اونيۏرسيتي تيکنيکل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The Effect of Thermal Responsive Material Polymeric Filament to Strength and Transformation in 4D Application

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

by

MUHAMAD AKASHAH BIN ROKY

B051710185

961029-02-6101

FACULTY OF MANUFACTURING ENGINEERING

2021

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **The Effect of Thermal Responsive Material Polymeric Filament to Strength and Transformation in 4D Application**

Sesi Pengajian: **2020/2021 Semester**

Saya **MUHAMAD AKASHAH BIN ROKY (961029-02-6101)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA

☑ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

☐ TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:

No 24, Taman Sri Bagan, Batu 3
Tandop, 05400 Alor Star,
Kedah Darul Aman

Tarikh: 14 SEPT 2021

Cop Rasmi:

RIZZY HARYATI BINTI HAMBALI
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka

Tarikh: 14 SEPT 2021

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD

DECLARATION

I hereby, declared this report entitled "The Effect of Thermal Responsive Material Polymeric Filament to Strength and Transformation in 4D Application" is the result of my own research except as cited in references.

Signature : ……………………………………………

Author's Name : MUHAMAD AKASHAH BIN ROKY

Date : 14 September 2021

APPROVAL

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

....

(MDM RUZY HARYATI BINTI HAMBALI)

RUZY HARYATI BINTI HAMBALI
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka

ABSTRAK

Kajian yang bertajuk "The Effect of Thermal Responsive Material Polymeric Filament to Strength and Transformation in 4D Application" telah pun dilaksanakan. Tujuan keseluruhan kajian ini dijalankan adalah untuk menentukan kualiti filamen bahan pintar yang mempunyai sifat ingatan memori bentuk asalnya. Kajian ini dimulakan dengan pencarian dan pemahaman tentang bagaimana 4D printing berlaku dan juga kriteria yang ada pada bahan pintar ini. Bahan yang akan digunakan dalam kajian ini adalah bahan pintar yang bertindak balas dengan tindak balas haba kerana tindak balas ini menggunakan bahan pintar yang senang didapati kerana terbatas oleh wabak pandemik sekarang. Proses penghasilan 4D printed part akan dihasilkan dengan menggunakan Fuse Deposition Modelling (FDM) cara 3D print. Pengetahuan tentang proses mengendalikan 3D printing ini termasuk kriteria, bahan parameter dan juga karakteristik bahan tersebut untuk mencapai tujuan utama kajian ini. Dengan menggunakan permerhatian terhadap tindak balas hasil produk cetakan dan merekod pergerakannya dengan hasil tindak balasnya. Kertas kajian ini juga akan menerangkan tentang sifat mekanikal yang ada pada PLA tambahan kayu dan Thermoplastic Polyurethane (TPU) Dengan menggunakan ujian tegangan, Kekuatan bahan pintar akan dikenal pasti sebelum dan selepas tindak balas dengan rangsangan akan mengerluakan data analisa tentang sifat mekanikal bahan ini. Hasil penyelidikan ini menunjukkan bahawa bahan yang digunakan menunjukkan tindak balas yang positif terhadap stimulus yang diapllikasikan kepada bahan ujian. Kekuatan bahan yang dihasilkan juga di dalam tahap yang sama dikeluarkan oleh bahan PLA dan juga SMP itu sendiri. Perbincangan tentang kualiti bahan ini akan dibincangkan didalan kajian yang dilakukan ini.

ABSTRACT

Experimental research titled "The Effect of Thermal Responsive Material Polymeric Filament to Strength and Transformation in 4D Application" has been carried out. The main aim of this study is to determine the quality of smart material polymeric filament that have shape memory effect. Currently 4D printing application to the industry is low because of the material is still not universal. Further study on the material for 4D application still needed to make sure this application is more. Some material that recently used for 3D printing have potential in 4D application since the material is printing above melting and boiling temperature and this will cause the material to have special transition when certain temperature is applied on the material. This project starts with the study of and research on how 4D printing work and the characteristic of the smart material. Material that has smart properties is used in this project focussing on the material that react with thermo stimuli which known as simplest stimuli that the material could respond. The process of fabrication the printing part will be conduct by using Fuse Deposition Modelling (FDM) Additive Manufacturing (AM) method. Extensive information of AM process includes the composition of material, parameter of 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 Polylactic Acid (PLA) + Wood and Thermoplastic Polyurethane (TPU). Using tensile test, the strength of the smart material will be identified before and after the reaction with the stimuli and the Tensile test will reveal it mechanical properties especially its thermomechanical properties. The material gives positive feedback toward thermal stimuli when heat is applying toward the material, the samples start to bending and little twist. The mechanical properties show by the material after compared to the SMP also produce significant strength. The discussion on the quality of smart material will be discussed on this paper.

