INTEGRATION OF TOPOLOGY OPTIMIZATION AND DESIGN SELECTION FOR 3D PRINTING PRODUCT

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This report is submitted in fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this project report entitled “Integration Of Topology Optimization And Design Selection For 3d Printing Product” is the result of my own work except as cited in the references

Signature	:	....
Name	:	....
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design & Innovation).

Signature	:	....
Supervisor's Name	:	....
Date	:	....

DEDICATION

To my beloved parents, siblings, and friends, all of whom I adore. Their support and inspiration have been a constant source of encouragement and motivation for me throughout my life.

ABSTRACT

Layer-by-layer material deposition techniques are used in additive manufacturing (AM) procedures in order to produce complicated shapes. Designers may express themselves more freely via the use of these procedures, which are well-known for producing intricate structures that would be impossible to make otherwise. It is possible to modify technical processes and redesign items thanks to the advancement of additive manufacturing. Design optimization via the integration of topology optimization techniques is one of the most often used approaches to assist additive manufacturing, and it allows for the creation of complicated forms. Using Topology Optimization (TO), this research offers a comparison of design processes for Fused Deposition Modelling (FDM) 3D printing and gravity die casting with the objective of decreasing the mass of a Steel Clevis Bracket while fully satisfying the design limitation. You may mount a cylinder or even an ordinary rod on any flat surface with this bracket. It is specifically designed for 3D printing and uses a limited topology optimization method for component development. With the help of a simulation, the advantages of the proposed FDM 3D printing design framework are shown and confirmed. The simulation shows a 14% increase in factor of safety and a 39% decrease in the bracket's weight. The reduction in production time and cost are among the other benefits discovered. Traditional manufacturing has many design restrictions that FDM 3D printing overcomes.

ABSTRAK

Teknik pemendapan bahan lapisan demi lapisan digunakan dalam prosedur pembuatan tambahan (AM) untuk menghasilkan bentuk yang rumit. Pereka bentuk boleh mengekspresikan diri mereka dengan lebih bebas melalui penggunaan prosedur ini, yang terkenal kerana menghasilkan struktur rumit yang mustahil untuk dibuat sebaliknya. Ia adalah mungkin untuk mengubah suai proses teknikal dan mereka bentuk semula butiran atas sebab kemajuan pembuatan tambahan. Pengoptimuman reka bentuk melalui penyepaduan teknik pengoptimuman topologi adalah salah satu pendekatan yang paling kerap digunakan untuk membantu pembuatan bahan tambahan, dan ia membolehkan penciptaan bentuk yang rumit. Menggunakan Pengoptimuman Topologi (TO), penyelidikan ini menawarkan perbandingan proses reka bentuk untuk cetakan 3D Pemodelan Pemendapan Terlakur (FDM) dan penuangan beracuan dengan objektif untuk mengurangkan jisim Pendakap Clevis Keluli sambil memenuhi had reka bentuk sepenuhnya. Anda boleh memasang silinder atau rod biasa pada mana-mana permukaan rata dengan pendakap ini. Ia direka khusus untuk pencetakan 3D dan menggunakan kaedah pengoptimuman topologi terhad untuk pembangunan komponen. Dengan bantuan simulasi, kelebihan rangka kerja reka bentuk pencetakan 3D FDM yang dicadangkan ditunjukkan dan disahkan. Simulasi menunjukkan peningkatan 14% dalam faktor keselamatan dan penurunan 39% dalam berat pendakap. Pengurangan dalam masa dan kos pengeluaran adalah antara faedah lain yang ditemui. Pembuatan tradisional mempunyai banyak halangan reka bentuk yang diatasi oleh percetakan 3D FDM.

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Faiz Redza Bin Ramli from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this project report. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

Special thanks to UTeM short term grant funding for the financial support throughout this project. Particularly, I would also like to express my deepest gratitude to all my peers, my beloved mother, father and siblings for their moral support in completing this degree. Lastly, thank you to everyone who had been to the crucial parts of realization of this project.

