THE THERMAL EFFECT OF POLYMERIC FILAMENT WITH SHAPE EFFECT FOR 4D PRINTING APPLICATION

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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I hereby, declared this report entitled "The Thermal Effect of Polymeric Filaments with Shape Effect for 4D Printing Application" is the result of my own research except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for the Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRACT

The study focuses is to determine the thermal effect of polymeric filaments of smart material characteristics for the 4D printing application. This project started with the study and research on most of the important how 4D printing works. The 4D application has various kind of field and 4D in medical is one of them. Material that has smart properties targeted and could react with thermal-responsive, will be used in this project. As well as to confirm that the material has the ability to self-assembly, self-adaptability and self-healing. Reported that 4D printing has a major impact on the engineering application if human tissue replacement. However, quality studies on performance and adaptability were still limited. In this work, tensile test and thermal testing are applied to observe and study the reaction of the 4D printing parts. After a few possible processes have been studied, the process of fabrication of the printing part targeted to use the Fused Deposition Modelling (FDM) Additive Manufacturing (AM) method. Extensive information on AM process includes the composition of the material, parameters of the printing process and the mechanical properties of smart material applied to fabricate the 4D printed part. By the experimental and observation conducted, data recorded the respond of the material toward its stimulus. The strength and the response of the smart material also will be tested on the material. Using the tensile test, the strength of the smart material will be identified before and after the reaction with the stimuli. The work contributes to the study for 4D application.

ABSTRAK

Fokus kajian adalah untuk menentukan kesan haba filamen polimer ciri-ciri bahan pintar untuk aplikasi percetakan 4D. Projek ini bermula dengan kajian dan penyelidikan tentang kebanyakan perkara penting bagaimana pencetakan 4D berfungsi. Aplikasi 4D mempunyai pelbagai jenis bidang dan 4D dalam perubatan adalah salah satunya. Bahan yang mempunyai sifat pintar disasarkan dan boleh bertindak balas dengan responsif haba, akan digunakan dalam projek ini. Serta untuk mengesahkan bahawa bahan itu mempunyai keupayaan untuk pemasangan diri, penyesuaian diri dan penyembuhan diri. Dilaporkan bahawa percetakan 4D mempunyai kesan besar ke atas aplikasi kejuruteraan jika penggantian tisu manusia. Walau bagaimanapun, kajian kualiti mengenai prestasi dan kebolehsuaian masih terhad. Dalam kerja ini, ujian tegangan dan ujian haba digunakan untuk memerhati dan mengkaji tindak balas bahagian cetakan 4D. Selepas beberapa kemungkinan proses telah dikaji, proses fabrikasi bahagian cetakan disasarkan untuk menggunakan kaedah Fused Deposition Modeling (FDM) Additive Manufacturing (AM). Maklumat meluas tentang proses AM termasuk komposisi bahan, parameter proses pencetakan dan sifat mekanikal bahan pintar yang digunakan untuk membuat bahagian cetakan 4D. Melalui eksperimen dan pemerhatian yang dijalankan, data merekodkan gerak balas bahan terhadap rangsangannya. Kekuatan dan tindak balas bahan pintar juga akan diuji pada bahan. Menggunakan ujian tegangan, kekuatan bahan pintar akan dikenal pasti sebelum dan selepas tindak balas dengan rangsangan. Kerja ini menyumbang kepada kajian untuk aplikasi 4D.

DEDICATION

TO MY DEAREST MOTHER,

SAUDAH BINTI SHARIF

For keep encouraging me to complete this study and be my backbone to support me to come out with a project during my degree study

TO MY HONOURED SUPERVISOR

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For her advice, support, motivations, and guidance during the accomplishment of this project and also the kindest person I have ever known

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That supports the accommodation and moral to finish the research

