CHAPTER 8

CONCLUSION AND SCOPE FOR FUTURE WORK

This chapter presents the conclusion based upon the work done to meet the objective set. This chapter also describes the implications of the thesis work and the future directions for research based on the outcome of this work.

8.1 CONCLUSION

AM processes have been identified as one of the effective manufacturing process technology for fabrication of multiple material structures (Chapter 1). However, fabrication of AM parts with more than one material within a layer at desired direction and orientation (discrete type MM structure) hasn’t been explored much. Discrete type AM MM structures has equal advantageous as that of continuously graded MM structure like functionally graded materials and it is used in many engineering applications which requires parts/components with different materials in specific position and orientation to achieve different functional properties (Chapter 2).

In this thesis work, methodology has been proposed to fabricate discrete type MM structure through AM process based upon on CAD modelling strategy (Chapter 3). AM process used for fabrication is Polyjet 3DP and materials used are Vero White (reinforcement) and Durus White (matrix). Fabricated AM MM structures with various position, orientation and vol. % of reinforcement are characterized under various conditions such as tensile, shear and flexural loading (Chapter 4). Besides experimentation, analytical method (Chapter 5) and numerical method (Chapter 6) are proposed to predict the mechanical properties of AM MM structure under various loading conditions. The following conclusions are drawn from this study.
1) By considering various AM process parameters, methodology for CAD modelling of MM structure with reinforcement in random direction, uni-direction and multi-direction have been developed. This methodology overcomes the limitations of MM modelling based upon parametric and boundary-representation solid modelling techniques.

2) Compared with unreinforced AM structure, adding secondary material in the form of reinforcement has increased the mechanical properties. It is observed that the strength of various AM MM structures (directional reinforced) have increased approximately more than 100% with least compromise on percentage of elongation (in average, the decreases in percentage of elongation is approximately 21.76%).

3) Unidirectional reinforced AM MM structure with longitudinal direction has high strength (tensile and flexural) and AM MM structure with inclined reinforcement has high shear strength.

4) Among various multidirectional reinforced AM MM structures, the quasi-isotropic ply AM MM structure has higher tensile strength and flexural strength. The shear strength is high in AM MM structure with angle ply laminates.

5) The AM MM structure test specimens are put through fractographic analysis in order to discern their mechanical characteristics. It is observed that, fracture mechanisms such as shear yielding, crack pinning and transverse matrix cracking are predominant in AM MM structure considered for the study. These failure mechanisms are affirmed through
imaging of the fractured specimen under a scanning electron microscopy.

6) Behaviour of AM MM structure in most cases are similar to laminated composite structure. However, two distinct features have been observed in experimentation. They are (i) reinforcement pull out and interface de-lamination between matrix and reinforcement as observed in laminated composite which is not present in AM MM structure (ii) unidirectional reinforced AM MM structure with reinforcement in transverse direction displays catastrophic failure and poor mechanical properties under tensile, flexural and shear loading.

7) The mechanical properties (tensile and flexural strength) of random reinforced AM MM structure increases with the increase in vol. % of reinforcement. Under shear loading increase in vol. % of reinforcement beyond 20% results in decrease in shear strength.

8) Experimental results show that mechanical properties of AM MM structure can be tailored according to specific loading conditions (direction of loading and type of load).

9) To overcome the difficulties associated with experimentation on orthotropic AM MM structure, analytical method based on CLT of mechanics of composite material is used to predict its mechanical behaviour. The feasibility of using analytical method has been comprehensively validated with experimental results. It is observed that other than AM MM structures with transverse reinforced layers, the maximum
deviation of result predicated through analytical method with respect to experimental method is within 8.48%.

10) Numerical method based upon composite layup module of ABAQUS CAE package has been used to simulate the mechanical response of AM MM structure and it is evaluated with experimental results. Deviation of numerical simulation result with experimental result is within 10.75% (expect AM MM structure which have transverse reinforced layer alone). Effect of transverse reinforced layer in cross ply laminates AM MM structure has been reduced by layers with reinforcement in other angular orientation.

11) The experimental and prediction methods (CLT and FEA with composite layup module) have quite good agreement; hence in future, methodology proposed can be used for estimating the mechanical properties of AM MM structure with different material constituent and loading conditions.

12) The investigations and conclusions obtained from this research work will further compliment the potential applications of AM process in multiple material part fabrication for various functional applications (Complaint mechanism, living hinges, grippers, snap fits, etc.).

8.2 SCOPE FOR FUTURE WORK

Discrete type AM MM fabrication and its characterization have demonstrated some promising results and it can be expected that their use will spread more in the near future. Scope for future work based upon the work presented in this thesis are described as follows
Present research is focused towards fabrication of AM structure with fixed percentage of reinforcement, shape and aspect ratio. However, various percentages of reinforcement and reinforcement with various shapes for better anchorage have to be investigated. Interlayer bonding strength between adjacent layers of AM MM structure can be enhanced by placing reinforcement in 3D space instead of 2D space as demonstrated in this work.

Transverse reinforced AM MM structure displays de-lamination of inter-layers. This phenomenon can be incorporated in FEA analysis of AM MM structure which has transverse reinforced layers, in order to minimize the deviation between numerical analysis and experimental results in transverse reinforced AM MM structure.

Polyjet 3DP parts are used as living hinges, gaskets, cartilage, and over moulds, etc. In some of the above mentioned applications, it is necessary to have a certain level of stiffness in a specific direction without compromise in flexibility. These properties can be achieved by reinforcing flexible material with desired percentage and orientation of rigid material, which can give desired mechanical properties close to the requirement in applications.

Curling and distortion effects are high on photopolymer based AM parts. MM structures which have an inherent anisotropic property can be used in order to reduce the curling and distortion.

The proposed framework can also be extended to fabrication of discrete type MM structure based upon other materials (elastomers and ceramics) and other AM process were multiple material deposition nozzle system is used.