A Study of 3D Printed Silver-Polymer Composite Structures

Cynthiya Shrestha

University of New Orleans

Follow this and additional works at: https://scholarworks.uno.edu/honors_theses

Part of the Mechanical Engineering Commons

Recommended Citation
https://scholarworks.uno.edu/honors_theses/121

This Honors Thesis-Restricted is protected by copyright and/or related rights. It has been brought to you by ScholarWorks@UNO with permission from the rights-holder(s). You are free to use this Honors Thesis-Restricted in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Honors Thesis-Restricted has been accepted for inclusion in Senior Honors Theses by an authorized administrator of ScholarWorks@UNO. For more information, please contact scholarworks@uno.edu.
A Study of 3D Printed Silver-Polymer Composite Structures

An Honors Thesis

Presented to

The Department of Mechanical Engineering
of the University of New Orleans

In Partial Fulfillment of

The Requirements for the Degree of Bachelor of Science,

with University High Honors and Honors in
Mechanical Engineering

by

Cynthiya Shrestha

May 2018
Acknowledgements

Firstly, I would like to express my gratitude towards my research mentor and thesis advisor, Dr. Damon Smith for his consistent guidance and support throughout the span of this project. My sincere thanks to Dr. Paul Schilling and Dr. Paul Herrington for being the second and third thesis reader, respectively. I am grateful to Dr. Wendy Schluchter from the Biological Sciences Department at University of New Orleans and Dr. Jibao He from Tulane University for letting me use their laboratory facilities for the completion of this project. I owe my sincere thanks for the helping hands of Jenna Walker, John Marshall Arnold, Michael Wong, Alexis Blanco, Lyndsay Ann Carrigee, Mark Granier, Erin Sutherland and Francisco Avelar.

Finally, I would like to recognize my family and my friends at University of New Orleans for their unconditional love, support and motivation. Also, I am grateful to the Honors Council at University of New Orleans for providing me with this platform.

This thesis is dedicated to my parents, Hari Pratap Shrestha and Durga Laxmi Shrestha.
# Contents

I. Abstract 1

II. Introduction 2

1. Additive Manufacturing 2
2. Fused Deposition Modeling 3
3. Applications of 3D Printing 4
4. 3D Printing with Polymer Matrix Composites 6

III. Methodology 7

1. Filament Synthesis 7
2. Anti-Microbial Test Procedure 10

IV. Results and Discussions 11

1. Differential Scanning Calorimetry Results 11
2. UTM Tensile Testing Results 13
3. Anti-Microbial Test Results 18

V. Conclusions 20

VI. Future Work 21

VII. References 22
## List of Tables

1. DSC Results for Varying Silver Weight Concentrations  
   11
2. Tensile Test Results for Varying Silver Weight Concentrations  
   15
List of Figures

1. The Flow of Data in AM Technology ...................................................... 2
2. Several Kinds of Additive Manufacturing Technology ......................... 3
3. Schematic of Fused Deposition Modeling ............................................ 4
4. a. 3D Printed Medical Forceps ............................................................. 5
4. b. 3D printed Medical Forceps with Ag-PLA Composite ...................... 5
5. Silver Composite Filament Synthesis Procedure .................................. 7
6. PLA Filament with Varying Ag Concentration ..................................... 9
7. SEM Image of the 2.5% wt. Filament Cross-section .............................. 9
8. DSC Graph for Plain PLA Filament .................................................... 12
9. DSC Graph for 1% wt. AG +PLA Filament ......................................... 12
10. DSC Graph for 2.5% wt. AG +PLA Filament ...................................... 12
11. DSC Graph for 5% wt. AG +PLA Filament ......................................... 13
12. Stress vs. Strain Graph for Plain PLA ................................................. 14
13. Stress vs. Strain Graph for 1% wt. Ag+ PLA ...................................... 14
14. Stress vs. Strain Graph for 2% wt. Ag+ PLA ...................................... 14
15. Stress vs. Strain Graph for 3% wt. Ag+ PLA ...................................... 15
16. Typical Stress vs. Strain Graph for Brittle and Ductile Material .......... 15
17. Comparative Strain at Fracture Analysis Graph .................................. 16
16. Comparative Maximum Stress Analysis Graph .................................. 17
17. SEM Image of the Dog-bone Sample Fracture Surface ....................... 17
18. Comparative Antimicrobial Test Results .......................................... 18
19. Comparative Antimicrobial Test Results .......................................... 18
20. Comparative Antimicrobial Test Results .......................................... 19
I. ABSTRACT

This research project primarily focuses on three major aspects: synthesis and inclusion of silver micro-particles and nanowires within a polymer matrix, extrusion of composite filaments and, three-dimensional (3D) printing of multifunctional polymer composites. Since very few studies have explored the inclusion of silver nanoparticles in 3D printing materials, the findings from this study can be significant for additive manufacturing technology. Over the past few decades, the applications of additive manufacturing has been expanding considerably in several industries like automobile, biomechanics, aerospace, hardware engineering, to name a few. We are particularly interested in silver particles and nanowires because of their enhanced antimicrobial, mechanical and optical properties.