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LIST OF ABBEREVATIONS

3DSP	3D Sand Printing
AM	Additive Manufacturing
CAD	Computer Aided Design
TO	Topology Optimization
FEA	Finite Element Analysis
UTS	Ultimate Tensile Strength
SIMP	Solid Isotropic Penalty Material
DED	Directed Energy Deposition
ASTM	American Society for Testing and Materials
LENS	Laser Engineered Net Shaping
UV	Ultraviolet
EBM	Electron Beam Melting
SLS	Selective Laser Sintering
SHS	Selective Heat Sintering
LOM	Laminated Object Manufacturing
UAM	Ultrasonic Additive Manufacturing
SLA	Stereolithography
DLP	Digital Light Process
FDM	Fused Deposition Modelling
UTM	Universal Testing Machine

LIST OF SYMBOLS

F	=	External load
K	=	Stiffness matrix
u	=	Displacement of F
ρ_e	=	Pseudo-density of e
v_e	=	Volume of e
e	=	Element
V	=	Maximum allowed design volume

CHAPTER 1

INTRODUCTION

1.1 Background

3D sand-printing (3DSP) is a technique for creating physical items from a geometrical abstraction by adding layers of material one at a time. This 3D method has seen tremendous growth in recent years, with many people claiming it to be the most advanced in the world. Charles Hull was the first to commercialize 3D printing technologies, which occurred in the year 1980 (Shahrubudin et al., 2019). In contrast to conventional manufacturing methods such as subtractive, formative, and joining procedures, 3DSP or additive manufacturing (AM) fabricate a component layer by layer from a 3D model of the target component. Vat polymerization, sheet lamination, material extrusion, material jetting, binder jetting, powder bed fusion, and direct energy deposition are several additive manufacturing techniques (Wang et al., 2019).

Complex components, such as high-performance parts or highly customized and specialized parts, may be created utilizing additive manufacturing technology. It is now feasible to create components for practically any application or in virtually any shape or size. It is feasible to produce batches of unique components since component complexity and geometrical characteristics have little impact on product cost and manufacturing time. The ability to create prototypes and end-use components in a timely way is now possible because of the direct link between a computer-aided design (CAD) model and a produced component (Dalpadulo et al., 2020).

The outcome has been the replacement of various breakthroughs by additive manufacturing, despite the fact that this requires a full redesign of both the product and the manufacturing process. In the past, other technological advancements have impacted the manufacturing of parts and components as well. During the 2000s, for example, metal substitution or metal to plastic replacement became one of the most significant industry trends, impacting a broad variety of sectors and continuing to this day. In a similar vein, although more recently, AM technologies have played a similar role. The primary goal of these developments is to develop components that are lighter and more cost-effective to manufacture. AM will also benefit from its connection with topology optimization (TO), which may result in complicated morphologies and free form models, in addition to an increase in product customization.

To maximize the performance of the geometry, topology optimization (TO) is used. It is an optimization method that repeatedly determines the optimum arrangement of material in a component within a design space for a given combination of loads, boundary conditions, and restrictions. Many studies have emphasized TO's capacity to construct buildings that are both lightweight and structurally optimized. When it comes to the manufacturing of optimum design structures, it has been shown that AM makes full use of the advantages of TO, which are methods that have been used in traditional sand casting to redesign cast components and riser designs to improve yield and quality.

Traditional sand casting in metal castings provides only a limited amount of design flexibility due to the process's inherent design and production constraints. The rules for casting quality control and the regulations for mould-making are the two significant kinds of component construction regulations that must be followed in conventional sand casting. They are as follows: rules for casting quality control and regulations for mould-making. For quality control purposes, casting rules refer to those that govern filling, solidification, and distortion, such as minimum wall thickness, uniform sections, fillets, intersections, and axial solidification. On the other hand, Mould-making rules relate to component design restrictions that must be fulfilled for mould manufacturing to be successful before metal pouring. Examples include having consistent and plane parting lines, draught along the walls, and avoiding characteristics like as undercuts to remove a design from moulding sand without harming it successfully. The need to devote significant time and money to pattern and core box tooling and the storage and ultimate wear of component features resulting from this wear is an essential issue in the sand-casting manufacturing process.