DEDICATION

TO MY DEAREST PARENT,

ROKY BIN YAACOB AND PHATIMAH BINTI ABD MUTALIB

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

MDM RUZY HARYATI BINTI HAMBALI

For her advice, support, motivations, and guidance

during accomplishment of this project

TO ALL STAFF & TECHNICIANS

For their direction and advice during completion of this project

TO ALL MY BELOVED FRIEND,

That support the accommodation and moral to finish the research

ACKNOWLEDGEMENT

"In the name of Allah, Most Gracious, Most Merciful"

First and foremost, I would like to take this opportunity to express my gratitude to my supervision lecturer Madam Ruzy Haryati Binti Hambali, for her enthusiastic support for science, the ink for knowledge and persistence in this research. I have been able to successfully complete my final year project without any difficulty.

I would like to thank University Technical Malaysia Melaka for their support which made this project happen. I would also like to express my thanks and gratitude to my friends for being helpful throughout the course and for their inestimable help. Their friendship and guidance were a strong wind that helped to safely lead this study to the port.

On the other hand, I also need to thank my family members, especially my father, Roky Bin Yaacob and Phatimah Abd Mutallib, for giving me motivation and support. These motivations have always driven me through a lot of hardship.

Finally, I would like to say thank you to all who contributed to this final year project paper, and I apologise for not being able to name each one of you individually.

TABLE OF CONTENTS

ABSTRAK	i
ABSTRACT	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xi
CHAPTER 1	**1**
INTRODUCTION	1
1.1 Project Background	1
1.1.1 Printing Device	2
1.1.2 Stimulus	2
1.1.3 Material and Design	3
1.1.4 Mathematical Modelling	3
1.2 Problem Statement	4
1.3 Objectives	5
1.4 Scope Of Project	6
1.5 Organization of Report	7
1.6 Summary	7
CHAPTER 2	**8**
LITERATURE REVIEW	8
2.1 Definition of 4D Printing to Additive Manufacturing	8
2.2 Additive Manufacturing process for 4D Printing	10
2.2.1 FUSED DEPOSITION MODELING (FDM)	11
2.2.2 Direct Ink Writing (DIW)	12

2.2.3 Inkjet 14
2.2.4 Stereolithography (SLA) 15
2.2.5 Summary On 4D Fabrication 16
2.2.6 Smart Material 17
2.2.7 Capabilities of smart material 17
2.3 Smart Material in 4D Application 18
2.3.1 Shape Memory Effect (SME) 19
2.3.2 Shape Memory Polymer (SMP) 20
2.3.3 Thermally induced SMP 21
2.3.4 Photochromic SMP 22
2.3.5 Hydrogels 22
2.3.6 Thermal Responsive Hydrogels 23
2.4 Self-Construction Structure 24
2.4.1 Containers 25
2.4.2 Surface Curving 25
2.4.3 Lockers And Safe Boxes 26
2.4.4 Multifunctional Materials 28
2.5 Shape shifting Behaviours 29
2.5.1 Shape Changing vs Shape Memory Materials 29
2.5.2 Dual, Triple and Shape Memory Effects 30
2.5.3 Folding vs Bending 31
2.6 Shape Shifting Type and Dimensions 32
2.6.1 1D to 1D Expansion/Contraction 32
2.6.2 1D to 2D Folding 33
2.6.3 1D to 3D Printing 34
2.6.4 1D to 3D Folding 34
2.7 Summary 35
CHAPTER 3 **36**
METHODOLOGY 36
3.1 Overview of the project flow chart 36
3.2 Data Collection on Material with Smart Material Properties and 4D Printing 38

