DESIGN AND PRINTING OF ORIGAMI STRUCTURE WITH FUSED DEPOSITION MODELING 3D PRINTER

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

by

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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 Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

………………………...

(Prof. Madya Ts. Dr SHAJAHAN BIN MAIDIN)

ABSTRAK

Projek ini memperkenalkan teknik lipatan dari origami untuk berkembang dari bahan rata kepada keadaan penggunaan aplikasi pembuatan aditif. Kajian ini bertujuan untuk merancang pelbagai struktur origami dari teknik lipatan yang berbeza, memahami mekanisme asasnya, membuat model fizikal dan simulasi untuk menunjukkan dan membandingkan kemungkinan mereka. Lipatan gunung dan lembah, teknik lipatan lain dan bentuk origami, telah dikenal pasti. Semua konsep ini diterapkan dalam reka bentuk struktur origami. Bagi menentukan kebolehan struktur origami dalam lipatan, tujuh idea origami dikembangkan. Model ini dikembangkan menggunakan alat CAD (SolidWorks, Oripa, dan Origami Simulator). Tiga analisis pada tiga idea lipat telah menunjukkan hasil ubah bentuk reka bentuk menggunakan analisis regangan. Penyelidikan menunjukkan bahawa perubahan regangan pada lipatan mempunyai nilai selamat untuk dilipat berkali-kali. Perbezaan nilai regangan antara lembah dan gunung lipatan pada lipatan dengan lubang (regangan maksimum adalah 7.917E -03, regangan maksimum ketika lipatan berlaku 5.9387E -03) lebih rendah daripada lipatan tanpa lubang (regangan maksimum adalah 5.957E -03 , regangan maksimum ketika lipatan berlaku ialah 5.957E -03), membuktikan bahawa lipatan dengan lubang di titik tengah lebih kuat dan lebih selamat. Terakhir, Printer 3D FDM digunakan untuk menguji daya maju struktur origami pada bahan PETG. Hasilnya menunjukkan bahawa pencetak 3D FDM dapat membuat struktur origami dengan pelbagai reka bentuk origami dengan berkesan.

ABSTRACT

This project introduces folding techniques from origami to evolve from flat material to the additive manufacturing application's deployed state. This study aims to design various origami structures from different folding techniques, understand their underlying mechanisms, create physical models and simulations to demonstrate and compare their feasibility. Mountain and valley folds, among other folding techniques and origami shapes, have been identified. All this concept was applied in the design of the origami structure. To determine the structural abilities of origami on folding, seven origami ideas were developed. The model was developed using CAD tools (SolidWorks, Oripa, and Origami Simulator). Three analyses on three folding ideas have demonstrated the outcomes of design deformation using strain analysis. The research revealed that the change in the strain at the fold has a safe value for folding many times. The difference in strain values between the valley and mountain folds on folds with holes (maximum strain is 7.917E -03, maximum strain when folding occurs is 5.9387E -03) is lower than on folds without holes (maximum strain is 5.957E -03, maximum strain when folding occurs is 5.957E -03), proving that folds with holes in the center point are stronger and safer. Lastly, The FDM 3D Printer was used to test the origami structure's viability on PETG materials. The result demonstrates that an FDM 3D printer can create origami structures with a variety of design origami.

DEDICATION

Only

my beloved father, Hasan Bin Mohd

my appreciated mother, Jamilah Binti Husin

my adored sister and brother, Hasmawita, Jasny, Hafiz, Siti, Habib, Zulkifli, Faiz, Farah, Fazila, and Aina

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
FDM	-	Fused Deposition Modeling
FFF	-	Fused Filament Fabrication
SLS	-	Selective Laser Sintering
STL	-	Standard Triangle Language
CAD	-	Computer Aided Design
3D	-	3 Dimensions
2D	-	2 Dimensions
ABS	-	Acrylonitrile Butadiene Styrene
PLA	-	Polylactic Acid
DDM	-	Direct Metal Part Fabrication
STL	-	Standard Tessellation/Triangulation Language
RP	-	Rapid Prototyping
RM	-	Rapid Manufacturing

LIST OF SYMBOLS

Mm/min	-	Millimeters per minute
Vc	-	Cutting speed
Kg	-	Kilogram
g	-	Gram
Mm	-	Millimeters
Mm	-	Micrometers

CHAPTER 1

INTRODUCTION

This chapter introduces the project and briefly describes the study's objectives and scope. This chapter will give an overview of the implementation of the project.

1.1 Project Background

According to Wang et al., (2019), origami structures are typically created by folding a two-dimensional sheet that makes for a certain crease pattern. The presence of abundant crease patterns suggests that diverse sheet materials, including thin-walled tubes and arcs, can be used to create several three-dimensional structures. It is also possible to use certain origami structures as core structures, sandwich plates, or arches. On the other hand, other structures of this type may be stacked to form metamaterials, which are materials meant to contain properties that are not readily available in nature. Since these structures' mechanical efficiency generally depends on their geometry, these structures' properties may be built and modified by choosing and optimizing the necessary geometric parameters.