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LIST OF ABBREVIATIONS

TED	Technology, Entertainment, Design
2D	2-Dimensional
3D	3-Dimensional
3DP	Jet 3D printing
4D	4-Dimensional
ABS	Acrylonitrile butadiene styrene
AM	Additive Manufacturing
BMSC	Bone Marrow Stem Cells
CFRTC	Continuous Fibre-reinforced Thermoplastic Composite
DIW	Direct Ink Writing
ECM	Extracellular Matrix
FDM	Fused Deposition Modelling
MIT	Massachusetts Institute of Technology
MSC	Mesenchymal Cell
PCL	Poly(ε-caprolactone)
PETG	Polyethylene Terephthalate Glycol
PLA	Polylactic Acid
Ppy	Polypyrrole
SCE	Shape Change Effect
SLA	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
SMA	Shape Memory Alloy
SMC	Shape Memory Ceramics
SME	Shape Memory Effect
SMG	Shape Memory Gel
SMH	Shape Memory Hybrids
SMM	Shape Memory Materials
SMP	Shape Memory Polymer
UV	Ultraviolet

CHAPTER 1

INTRODUCTION

This chapter describes The Thermal Effect of Polymeric Filaments with Shape Effect For 4d Printing. Background, problem statement, aims, scope, significance of the study, report organization, and summary are all included in the introduction chapter.

1.1 Background

Skylar Tibbits demonstrated how 3-Dimensional (3D) printing causes alterations in a statically created item over time at the Technology, Entertainment, Design (TED) conference at the Massachusetts Institute of Technology (MIT) in 2012. A basic 3D structure can be converted into a complicated structure over time has been demonstrated. Resulted, a new printing age incorporating a new dimension in 3D printing, such as time and was given its own term, 4-Dimensional (4D) printing technology (Ahmed et al., 2021).

4-dimensional printing that known as active origami or shape-morphing systems, employs the same processes as 3D printing to build a three-dimensional item by computer-programmed deposition of material in consecutive layers. In 4D printing, morph into multiple shapes in response to external stimuli. 4-dimension being time-dependent shape change after printing. Printed product reacts to environmental elements such as humidity, temperature and voltage that changing its shape appropriately.

The majority of 4D printing technologies rely on a network of fibres with varying sizes and material qualities. 4D printed components may be developed on both the micro and macro scales. A complex molecule or fibre simulations that mimic the aggregated material characteristics of all the materials utilised in the sample are employed to accomplish micro-scale design. The deformation shape upon stimulus activation is related to the size, modulus, shape and connecting the pattern of these material building pieces.

Tissues are living structures made up of many cell types, an Extra Cellular Matrix (ECM) and a range of signalling chemicals. The ECM is an important component of the cellular microenvironment, forming a complex 3D network (Marchand et al., 2019). ECM, which has diverse architectural shapes and structures in different tissues, is a complex 3D network made up mostly of collagen and elastic fibres, as well as proteoglycans, multi-adhesive proteins, and glycosaminoglycans (Tamay et al., 2019). 3D printing has shown a high potential for designing functioning tissues or organs to mend or replace defective or necrotic tissues or organs, offering a possible solution to severe tissue or organ shortages (Cui et al., 2017). 3D printing is rapidly growing into a world-class biomanufacturing technology (Holmes et al., 2016). Based on all of the advanced features of 3D printing, 4D printing combines a time-dependent dynamic process in the fabrication design, which is expected to transform present tissue fabricating platforms. Various 3D bioprinting methods have been utilised to create biological structures such as blood arteries, bone, liver tissue and heart tissue (Arslan-Yildiz et al., 2016). However, 3D bioprinting has a key disadvantage in that it only analyses a printed object's starting condition and deems it to be inert and immobile. Natural tissue regeneration entails complex 3D structures, extracellular matrix compositions and microarchitectures, as well as the production of tissue with unique functionalities obtained by dynamic changes in tissue conformation. The majority of these dynamic functional conformational changes are mediated by built-in systems that respond to external stimuli, which 3D bioprinting could not replicate (Wan et al., 2020).

Previous researches stated that 4D printing has already been used in many types of applications, one of them is in the medical field but the there are still limited studies related with the quality study of the application (Sydney Gladman et al., 2016). Thus, this project aims to investigate the quality of the new substance of material that could be the human tissue replacement which is the 4D applying the shape memory effect.