3.2.1 Mechanism of responsive material on thermo responsive 38
3.3 Material Selection for 4D Printing 39
3.4 Designing the printing part by using CAD Modelling 40
3.4.1 Dog Bone Specimen 41
3.5 Creality Slicer 43
3.5.1 STL File Format 44
3.6 Fabrication 4D Printing 44
3.6.1 Fuse Deposition Modelling (FDM) 45
3.7 Heat Treatment 47
3.8 Deflection Measurement 49
3.9 Tensile Testing 50
CHAPTER 4 **53**
RESULT AND DISCUSSION 53
4.1 Fabricating Process 53
4.2 Heat Treatment 55
4.2.1 Deflection Result from The Effect of Thermal Responsive 56
4.3 Tensile Test 59
4.4 Tensile Test Analysis 60
4.5 Tensile Stress Curve 63
CHAPTER 5 **65**
CONCLUSION AND RECOMMENDATION 65
5.1 Conclusion 65
5.2 Recommendation of the study 66
5.3 Sustainability Element 67
5.4 Lifelong Learning Element 68
References 69
Appendices 1

LIST OF TABLES

Table 1 Characteristic difference between 3D and 4D printing (Bajpai et al., 2020) 9

Table 2 Table data record for the material response/5 minutes 49

Table 3 Parameter of Tensile test 52

Table 4 Deflection response on 60 ℃ 56

Table 5 Deflection response on 100 ℃ 57

Table 6 Deflection response on 140 ℃ 58

Table 7 Range of Max force & Tensile strength for PLA & SMP (Manufacturer e-Sun) 62

LIST OF FIGURES

Figure 2.2-1 3D printing system for smart material 10

Figure 2.2-2 The whole simulation process of fusion deposition (FDM). Illustration above Circular rings and square lattices based on polylactic acid (PLA) are printed using fusion. As heated to 90 C, deposition modelling (FDM) was converted to hexagons and quadrangles. (Chu et al., 2020) 12

Figure 2.2-3 2 Graphic example of a 4-dimensional (4D) printing ink direct typeface (DIW) example. (a) Micro-nozzle extruded ink UV-circulated (UV); (b) UV-positive ink; (Pei & Loh, 2018) 13

Figure 2.2-4 Diagram of stimuli smart material 18

Figure 2.3-1 A typical thermo-mechanical loading/unload in cycle in a SMP application 21

Figure 2.3-2 A hydrogel tensile specimen will swell at various temperatures: 20 °C, and 60 °C, Isopropylacrylamide, alginate and poly(N-isopropylacrylamide) (PNIPAm) ionic covalent inhalation (ICE). (Pei & Loh, 2018) 24

Figure 2.3-3 The printing pattern and various temperature stimuli created a cubic box. 24

Figure 2.4-1 An example of complect curve surface deformed 26

Figure 2.4-2 A sequentially folded stipe that can lock itself 27

Figure 2.4-3 Self Nested boxes that joint are print with different colours 27

Figure 2.4-4 Multifunctional material with tuneable poison's ratio 29

Figure 2.5-1 Illustration of the difference between one-way and two-way shape memory material (Hager et al., 2015) 30

Figure 2.5-2 Illustration of dual and triple SME (Hager et al., 2015), where A is the permanent shape 31

Figure 2.5-3 The difference folding and bending (liu et al., 2016) 32

Figure 2.6-1 The illustration of 1D-to-1D shape shifting by linear expansion/contraction adapted from (Raviv et al., 2014) 33

Figure 2.6-2 The illustration of 1D to 2D shape shifting by self-folding (Tibbits et al., 2014) 33

Figure 2.6-3 The transformation of 1D strand to 3D wireframe cube by self-folding (Tibbits et al., 2014) 35

Figure 3.1-1 Flow Chart of the project 37

Figure 3.4-1 Specimen design 40
Figure 3.4-2.5-2 Dimension of the specimen 41
Figure 3.5-3.6-1 The Enders 5 pro 3D FDM Machine 45
Figure 3.6-2 1 Parameter of printing PLA + Wood filament 46
Figure 3.6-3 Printing parameter for TPU filament 46
Figure 3.8-3.8-1 : Measurement that will be measured for observation 49
Figure 3.9-1 Shimadzu AGS-X at FKP lab 50
Figure 3.9-2 Stress-Strain Diagram (Y. Song et al., 2017) 51
Figure 4.1-1 Printing process of dog bone 53
Figure 4.1-2 3D printed sample of the PLA + wood filament 54
Figure 4.1-3 3D printed sample of the TPU 54
Figure 4.2-1 Specimen soaked in oil in the oven 55
Figure 4.3-1 Specimen of PLA + Wood After tensile test 59
Figure 4.3-2 Specimen of TPU after tensile test 60
Figure 4.5-1 Stress-strain graph for PLA + Wood 63
Figure 4.5-2 Stress-strain graph for TPU 63

LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
CNT	-	Carbon nanotubes
CVD	-	Chemical vapour deposition
DETA	-	Diethylene triamine
DMA	-	Dynamic mechanical analysis
DWCNTs	-	Double walled carbon nanotubes
MWCNTs	-	Multi walled carbon nanotubes
SOP	-	Standard operation procedure
SWCNTs	-	Single walled carbon nanotubes
1D	-	1 Dimension
2D	-	2 Dimension
3D	-	3 Dimension
4D	-	4 Dimension
CAD	-	Computer Aided Design
FEA	-	Finite Element Analysis
SM	-	Smart Material
PU	-	Polymeric Urethane
SMPE	-	Smart Material Polymeric Urethane
FDM	-	Fuse Deposition Modelling
SLA	-	Stereolithography
DIW	-	Direct Ink Writing
PLA	-	Polylactic Acid
SMA	-	Smart Material Alloy
SMP	-	Smart Material Polymer
SME	-	Smart Memory Effect
SMM	-	Smart Memory Material

CHAPTER 1

INTRODUCTION

This chapter gives a brief introduction of project's background based on the general information regarding the 4D printing and smart material polymeric with shape memory effects. The problem statement, objectives and scopes will also be explained in this chapter. Project planning and execution of this project, rationale of the project will also include in this project.

1.1 Project Background

According to the Nkosinathi (2018), 3D printing is a widely established method for the additive production of digital objects, for example computer-assisted modelling, for scholars, producers, and law firms to create unique 3D items (CAD). 4D printing is described by using AM for generating stimulation modules capable of changing shape or changing form in appropriate jolts without depending on mechanical technology or electromechanical gadgets, while 4D printing must be fundamental to form the reality of 4D in a matter of sections. The material used for 4D printing is reacts to its environment and changes over time and act as programmable matter to its function.

4D printing opens new areas of operation in which a system can be enabled by environmentally free energy for self-assembly, reconfiguration, and reproduction. There are several advantages of this technology, such as considerable reduction in storage room and enhancements to be produced by the flat kit of 4D impressed frameworks (Ge et al., 2016). Another example is that fundamental components from intelligent materials may be first printed 3D and then installed to create the ultimate complex shape rather than creating complex constructions using 3D design (Gardan, 2019).

4D printers are in their infancy, and substantial study is needed on the printing of broad clever structures in many segments of additive manufacturing. When evaluating all facets of this state-of-the-art technology, a completely new architecture strategy is proposed. For some crucial application, including artificial cardiac organs and cardiovascular stent, a dedicated 4D printing technique and printers can be created. A modern, dedicated printing application may be used to print biocompatible and biodegradable smart materials. The intelligent material may even be revealed, and the utilization of this intelligent material helps the business and material production. Following this analysis, the process of 4D printing and smart material reaction can be described by the mechanical characteristics of the smart material.

1.1.1 Printing Device

A very critical in 3D printer. Part of a 4D process which uses the instructions of the machine to create an object layer by layer with materials such as polymers, ceramics, and metals. The main manufacturers of 3D printers are Stratasys, ExOne, Materialise and Proto Laboratories. 4D printing goods are created with the addition of a single additive or by a combination of several intelligent materials and can be produced over time. The design changing processes of the whole device will lead to shifts in material properties such as memory of structure, thermal expansion, contraction or stretching.

1.1.2 Stimulus

Stimulus is important for promoting the accessibility, characteristics, and shape of the written system in the physical, chemical, and biological families, triggers can be categorized. Physical stimuli are temperature, humidity, electricity, and illumination. Chemical pH, ion pressure and chemical stimuli. Chemical stimuli. Glucose and enzymes are nevertheless considered to be a metabolic cause. Scientists used a mixture of sensations in 4D printing to produce printed parts, including heat and light, water, and temperature combinations.

