Characterization Of 3d Stereolithography (sla) Printed Polymer For Autonomous-Flow Microfluidic Devices

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CHARACTERIZATION OF 3D STEREOLITHOGRAPHY (SLA) PRINTED POLYMER FOR AUTONOMOUS-FLOW MICROFLUIDIC DEVICES

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To my family and friends who supported and encouraged me throughout my education.

Thank you for making me see this journey till the end.
CHARACTERIZATION OF 3D STEREOLITHOGRAPHY (SLA) PRINTED POLYMER FOR AUTONOMOUS-FLOW MICROFLUIDIC DEVICES

by

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THESIS

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Abbreviations

ASTM (American Society for Testing and Materials), ATR (Attenuated Total Reflectance), DNA (Deoxyribonucleic Acid), FTIR-ATR (Fourier-Transform Infrared – Attenuated Total Reflectance), HUVECs (Human Umbilical Vein Endothelial Cells), IMSTEL (Inspired Materials & Stem-Cell Based Tissue Engineering Laboratory), LIF (Laser Induced Fluorescence), MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2H-tetrazolium bromide), PAA (Polyacrylic Acid), PBS (Phosphate-Buffered Saline), PTB (Preterm Birth), SEM (Scanning Electron Microscopy), SLA (Stereolithography), US (United States), UV-VIS (Ultraviolet-Visible).
Abstract

3D Stereolithography (SLA) printing is a high-throughput, precise and reproducible manufacturing platform which makes it a desirable technique to develop microfluidic devices for bioanalytical applications. However, limited information exists regarding the physical, chemical, and biological properties of the polymer resins used in 3D SLA printing. This project demonstrates the characterization of a commercially available 3D SLA printed resin polymer used to develop an autonomous-flow (self-driven) microfluidic device. In this investigation, time-dependent materials characterization was done on the Formlabs clear V4 resin to observe changes in mechanical and surface properties. The clear, printed polymer was analyzed with attenuated total reflectance (ATR), tensile test, impact test, and scanning electron microscopy (SEM). Polymer biocompatibility was assessed with MTT cell cytotoxicity. Results from the surface characterization and mechanical testing demonstrated the polymer is a self-curing resin and its strength increased with time. These time-dependent mechanical and surface properties of the polymer along with its biocompatibility and cytotoxicity in cell culture informed the design of a microfluidic device capable of maintaining autonomous fluid flow. This study demonstrates the commercially available clear resin is capable of being used to design and develop autonomous-flow microfluidic devices for bioanalytical applications, however, improvements in “shelf-life” and optical clarity are necessary. Overall, this project contributes to the expanding movement towards integrating 3D SLA printing with high-throughput manufacture of microfluidic devices.
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CHAPTER 1

Introduction

1.1 Background

1.1.1 Stereolithography (SLA)

Stereolithography (SLA) 3D printing has become a popular form of additive manufacturing design and production for bioanalytical microfluidic devices due to its ability to rapidly print, form accurate and precise parts, and its low-cost effect. This innovative form of technology has been altered to become biocompatible and transparent for the use in biomicrofluidics. An SLA printer uses low print temperatures under a tightly closed print area to obtain high quality, precise parts. (Finnes & Letcher, 2015; Formlabs, n.d.; Kuo et al., 2019; Quan et al., 2020) The SLA 3D printing process is a form of additive manufacturing that creates 3D design parts layer by layer. It uses a light source, laser with a specific wavelength, that chemically reacts with a photosensitive material through a process called curing. Curing catalyzes a polymer’s molecular structure by crosslinking polymeric chains to harden the resin. To prevent damage to the original structure of the 3D figure, supports are built in with the figure, for easy removal. Figure 1.1.1.1 demonstrates the process of printing of an SLA 3D printer. In SLA, the light emitting laser, illuminates the transparent bottom of the 3D printer’s tank containing the resin. As the 3D object solidifies it is slowly moved up with a lifting platform. (Appuhamillage, 2018) Uniformity is provided through the position of the x and y axis. The x axis will contain the print design in 2D. One layer of the design is printed and solidified, then, the platform moves in the z axis, perpendicular to the print design, to form another layer. The part of additive manufacturing process used in SLA is photopolymerization. It assembles liquid, radiation-curable resins to react with ultraviolet (UV) radiation to form 3D components. (Finnes & Letcher, 2015; Gibson et al., n.d.) Vat photopolymerization is the chemical
reaction that occurs when photopolymers react with a form of radiation to solidify. Photopolymers contain a photo initiator, which is a molecule that helps create free radicals that will react when exposed to light. (Jakubiak*’ & Rabek, n.d.) This will initiate a chain reaction and crosslink the polymer to form solidified chains and create a geometric component. Photopolymerization was used in the mid 1980s, when Charles (Chuck) Hull, used a laser to harden a UV-curable material. When curing one layer over another, Charles determined he could form a 3D component. (Gibson et al., n.d.) SLA printing is cost effective as it does not require the build and fabrication of a mold, which is limited to 2D layered geometries. (Kuo et al., 2019) Unlike 3D printing which allows for complex geometric designs that are free to design and generate using a 3D printer.

![Figure 1.1.1.1 Depiction of 3D SLA printer process.](Appuhamillage, 2018)

As interest in SLA 3D printing has grown, so has need to find commercially available polymers that are capable for use in microfluidics, containing biocompatible and transparent properties. Materials used are commercially available polymers that contain crosslinking properties. The first SLA resins used for 3D printing were acrylates and epoxy resins. (Gibson et al., n.d.) Acrylates have a high reactivity, but due to their thermoplastic properties, curing cannot be completed, and it causes shrinkage in the print design. The structural integrity of the print design would get damaged, as the radiation would penetrate the partially cured layer, increasing internal
stresses that would cause the layer to shrink. Epoxy resins are strong, brittle, and provide a smaller percent shrinkage when printed than acrylates. Disadvantages in epoxy resins are brittleness and sensitivity to humidity, as a result, the combination of epoxy resins with acrylates can combine the advantages of both polymers to provide a better print quality. (Gibson et al., n.d.) Polyacrylic acid (PAA) is a known commercially available polymer that is accessible, biodegradable in nature, and nontoxic. PAA is a thermosetting polymer due to its ability to crosslink. Thermosets will harden when cured in a viscous state when subjected to light, this form of hardening will be irreversible, making it suitable for SLA 3D printing. PAA contains a carboxylic acid organic compound which makes it suitable to be used in a pH-responsive delivery system. (Pandey et al., 2019) These qualities are suitable for a bioanalytical microfluidic device.
1.1.2 Formlabs 3D printer