The unique antimicrobial properties of the silver-polymer composite will especially be applicable in the food and meat industry, where microbial infection is a major concern because of the exposure of microbes in the polymer belts that are used to transfer and package the items in the factory. It costs the industries a considerable amount of time, money and labor to regularly clean and sanitize those belts. If we are able to develop polymer belts with embedded antimicrobial properties, it could have tremendous applications in the food and meat industries. The morphology of the particles will be studied using scientific techniques like Transmission electron microscopy (TEM) and Scanning Electron Microscopy (SEM). The idea is then to nanoparticles will be incorporated into PLA polymer pellets and extruded into composite filaments that can be used for 3D printing of dog-bone test structures. After the fabrication process, tensile tests and fracture surface analysis will be conducted to study the extent of enhancement of the mechanical properties as compared to neat polymer 3D printed specimens. The critical challenge in this project would be to ensure homogenous distribution of the nanoparticles throughout the polymer filaments. This project will integrate concepts and applications from three different fields: nanotechnology, material science, and additive manufacturing.

Keywords: additive manufacturing, 3D printing, composite materials, nanotechnology, silver microparticles
II. INTRODUCTION

1. Additive Manufacturing

Additive Manufacturing (AM) is an emerging technology that creates objects from bottom-up by adding material one cross-sectional layer at a time. It can also be referred to as 3D printing, rapid prototyping, or solid-freeform. This term was first described in 1986 by Charles Hull. It begins with a meshed 3D computer model that can be created by acquired image data or structures built in computer-aided design (CAD) software. A STL (Surface Tessellation Language) file is commonly created. The meshed solid model will be further sliced into a build of 2D layers and sent to the 3D printing machine. Figure 1 below shows the flow of data in a typical additive manufacturing process.

![Flow of Data in AM Technology](image)

The common materials used to generate the 3D printed models include thermoplastic polymer materials such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyamide (PA) and polycarbonate (PC) as well as thermosetting polymer materials like epoxy resins. Additive manufacturing incorporates several techniques such as Fused Deposition Modeling (FDM), Direct Laser Deposition (DLD), Inkjet 3D Printing, Stereo lithography (SL), 3D plotting (3DP) and
Selective Laser Sintering (SLS). The flowchart below categorizes the techniques based on methods used to create the 3D products. Fused Deposition Modeling (FDM) technique was used in this research project.

![Flowchart](image)

**Figure 2: Several Kinds of Additive Manufacturing Technology**

2. **Fused Deposition Modeling**

Fused deposition modeling is an additive manufacturing process in which a thin filament of polymer feeds into the 3D printer, where a print head melts it and extrudes it in a thickness of approximately 40 micrometer to form the 3D object. FDM printers are the most commonly used printers for fabricating polymer composites and they work by controlled extrusion of thermoplastic filaments. The quality of printed parts can be controlled by altering printing parameters, such as layer thickness, printing orientation, infill percentage, raster width, raster angle, and air gap. The advantages of FDM include no chemical post-processing required, no resins to cure, high printing speed, less expensive machine, and materials resulting in a more effective process. One of the common drawbacks of FDM is that the composite materials have to be in a filament for to enable the extrusion process. It can be challenging to homogenously disperse reinforcements and the usable material is limited to thermoplastic polymers with suitable melt viscosity and glass
transition technology. The schematic in the next page demonstrates the printing process along with the directional movements of the print bed and print head.

Figure 3: Schematic of FDM

3. Applications of 3D Printing

Since the past few decades, the applications of 3D printing have been increasing remarkably in several fields of science, technology, product development and design. Some of the most common applications of additive manufacturing across several industries have been described below:

- **Manufacturing**: 3D printing is extensively used in industrial level to create simplified models and prototypes during the product’s design and development phase. It is much cheaper and time efficient alternative to casting and injection molding processes, especially for short series production.