For train collision prevention, the suggested origami-inspired framework is successfully applied. In optimizing the IPCF for the energy absorption method, the optimum structure is greatly beneficial (Wang et al., 2019). Origami, also known as paper folding, has shown the ability to create 3D structures on a flat sheet from designed crease patterns. This paper proposes a common six-crease basis for making axisymmetric 3D origami. The crease lines' lengths may be normal or unusual, inspired by the conventional six-crease bases, i.e. the waterbomb base or Yoshimura base, where six regular crease lines converge at the inner vertex. The design of crease patterns is based on this process (Zhao et al., 2018).

On the other hand, additive manufacturing is an apt name to characterize the innovations that create 3D structures by applying material layer-on-layer, whether plastic, metal, concrete, or human tissue is the material. This distinction is important because the first suggests that the item is usually made using subtractive processing as a replica of traditionally manufactured things. In comparison, additive manufacturing, without subtractive manufacturing restrictions, opens up a world of design opportunities. Powder Bed Fusion, Binder Jetting, VAT Photopolymerisation, Layer Jetting, Material Extrusion, Sheet Lamination, and Guided Energy Deposition are the seven standardized AM technologies ASTM International (Pelleg, 2020).

Additive manufacturing (AM) varies fundamentally from standard formative or subtractive production. Instead of casting or forming through technology such as welding or machining, it is the nearest to 'bottom-up' construction where a structure can be formed into its planned shape using a 'layer-by-layer technique. AM is versatile, scalable, highly adjustable, and can suit most industrial development sectors. Materials may be of a generally differing form to produce these parts/objects. This involves metallic, ceramic, and polymeric materials and plastic, hybrid, or mechanically graded material blends (FGMs). However, the challenge persists to translate these 'making' types and mechanisms through the acquisition of usable objects. In AM, a great deal of work is needed to overcome the problems associated with its two main technologies: ' materials' and 'metrology,' to accomplish this capability in a predictive and reproductive manner (Tofail et al., 2018). In industry, "One production line produces the same products a thousand times over while maintaining the same quality," says Löber. The still-young technology will develop its full potential on a wide front and pave the way for new products in many industries only when this leap is successful. For example, lightweight and vibration-damping engine mounts are of interest. Additive manufacturing may contribute greatly to the realization of these specifications.

Many current researchers like Wagner et al., (2020) demonstrate novel metamaterials featuring unique properties by Combining patterns inspired by origami and additive processing. In particular, flexural hinges have distinct benefits for miniaturization and processing, but due to the hinges' restricted loading and fatigue tolerance, there are limited applications. This research focuses on measuring and characterizing flexural hinges' mechanical properties so that their results in 3D-printed origami structures could have immediate applications—aramid fiber composite hinge on equating it to a polyamide single-material hinge and a photopolymer multi-material hinge.

Metamaterials inspired by origami were designed, tested mechanically, and modelled. When using a triangular based crease pattern, one novel origami model was folded, and the other was folded using a rectangular based crease pattern. Metamaterial sheets inspired by origami were made from polylactic acid using fused deposition additive manufacturing (Wickeler & Naguib, 2020).

This project introduces folding techniques from origami to evolve from flat material to the additive manufacturing application's deployed state. A review of recent origami and kirigami techniques used for this purpose will be done to understand their underlying mechanisms and create physical models to demonstrate and compare their feasibility through fused deposition modelling 3D printer (FDM). Many current researchers like (Ceretti et al., 2017), (Heidari-Rarani et al., 2019),(D. Yadav et al., 2020), and (Helú & Liu, 2020) are interested about FDM 3D printer as a good platform to produce product by using the additive manufacturing application.

1.2 Problem Statement

A new class of mechanisms is termed Multiloop Origami-Inspired Spherical Mechanisms (MOISM). Typically, designers use well-known origami frameworks when new origami-inspired techniques are created. This methodology has limits on the current systems in origami. Using conventional origami designs as building blocks for intrinsic spherical mechanisms produces limited instruments. Each building block has only one loop in classical origami folds due to the constraint posed by the need for folds to overlap to make more complicated building blocks (Barreto et al., 2021).

Grey et al., (2020) stated that engineers should be careful when using paper to analyze origami structures' mechanical properties. Paper folds' non-linear, pseudo-plastic behavior complicates the simulation of an origami system's mechanical properties. The majority of origami models available are limited to the idealization of folds as zero-order geometric continuity creases, which are not suitable for origami structures of non-negligible fold thickness or maximal curvature folds constrained by material limitations (Peraza Hernandez et al., 2016).

A door hinge, a thick interpretation of a single line fold, is the simplest thick rigid origami structure. In this case, the rotational axis is located on the fold line's valley side. Axis-shift as the axis is pushed to the side of the thick panel's valley. Axis-shift can also transform a corrugated surface without internal vertex to a folding screen consisting of thick plate mechanisms, such as repeated mountain and valley patterns. This type of structure can fold and unfold completely from 0 to π. However, for a standard rigid origami mechanism with interior vertices, the axis shift approach is not always useful (Tachi, 2016).