Formlabs 3D printer was used to produce the microfluidic device. The printer has a laser power of 250mW and a layer thickness that can range from 25-300 microns, which allows for a finer and more optimized print. The resin used was the V4 clear resin, meaning it is the fourth version of the clear resin made from Formlabs. It has not undergone extensive material characterization and biocompatibility. The design of the microfluidic device and mechanical testing components were created on Shapr3D software and exported to Preform for 3D printing. In PreForm, auto-generated supports with a touchpoint size of 0.75 mm to build onto the designs. One the design was printed on the 3D printer it had to be rinsed and cured. To rinse the 3D printed component, it must be washed in isopropyl alcohol (IPA). IPA helps remove residual resin from the surface of the print. Form Wash is used to submerge the 3D printed design in IPA for 10 minutes. Then, Form Cure is used by placing the washed 3D material in a 60-degree Celsius heating system that contains 13 multi-directional LEDs for curing. Curing is a chemical reaction that takes place in a polymer by crosslinking polymer chains, therefore hardening the polymer. The Form Cure machine contains a rotating turntable that will move the component at 1 revolution per minute for 15 minutes.
1.1.3 Autonomous Microfluidic Devices

The use of a single use component capable of detecting cell/biological samples when subjected to fluid flow has become widely used. Microfluidics can manipulate the flow of liquids to help detect certain aspects within the fluid. Bioanalysis applications are used in cell/biological sample processing and disease diagnosis. Self-driven (autonomous flow) microfluidic devices are beneficial for bioanalytical or clinical disease detection applications due to its need for small sample volumes of liquid media compared to other forms of disease detection, such as a biopsy. The cost of analyzing the biological samples is greatly reduced due to the amount of small volumes used.

These autonomous microfluidic devices are governed by capillary microfluidics which is a rapid liquid delivery technique capable of operating without external control. The liquid is governed by surface tension effects and the geometry and surface chemistry of the solid material and microchannel dimensions. Wettability is the ability of the liquid to form a surface boundary with a solid. Contact angle is a way of measuring the wettability of a surface by measuring the angle the liquid makes at the point it meets the solid. Liquid must be attracted to the surface molecules of the container to increase wettability between the liquid and the solid, therefore decreasing the contact angle. (Contact_Angles, n.d.) Hydrophilic surfaces can be wetted by water; the water will spread over the surface providing a low contact angle under 90. Wettable surfaces have a contact angle below 90 degrees, allowing for a negative suction pressure, which prevents circuit dysfunctionality. When designing capillary circuits, a low height-to-weight ratio microchannel will have to be made with the same material or similar contact angle to prevent an interruption in the flow of the liquid. (A. O. Olanrewaju et al., 2016) Fluid flow in microfluidic devices can be determined using the Navier-Stokes equation in fluid mechanics for the flow of
incompressible fluids. The flow rate, \( Q \), of a liquid in a rectangular microchannel can be calculated using the Navier-Stokes equation:

\[
Q = \frac{h^3w\Delta P}{12\eta L(t)} \left[ 1 - 0.630 \frac{h}{w} \right] \tag{1}
\]

Where \( h \) is the height of the microchannel, \( w \) is the width of the microchannel, \( \Delta P \) is the change in capillary pressure in the microchannel, \( L \) is the length of the liquid in the microchannel, \( t \) is the time, and \( \eta \) is the viscosity of the liquid. (A. Olanrewaju et al., 2018) To calculate the change in pressure, the Young-LaPlace equation used to determine the change in capillary pressure with respect to contact angle and microchannel size was used:

\[
\Delta P = -2\gamma \left[ \frac{\cos \theta_t + \cos \theta_b}{h} + \frac{\cos \theta_l + \cos \theta_r}{w} \right] \tag{2}
\]

Where the surface tension of the liquid used in microchannel, \( \gamma \), height of microchannel, \( h \), width of microchannel, \( w \), and contact angle of liquid in the top, bottom, right and left walls, respectively, \( \theta_t \), \( \theta_b \), \( \theta_l \), and \( \theta_r \). To obtain a fluid flow that can be governed by capillary action the capillary pressure has to be positive for the liquid to advance. Therefore, incorporating the dimensions (width and height) of the channels within the microfluidic device that give a positive capillary pressure from the Young-Laplace equation is indicative of autonomous fluid flow. To obtain a hydrophilic surface, the contact angle must be less than 90 degrees. (A. Olanrewaju et al., 2018) To obtain the contact angle of the polymer, contact angle experiments were previously done on the polymer and it was determined the contact angle had an average of 58.4 degrees (±2.5, n=3).
1.1.4 Background Literature

Recently, many studies have evaluated the physical properties and biocompatibility of different commercially available stereolithography resins and polymers. MacDonald et al., demonstrated the biocompatibility of commercially available 3D printed photopolymers by measuring toxicity with the use of zebrafish embryos. (MacDonald et al., 2016) The design model involved 3D printing disks using four different types of SLA resins (photopolymers). The four polymers used for the experiment were VisiJetCrystal EX200, Watershed 11122XC, Fototec SLA 7150 clear and ABSplus P-430, which are all commercially available polymers that are optically clear. (MacDonald et al., 2016) These SLA printed disks were cultured with zebrafish embryos in a 24-well tissue culture polystyrene plate. The viability and development of zebrafish embryos was analyzed when cultured with these photopolymer materials. The authors determined toxic compounds from the 3D printed parts leached into the embryos. However, washing the printed disks with ethanol could get rid of toxic chemicals so the polymers could support embryo viability and allowed normal development. (MacDonald et al., 2016)

Beauchamp et al. used 3D SLA printing to develop a diagnostic microfluidic device to determine risk for preterm birth (PTB). The microfluidic device contained square channels which facilitated the use of electrophoresis for the separation of PTB DNA biomarkers and Laser Induced Fluorescence (LIF) detection. (Beauchamp et al., 2019) This study demonstrated 3D SLA printed microfluidic devices have the capacity to analyze medically relevant biomarkers.