- **Medical Applications**: 3D printing has vast applications in the medical technology. From customized prosthetics to regenerative organ printing, additive manufacturing has been proven effective for numerous applications. 3D printing enables making of very high quality bone transplants and models of damaged bone of the patients for analysis by permitting to scan and build a physical model of defective bones from the patients. Because
of the limitless form or shape of what could be built, doctors have the option to create customized and highly precise transplants and prosthetics. Additive manufacturing is also a great tool for dentists to build a plaster model of a patient’s mouth or replace the teeth using 3D printed implants. The use of 3D printing technology can provide geometrically appropriate electronic prototypes with reduced development time. When combined with electrical materials, 3D printed polymer composites are able to function as electronic devices that can be used in a number of ways. Bio-fabrication using living cells for tissue and organ transplantation is another new paradigm of 3D printed polymer composite applications. Several tissues and organs, such as ears, vasculatures, aortic valves, cartilage constructs and liver tissue constructs have already been successfully printed to meet the functionality requirement for transplantation.

- **Aerospace Industries:** 3D printing is used by major aerospace companies like GE and Boeing to create small parts with complex geometries which are time consuming and costly to be manufactured. The common aerospace components that are 3D printed include engine exhaust, propellers and fuel nozzles. When polymer composites are used to print these components, they get the advantage of being light and corrosion resistant.

![Figure 4(a): Medical forceps being 3D printed in Smith Lab using commercially available red PLA Filament.](image)

![Figure 4(b): Medical forceps 3D printed in Smith Lab using Ag-PLA composite Filament.](image)
4. 3D Printing with Polymer Matrix Composites

Polymer materials with low melting point or in liquid state are widely used in 3D printing industry due to their low weight, low cost, and processing flexibility. Although 3D printed polymer products could have geometric complexity, lack of mechanical strength and functionality is a bug challenge for their wide applications. One of the promising ways to solve this problem would be by adding other materials with desired mechanical and functional properties. Reinforcing nanomaterials into the polymer matrix has particularly been observed to be highly successful in the recent studies. Some of the particles previously used for reinforcement include glass beads, iron, copper, silicon, aluminum, carbon, ceramic, and tungsten. An exciting development in 3D printing of particle reinforced composite is the capability to print structural components for potential real world applications. The addition of particles into polymers also helps address some difficulties in the printing process. One obstacle for FDM printing process is the distortion of final printed parts, which is caused by the thermal expansion of polymer. Embedding metal particles into polymers was proved to be an efficient solution to this problem. Moreover, particle reinforced polymer matrix has been proven to have enhanced modulus of strength, thermal conductivity, dielectric permittivity, heat transfer coefficient, and reduced frictional factor.

Our interest in choosing Polylactic Acid (PLA) as the polymer base is because of the fact that biodegradable polymers have been of commercial interest due to a growing environmental concern directed toward sustainable development. PLA derived from the ring opening polymerization of lactide from the fermentation of the sugar feedstock, has been considered as an attractive bio-based polymer due to its biocompatibility, nontoxicity, and biodegradability. Because of the aforementioned characteristics, it has found several versatile medical applications,
III. METHODOLOGY

1. Filament Synthesis

The process of obtaining 3D printed samples from the silver (Ag) microparticles-polymer matrix has been discussed in this section. The process has been reformed and optimized based on previously published literature with similar synthesis. The entire process flow for synthesizing 5% (by weight) Ag-microparticles concentration in PLA filament has been illustrated below in stepwise manner.

Figure 5 Silver Composite Filament Synthesis Procedure
1. 5 grams of Ag-microparticles is weighed out and placed on a clean glass dish. PVP is then added in a 10% by weight concentration as compared to the silver powder, which is 0.5gm of PVP.

2. About 100ml of chloroform is added on the powder mixture. The mix is then stirred using magnetic stirrers over the hot-stir plate for about 10 minutes to ensure the powder particles have dispersed evenly. Here, PVP is used as dispersant. Glass dish is strictly used because of chloroform’s ability to dissolve several polymers.

3. The hot plate is set to medium heat and about 20gm of PLA pellets is then slowly added to the solvent while stirring the mix using a clean glass rod.

4. Chloroform is slowly added stirred onto the mix in batches of 20ml until the PLA is completely dissolved and the silver particles are dispersed evenly in the viscous mix.

5. The mix is then let to cool down and settle overnight. Parafilm is used to seal the glass vessel to prevent contamination.

