THE 3D PRINTABILITY AND MECHANICAL PROPERTIES OF POLYHYDROXYBUTYRATE (PHB) AS ADDITIVES IN BLENDS POLYMER FOR 3D PRINTED ARM CAST

AHMAD ADNAN BIN ABU BAKAR

UNIVERSITI SAINS ISLAM MALAYSIA

THE 3D PRINTABILITY AND MECHANICAL PROPERTIES OF POLYHYDROXYBUTYRATE (PHB) AS ADDITIVES IN BLENDS POLYMER FOR 3D PRINTED ARM CAST

Ahmad Adnan bin Abu Bakar

Thesis submitted in partial fulfillment for the degree of
MASTER OF SCIENCE

UNIVERSITI SAINS ISLAM MALAYSIA

December 2023

AUTHOR DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

Date : 18th December 2023

Signature :
Name : Ahmad Adnan Bin Abu Bakar
Matric No : 3201064

APPROVAL FOR SUBMISSION

I certified that this thesis entitled **"THE 3D PRINTABILITY AND MECHANICAL PROPERTIES OF POLYHYDROXYBUTYRATE (PHB) AS ADDITIVES IN BLENDS POLYMER FOR 3D PRINTED ARM CAST"** was prepared by **AHMAD ADNAN BIN ABU BAKAR** has met the requirement standard for submission in partial fulfillment of the requirements for the awards of Master of Science.

Approved by,

.....

DR. MOHD IFWAT MOHD GHAZALI
Main Supervisor
Faculty of Science and Technology
Universiti Sains Islam Malaysia
Date: 18th December 2023

APPROVAL FOR SUBMISSION

I certified that this thesis entitled **"THE 3D PRINTABILITY AND MECHANICAL PROPERTIES OF POLYHYDROXYBUTYRATE (PHB) AS ADDITIVES IN BLENDS POLYMER FOR 3D PRINTED ARM CAST"** was prepared by **AHMAD ADNAN BIN ABU BAKAR** has met the requirement standard for submission in partial fulfillment of the requirements for the awards of Master of Science.

Approved by,

.....

DR. SHAHINO MAH ABDULLAH
Co-Supervisor
Faculty of Science and Technology
Universiti Sains Islam Malaysia
Date: 18th December 2023

ACKNOWLEDGEMENTS

Foremost, I would like to offer my endeavor to our God Almighty, Allah S.W.T. and His Messenger Muhammad SAW for His wisdom bestowed upon me strength, health in mental and physical throughout the completion of this work. I would like to thank my family, especially my parents, Abu Bakar Mamat and Che Minah Mohd Noor, who have continuously inspired, encouraged and supported me through ups and downs.

Next, I humbly express my gratitude towards my dearest and kind supervisor, Dr. Mohd Ifwat Mohd Ghazali for helping me a lot during the making of this research. The guidance and advises making me easier to finish my research and I am very thankful to him as he spend time for me whenever I made appointment to see him seeking his knowledge and guidelines. He should receive most of my gratitude for what I have achieved during the entire course of my master degree. Besides, my thanks and appreciation towards Dr. Nizam Tamchek, Dr. Ikhwan Syafiq Mohd Noor and Dr. Shahino Mah Abdullah as they are always gives me guidance with their critics and comments towards my research findings to keep me in the right track.

I want also show my token of appreciation and be grateful to have my wonderful friends especially SMART RG members which are Muhammad Zulhilmi Zainuddin, Muhammad Faishal Norjeli, Ahmad Nurhelmy Adam, Muhammad Afiq Hazizi Mahamood and Irfan Yahaya that always give me their hands willingly especially whenever I am in need of helps. It is worth noting to receive financial assistance for my research work from the Ministry of Higher Education of Malaysia under Fundamental Research Grant Scheme (FRGS/1/2020/STG05/USIM/02/1). Last but not least, thanks to everyone, who is not, mentioned here, for his/her contributions, direct or indirect during the completion of my research work.