Piironen et al. evaluated Formlabs Clear, High Temp, Dental SG V2, and Dental LT Clear V2 resins printed with a Formlabs Form2 3D SLA printer. (Piironen et al., 2020) Two distinctive designs were 3D printed to determine cell proliferation, including 3D printed Petri dishes and microchannels. Short term, 7 days, and long term, 56 days, assessments were done on all 3D
printed surfaces with BALB/c mouse embryonic fibroblasts (3T3), human hepatoma cells (Huh7) and human-induced pluripotent stem cells (hiPSC) cell types. The authors determined autoclave sterilization was necessary for long-term cell survival. Overall, these studies demonstrate commercially available 3D SLA resins and polymers must be evaluated prior to usage in bioanalytical devices or applications.
1.2 Goals

Improvement of biocompatible polymer resins warrants the investigation of suitable materials for the manufacturing of a 3D printed microfluidic device that can be used at the point-of-care. The clear resin from Formlabs is currently commercially available and yet to be determined if it is biocompatible. Some benefits of the clear resin are its ability to be rapidly printed using an SLA printer, it can be built into precise parts, and it is cheap to manufacture. Some plastics that are currently used for 3D printing of biocompatible components are epoxy resins and acrylates. This work presented in this thesis will expand upon characterizing the clear resin used in the SLA 3D printer and developing a microfluidic device using the commercially available clear resin. This study evaluates the physical and chemical properties of a clear polymer resin to develop an autonomous-flow microfluidic device for potential used in disease diagnosis. Time-dependent materials characterization of the clear, printed polymer was performed with Fourier-transform infrared - attenuated total reflectance (FTIR-ATR), tensile test, impact test, and scanning electron microscope (SEM). Biocompatibility was assessed with toxicology and cell viability studies which included 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2H-tetrazolium bromide (MTT) cell proliferation assay. Autonomous flow will be determined by calculating the theoretical and experimental data of fluid flow in the microchannel of the device. The goal of this study was to demonstrate the use of a commercially available polymer to manufacture a 3D SLA printed microfluidic device capable of autonomous flow. This study aims to contribute to the expanding movement toward integrating high throughput 3D printing with complex bioanalytical devices. The novelty of this study is that this resin has not undergone in-depth temporal analysis of physical and biocompatibility properties, this will demonstrate that the resin can be used or has properties necessary for an autonomous microfluidic device. This thesis addressed all the points in the
material’s tetrahedron paradigm: performance, properties, process, and structure. Under the paradigm the study focused on characterizing the mechanical and chemical properties of the commercially available clear resin. This work also studied the effects of processing the polymer with 3D stereolithography printing to develop a microfluidic device. The polymer performance was assessed through mechanical tests and its ability to drive autonomous fluid flow as a microfluidic device. By using the material’s paradigm, the commercially available clear resin underwent surface characterization techniques, to determine the chemical structure and biocompatibility, and mechanical analysis, to determine its mechanical properties during a specific post-printing time. The 3D SLA printing process will be thoroughly explained, and the knowledge of capillary action and wettability will be used to design and produce a microfluidic device. My hypothesis is to demonstrate that the commercially available clear resin is capable of being used to design and develop autonomous-flow microfluidic devices for bioanalytical applications during a specific post-printing time.
1.3 Broader impacts

The importance of characterizing this polymer is to acquire in-depth temporal analysis of the polymer and determine its biocompatibility for use in bioanalytical microfluidic devices. The characterization of this polymer will provide useful information about its chemical and mechanical properties for future development of bioanalytical devices with commercially available 3D stereolithography printing technology. The device I developed in this work has the potential to provide a low-cost diagnostic tool with minimum energy requirements that can be used at the point-of-care. This tool has the potential to make the early detection of acute myeloid leukemia cancer accessible to patients in low-income and underdeveloped communities where late diagnosis is prevalent. The type of cancer that will diagnosed is very hard to be diagnosed in a rapid manner and without it being invasive. This will help benefit society by reducing the cost and time of diagnosing cancer. Furthermore, this microfluidic device can be used in medical institutions, such as hospitals, who will benefit by using a non-invasive option for detecting acute myeloid leukemia. This research will be disseminated through published works in Biomedical Engineering journals for the improvement of autonomous microfluidic devices.
1.4 Aims

1.4.1 Materials Characterization of commercially available clear resin intended for microfluidic device

Polymeric materials have distinctive characteristics that are used to identify them, high strength, high toughness, transparent, and cheap. These properties are useful for the design of a microfluidic device. It is necessary to obtain a strong and tough material that is cheap, so it can be used and produced in high quantities, while also having transparency to view the micro fluidity of the device. The cost of the microfluidic device when comparing the dimensions of the device to the cost of the clear resin will generate an outcome of $0.68 per device. Commercially available resins can be used in 3D stereolithography (SLA) printing to design a microfluidic device. Despite the resins being labeled biocompatible, careful mechanical and chemical characterization of the printed polymers are necessary to assess the material’s “shelf-life” and its toxicity to biological samples. This study evaluates the physical and chemical properties of a clear polymer resin to develop an autonomous-flow microfluidic device for potential used in disease diagnosis. Time-dependent materials characterization of the clear, printed polymer was performed with tensile and impact tests, SEM fracture surface analysis, and FTIR-ATR. V4 clear resin from Formlabs has yet to undergo materials characterization during a specific post-printing time. If clear resin testing specimen are printed and allowed to rest for a certain period before testing, its mechanical and surface properties will change. The maximum timepoint being used will be a post-printing time of 30 days in all mechanical tests.
1.4.2 Developed microfluidic device using commercially available clear resin

3D SLA printing devices have become a popular form of design and production for bioanalytical microfluidic devices. The use of a single use component capable of detecting cell/biological samples when subjected to fluid flow has become widely used. Microfluidics can manipulate the flow of liquids to help detect certain aspects within the fluid. The use of a 3D SLA printer helps design a component that is biocompatible, capable of culturing cells, and keeps the fluid flowing with the use of capillary circuits. With a commercially available clear resin, the transparency will allow for the visibility of the fluid flow and determine if it is autonomous. Biocompatibility of the clear resin was assessed with cell viability studies which were done with MTT cell proliferation assay. The properties of the clear resin will determine biocompatibility and fluid flow of the microfluidic device.
CHAPTER 2

Materials characterization of commercially available clear resin tended for microfluidic devices