6. After the mix is completely dried, a solid disc is formed, as depicted in step 5, is formed. The disc is taken out of the dish and cut into smaller pieces of about half inch edges. The pieces are then put into the grinder to get fine granules of the composite material. 80 gm of plain PLA is also granulated in the grinder and properly mixed with the composite granules.

7. The Filabot™ extruder is heated up to 180°C. The composite granules are put in to the hopper to extrude it into a filament, which is then spooled using the Filabot™ spooler. The speed of extrusion is required to be adjusted manually to maintain the consistent diameter of the filament to about 1.75mm.

8. The extruded filament is then loaded onto the 3D printer. The print temperature is set to 200°C. The dog-bone sample structures can be printed in three different orientations: horizontal, vertical, and crosshatch. The infill percentage is maintained at 100%.

9. The same procedures are repeated to 3D print the 1 in diameter discs for the anti-microbial tests.

10. Due to PLA’s tendency to absorb the moisture, all the printed samples and composite filament must be properly stored in a descendent cabinet. To prevent further contamination, the composite discs must be store under the fume hood in a sealed container.
The picture on the left presents a visual comparison of the PLA filaments using the microscope. The top one is a plain PLA filament, and the rest with Ag particles have been labeled respectively. The increase in silver particle concentration can be qualitatively observed. At 5% wt. concentration, the accumulation of silver particles is visible.
2. Anti-microbial Test Procedure

1. The primary *E Coli*. Culture of strain **85W1660** is cultured on a TSB broth and properly stored in the refrigerator.

2. 10µl of the main culture is pipetted onto 990 µl of autoclaved saline solution.

3. The optical density of the saline solution is measured using a Spectrophotometer. The optical density of 0.1OD, which equals to roughly $10^8$/ml concentration of bacteria, is desired. Thus, additional amount of either main culture or saline solution is added until the desired concentration is achieved.

4. Once about 1ml of 0.1OD saline solution is prepared, 10 µl of that solution is transferred onto 990 µl of plain saline solution to dilute the bacteria concentration to $10^6$/ml of the solution.

5. The prepared solution is then carefully dropped onto the surface of the silver-PLA composite 3D-printed discs, which are placed on top of petri dish. These discs and the petri dishes are sanitized under UV light for about 20 minutes beforehand.

6. The plates are properly covered and kept under a well-regulated fume hood for a period of 24 hours (variable).

7. After 24 hours, the plates are washed using 5ml of Phosphate Buffer Solution (PBS).

8. 10 µl of the washed solution is plated onto the TSA plates and put into the 37°C incubator for 24 hours. After observing the number of bacteria colonies formed in 24 hours the petri dishes are properly sealed and stored in refrigeration to prevent the bacterial growth.
IV. RESULTS and DISCUSSIONS

1. Differential Scanning Calorimetry (DSC) Results:

Differential Scanning Calorimetry (DSC) is an effective analytical tool for characterizing the physical properties of a polymer. DSC enables determination of melting, crystallization, and mesomorphic transition temperatures, and the corresponding enthalpy and entropy changes, and characterization of the glass transition and other effects which show either changes in heat capacity or a latent heat. It is especially important for us to record the melting point and the glass transition temperature of the filament. The quality of the print will be negatively affected if the temperature of the print head is either too low or too high, as compared to that of the filament. Thus, it is important to adjust the temperature of the print head in accordance to the melting point of that filament.

The glass transition temperature \( T_g \) is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material. \( T_g \) is not a discrete thermodynamic transition, but a temperature range over which the mobility of the polymer chain increases significantly. The convention, however, is to report a single temperature defined as the midpoint of the temperature range, bound by the tangents to the two flat regions of the heat flow curve. The glass transition temperature is an important material property that has effects on several other properties like the modulus, lap shear and coefficient of thermal expansion. PLA is a semi-crystalline or amorphous polymer with a glass transition temperature \( T_g \) and melting point temperature \( T_m \) of approximately 55°C and 170 to 180°C, respectively. The graphs obtained from the DSC measurements were analyzed to obtain the \( T_m \) and \( T_g \) for the PLA filament with different concentration of silver microparticles. The graphs have been further discussed in the next page.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Glass Transition (°C)</th>
<th>Melting point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain PLA</td>
<td>56.21</td>
<td>176.88</td>
</tr>
<tr>
<td>1% Ag + PLA Composite</td>
<td>55.95</td>
<td>176.15</td>
</tr>
<tr>
<td>2.5% Ag + PLA Composite</td>
<td>53.32</td>
<td>173.95</td>
</tr>
<tr>
<td>5% Ag + PLA Composite</td>
<td>52.51</td>
<td>174.65</td>
</tr>
</tbody>
</table>
Figure 8: DSC Graph for Plain PLA Filament

