PERFORMANCE EVALUATION OF NICKEL COATED STEREOLITHOGRAPHY MOULD INSERT FABRICATED USING DESKTOP 3D PRINTING

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A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

MARCH 2023

Special thanks to my strength on their support and cares, father, mother, wife, and children.

ACKNOWLEDGEMENT

All the praises and thanks be to Allah Almighty for granting me the chance to pursue my doctoral studies, and for providing me with resilience to overcome any challenges that have arisen along the way. Throughout this journey, I would like to express my sincerest appreciation to my supervisor, Prof. Ir. Dr. Md Saidin bin Wahab, whose guidance, encouragement, and expertise have been instrumental in shaping me as a researcher. His insights have been invaluable in helping me to develop both personally and professionally. Additionally, I am deeply grateful to my co-supervisor, Ts. Dr. Khairu bin Kamarudin for his constructive criticism and friendship throughout my PhD journey.

Many thanks to the members of the Advanced Manufacturing and Materials Centre (AMMC), the technical staff of the Modern Machining Technology Workshop, the Material Science laboratory, and the Metrology laboratory at UTHM for their help and support. Their cooperation is very crucial to my success.

I also would like to extend my gratitude to Amin Shah bin Md Shah, Muhammad Alif bin Azizi, Goh Fook Zen, Mohd Rizam bin Rostam, Siti Masitah binti Mohd Redzuan, Nurul Nabilah binti Md Tahir, Lai Wai Shun, Runizsyazrizan bin Basirun, Muhammad Fakrul Razi bin Abd Malek, Lee Kah Ching, Muhamad Abdul Baasith Kharrazi bin Md Sharizam and Anas Amzar bin Roslan for their help in taking data for the experiment. May all the good deeds done be blessed by Allah S.W.T.

Finally, I would like to express my heartfelt appreciation to my father, Ahmad bin Ihsan, my mother Junaidah binti Sahib, my beloved wife Norasliza binti Mohd Bisri, my children Muhammad Faris, Muhammad Faiz, Muhammad Faiq and all my family members for their support and unwavering encouragement throughout this journey. Their love and belief in me have been a constant source of motivation and inspiration.

ABSTRACT

Advanced developments in Additive Manufacturing Technology have provided benefits in many areas, including plastic injection moulding applications using the stereolithography (SLA) 3D printing process. However, the significant problem in the limited lifespan of SLA moulds is often caused by failures during the moulding process that can be attributed to the ejection force required to remove the product from the mould core. This research aims to evaluate the performance of metallised SLA mould inserts by coating the mould with copper and nickel through electroless and electrodeposition processes, respectively. In addition, an evaluation was also carried out for the design of the SLA mould gate system, the effect of cooling time on moulded part shrinkage and ejection force during the moulding process. Relevant tests were conducted on metallised SLA material such as adhesion test, tensile strength, and plastic injection moulding experimental work. The copper adhesion test results according to ASTM D3359 showed that etchant concentration was a significant contributor to adhesion quality, followed by etching time, formaldehyde reducing agent and deposition time. For the tensile test results conducted according to ASTM D638 type V, the Young's modulus with a deposition thickness of 120 µm has shown an increase of 240% compared to the SLA specimen without metallisation. The final tensile strength results showed a decrease for the deposition thickness of 30 µm but increased for the deposition thickness of 60 µm and 120 µm. Meanwhile, the elongation percentage at break was reduced from 24.30% to 14.95% for the SLA specimen with a deposition thickness of 120 µm. Evaluation of the injection moulding process showed that the SLA core insert with metallisation was intact until the last moulding cycle of 350 compared to the core without metallisation which cracked at 222 moulding cycles. Research findings conclude that metallisation on SLA mould inserts increases tensile strength, thereby extending the life of SLA mould.