2.1 Mechanical Analysis

2.1.1 Tensile Test

2.1.1.1 Introduction

Tensile Test specimens were printed using Formlabs3B SLA 3D printer following ASTM standard D638 Type V specimen, Standard Test Method for Tensile Properties of Plastics and tested on an MTS Criterion C44 tensile machine. (Standard Test Method for Tensile Properties of Plastics 1, 2014) The dimensions of a Type V specimen are of 63.50 mm by 9.53 mm. The test will help determine the elasticity of the polymeric material by applying load on a uniaxial direction. A print direction of 0°, parallel to applied load, was chosen, it would have the same results as having printed the tensile specimen at a 90° print orientation. (Saini et al., 2020; Torrado & Roberson, 2016)

2.1.1.2 Methods

The tensile test specimens were 3D printed parallel to the direction of the applied stress. It will help determine if the material has polymeric properties of high tensile strength. The samples were printed and tested on different post-printing dates to determine if shelf life would influence the mechanical properties of the material. The testing dates for these samples were done on post-print days 0, 1, 3, 7, and 30 after printing. A strain rate of 1 mm/min was used for all tensile samples. A total of 15 tensile specimen was performed and analyzed: three samples for each specific testing day. What can be seen from figure 2.1.1.1 and illustration 2.1.1.1, shows the tensile specimen for days 0 and 30 prior to break and an illustration of the tensile sample with dimensions.
2.1.1.3 Results and discussion

Tensile testing of a clear polymer resin was executed to determine if the material will be negatively impacted if stored for a length of time. As can be seen in figure 2.1.1.3, the results indicated that tensile strength is gradually increasing from day 0 to day 30, however, no statistically significant difference was detected. In the table 2.1.1.1, the percent elongation at break can be seen to increase when the days pass, however the values are low, therefore the material is determined to be brittle. Figure 2.1.1.2 confirmed that both tensile test breaks were of brittle fracture. This can be seen from the clean break at the point of failure, no visible plastic deformation was observed.
Figure 2.1.1.2: Photographs of A) Day 0 and B) Day 30 of tensile specimen after tensile break.

Table 2.1.1.1: Tensile Test Values for 3D printed clear resin

<table>
<thead>
<tr>
<th>Testing Day</th>
<th>Tensile Strength (N/mm²)</th>
<th>% Elongation at Break</th>
<th>Sample Size (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVG</td>
<td>STDEV</td>
<td>AVG</td>
</tr>
<tr>
<td>0</td>
<td>54.57</td>
<td>3.98</td>
<td>0.01</td>
</tr>
<tr>
<td>1</td>
<td>49.17</td>
<td>1.67</td>
<td>0.018</td>
</tr>
<tr>
<td>3</td>
<td>55.7</td>
<td>2.92</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>56.37</td>
<td>3.69</td>
<td>0.007</td>
</tr>
<tr>
<td>30</td>
<td>56.17</td>
<td>3.37</td>
<td>0.008</td>
</tr>
</tbody>
</table>

A hypothesis test was run to determine if the probability of the values obtained are significantly different. When there is significant difference between the groups then the hypothesis will be correct. The p-value was calculated to determine if the percent probability that the values that were acquired were at random, so the smaller the p-value the more significant the results are. (Stephanie Glen, n.d.) P values are measure in stars, 1 star means there is less than a 5% chance of the values being random, 2 stars means there is less than 1% chance of the values being random, and 3 stars means there is less than .1% chance of the values being random. From figure 2.1.1.3, there was no significant difference between all groups, therefore it can be determined that the material remains brittle and will not change over time.
Figure 2.1.1.3 Comparison between print day and tensile strength for the tensile results

2.1.1.4 Conclusion

In conclusion, the results from the tensile test indicated that the polymer has brittle fracture features, no visible plastic deformation was observed. No significant difference was observed between post-print days 0 and 30. Therefore, this indicated the material will remain brittle over a time period of 30 days and will not change over time.
2.1.2 Izod Impact Test

2.1.2.1 Introduction

Izod impact specimens were printed using Formlabs3B SLA 3D printer following ASTM standard D256 (notched) and tested with a Tinius Olsen Model Impact 104 machine. (Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics 1, 2018) The test was used to determine the impact toughness of a material by calculating the energy absorbed during fracture. The impact test specimens were 3D printed perpendicular to the direction of the applied stress. Print direction of 0°, perpendicular to the applied load was chosen according to (Saini et al., 2020), since the print orientation is perpendicular to the direction of blow it will have the maximum resistance to impact.

2.1.2.2 Methods

Impact test values are acquired by dropping a suspended pendulum that will strike the impact sample at the notch. 15 impact samples were printed and tested on different post-print dates to determine if the “shelf life” influences the mechanical properties of the material. Three samples for each specific testing date were printed for post-print days 0, 1, 3, 7, and 30 after printing. What can be seen from Figure 2.1.2.1 and Illustration 2.1.2.1, is the impact specimen for days 0 and 30 prior to break and a drawing of the impact sample with dimensions.

Figure 2.1.2.1: Photographs of A) Day 0 and B) Day 60 of impact specimen
Illustration 2.1.2.1: Drawing of Izod impact specimen with dimensions

2.1.2.3 Results and discussion

The results showed that the impact resistance increased when the testing date from print time increased. As seen from the Table 2.1.2.1 below, the data gathered from the impact specimen generated an impact strength that slightly increased as the days from printing passed, making the material tougher. Impact strength is the amount of energy that a material can absorb. It can be seen from the Figure 2.1.2.3 that the impact strength increased, however no significant difference was observed. As can be seen from Figure 2.1.2.2 a brittle fracture surface on an impact specimen has a smooth and flat surface. Day 0 and day 30 have smooth parts in the surface; therefore, it can be determined the material remains brittle.

Figure 2.1.2.2: Photographs of A) Day 0 and B) Day 30 of impact specimen fracture surface after impact break
Table 2.1.2.1: Impact Test Values for 3D printed clear resin

<table>
<thead>
<tr>
<th>Testing Day</th>
<th>Impact Strength J/m² AVG</th>
<th>Impact Strength J/m² STDEV</th>
<th>Impact Resistance (J/m) AVG</th>
<th>Impact Resistance (J/m) STDEV</th>
<th>Sample Size (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1423.33</td>
<td>92.86</td>
<td>15.17</td>
<td>0.99</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1296.67</td>
<td>145.22</td>
<td>13.7</td>
<td>1.49</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1340</td>
<td>212.3</td>
<td>13.97</td>
<td>2.21</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>1380</td>
<td>94.16</td>
<td>14.47</td>
<td>0.77</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>1376.67</td>
<td>201.38</td>
<td>14.37</td>
<td>1.93</td>
<td>3</td>
</tr>
</tbody>
</table>

Impact Test

Figure 2.1.2.3: Comparison between print day and impact strength for the impact test results

2.1.2.4 Conclusion

In conclusion, the results from the Izod impact test indicated that the polymer has brittle fracture features, the fracture surface is smooth. No significant difference was observed between post-print days 0 and 30. Therefore, this indicated the material will remain brittle over a time period of 30 days and will not change over time.
2.1.3 Scanning Electron Microscope

2.1.3.1 Introduction

The surface characterization of the breaking point from the tensile samples testing date 0, 1, 7, and 30 were analyzed with a SEM to compare the fracture surfaces. The fracture tensile samples were sectioned off through the gage length to understand the fracture mechanics on why waiting to test the tensile sample from day 0 to day 30 will have no effect on tensile strength.

