of secondary material; thus, MM structures with 10%, 20%, and 30% vol. Figure 4 depicts a 1:10 aspect ratio of reinforcement.

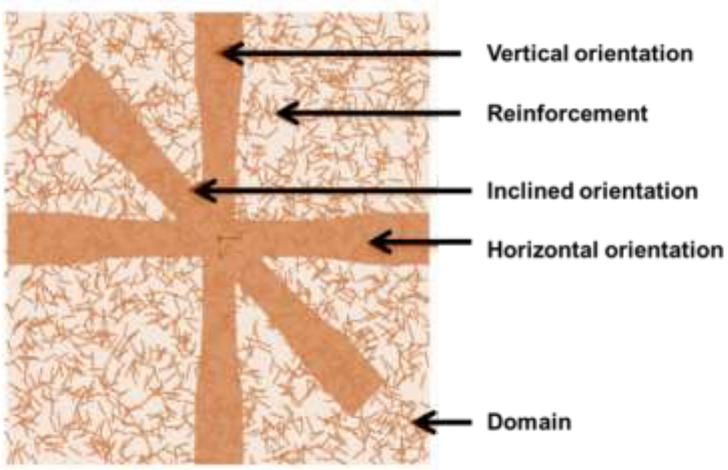

Figure 3: Reinforcement is randomly dispersed throughout a domain.

With 10 Vol.% Reinforcement

With 20 Vol.% Reinforcement

With 30 Vol.% Reinforcement

Figure 4: Model for a random reinforced multi-material structure with varied volumetric reinforcement percentages

A manufactured MM model with random reinforcement orientation MM structures is created using the AM technique and evaluated in a variety of conditions to comprehend their mechanical behavior under different loading scenarios.

REINFORCED DIRECTIONAL MULTI-MATERIAL STRUCTURE

The sequence of reinforcement orientation and stacking in an MM Structure provides the strength and rigidity needed in a particular direction. To examine the impact of various stacking arrangements and orientations of strengthening over the AM MM structure's mechanical characteristics, including designs (with varying orientation and stacking order) are taken into consideration for modeling.

Six layers of reinforcement in the MM model are aligned in the same direction. The following directions: (i) unidirectional ply - $(0)_6$Reinforcement in all six layers. (ii) unidirectional ply- (45)6 - Reinforcement in all six layers is inclined 45 degrees concerning the loading direction (Inclined Reinforced); ii) unidirectional ply- $(90)^6$ - Reinforcement in all six layers is along the loading direction (Longitudinal Reinforced); and iii) unidirectional ply- $(90)^6$

- all six layers of reinforcement are parallel to the direction of loading (Transverse Reinforcement).

The elastic characteristics of MM with reinforcement in different orientations must be determined, hence longitudinal and transverse orientations are taken into consideration. The mechanical parameters of the inclined reinforced MM structure are thought to be validated by analytical and numerical calculations that are based on experimental data. 45° to the loading direction, the reinforcement Figure 5 reveals the interior MM tensile test specimen model constructions for unidirectional reinforcement having reinforcement placed in the transverse, inverted, and longitudinal directions.

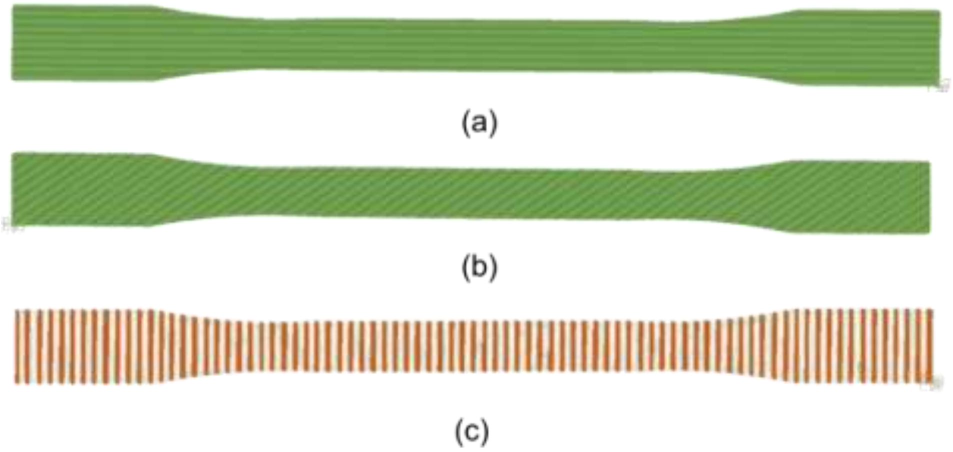

Figure 5: Interior of reinforced longitudinal (a), inclined (b), and transverse (c) MM models.