ABSTRAK

Perkembangan terkini dalam Teknologi Pembuatan Aditif dapat memberikan faedah dalam banyak perkara, termasuk aplikasi pengacuan suntikan plastik menggunakan proses pencetakan 3D stereolitografi (SLA). Namun, masalah ketara dalam jangka hayat acuan SLA yang terhad selalunya disebabkan oleh kegagalan semasa proses pengacuan yang boleh dikaitkan dengan daya tolakan yang diperlukan untuk mengeluarkan produk daripada teras acuan. Penyelidikan ini bertujuan untuk menilai prestasi sisipan acuan SLA berlogam dengan menyalut acuan dengan kuprum dan nikel melalui proses tanpa elektro dan elektrodeposisi, masing-masing. Selain itu, penilaian juga dijalankan untuk reka bentuk acuan SLA, kesan masa penyejukan terhadap pengecutan bahagian acuan dan daya tolakan semasa pengacuan. Ujian yang berkaitan telah dijalankan ke atas bahan SLA berlogam seperti ujian lekatan, kekuatan tegangan, dan eksperimen pengacuan plastik. Keputusan ujian lekatan kuprum mengikut ASTM D3359 menunjukkan kepekatan etsa merupakan penyumbang utama kepada kualiti lekatan, diikuti dengan masa etsa, agen pengurangan formaldehid dan masa mendapan. Bagi keputusan ujian tegangan yang dijalankan mengikut ASTM D638 jenis V, modulus Young dengan ketebalan pemendapan 120 µm telah menunjukkan peningkatan sebanyak 240% berbanding spesimen SLA tanpa metalisasi. Keputusan kekuatan tegangan akhir menunjukkan penurunan untuk ketebalan pemendapan 30 µm tetapi meningkat untuk ketebalan pemendapan 60 µm dan 120 µm. Sementara itu, peratusan pemanjangan semasa putus telah berkurang daripada 24.30% kepada 14.95% bagi spesimen SLA dengan ketebalan pemendapan 120 µm. Penilaian proses pengacuan suntikan menunjukkan bahawa sisipan teras SLA dengan metalisasi adalah utuh sehingga kitaran pengacuan terakhir sebanyak 350 berbanding teras tanpa metalisasi yang retak pada kitaran pengacuan ke-222. Dapatan penyelidikan ini menyimpulkan bahawa metalisasi pada sisipan acuan SLA dapat meningkatkan kekuatan tegangan, dengan itu memanjangkan hayat acuan SLA.

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	-	2 Dimensional
3D	-	3 Dimensional
3DP	-	Three-dimensional printing
°C	-	Degree Celsius
Ø	-	Diameter
%	-	Percent
ABS	-	Acrylonitrile butadiene styrene
ACES	-	Accurate clear epoxy solid
AM	-	Additive manufacturing
AMMC	-	Advanced Manufacturing and Materials Centre
ANN	-	Artificial neural network
ANOVA	-	Analysis of variance
ASTM	-	American Society for Testing and Materials
BPNN	-	Back propagation neural network
CAD	-	Computer aided design
CMM	-	Coordinate measuring machine
CNC	-	Computer numerical control
DAQ	-	Data acquisition system
DC	-	Direct current
DF	-	Degrees of freedom
DMLS	-	Direct metal laser sintering
DOE	-	Design of experiment
DT	-	Deposition time
EBM	-	Electron beam melting
EC	-	Etchant concentration
EDM	-	Electrical discharge machining

EOF	-	End of fill
EOP	-	End of packing
ET	-	Etching time
FDM	-	Fused deposition modeling
GN	-	Gate number
GS	-	Gate size
HT	-	High temperature
ID	-	Inner diameter
IMT	-	Innovative Manufacturing Technology
IP	-	Injection pressure
IPA	-	Isopropyl alcohol
ISO	-	International Organization for Standardization
IT	-	Injection time
LKM	-	Lung Kee Group
LO	-	Length overall
LT	-	Layer thickness
MEMS	-	Microelectromechanical systems
MFR	-	Melt flow rate
MSD	-	Mean square deviation
MT	-	Melt temperature
NI	-	National Instruments
OA	-	Orthogonal arrays
OD	-	Outer diameter
PE	-	Polyethylene
PET	-	Polyethylene terephthalate
PIM	-	Plastic injection moulding
PMMA	-	Polymethyl methacrylate
POM	-	Polyoxymethylene
PP	-	Polypropylene
PSE	-	Parametric sampling evaluation
RC	-	Reducing agent concentration
RM	-	Rapid manufacturing
RP	-	Rapid prototyping