2.1.3.2 Methods

Samples were mounted on aluminum stubs using double-sided conductive adhesive tape and were imaged using a HITACHI SU-3500 SEM at a vacuum pressure of 30Pa and a voltage of 15kV. Figure 2.1.3.1 shows the fracture surfaces of day 0, day 1, day 7 and day 30 respectively. Day 0 and day 1 have a magnification of 35x and day 7 and day 30 have a magnification of 42x.

2.1.3.3 Results and discussion

The fracture surface of the printed polymer demonstrates brittle features that can be seen in the SEM images. Crazes will develop when excessive tensile stress is applied to a polymer, which will form voids perpendicular to the applied stress. These voids contain coalesced fibrils that form at the boundaries of the voids, when the fibrils break, they form two surfaces, forming a crack. (Hayes et al., 2015) During crazing a polymer is more than likely to have a brittle fracture. (Hayes et al., 2015) From Figure 2.1.3.1, what can be observed are fracture features that demonstrate mirror, mist, and hackle regions. These can be seen in all post-print date images. Mirror, mist, and hackle transitions are typical of a brittle fracture mode. (Becker et al., 2002) The crack initiation, indicated by the yellow arrows in Figure 2.1.3.1, are followed by a small mirror and mist region (Figure 2.1.3.1, green arrows). The mirror zone is proceeded by a craze formation, crazing can be visually seen as whitening of the polymer, it can be observed in Figure 2.1.3.2, as
white lines. (Swallowe, 1999) The hackle region takes up most of the fracture surface, Figure 2.1.3.2 blue arrows, it is typically observed as a rough surface with lines that point along the direction of crack propagation. (Becker et al., 2002)

Figure 2.1.3.1: SEM micrographs of tensile tests from 3D SLA printed clear resin as follows
A) Day 0, B) Day 1, C) Day 7, and D) Day 30.
2.1.3.4 Conclusion

In conclusion, the SEM data supports the data from the tensile and impact tests, which demonstrates classic brittle fracture features for polymers: mirror, mist, and hackle regions. Crazes can be seen as whitening of the polymer in the SEM images. The brittle fracture features can be seen on post-print day SEM images of day 0, day 1, day 7 and day 30. Indicating the material remains stable over a time of 30 days.
2.1.4 Autoclave Sterilization

2.1.4.1 Introduction

Autoclave sterilization is a way to disinfect a medical device by placing the material under pressure, temperature, and vapor for a certain period of time. Under these controlled variables, any harmful bacteria or microorganisms on the material will be killed to provide a sterile environment. High pressure is used to help obtain a high temperature quickly enough to kill the microorganisms. (CDC, 2016)

2.1.4.2 Methods

To determine how the clear resin will react to being autoclaved, tensile and impact samples were 3D printed and underwent the autoclave process. Samples were autoclaved using Getinge 443HC autoclave at 121 degrees Celsius and at a pressure of 15 psi under steam for 30 minutes. This will help determine if the polymer could withstand the high pressure, temperature, and vapor from the autoclave. Autoclaved tensile and impact samples were tested on post-print days 0, 1, 3, and 7 (n=3). All quantitative measurements were performed at least in triplicate samples and values are expressed as mean ± standard deviation (SD). One-way ANOVA with post-hoc Tukey tests were used to compare treatment groups and p < 0.05 was used to assess statistical significance using Prism Software. (Statistics How To, 2022)

2.1.4.3 Results and discussion

When comparing the results of the control to the autoclaved samples, what can be seen from Figure 2.1.4.1 there is no significant increase in strength over time, therefore the results indicate the polymer’s tensile strength does not significantly change over time. Results of the autoclave samples for impact specimen, Figure 2.1.4.2, demonstrate an increase in fracture
toughness, however this was not found to be statistically significant increase relative to the control samples.

![Control vs. Autoclave Tensile Test](image)

**Figure 2.1.4.1:** Comparison between control and autoclave samples for tensile test results

![Control vs Autoclave Impact Test](image)

**Figure 2.1.4.2:** Comparison between control and autoclave samples for impact test results
2.1.4.4 Conclusion

In conclusion, autoclave sterilization uses controlled variables of pressure, vapor, and temperature to sterilize a material. Tensile and impact specimen sterilized with an autoclave had a decrease in tensile strength and an increase in impact strength, however, the data was not found to be statistically significant. Therefore, it can be determined that the autoclave has no effect on the mechanical properties of the polymer.
2.1.5 Ethanol Immersion Sterilization

2.1.5.1 Introduction

Another form of sterilizing a medical device can be done by submerging the device in 70% ethanol. Ethanol immersion under 70% ethanol will sterilize a component by penetrating cell walls, therefore killing off any microorganism. A higher percentage of ethanol is not used because it will not cause the solution to kill of more bacteria than the 70% ethanol solution. At a solution of >90% ethanol will require a disinfection time to be greater, produce more toxic fumes, and will be more flammable. (ORIGIN BG OOD, 2020)

2.1.5.2 Methods

To determine how the clear resin will react to being submerged in ethanol, tensile and impact samples were 3D printed and underwent the ethanol immersion process. The tensile samples were weighed prior to being immerged in ethanol and after the immersion process. Tensile and impact samples that were submerged in 70% ethanol for 10 minutes and 30 minutes were tested to determine if ethanol has any effect on the mechanical properties of the polymer (n = 3). SEM analysis was performed on the fracture surface of the tensile samples to determine if there is a change in fracture features.