Figure 9: DSC Graph for 1% wt. Ag + PLA

Figure 10: DSC Graph for 2.5% wt. Ag + PLA
From the data in table and the figures above, we observe that there isn’t a significant change in either glass transition temperature or the melting point of the filament. Although there is slight change in the temperature values, they are not significant enough to change in the print temperature of the printer head. The 3D samples are printed at 180°C, since the melting point temperature of each of the filament is between 170°C and 180°C, it is not necessary to change the temperature settings to achieve good quality print. While gradually increasing the concentration of the silver micro particles in the PLA matrix from 1% to 5%, the thermal properties are not remarkably changed.

2. UTM Tensile Testing Results

Tensile testing is an engineering testing technique in which a material is subject to tensile load until failure. For this project, a countertop Universal Testing Machine (UTM), pictured in the next page, is used to test the 3D printed dog-bone samples under tensile loading. The standard dog-bone testing structures are 63.75mm in length, 9.40mm in width, 3.25mm in width at the bridge, and 3.8mm in thickness. The results obtained from the tensile testing is then plotted on a stress versus strain graph for comparative study of the mechanical properties of the samples with varying weight percentage of silver microparticles. The properties of interest are ductility, strain at break, and the maximum stress.
**Figure 12 Stress vs Strain Graph for Plain PLA**

**Figure 13 Stress vs Strain Graph for 1% wt. Ag + PLA**

**Figure 14 Stress vs Strain Graph for 2% wt. Ag + PLA**
Table 2 Tensile Test Results for varying Silver Weight Concentrations

<table>
<thead>
<tr>
<th>Sample</th>
<th>Avg. Strain at Break</th>
<th>Avg. Maximum Stress (MPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain PLA</td>
<td>0.0241</td>
<td>56.6</td>
</tr>
<tr>
<td>1% Ag + PLA Composite</td>
<td>0.0424</td>
<td>53.6</td>
</tr>
<tr>
<td>2% Ag + PLA Composite</td>
<td>0.0391</td>
<td>50.8</td>
</tr>
<tr>
<td>3% Ag + PLA Composite</td>
<td>0.0388</td>
<td>39.5</td>
</tr>
</tbody>
</table>

From the comparative stress vs strain graph for the brittle and ductile materials above, we can observe that even though, the yield strength is higher for brittle material, and the strain at failure is much higher for
ductile material. This is because the ductile material undergoes a larger amount of deformation before failure. PLA is a brittle material with low crack initiation energy and low crack propagation energy (14). It has been quite a challenge to increase the ductility of parts 3D printed using PLA as filament material. As compared to the samples printed with plain PLA, the samples with 1% and 2% of silver additives have higher strain at break, which indicates enhanced ductility. From the graphs obtained from the tensile testing and the data table 2, we can observe this increase in ductility in the expense of decrease in the maximum stress withstood by the samples. The decrease in maximum stress could have resulted due to the stress concentration because of the presence of silver microparticles in the polymer matrix. One of the main reasons for the low mechanical strength of 3D printed materials is the presence of void in printed parts. The addition of reinforcement may further increase the porosity due to the poor interfacial bonding with the matrix (1). Due to the increase in strain at break, the ductility of the samples can be calculated to be increased by nearly 60%. The comparative graphs below present the range data obtained from several tensile testing of the samples. Figure 16 suggests enhanced strain at fracture of the composite samples as compared to the plain PLA samples, while Figure 17 suggests decrease in peak stress.

![Strain from Max Stress to Fracture](image)

*Figure 17 Comparative Strain at Fracture Analysis Graph*
Figure 18 Comparative Peak Stress Analysis Graph

The figure below is an SEM image of the fracture surface of specimen with reinforced silver particles. The cross-sectional image shows the gap in between the layers and the roughness of the fracture surface.

Figure 19 SEM Image of the Dog-bone Fracture Surface
3. Anti-Microbial Results

After dispersing the diluted bacteria culture on the TSA plates and incubating the plates for 24 hours, the colonies of bacteria are formed on the plates. The pictures below present the visual results for several batches of the tests. For each batch the procedure has been exactly followed and the temperature and environmental factors have been kept constant for every plate.