RS	-	Runner size
RT	-	Rapid tooling
S/N	-	Signal to noise
SLA	-	Stereolithography
SLM	-	Selective laser melting
SS	-	Sum of square
STDEV	-	Standard deviation
STL	-	Standard tessellation language
UTHM	-	Universiti Tun Hussein Onn Malaysia
UTS	-	Ultimate tensile strength
UV	-	Ultraviolet
WO	-	Width overall

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CHAPTER 1

INTRODUCTION

1.1 Background of the research

Plastic products and materials play an important role in human life and the global economy. According to Sheppard, Gilman, Neufeld, and Stassen (2016), global plastics production data shows an increasing trend since the year 1950 and if this trend continues, production is expected to reach more than 930 million tonnes by the year 2050. Furthermore, the demand for plastic injection moulding (PIM) machines will also increase in line with the increased use of plastics (Pulidindi & Prakash, 2021). Plastic injection moulding is a major method used to process plastic products with a history of nearly 150 years (Fu et al., 2020). It is estimated that one-third of all thermoplastic materials are made through injection moulding techniques, and injection moulding equipment accounts for nearly half of all polymer processing equipment (Yilmaz, Ellingham, & Turng, 2018). The injection moulding process is ideal for making mass-produced and economical goods (Ahamed, Dawood, & Karthikeyan, 2013). Despite the fact that additive manufacturing (AM) is emerging as a new manufacturing process, injection moulding parts are still required because the mechanical properties of the 3D printed parts are still lower to that of the injection moulded parts (Lay et al., 2019). Currently, injection moulding manufacturers are challenged to produce high quality parts in the least amount of time and at lower cost in a competitive market as demanded by customers (Hussin et al., 2021; Lee & Lin, 2013).

Stereolithography (SLA) is a 3D printing technique that involves the curing of a liquid photopolymer resin with a laser to create three-dimensional objects from digital files. The invention was made by a researcher from Japan named Dr. Hideo Kodama in the year 1981 while Charles W. Hull created the term "stereolithography" and patented the technology in the year 1986. He later founded the 3D Systems company to commercialise the technology, and produced the SLA-1 machine in the year 1987 (Christina & Deepak, 2018; Teemu, 2019). Industrial SLA machines typically use the right-side-up methods which requires a large resin tank thus requiring high initial investment and high operating cost (Rahmati, 2014). Meanwhile, the arrival of inverted SLA changed the scenario as the upside-down method requires a much smaller resin tank compared to the build volume. The creation of upside-down machines allowed stereolithography to move to the desktop, with a smaller area and much lower cost (Taormina, Sciancalepore, Bondioli, & Messori, 2018). There is an increasing trend of SLA market growth for stereolithography machines and it is expected that by the year 2025, the market will reach 16% of the total 3D printing technology. Desktop SLA machines are now offered in various specifications and sizes to meet the needs of the customers and are available at affordable and competitive prices (Bournias-Varotsis & Schoffer, 2019; Mele, Campana, & D'Avino, 2020).

Conventional plastic injection moulds are typically made of metals such as hardened steel, pre-hardened steel, aluminium, and beryllium copper alloys that require a machining process for fabrication. In line with the advancement of product design to meet market needs, the manufacture of plastic injection moulds also requires a different approach to cater for such developments (Hussin et al., 2021). There are many challenges faced by mould makers as product designs become more complex and parts with higher accuracy are required. In addition to the complex geometry, other challenges of metal moulds are longer lead times and higher costs for mould making (Hopkinson & Dickens, 2000; Leon Cabezas, Martinez Garcia, & Varela Gandia, 2017). The mould fabrication process involves subtractive machining processes including computer numerical control (CNC) machining to produce more precise mould inserts. All these types of machining processes require careful planning, longer machining time and limited machine flexibility for design changes are the main disadvantages in plastic injection mould manufacturing (Lanxess, 2007; Matinho, 2010).

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