2.1.5.3 Results and discussion

The visible difference between the control samples, figure 2.1.1.1, and the ethanol immersed samples for 10 minutes and 30 minutes, figure 2.1.5.1, showed a change in color, the samples became opaque. Stereomicroscope images (25x magnification) of tensile samples immersed in 10 minutes and 30 minutes in ethanol were taken, figure 2.1.5.2 and figure 2.1.5.3. The stereomicroscope images, figure 2.1.5.2, show degradation in the tensile sample (white arrows) where the polymer is breaking down. The gage length area appears to have a loss in bulk
material and possible delamination in the polymer. Table 2.1.5.1 compares the weight of the tensile samples before and after ethanol immersions. There was a slight increase in weight between the control sample and the 10 minute and 30-minute immersion in ethanol, indicating ethanol was absorbed by the polymer.

Figure 2.1.5.1: Images of 10-minute ethanol immersion (left) and 30-minute ethanol immersion (right)

Figure 2.1.5.2: Stereomicroscope images of tensile sample immersed in 10 minutes of ethanol. a) and d) left grip of tensile sample, b) and e) gage length of tensile sample, and c) and f) right grip of tensile sample.
Table 2.1.5.1: Comparison of weight before and after 10-minute immersion in ethanol and 30-minute immersion in ethanol.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Control (g)</th>
<th>Ethanol 10 min (g)</th>
<th>Control (g)</th>
<th>Ethanol 30 min (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.1</td>
<td>2.25</td>
<td>2.11</td>
<td>2.24</td>
</tr>
<tr>
<td>2</td>
<td>2.12</td>
<td>2.22</td>
<td>2.12</td>
<td>2.17</td>
</tr>
<tr>
<td>3</td>
<td>2.1</td>
<td>2.23</td>
<td>2.12</td>
<td>2.17</td>
</tr>
</tbody>
</table>

The comparison between the control samples and the samples immersed in ethanol showed an increase in tensile and impact strength (figure 2.1.5.4 and 2.1.5.5). Between the control group and ethanol immersion tensile values, there was a significant different between the control and 30 minutes ethanol immersion. A p-value of 1 star determined there was less than a 5% chance of the values being random. Between the control group and ethanol immersion impact test, there was a significant difference between the control and 10 minutes ethanol immersion. A p-value of 3 stars determined there was less than .1% chance of the values being random. With these results we can determine there is significant difference in the data gathered from the ethanol immersion test. Between the control and 30-minute ethanol immersion there is a less than 5% chance that the data
Ethanol can influence the properties of polymers by penetrating the matrix of the resin and expanding the polymer chains. (Felipe et al., 2007; Ratto De Moraes et al., 2007; Spencer et al., 2013) The mechanism that can cause a polymer to expand its chains called polymer swelling. In polymer swelling, the polymer will absorb the component with the lowest concentration within the solution, in this case it will be water since it’s only 30%. Since the water is being absorbed, it will group together and form clusters in the polymer, therefore, expanding the polymer chains. (Chuang et al., n.d.) It is possible the water in the ethanol solution degrades the polymer, therefore decreasing the cross-sectional area of the tensile test sample. The polymer will appear to be getting stronger since the engineering stress is the applied load divided by the original cross-sectional area. It does not take into the account the actual cross-sectional area changing with respect to time. It is possible that the immersion of the clear resin in 70% ethanol expanded the polymeric chains and degraded the bulk polymer tensile test samples, which caused an appearance of increased strength.

![Control vs Ethanol Tensile Test](image)

**Figure 2.1.5.4:** Comparison between control and ethanol immersion for 10 minutes and 30 minutes samples for tensile test results for day 1.
Figure 2.1.5.5: Comparison between control and ethanol immersion for 10 minutes and 30 minutes samples for impact test results for day 1.

SEM images of the fracture surface of tensile samples immersed in 10 minutes of ethanol and 30 minutes of ethanol can be seen in figure 2.1.5.6. Immersion in ethanol had a significant increase in tensile strength, indicating the material is hardening. The SEM images of the tensile immersed samples indicating a brittle feature of mirror, mist, and hackle lines. The crack initiation (yellow arrow) is followed by a mirror and mist region (green arrow), which is seen as a smooth region that indicated a planar form of crack growth. The hackle region in the ethanol immersed SEM images compared to those of the control tensile SEM images, has a more extensive hackle region in which the ridges can be seen more branched off. This indicates the polymer has produced a shattering, brittle fracture. (Becker et al., 2002)
In conclusion, immersion in ethanol caused the polymer to become cloudy. There was an increase in weight before and after the immersion in ethanol for the 10-minute immersion and 30-minute immersion, indicating the polymer absorbed some of the 70% ethanol solution. The data from the tensile and impact test showed significant increase in tensile and impact strength, indicating that ethanol will make the polymer stronger. The mechanism that causes the polymer to absorb the ethanol is polymer swelling. SEM images indicate shattering, brittle fracture caused by the hardening of the material in ethanol immersion.
2.2 Surface Characterization

2.2.1 Attenuated Total Reflectance

2.2.1.1 Introduction

Attenuated total reflectance (ATR) is a surface characterization technique that uses an infrared (IR) beam to record the amount of energy that is absorbed by the molecules in the sample. The attenuated frequency is then read by the ATR machine. Different bonds generate a different frequency which will help determine the type of material.

2.2.1.2 Methods

3D printed SLA polymer samples were analyzed by way of Fourier transform infrared (FTIR) using a Nicolet™ iS™ 5 FTIR equipped with an iD7 attenuated total reflectance (ATR) Diamond (Thermo Fisher Scientific, Waltham, MS, USA). A 3D printed SLA resin sample was printed for post-print days 0, 1, 3, and 7, with .5 X .5 X .25 in$^3$ (L X W X H) dimensions was designed to be used in the ATR.

2.2.1.3 Results and discussion

Analysis of the surface characterization via ATR revealed that the clear resin has a high probability of it being polyacrylic acid (PAA). PAA is highly probably because it is a thermosetting polymer. A thermoset will harden when exposed to a light source, which is what occurs in an SLA 3D printer. Figure 2.2.1.1 depicts the chemical structure of PAA. It contains a C=O bond, CH bond, and a CH$_2$ bond. In the Figure 2.2.1.2, the peaks are specific to different chemical bonds that can be found in PAA. The characteristic chemical bonds found in PAA (C=O at 1700 cm$^{-1}$, CH at 3000-2800 cm$^{-1}$, and CH$_2$ at 1451 cm$^{-1}$) are shown in the ATR spectra of a printed sample in figure 2.2.1.2. (Biermann et al., 2001; Yi et al., 2017) As can be seen from the Figure 2.2.1.2, below, the
wavelength of post-print days 0, 1, 3, and 7, when compared, remained the same. Therefore, it can be concluded that the chemical structure of the surface does not have an effect with time change.