Fig. 17 Comparative Antimicrobial Test Results
A: Plated on Plain PLA disc for 24 hrs.
B: Plated on 2.5% PLA disc for 24 hrs.
C: Plated on Plain PLA disc for 24 hrs.

Fig. 18 Comparative Antimicrobial Test Results
A: Plated on Plain PLA disc for 24 hrs.
B: Plated on 1% PLA disc for 24 hrs.
C: Plated on 2% PLA disc for 24 hrs.
Qualitative results can be drawn from the pictures above. The colonies of *E Coli* can be observed to be significantly less in the when plated on the 3D printed Ag-PLA composite plates. The results repeatedly indicate the enhanced antimicrobial property of the discs with certain weight percentage of silver micro-particles as compared to the plain PLA discs. While the colonies of bacteria formed for the Plain PLA discs is almost uncountable in most cases, the ones for Ag-composite discs is countable and almost none at all in some cases.

Fig. 19 Comparative Antimicrobial Test Results
A: Plated on Plain PLA disc for 4 hrs.
B: Plated on 2.5% PLA disc for 24 hrs.
V. CONCLUSIONS

The preliminary study and test results indicate several advantages of adding silver microparticles into the PLA polymer matrix over the traditional methods. Comparative studies were done based on several vital properties like mechanical, thermal, and antimicrobial. The silver particles where added to the polymer matrix in several weight percentage amount, namely, 1%, 2%, 2.5%, 3% and 5%. Due to the tendency of filament with silver additives to clog the very fine tip of the print head nozzle, it has been quite challenging to properly print the PLA filament with silver concentration of 5% or higher. Due to this the study has been limited to silver concentration of up to 3%. Addition of silver microparticles have been accounted for enhancement of ductility of the 3D printed dog-bone test structures, which can be attributed to the increase in the strain at failure. The DSC results indicate minimal change in the melting point and the glass transition temperature of the PLA filaments with silver additives as compared to the plain ones. The 3D printed is set to print at 180°C for PLA. Due to the minimal change in temperature, the temperature of the nozzle head of the 3D printed need not be changed to obtain fine quality of print. Finally, the preliminary anti-microbial results have been very encouraging. The qualitative results clearly indicated the enhanced anti-microbial properties of the silver-PLA composite discs as compared to the regular PLA ones. Although a linear trend or correlation has not been yet developed between the varying weight percentage of the silver and the effect on the ductility, thermal, and anti-microbial properties. This is mainly because of the challenges in evenly distributing the silver microparticles in the PLA matrix, which can be attributed to several factors such as high viscosity of PLA, tendency of silver particles to accumulate together, and incompatibility of chloroform with other plastic container. Due to the uneven distribution during the synthesis process, a certain part of 1% silver filament might have more concentration of silver particles as compared to a certain part of 3% silver filament. Due to these uncertainties a clear conclusion cannot be drawn on the effect of a certain silver weight percentage on the enhancement of various mechanical, thermal, and anti-microbial properties.
VI. FUTURE WORK

Although the preliminary results have been very encouraging, there is still plenty of room for optimizing the process of synthesizing, printing and testing the composite 3D printed structures. The work in the future will be geared towards optimizing the process and obtaining more data points to draw conclusive results. The possible future work have been discussed below:

1. Increase the level of dispersion of silver particles in the PLA matrix in order to minimize the clogging up of the printer head as much as possible, especially when higher weight percentage of silver filament is used for printing.

2. Further comparative study on the effect of concentration of silver particles on the ductility and the strength modulus of the 3D printed samples.

3. Study of the fracture surface of the dog-bone test structures to better understand the causes and points of structure failure during the tensile tests.

4. Synthesis of silver nanoparticles and nanowires using the Polyol method and producing the composite using the nanomaterials by following the same protocol. Eventually, similar study of enhancement of several properties in the structures 3D printed using the nanomaterial composite filament. The high aspect ratio and larger surface area of the additive will allow for increased interaction with polymer host materials, which could possibly result in remarkable enhancement of mechanical and antimicrobial properties at lower concentrations.

5. Optimization of the anti-microbial test procedure to obtain data points at several hours of plating time to better understand the growth of bacteria over time. Further comparative study on the enhancement of antimicrobial properties with increasing weight percentage of silver particles in the 3D printed test discs.

6. The addition of silver particles could possibly enhance the optical and electrical properties of the 3D printed structures. Since it is a highly desirable property for applications of 3D printing in medical and computing industries, further scientific study of these properties is very promising.
REFERENCES