On the other hand, three-dimensional solidification (3DSP) offers foundries a cost-effective and time-efficient method of producing moulds and cores for highly intricate. Also, specialized low-volume castings that would otherwise be prohibitively expensive to produce using traditional sand-casting methods.

1.2 Problem Statement

In general, a bracket is a tool used to secure a cylinder or a simple rod to a surface. The cylinder or the plain rod is often used to secure a large amount of weight. This is why the bracket is constructed of heavy-duty materials such as steel or iron, which allows it to bear a significant amount of weight. There are many different sorts of brackets, and each of those brackets is specifically designed to complement the architecture of a system while also providing the same function. The design of a Steel Clevis Bracket manufactured by a firm known as Parker Hannifin Corporation is chosen as the topic of this research project. It can be noticed that the design of this bracket has a solid flat surface and that there hasn't been any optimization done in the process. The Steel Clevis Bracket's mass may be lowered by using TO, and at the same time, its form will be altered while the size and qualities of the bracket remain same.

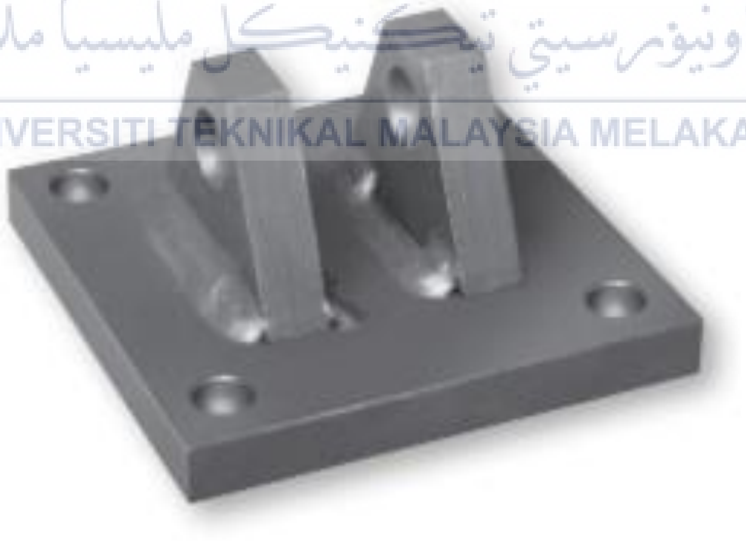

Figure 1.1: Steel Clevis Bracket

1.3 Objectives

The objectives of this project are as follows:

1. To reduce the mass of the steel clevis bracket without compromising the other relevant factors by using topology optimization tools in Solid Thinking Inspire.
2. To compare between traditional casting and 3D Printing process in term of material, cost and time.

1.4 Scope of Project

The scopes of this project are:

1. Comparison between conventional and AM method for the clevis bracket are studied in this report.
2. Topology optimization of the bracket is simulated through a software, SolidThinking Inspire.
3. Simulation of conventional and AM process using Inspire and Ultimaker Cura software.
4. Produce the component by utilizing the AM process available.

CHAPTER 2

LITERATURE REVIEW

2.1 Alcoa Aircraft Bracket Case Study

In this case study, a desired metal part for a basic mechanical loading application was created using a 3D-printed sand mould, and the component was cast using the mould. Design guidelines that had been devised for 3DSP, as well as casting limitations, were put into practice. Mechanical testing was carried out on the finished part to ensure that the design framework had been thoroughly validated. Four high-strength bolts secure this bracket to the control surface, which makes it a popular component on control surfaces, as in Figure 2.1.