1.1.3 Material and Design

The most important elements of 4D printing are sensitive fabrics and geometrical design. Memory, decision-making, self-sensation, self-healing, self-sufficiency and multifunctionality are the necessary class of materials. The structure of the printed components affected the material memory type greatly, which implies that optimal design is needed to restore the deep shape. The answer will exactly be regulated by the width of the text (Pei & Loh, 2018).

1.1.4 Mathematical Modelling

Mathematical simulation is essential for the creation of a variety of materials within the system to be spread. In nature, 4D printing relies on coordinating active and passive distribution of materials to carry out the desired actions. There are two to three stable states in the 4D printed structure, and the entire structure will change its condition if it is subjected to unique stimuli. Mathematical simulation of 4D printing is for three purposes.

I. Prediction of time-dependent change in form.
II. Preventing collusion between sections while self-assembly.
III. Reduction of different experiments.

The interaction function is most widely used to trigger a quick modification to a written form. The swelling effect is introduced by modelling in the form of memory polymers with the proper stimulus mixture.

1.2 Problem Statement

4D printing is characterized as the use of Additive Manufacturing to produce stimulus-responsive parts that. can change shape or work from one type to another, whether they are subjected to suitable stimuli without depending on robotics or electromechanical equipment. Conventional technology for 3D printing focus on manufacturing a single material static framework that cannot fulfil all complex requirements. Appliances such as soft grippers for service, self-folding and adaptive wind turbines include functions (z. Zhang et al., 2019) however, there are gap that 4D printing need to be focussed on the success to fabricate the part. First, the how must ensure that the material used for 4D printing is able to reacts to its environment and changes over time where act as programmable matter to its function. The final product of print by using this smart material is vague in term of the quality of the print stability of the quality of printing as compared traditional material filament used in 3D printing. The strength of the material with smart properties also need to be identified in any incremental strength to the product or parts or it is same after the product have been produce by using the additive manufacturing method (Tibbits, 2014). This is because the material reacts with the stimuli either it is stretch or shrink to another form of shape. The material needs to be tested to check either the strength is same as the 3D print or compare it due to the application of the product.

Not all stimulus-responsive components will experience the expected transition as they are exposed to maximal stimulus. It needs a fixed interaction process to schedule a series of pattern-shifting. actions when the cue is activated within an acceptable period. Mechanical loading approaches or strategies of physical process modulation must be configured to curve and momentarily program the framework for the recuperation of formal memory materials. It is essential for mathematical modelling. to plan the time series and stimulation appropriate for the stimulus-responsive section to work. This technique also involves configuration of material orientation and delivery for single 4D multi-materials printing, measurement of the different expansion or contraction speeds of each stimulation material to fully operate in an efficient auto-transformation device. (Huang et al., 2010). The mathematical simulation is normally carried out by computer-assisted-design (CAD) and final-element analysis along with geometrical programming (FEA). Before the 4D printing component is finished, concerns have to be discussed by the team.

Due to the distinct advantages and the challenging freedom of design, 4D printing predicted has a big part to play soon. Printed devices can be quickly distributed at subsidized rates with lower labour costs. Printed with an additive production component, self-actuators will enable researchers to invent intelligent devices without energy sources or batteries .(Chalissery et al., 2019). In various fields, 4D applications, for example organ and tissue engineering, bio-medical appliances, mobile devices, protection, and development were recorded. Smart buttons, regenerative modelling, electromechanical switches, smart garments and specially shaping surfaces for optics and soft actuators. This scandalous maturity innovation will in the foreseeable future be feasible for more implementations that seem to be incompatible.

1.3 Objectives

Based on the problem statement stated before, it is very crucial and essential to draw out the possible solutions to curb the problem. The objectives are as follow:

I. To study the various transformation and reaction polymeric filament of smart material in 4D application focusing on the thermal-responsive of the material.
II. To fabricate the thermal-responsive 4D smart material printing parts.
III. To determine the tensile strength of the thermal-responsive 4D parts.

1.4 Scope Of Project

This project will focus in fabricating the 4D printing and determining the quality of smart material polymeric filaments that have shape memory effect for the application of 4D Printing.