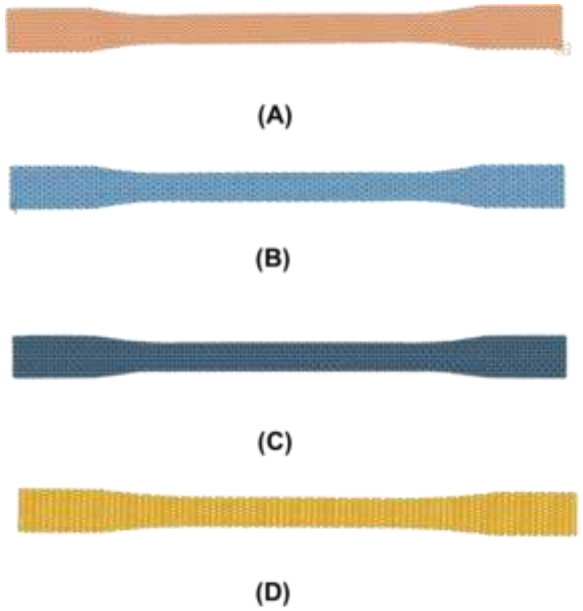

Figure 6: Internal organization of the MM model with the following lamination arrangements: (a) cross-ply (b) angle ply (c) quasi-isotropic I and (d) quasi-isotropic II

The following four designs with symmetrical arrangements are taken into consideration for the modeling of multidirectional reinforced MM structures with six layers. These designs are based on the Classical Lamination Theory (CLT) of mechanics of composite materials as stated in the paper. Consider the following arrangements: I cross-ply - (90/0/90)s - Reinforcement is parallel to the loading direction in the first layer and perpendicular to it in the third layer. ii) angular ply - ((-45)2/45)s - Reinforcement is inclined 45° about loading in the first and second layers in a clockwise direction, and 45° concerning loading in the third layer in an anti-clockwise direction. iii) quasi-isotropic ply I - (0/60/-60)s - Reinforcement runs parallel to the loading direction in the first layer, is inclined 60 degrees for the loading in the second layer's counterclockwise direction, and is inclined 60 degrees concerning the loading in the third layer's clockwise direction. iv) Quasi-isotropic ply II - (90/-30/30)s - Reinforcement in the first layer is perpendicular to the loading direction, in the second layer it is inclined 30 degrees in a clockwise direction, and in the third layer, it is inclined 30 degrees in an anti-clockwise direction. These constructions are referred to as multidirectional reinforced MM laminates because each layer in an MM structure has reinforcement orientated in a different direction. The internal structure of the MM tensile test specimen is shown in Figure 6 with an arrangement of angle ply, cross-ply, quasi-isotropic ply-I, and quasi-isotropic ply-II.

The choices already present in CAD software are used to model directional reinforced MM structure since reinforcement orientation and stacking sequence are less complex in directional reinforced MM structure than in random reinforced MM structure. A lot of AM processes also accept CAD models in STL format. However. STL simply approximates the surface; the material representation is unknown. Therefore, Boolean operation along with assembly operation is utilized to develop and represent the MM model to represent numerous materials from region to region inside a layer in a directional reinforced MM structure.

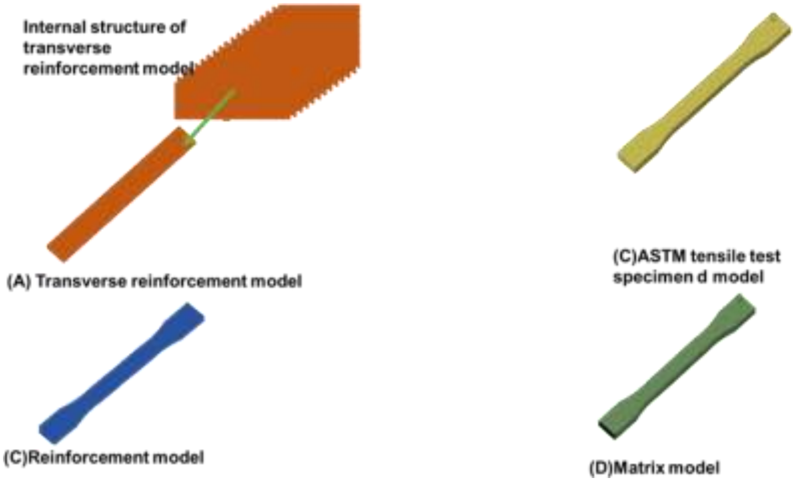

Figure 7: Modeling of transverse reinforced MM structure

Transverse reinforced MM structure modeling and assembly processes are shown in Figure 7 to model MM structures, reinforcement that is oriented in the transverse direction is first modeled as shown in Figure 7(a), and a second model that takes into account the shape of the tensile test specimen is then modeled as shown in Figure 7(b). Figure 7(c) models the reinforcement structure using a Boolean intersection operation between Figure 7(a) and Figure 7(b), and Figure 7(d) models the matrix structure using a Boolean subtraction operation between Figure 7(a) and Figure 7(b). The reinforcing structure and the modeled matrix are exported to the AM machine separately. Their STL files and related resources have been assigned. The aforementioned procedure was used once more to model several directed and random reinforced MM structures. For all reinforced structures, the reinforcement volume is maintained at 30%.