1.3 Aims

This project aims to investigate origami structures that can create 3D geometries from flat materials or that have emerged as an exciting manufacturing paradigm on a broad range of length scales and can be particularly useful in cost-sensitive or planar-limited fabrication applications. The project aims to design various origami structures from different folding techniques, understand their underlying mechanisms, create physical models and simulations to demonstrate and compare their feasibility.

1.4 Objective

The objectives are as follows:

a) To design various origami structures from different folding techniques
b) To simulate and study the folding mechanism of the designed origami structures using SolidWorks and Oripa origami
c) To study the folding efficiency of the 3D printed origami specimen

1.5 Scope of the Project

This project focuses on designing and printing origami structures with fuse deposition modeling 3D printers (FDM). Thus, this project introduces folding techniques from origami to evolve from flat material to the deployed state for the additive manufacturing application in the case of study. The CAD model was designed using CAD designs, reducing product development cycle time, simulation on folding technique, and applying origami structure design to the fuse deposition modeling (FDM) 3D printer.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the design-related awareness of origami structure on additive processing for an application, advantages, disadvantages, and FDM machine parameters. The aim is to illustrate the origami model and procedures used in chronological order. The 100 percent origami structure theory will also be explored and turned into a product using the origami concept. Much of the references come from textbooks, papers, dissertations, and other tools.

2.2 Additive Manufacturing (AM)

2.2.1 Definition of AM

"Additive Manufacturing" (AM) is a layer-based automated fabrication process for producing scaled 3-dimensional physical objects immediately from 3D-CAD data without applying part-depending tools. It was called "3D Printing" and is still frequently called Additive manufacturing (AM) is an automated and revolving process built from the principle of layer-based technology. It is characterized by a process chain shown in Figure 2.1. It begins with the production represented by a (virtual) 3-dimensional CAD data set (solid). In engineering, 3D CAD design or scanning or other imaging methods such as computerized tomography scanning are usually used to collect data (CT-Scanning) (Gebhardt, 2011).

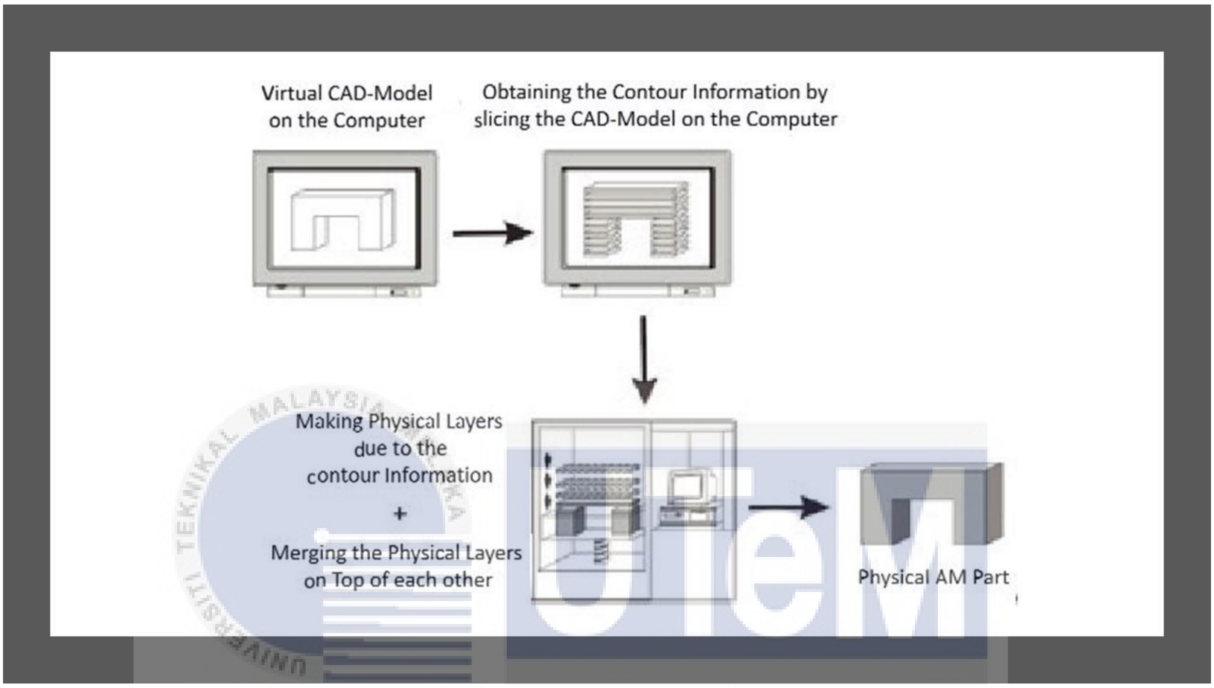

Figure 2.1: Additive Manufacturing process chain (Gebhardt, 2011).

AM technology involves three required steps (Huang et al., 2013):

a) A computerized 3D solid model is developed and transformed into a standard AM file format, such as the traditional standard tessellation language format (Kumar & Dutta, 1997) or the latest additive manufacturing file format.
b) The file is sent to an AM machine where it is manipulated, e.g., changing its position and orientation or scaling the part.
c) The part on the AM computer is assembled layer by layer.