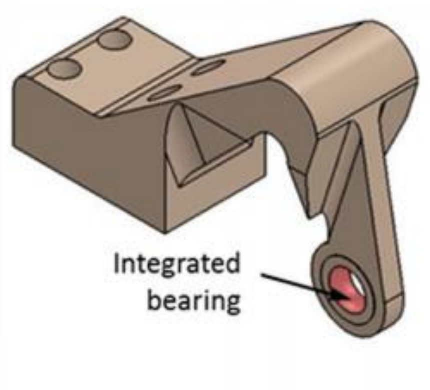

Figure 2.1(a): Alcoa bracket

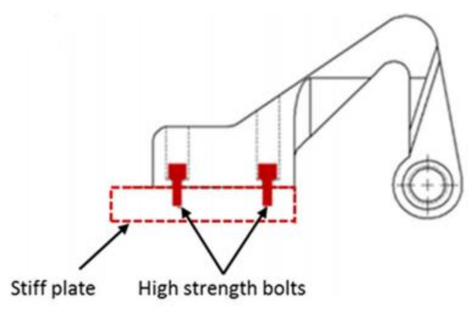

Figure 2.1(b): FBD of Alcoa boundary conditions

Topology optimization was carried out in Abaqus CAE 6.14, which is a topological optimization software package, using the Abaqus Topology Optimization Module as the primary tool (ATOM). ATOM is a SIMULIA TOSCA-based tool that integrates structural optimization with Abaqus finite element analysis. In Abaqus CAE, the desired bearing bracket was imported as a STEP file, and it was then modified. It was necessary to add four bolts and the area that interacted with the bearing in this example to be considered non-design space (Ntintakis et al., 2020). The design space was defined as the portion of the bracket that was not used. The stiff spherical bearing was excluded from the assembly in order to make the TO setup more straightforward. Instead, a kinetic coupling interaction was introduced between the surface supporting the bearing and the spherical centre of the bearing to imitate the movement of the bracket when a load is applied to it. This interaction might retain the geometry of the surface while forcing the surface to move in the same direction as its centre, allowing loads to be delivered directly to the centre of the surface.

Figure 2.2(a): Original loading conditions

Figure 2.2(b): Assumed loading condition

The bracket was tested under three different load situations in the original Alcoa challenge, as in Figure 2.2(a). Meanwhile, Figure 2.2(b) shows an example of how the authors assumed that the bracket was only subjected to one load F_{TO} for the sake of this case study. A value for F_{TO} was computed so that the goal bracket has a safety factor of one to make it easier to compare the performance of the bracket before and after topology improvement. The permanent bounds were the non-design area, which was marked by the presence of four bolts. However, it should be emphasized that in this research, class 30 grey cast iron metal is employed instead of the original stainless steel 15-5PH metal that was recommended in the design competition (Hu et al., 2020). This is due to the melting restrictions imposed by the furnace to which the authors have access, which makes it impossible for them to melt all of their materials. The authors' principal goal, which seems to demonstrate that complicated topology-optimized structures may be cast quickly and efficiently without sacrificing their mechanical qualities, would not be affected by this adjustment. The Alcoa Bracket was selected not because it standardized qualities but rather because of its recognition in the structural optimization business, and therefore casting this difficult part will indeed effectively demonstrate the capacity of the AM process. Because Class 30 grey cast iron seems to have very low ductility, mechanical characteristics were specified in Abaqus CAE using both the elasticity and cast-iron plasticity models. 57 Material data, such as density, Young's modulus, Poisson's ratio, and hardening curves under tension and compression, were uploaded into Abaqus using a spreadsheet programme.

To decrease the volume of the bracket by 60 percent, TO was conducted on the bracket. The resultant design was saved as an STL file, imported. SolidThinking Inspire 2016 and SolidWorks 2016 were used to enhance and revise the final product. The PolyNURBS tool in Inspire was used to produce a solid body from the extracted mesh. The solid-body was based on the extracted mesh. PolyNURBS is a robust approach for generating smooth freeform solid bodies from meshes that is easy to learn and use. Part design changes were carried out over this solid object and use the same tool and redesign