1. Extensive research, design, and printing 4D parts using PLA + Woods & Thermoplastic Polyurethane (TPU) that have thermal deformation in response to thermal stimulus.
2. Apply Additive Manufacturing Technology on fabricating the test specimen and 4D printing part by using Fused Deposition Modelling (FDM).
3. Examine and analyse the transformation of the smart material response to the temperature apply on the printed specimen by exposing on the temperature 60 °c, 100 °c, 140 °c.
4. Determine the quality of the 4D specimens focus on the strength of the printed part by using Ultimate Tensile Machine follow standard (ASTM D638)

1.5 Organization of Report

This project introduces the analysis and implementation of 4D printing material for the consistency of the intelligent material. Three chapters are included in this article. The first chapter outlines the context, purpose, issue statement and complexity of the project as a short introduction to the project. Chapter 2 provides a literary analysis of recent work on system and concept theory and practice. In this project, Chapter 3 explains examples of machinery, part, method, rule, and technique. For Chapter 4, the chapter for result and discussions will discuss the output that obtain from this study and lastly the last chapter which is chapter 5 and chapter 6 discussed on what need to be done in the future.

1.6 Summary

In this section, background of study related to 4D printing is made. The problem statement and objective are constructed which will be specific, measurable, and achievable. Next, the scope of the project is defined, and organization of report is made to describe the flow of the report in every chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss literature of 4D printing, smart material with all the criteria of other element, and lastly the reaction of stimuli for response on every factor by previous researchers. An overview of the 4D printing on its potential application, stimulus-responsive subject to specific stimuli on the smart material.

2.1 Definition of 4D Printing to Additive Manufacturing

AM is commonly referred to as three-dimensional (3D) printing. Common manufacturing technique due to its ability to create complex, personalized 3D computer-aided design (CAD) structures. 4D printing is a 3D material production technique that can change shape over time or in response to an environmental stimulus. This method reveals a fundamental change in additive manufacturing (Tibbits, 2014). Thanks to revolutionary advances in science and technology, the new twentieth century was contemporary. The most significant advancement between present 3D printing and traditional manufacturing capabilities is stated as a new principle of additive printing. 4D printing consists of an encapsulation of the latest additive production's other "Time" component and an additional dimension blueprint seen in the Abstract Graphics. 3D printing of time-dependent, sensitive, predictable, self-developing materials is called 4D printing (Zafar & Zhao, 2020). In 2013, MIT scientist Tibbit Skylar, the Self-Assembly Laboratory Director, unveiled and named the innovation. Researchers have refined the term as 3D-pressed structures that display targeted shape or transformation of properties under outside stimuli (J. Choi et.al 2015). Most of the research clearly focuses on the potential to alter the shape of 4D-printed structures, like folding, elongation, rotating and corrugating. This can be designed further to create lockers, lifts, microtubes, robotics and even dolls.

However, this property in crafted artifacts has not been reached until recently. The advancement of additive processing is at the centre of this study. Methods of printing using intelligent materials to build the constructs and metals in four dimensions. This 3D systems are interactive and can be self-transformed in response to programmed environmental factors such as energy, illumination, temperature or humidity to have a fourth dimension of time (Khoo et al., 2015). During printing, stimulation-responsive smart materials are used to build selective frameworks and configurations that offer the framework the ability to alter its function, shape or physical properties, such as the Youngs' module (Ramesh et al., 2018). After printed with shape shift capability the research focusses on the consistency of the intelligent content in 4D printing. The different characteristic between the 3D print and 4D printing are shown in the Table 2.1-1 below

Table 1 Characteristic difference between 3D and 4D printing (Bajpai et al., 2020)

Characteristics	3D Printing	4D Printing
Build Process	• Structure formed by sequential layering of 2D material "ink"	• Extension of 3D printing but with shape-memory programming step
Materials	• Thermoplastics, ceramics, metals, biomaterials, nanomaterials	• Smart materials: shape-memory polymers (SMP), shape-memory alloys (SMA), hydrogel composites, biomaterials,
Shape flexibility	• Creates rigid structure	• Characteristics of structure change upon exposure to external stimulus
Shape-memory programming	• No programming step	• Thermomechanical training, multi-material printing to create differential stresses
Applications	• Medicine, engineering, dentistry, automotive, robotics, fashion, aerospace, defence etc.	• Adds dynamic element to all 3D printing applications