1.2 Problem Statement

4D printing as the use of Additive Manufacturing (AM) to create stimulus-responsive components that may change its shape or its function from one kind to another when subjected to appropriate stimuli without the usage of robotics or electromechanical equipment. Traditional 3D printing technology focuses on producing a single material static structure that cannot meet all complicated needs. Functions are included in appliances such as soft grippers for service, self-folding and adaptable wind turbines (Zhang et al., 2019). As previously noted in the study, the majority of the 4D printed structures, created utilising existing 3D printing procedures for instance selective laser sintering (SLS), fused deposition modelling (FDM), stereolithography (SLA), jet 3D printing (3DP), direct ink writing (DIW), selective laser melting (SLM) (Ahmed et al., 2021).

Defect that can occur during 4D printing using FDM is warping, which refers to the bending or curling of the printed object due to uneven heating and cooling of the material throughout the printing process. Warping could cause internal stresses in the object and can lead to cracking or failure under load.

However, there is a gap that 4D printing needs to be focused on the success to fabricate the part. First, the how must ensure that the material used for 4d printing is able to react to its environment and changes over time and act as a programmable matter to its function. Moreover, limited access and consistent data of this 4D printing application are one part of the difficulty that needs to be faced as the 4D printing is about to develop.

The thermal effects in 4D printing are critical for the successful development of 4D printing technology and it is important to understand and control these effects to obtain the desired properties and functionality of the final object. When exposed to the maximum stimulus, not all stimulus-responsive components will undergo the predicted transition. To arrange a sequence of pattern-shifting, a fixed interaction method is required when the cue is engaged within a reasonable time frame, actions are taken.

1.3 Objective

The main aim of this project is to determine the thermal effecr of smart material polymeric filaments with shape effect for 4D printing applications. It is very crucial and essential to draw out the possible solutions to curb the problem. The objectives are as follows:

i. To fabricate 4D smart material printed parts for human tissue replacement.
ii. To determine the quality of mechanical properties 4D printed parts include the tensile test, dimensional accuracy and thermal testing.

1.4 Project Scope

This project analysis focuses on more to ascertain the design and simulation of the polymeric filament with memory shape effect for the biomedical application.

i. Catia 3D modelling and simulation software is used to propose modelling design and simulation
ii. Apply Additive Manufacturing Technology and 4D printing parts using Fused Deposition Modelling (FDM) on fabricating the test specimen.
iii. Determine the quality of the 4D specimens focus on the strength of the printed part by using Ultimate Tensile Machine following standards (ASTM D638).
iv. Examine and analyse the transformation of the smart material response to the temperature applied to the printed specimen by exposing it to the temperatures 60°C, 100 °C and 150 °C.

1.5 Significant of Study

The worlde competitiveness among technical behemoths, as well as interest in the new era of contemporary enterprises, commercial, automotive and aerospace application have fueled research and development of sophisticated materials and smart structures. Shape memory materials (SMMs), self-healing materials, and metamaterials are the three basic forms of phase change materials. Shape memory materials are those that alter the shape in response to an external stimulus. A self-healing material, as the name implies can self-heal when disorder or faults emerge and fill that area with the fresh matter. Metamaterials are man-made materials that have qualities that natural materials do not have (Mehta & Sahlot, 2021).

3D or 4D printing technologies are faster, more cost-effective and more exact than traditional techniques of production. They are increasingly desired for usage in a variety of areas. Furthermore, they overcome the difficulty of producing tough and intricate structures and forms produced by earlier approaches. As a result, these technologies have a wide range of applications, including construction, bone tissue engineering, optical compounds, biomedical engineering, radiology, actuators, medical fields, agriculture, dentistry, food industry, aerospace, osteochondral tissue engineering, surgery and medicine, drug delivery, tissue engineering, medical, neural tissue engineering and protein delivery (Mallakpour et al., 2022).

CHAPTER 2

LITERATURE REVIEW

This chapter describes The Thermal Effect of Polymeric Filaments with Shape Effect for 4D Printing. 4D printing to additive manufacturing, processes of additive manufacturing, smart material on 4D printing, origami approach, application-based on 4D printing, properties of 4D printed material and summary are all included in the introduction chapter.