![Chemical structure of PAA](image1)

**Figure 2.2.1.1: Chemical structure of PAA** (Kawagoe et al., 2019)

![ATR spectra for day 7 of polymer resin](image2)

**Figure 2.2.1.2: ATR spectra for day 7 of polymer resin.**
Figure 2.2.1.3: ATR Spectra comparison for A) Day 0, B) Day 1, C) Day 3, and D) Day 7 of polymer resin.

2.2.1.4 Conclusion

In conclusion, the ATR surface characterization technique provided a possible characterization of the polymer being PAA. When comparing the ATR spectra of post-print day samples of day 0, day 1, day 3 and day 7, it can be observed that the spectra is similar. Therefore, it can be determined that the chemical structure of the polymer will not be affected by a change in time. The data from the ATR is acute data, further characterization of the ATR for post-print day 30 will be needed to determine a change in chemical structure.
2.2.2 MTT Assay

2.2.2.1 Introduction

An MTT assay measures cellular metabolic activity using a colorimetric assay. (Kuete et al., 2017) MTT stands for a yellow tetrazolium salt. In this colorimetric assay, the yellow tetrazolium salt is reduced to purple formazan by metabolically active cells. The cells contain an enzyme that reduce the MTT to formazan. (Sigmaaldrich, 2022) MTT Assays were done to determine cell viability and proliferation when exposed to the clear resin from the Formlabs 3D SLA printer.

2.2.2.2 Methods

A 96-well plate and cell line HL-60 (ATCC CCL-240) was used for the assay. As can be seen in Illustration 2.2.2.1, the plate was prepared by culturing cells on columns 1-3 and rows A and G. Rows B and H were used as controls with PBS media with no cells. Rows G and H were exposed to the printer’s polymer using 3D printed cubes with 1 mm³ dimensions placed in the plate, whereas rows A and B were not exposed to the resin.

![Illustration 2.2.2.1: Placement of cells and culture media with and without clear resin in 96 well plate.](image)

Illustration 2.2.2.1: Placement of cells and culture media with and without clear resin in 96 well plate.
The cells were read on a plate reader, Synergy H1Hybrid Multimode Microplate reader, after an incubation period of 1, 3, and 7 post-print days to measure the absorbance of the cells at 570nm. (O’donnell, n.d.) The MTT data will show an acute data at 7 days for determining biocompatibility. Cell viability with respect to polymer exposure was calculated using the following equation (Guidelines for Cell Viability Assays _ Enhanced Reader, n.d.):

\[
\% \text{Cell Viability} = \frac{\text{cells with treatment}}{\text{cells no treatment}} \times 100
\]  

(3)

Cells with treatment contains the cells with exposure to the polymer resin and cells no treatment contains the cells with no exposure to the clear resin, it will be used as the control.

2.2.2.3 Results and discussion

What was determined from the data is that the average amount of absorbance from viable cells in the wells increased when the exposure time from the polymer increased. Figure 2.2.2.1 shows a statistically significant increase in absorbance from viable cells exposed to the polymer from day 1 to day 3, and day 1 to day 7, indicating the HL60 cells can proliferate in the presence of the polymer. Between day 3 and day 7 there is a less than 5% chance the data gathered is random and between day 1 and day 7 there is a less than 1% chance the data gathered is random. These results from the cell lines being exposed to the printed polymer indicate it is likely not cytotoxic.
2.2.2.4 Conclusion

In conclusion, the MTT assay was used to determine if the cells will be viable in the presence of a polymer that has been exposed for post-print days 1, 3, and 7. The cell absorbance when exposed to the polymer increases significantly from post-print days 1 and 3 and post-print days 1 and 7. This significant increase in absorbance indicates that the cells can proliferate in the presence of the polymer and that the polymer is likely not cytotoxic, toxic to cells.
CHAPTER 3

Developed microfluidic device using commercially available clear resin

3.1 Microfluidic Device

3.1.1 Device Design

The microfluidic device was designed as a preliminary study to determine if fluid can flow autonomously through the device. The device will have dimensions of 25 mm X 60 mm X 3 mm (W X L X H). What can be seen from Illustration 3.1.1.1 and Figure 3.1.1.1, the cells will be pipetted into the inlet and will flow through the microchannel. The second inlet, located at the top of the microchannel, will contain a PBS wash that will help move the cells into the reaction chamber. At the reaction chamber, the cells will be suspended, and a second PBS wash will flow through the inlet below the reaction chamber. The flow of liquid will stop right before it reaches the waste chamber to allow for an incubation period for the cells. A capillary burst valve was made by changing the geometric design of the waste chamber. A sudden change in equilibrium contact angle, between the straight section and vertical waste chamber wall that connects to it will be greater than 90°. When the equilibrium angle is greater than 90°, the liquid will only advance once an external driving pressure greater than the resisting capillary pressure pushes the liquid into the waste chamber. (Cho et al., 2007) A PBS wash placed in the first inlet will be used to increase the pressure and allow for flow into the waste chamber.
Illustration 3.1.1.1: Microfluidic device

Figure 3.1.1.1: Image of 3D SLA printed microfluidic device
3.1.2 Fluid Flow

3.1.2.1 Introduction

The theoretical velocity was compared to the experimental data gathered from the fluid flow studies. To calculate the theoretical velocity, the Young-Laplace equation (2) was used to calculate the change in pressure in the microchannels based on contact angle and channel dimensions. The contact angles, 59° and 60° were chosen based on the post-print date of the device. The values from equation (2) were used in equation (1) to calculate the flow rate. Velocity was determined using equation (4). To determine the theoretical velocity, the following equation can be used:

\[ Q = vA \]  

(4)

In equation 4, the flow rate (Q) is equal to velocity (v) times the cross-sectional area (A) of the microchannel.

3.1.2.2 Methods

To test the fluid flow of the device, DI water mixed with trypan blue, dye used to penetrate cell walls, was dropped into the inlet of the device using a pipette and removed to view the flow of the liquid. (Strober, 2015) The experimental velocity was obtained by timing the flow of the liquid from the inlet to the waste chamber.