ABSTRAK

Pembuatan aditif ataupun lebih dikenali sebagai percetakan tiga dimensi (3D) merupakan salah satu komponen yang penting dalam Revolusi Perindustrian yang keempat dalam ekosistem pembuatan merentasi pelbagai sektor industri termasuk elektronik, automotif dan perubatan. Dalam industri perubatan, teknik stereolitografi (SLA) muncul sebagai salah satu teknik utama kerana mempunyai keupayaan resolusi yang tinggi berbanding teknik-teknik pembuatan aditif yang lain. Penyelidikan ini bertujuan untuk menggunakan teknik bahan campuran dalam proses SLA iaitu sebatian polihidroksi butirat/uretana dimetakrilat (PHB/UDMA) bagi menghasilkan bahan baru percetakan 3D untuk kegunaan perubatan khususnya tuangan lengan. Kelikatan memainkan peranan yang penting dalam kebolehcetakan resin cetakan 3D. Untuk penyelidikan ini, kelikatan maksimum dicapai pada nilai 2188 sentipoise (cP) pada komposisi 11% PHB. Pada komposisi yang sama, kekuatan tegangan dan hentaman dapat dikekalkan pada degradasi minima iaitu hanya 3% berbanding resin UDMA tulen, iaitu pada 16% dalam tempoh sebulan. Kestabilan dan struktural integriti bahan bercetak 3D adalah disebabkan adanya campuran PHB. Berdasarkan piawaian yang telah ditetapkan untuk kegunaan klinikal, hanya komposisi 3% PHB gagal memenuhi syarat untuk tahap penukaran ikatan ganda dua (DC). Ini adalah petanda yang baik kerana kebanyakan komposisi menunjukkan proses pempolimeran yang lebih bagus, seterusnya menyumbang kepada prestasi yang lebih baik. Untuk indeks kehabluran (CI), campuran PHB menyumbang kepada struktur-struktur kristal dalam resin berasaskan UDMA dan menjadikan bahan bercetak 3D PHB/UDMA lebih senang patah, selaras dengan pengurangan prestasi mekanikal. Sementara itu, gambar mikroskop elektron pengimbasan pancaran medan (FESEM) menunjukkan dua kawasan fasa yang berbeza di antara PHB dan UDMA, sekaligus membuktikan lekatan antara muka yang lemah antara sebatian polimer tersebut. Berdasarkan keputusan keseluruhan, komposisi 7% PHB telah dipilih sebagai komposisi sebatian yang ideal untuk tuangan lengan bercetak 3D kerana prestasi mekanikal yang lebih baik dan melepasi tahap minima DC. Penyelidikan ini memberikan sumbangan yang signifikan dalam memahami hubungan di antara kebolehcetakan dan sifat mekanikal bahan bercetak 3D PHB/UDMA khususnya untuk tuangan lengan bercetak 3D menggunakan teknik SLA.

ABSTRACT

Additive manufacturing, widely known as three-dimensional (3D) printing is a substantial part of in Forth Industrial Revolution (IR 4.0) for the manufacturing ecosystem across a plethora of industrial sectors including electronics, automotive and medical. Within the medical industry, stereolithography (SLA) technique emerges as one of the predominant techniques due to the high-resolution capabilities which is better compared to other additive manufacturing technique. This research aims to utilize blended materials technique in the SLA process with using polyhydroxybutyrate/urethane dimethacrylate (PHB/UDMA) combination to fabricate a new 3D printed materials for medical application in particular arm cast. Viscosity plays a crucial role in the printability of the 3D printed resins. For this research, the maximum viscosity was achieved at approximately 2188 centipoise (cP) with the concentration of PHB at 11% weight ratio. Based on this composition, the tensile and impact strength were able to maintain with a minimal degradation of only 3% relative to the pure UDMA resin which is at 16% in a one month period. The inclusion of PHB is attributed to the structural integrity and stability of the 3D printed materials. Based on the clinical application standards, only 3% by weight composition of PHB failed to meet the requirements for the degree of double bond conversion (DC). These are good indications as most of the composition shows a more complete polymerization process which leads to better performance. For the crystallinity index, the inclusion of PHB contributed towards crystalline structures within UDMA based resin and make the 3D printed PHB/UDMA more prone to fracture, thus in line with the reduction of mechanical performance. Meanwhile, FESEM pictures portrayed two distinct phases region between PHB and UDMA proved the poor interfacial adhesion between the polymer blend. Based on the overall results, 7 wt. % of PHB content was selected as an optimal blending mixture composition for 3D printed arm cast due to better mechanical performance and passed the minimum standard level of DC. This research shows significant contributions in understanding the relationship between printability and mechanical properties of PHB/UDMA resins in particular for 3D printed arm cast using SLA technique.

TABLE OF CONTENTS

LIST OF TABLES

Tables ... **Page**

LIST OF FIGURES

Figures ... **Page**

LIST OF EQUATIONS

LIST OF ABBREVIATION

3D	Three Dimensional
AM	Additive Manufacturing
ASTM	American Society For Testing And Materials
Bis-EMA	Bisphenol A ethoxylated dimethacrylate
Bis-GMA	Bisphenol A-glycidyl dimethacrylate
BPA	Bisphenol A
CAD	Computer-aided Design
CI	Crystallinity Index
CLIP	Continuous Liquid Interface Production
DC	Degree of Double Bond Conversion
DED	Directed Energy Deposition
DLP	Digital Light Processing
FDM	Fused Deposition Modelling
FESEM	Field Emission Scanning Electron Microscopy
FRP	Free Radical Photopolymerization
FTIR	Fourier Transform Infrared
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PE	Polyethylene
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactide Acid
PP	Polypropylene
PTFE	Polytetrafluoroethylene
SDG	Sustainable Development Goals
SLA	Stereolithography
STL	Standard Triangulated Language
TEDGMA	Triethylene Glycol Dimethacrylate
TGA	Thermogravimetric Analysis
TPU	Thermoplastic Polyurethane
UDMA	Urethane Dimethacrylate
UTM	Universal Testing Machine
UV	Ultraviolet
XRD	X-Ray Diffraction