The materials selection for AM is vital and significant in terms of the kind of AM technique. To clear that the applicability of post-processing with the geometry tolerances and attributes during component printing, play an important impact in material selection. Furthermore, the full growth of the AM techniques and related materials is well-tailored to the specific technical applications.

In recent years, there has been a rise of interest in the issue of additive manufacturing of smart materials and structures, with the introduction of smart materials via 3D printing, the shape or attributes in the 4-Dimensional are transformed by an external force or act known as 4D printing. In order to accomplish critical functional performances, this chapter examines the importance of general material selection for AM, as well as smart materials, actuators for advanced applications, shape memory metallic alloys, and shape memory polymers.

2.1 4D Printing to Additive Manufacturing

Additive manufacturing is a process that allows complex objects to be constructed layer by layer. According to the forecast, substantial investment will be made in the 3D printing business during the next ten years. AM has had an influence on every industry area, including aircraft, construction, medicine, and the military. 3D printing allows for design freedom, considerable material savings, customization and uniqueness. In recent years, additive manufacturing has made great progress (Mitchell et al., 2018). According to the Royal Academy of Engineering, "it is not just a disruptive technology with the potential to replace many current manufacturing processes, but it is also an enabling technology that allows new business models, new products, and new supply chains to emerge." (Jiang et al., 2017). 3D printing allows products to be developed with minimal waste. With the advent of 4D printing, AM will have a profound impact on the economy and society over the next decade.

Sophisticated forms can be printed using a variety of materials, this approach is becoming increasingly popular. These strategies provided significantly greater flexibility and freedom throughout the design stage by allowing the designer to freely improve to develop unique forms and arrangements. It has a wide range of applications in industries such as automotive, aerospace, medicinal, consumer products, and many more. From the 1980s until the present, this technology has been constantly evolving with unique and efficient approaches which have limited material handling capacity (Patil & Sarje, 2021). Below, shows figure 2.1, the comparative analysis of the 3D and 34 printing

Table 2.1: Comparative Analysis of 4D printing and 3D Printing (Javaid & Haleem, 2019)

No.	Characteristics	3D Printing	4D Printing
1	Built Process	3D printing repeats a 2D structure layer by layer from bottom to top	4D printing is the extension of 3D printing
2	Material Used	Uses thermoplastics, ceramics, metals, biomaterials or nanomaterials	Smart, multi-material, and self-assembling materials are used to construct an item that changes shape after it is made.

			There is a need to create novel materials that meet the needs of the applications.
3	Flexibility	No flexibility, characterised by rigidity	Having flexibility, characterised by flexibility
4	Object shape flexibility	No flexibility, characterised by rigidity	Object shape is changed over time and with the change in temperature
5	Programming of material	Not use any programmable and advanced material	Use programmable and advanced (mostly new) material that can provide various functionalities
6	Applications	Its application is in medical, engineering, dentistry, automobile, Jewelry, toys, fashion, entertainment, aerospace and defence	Dynamically changing configuration for all applications by 3D printing

2.2 Processes of Additive Manufacturing

4D printing is a new method that promises to give AM the capacity to morph in real-time. It provides a versatile and economical manufacturing technique in particular by developing flat precursory design into 3D objects with complicated configuration. To equip the precursory structures with the needed transformation, solid mechanics concepts must be used to intelligently pre-embed mismatch deformations that may subsequently be activated by external inputs. In this way, 4D printing may be viewed as a mechanics-based manufacturing strategy in comparison to traditional fabrication approaches.

4D printing is primarily dependent on five parameters and must be considered when executing 4D printing. These five components are as follows which are the the material used for printing, additive manufacturing technique, stimuli, interaction mechanisms, and modelling. The AM technique allows for the manufacture of printing material from digital information given by the computer without the use of an intermediary instrument. There are various AM processes such as Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Jet 3D Printing (3DP), Selective Laser Melting (SLM),