3.1.2.3 Results and discussion

The theoretical and experimental flow rate and velocity were compared in Table 3.1.2.1. The experimental flow rate within the device was slower than the theoretical values which do not consider the viscosity of the liquid with the trypan blue and the difference in capillary pressure of the microchannel. The change in capillary pressure can vary greatly when there is a change in
channel cross-section, this will cause a difference in flow rate. However, theoretical and experimental velocities were similar when using the Navier-Stokes equation where the flow rate is divided by the cross-sectional area. This data demonstrates the printed microfluidic device can support autonomous (self-driven) fluid flow through the device.

**Table 3.1.2.1 Theoretical and experimental data for fluid flow in autonomous microfluidic device**

<table>
<thead>
<tr>
<th>Contact Angle</th>
<th>Theoretical Flow Rate (Q)</th>
<th>Theoretical Velocity</th>
<th>Experimental Flow Rate (Q)</th>
<th>Experimental Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>245.74 mm³/s</td>
<td>1.094 mm/s</td>
<td>0.295 mm³/s</td>
<td>1.315 mm/s</td>
</tr>
<tr>
<td>60</td>
<td>337.33 mm³/s</td>
<td>1.501 mm/s</td>
<td>0.295 mm³/s</td>
<td>1.315 mm/s</td>
</tr>
</tbody>
</table>

**3.1.2.4 Conclusion**

In conclusion, fluid flow studies were used to determine if fluid can flow through the microfluidic device autonomously. Even though the data gathered from the experimental fluid flow studies was lower than the data from the theoretical calculation, the fluid was still able to flow autonomously through the device. This data demonstrates the printed microfluidic device can support autonomous (self-driven) fluid flow.
3.1.3 Non-fluorescent Dynabeads

3.1.3.1 Introduction

Non-fluorescent dynabeads M-450 (Invitrogen) simulated the flow of cells as a preliminary proof of concept study to demonstrate autonomous fluid flow through the microfluidic device. They will help determine cell flow to make sure the cells, or dynabeads, do not sit on the inlet of the device and prevent flow. Dynabeads have the dimensions of 1-5 microns, which is similar to the dimensions of a cell, 0.1-5 microns.

3.1.3.2 Methods

The beads were diluted in PBS, 10 μL of beads to 1 mL of PBS. Once, the mixture was ready it was pipetted onto the inlet of the device. The pipette was removed to indicate that the fluid can flow autonomously. Using a stereomicroscope, a video and images were taken of the flow of the microbeads through the device at a magnification of 3 millimeters.

3.1.3.3 Results and discussion

The orange arrows indicate the direction of flow of the non-fluorescent dynabeads. The dynabeads were able to flow from the inlet of the device to the reaction chamber, therefore, cells will be able to flow when used in the microfluidic device. There was autonomous fluid flow in the microfluidic device, but the material was not optically clear.
Figure 3.1.3.1: Stereomicroscope images of microbeads. A) Cell inlet, B) microchannel below PBS wash inlet, C) entrance of reaction chamber, and D) exit of reaction chamber.

3.1.3.4 Conclusion

In conclusion, Dynabeads were used to simulate the flow of cells through the microfluidic device and determine if they will be able to flow from the inlet to the reaction chamber. Time lapsed stereomicroscope images of the Dynabeads flowing from the inlet to the reaction chamber can be observed, indicating that the Dynabeads have autonomous flow in the microfluidic device. However, the material is not optically clear.
CHAPTER 4

Conclusion and Potential Future Applications

4.1 Conclusion

In this work, the use of a commercially available clear resin was characterized to determine its application in an SLA 3D printed autonomous microfluidic device. Separate conditions including post-print day to determine shelf life, autoclave sterilization, and ethanol immersion were applied to the mechanical testing of the clear resin. Comparison between the print day and mechanical test showed an increase in mechanical properties and comparable properties in surface characterization. Based on the experimental data, the impact and tensile strength increase over time, but no significant differences were detected. Minimal percent elongation indicated this is a brittle material. The SEM imaging supports the data from the tensile and impact test, which demonstrates classic brittle fracture features of polymers. The formation of mirror, mist, and hackle patterns on the fracture surface of the polymer indicating a brittle failure. (Becker et al., 2002) The type of sterilization that had no impact on tensile and impact tests was autoclave sterilization, therefore, it would be the best form of sterilizing the polymer for use in the medical industry.

The discovery from the ATR of possible surface characterization of the clear polymer being PAA was indicative of a thermoset polymer. The ATR spectra remained consistent in post-print days 0, 1, 3, and 7, it can be determined the chemical structure of the resin remains consistent. MTT analysis assessed the cells metabolic activity. The absorbance from viable cells in the wells showed a statistically significant increase when the exposure time of the polymer increased, therefore, the polymer exposure indicates the printed polymer is likely not cytotoxic. The data
from the MTT is acute data at 7 days and more testing will need to be done to determine biocompatibility at 30 days.

The autonomous device was analyzed with theoretical and experimental fluid flow data, and it was determined that it can be used for autonomous fluid flow. However, the polymer is not optically clear. Overall, this polymer demonstrates significant potential for use in autonomous flow microfluidic device development due to its stable physical properties and it does not seem to be toxic to cells.
4.2 Potential Future Applications

Future development in this field can go different directions. First, an improvement in the design of the device can be done by implementing more retention burst valves and reaction chambers. Second, the clear resin was not optically clear, therefore, improving the transparency of the polymer will help with viewing the cells when flown through the device. This can be done by spraying the 3D printed device with a general-purpose clear coat spray prior to post-curing, to prevent any yellowing of the material. (Formlabs, 2022) The autonomous microfluidic device was intended for providing a low-cost diagnostic tool that can be used at the point of care and potentially provide early detection of acute myeloid leukemia cancer. The cost of the microfluidic device when comparing the dimensions of the device to the cost of the clear resin will generate an outcome of $0.68 per device.
References


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Vita

Michelle Gamboa was born in 1997 in El Paso, TX. During her time in school, she was a part of a journal publication in the Journal of Failure Analysis and Prevention: *Failure Analysis of Additively Manufactured Polyester Test Specimens Exposed to Various Liquid Media*. Obtained a Bachelor of Science degree in Materials and Metallurgical Engineering with a minor in Biomedical Engineering from the University of Texas at El Paso. She graduated in Fall 2020 and was awarded the Pathways to Success in Graduate Engineering (PASSE) scholarship to continue her studies in graduate school.

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