Conclusion

In this paper, the modeling of multi-material structures is explored for Additive manufacturing. This notion also applies to the RAND multi-material structure with reinforcement. The directional reinforced multi-material structure is also described in this study. Manufacturers may be able to produce previously unheard-of components due to multi-material structures for AM. A single continuous manufacturing process may enable the creation of materials with improved qualities compared to those produced using traditional production techniques. MM-AM machines combine materials to create composites, change the characteristics of existing materials, or create entirely new materials. New machines will be able to create flexible, responsive systems that add a user-participant interaction that has never been thought of before. Metal matrix composites, metal-ceramic systems, and "3D" form modifications made possible by MM-AM will likely lead to the development of new products that will affect and enhance everyday objects. In the near future, MM-AM will continue to advance and have a significant impact on how the designers, producers, and even regular consumers at home see the items they use daily.

Data availability

Not applicable.

Code availability

Not applicable.

Declarations

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Conflict of interest

The authors declare no competing interests.

Acknowledgments

There is no funding

REFERENCE

1. Zhou, S., Cai, Q., Tirichenko, I.S., Vilchez, V., Gavalda-Diaz, O., Bouville, F. and Saiz, E., 2023. Additive manufacturing of Al2O3 with engineered interlayers and high toughness through multi-material co-extrusion. *Acta Materialia*, *246*, p.118704.
2. Tao, F., Cheng, Y., Zhang, L. and Nee, A.Y., 2017. Advanced manufacturing systems: socialization characteristics and trends. *Journal of Intelligent Manufacturing*, *28*, pp.1079- 1094.
3. Vaneker, T.H.J., 2017. The role of Design for Additive Manufacturing in the successful economical introduction of AM. *Procedia Cirp*, *60*, pp.181-186.
4. Zhang, J., Wang, Z., Yang, H., Wang, Z. and Shu, X., 2018. 3D mesoscale modeling of reinforcement concrete with high volume fraction of randomly distributed aggregates. *Construction and Building Materials*, *164*, pp.350-361.
5. Urick, B., Sanders, T.M., Hossain, S.S., Zhang, Y.J. and Hughes, T.J., 2019. Review of patient-specific vascular modeling: template-based isogeometric framework and the CAD case. *Archives of Computational Methods in Engineering*, *26*, pp.381-404.

6. Chu, S., Xiao, M., Gao, L., Li, H., Zhang, J. and Zhang, X., 2019. Topology optimization of multi-material structures with graded interfaces. *Computer Methods in Applied Mechanics and Engineering*, *346*, pp.1096-1117.
7. Wang, D., Liu, L., Deng, G., Deng, C., Bai, Y., Yang, Y., Wu, W., Chen, J., Liu, Y., Wang, Y. and Lin, X., 2022. Recent progress on additive manufacturing of multi-material structures with laser powder bed fusion. *Virtual and Physical Prototyping*, *17*(2), pp.329- 365.
8. Zuo, W. and Saitou, K., 2017. Multi-material topology optimization using ordered SIMP interpolation. *Structural and Multidisciplinary Optimization*, *55*, pp.477-491.
9. Meschut, G., Hahn, O., Janzen, V. and Olfermann, T., 2014. Innovative joining technologies for multi-material structures. *Welding in the World*, *58*, pp.65-75.
10. Porter, M.M., Ravikumar, N., Barthelat, F. and Martini, R., 2017. 3D-printing and mechanics of bio-inspired articulated and multi-material structures. *Journal of the mechanical behavior of biomedical materials*, *73*, pp.114-126.
11. Zheng, Y., Da, D., Li, H., Xiao, M. and Gao, L., 2020. Robust topology optimization for multi-material structures under interval uncertainty. *Applied Mathematical Modelling*, *78*, pp.627-647.
12. Alcântara, C.C., Landers, F.C., Kim, S., De Marco, C., Ahmed, D., Nelson, B.J. and Pané, S., 2020. Mechanically interlocked 3D multi-material micromachines. *Nature communications*, *11*(1), p.5957.
13. Kang, Z., Wu, C., Luo, Y. and Li, M., 2019. Robust topology optimization of multi- material structures considering uncertain graded interface. *Composite Structures*, *208*, pp.395-406.
14. Liu, F., Li, T., Jiang, X., Jia, Z., Xu, Z. and Wang, L., 2020. The effect of material mixing on interfacial stiffness and strength of multi-material additive manufacturing. *Additive Manufacturing*, *36*, p.101502.
15. Ye, J., Hong, T., Wu, Y., Wu, L., Liao, Y., Zhu, H., Yang, Y. and Huang, K., 2017. Model stirrer based on a multi-material turntable for microwave processing materials. *Materials*, *10*(2), p.95.