MODELING OF GENERATIVE DESIGN FOR WIRE ARC ADDITIVE MANUFACYURING (WAAM)

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MODELING OF GENERATIVE DESIGN FOR WIRE ARC ADDITIVE MANUFACYURING (WAAM)

ABSTRACT

Generative design is a new design method that can generate many qualified models in a short period of time, which is very innovative and convenient. As a kind of additive manufacturing technology, wire arc additive manufacturing technology has a very wide range of applications, the wire size of wire arc additive manufacturing technology determines that it can be used to manufacture special parts of generative design models. For the generative design method and wire arc additive manufacturing, the report has carried out a very detailed introduction. This research also used Autodesk Fusion360 software to explore generative design, and performed shape optimization analysis on conventional model, and then performed static stress analysis on the model after generative design and shape optimization analysis. Through the comparison of static stress analysis results, a model that is more suitable for arc additive manufacturing is selected. Finally, a generative design guide that can be manufactured by arc additive manufacturing technology is initially explored, and future research work is prospected.

Keywords： Generative design， Wire arc additive manufacturing， Autodesk Fusion360，Static stress analysis

PEMODELAN REKA BENTUK GENERATIF UNTUK PEMBUATAN TAMBAHAN ARC WIRE (WAAM)

ABSTRAK

Reka bentuk generatif adalah kaedah reka bentuk baru yang dapat menghasilkan banyak model yang memenuhi syarat dalam jangka waktu yang singkat, yang sangat inovatif dan mudah. Sebagai sejenis teknologi pembuatan aditif, teknologi pembuatan aditif busur wayar mempunyai berbagai aplikasi yang sangat luas, ukuran dawai teknologi pembuatan aditif busur wayar menentukan bahawa ia dapat digunakan untuk pembuatan bahagian khas model reka bentuk generatif. Untuk kaedah reka bentuk generatif dan pembuatan aditif busur wayar, laporan ini telah membuat pengenalan yang sangat terperinci. Penyelidikan ini juga menggunakan perisian Autodesk Fusion360 untuk meneroka reka bentuk generatif, dan melakukan analisis pengoptimuman bentuk pada model konvensional, dan kemudian melakukan analisis tegangan statik pada model setelah reka bentuk generatif dan analisis pengoptimuman bentuk. Melalui perbandingan hasil analisis tekanan statik, dipilih model yang lebih sesuai untuk pembuatan adc arc. Akhirnya, panduan reka bentuk generatif yang dapat dihasilkan oleh teknologi pembuatan aditif arka pada awalnya diterokai, dan kerja penyelidikan masa depan dicari.

Kata kunci: Reka bentuk generatif ,Pembuatan bahan tambah wayar ,Autodesk Fusion 360,Analisis tekanan statik

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CHAPTER 1: INTRODUCTION

1.1 Project background

The wire arc additive manufacturing technology uses layer-by-layer surfacing to manufacture dense metal solid components. Because the arc is used as the energy beam, the heat input is high and the forming speed is fast. It is suitable for large-size complex components with low cost, high efficiency and rapid near-net forming. Its structural parts are gradually developing towards large-scale, integrated, and intelligent development, so this technology has incomparable efficiency and cost advantages in the formation of large-size structural parts that other additive technologies cannot match. The research of wire arc additive manufacturing has always been the focus of additive manufacturing technology and has very necessary research significance. The use of this technology must establish a model on the computer before manufacturing. Generative design is a design exploration method that uses cloud computing to find a new generative design solution. Therefore, it does not need to design separately like traditional design methods, and many design results that meet the conditions can be obtained very quickly.

The purpose of this research is to explore a modeling method that uses generative design methods, and can be manufactured by wire arc additive manufacturing technology. This is a very new exploration, so the research will be carried out from a simple part to lay the foundation for further research in the future.

1.2 Problem statement

Wire arc additive manufacture (WAAM) is an additive manufacturing technology that can produce near net-shape parts layer by layer in an automated manner using welding technology controlled by a robot. WAAM has been shown to produce parts with good structural integrity in a range of materials including titanium, steel and aluminium and has the potential to produce high value structural parts at lower cost with much less waste material and shorter lead times that conventional manufacturing processes. Generative design is an iterative design process uses advanced algorithms to find the best solution for the design. It usually relies on computers and artificial intelligence. Although the algorithm could propose the best design solution, but sometime the solution itself is not able to manufacture. There is also lack of information related to generative design development in WAAM.

1.3. Research objective

I. To generate new component using generative software.

II. To investigate stress analysis of the generative design using simulation software

III.Select models suitable for manufacturing by wire arc additive manufacturing technology

1.4 Project scope

The evolution of how product is manufacture using additive manufacturing technique has developed tremendously in the last decades. Currently, there is fast and high variation in the design of products, which require fast and efficient in the design and manufacturing process due to very high market competition. Design for additive manufacturing (DFAM) is one of the important methods for obtaining this global competition in terms of manufacturing. The manufacturing research is always focusing on developing and using manufacturing processes with lower cost and waste, and higher production rate.

This research mainly focuses on the combination of generative design method and wire arc additive manufacturing technology, and all adopts simulation method.In this research the modeling technique for generative design wire arc additive manufacturing (WAAM) is investigate. The performance of generative design is simulated to select the optimize design that is able to produce through WAAM process. （need to modify design ， stress analysis）

1.5 Report outline

The content of this report is mainly divided into five parts: introduction, literature review, methodology, results and discussion, summary and outlook. The first part mainly introduces the background of this research, the problems faced and the research objective; the second part mainly introduces the previous research on related content, including the introduction of additive manufacturing technology, the introduction of arc additive manufacturing technology, generative design, etc.; the third part is a demonstration of a specific process of this research method, showing which processes are needed and the specific important steps of each process; the fourth part is an analysis of the process results made in the third part , and discussed the reasons for this result and the suggestion that need to be taken; the fifth part is a summary and outlook, summarizing the general process of all the work, because the semester is short, so the future research work is prospected.

CHAPTER 2: LITERATURE REVIEW

2.1 Additive manufacturing technology

In recent years, the manufacturing industry in countries around the world has developed rapidly. Compared with the traditional subtractive manufacturing technology, the rapid development of additive manufacturing (AM) technology has attracted the attention of industries such as aerospace and biology. The appearance of parts is diversified. A series of advantages such as high utilization rate of materials and manufacturability of functionally graded materials. Now in the manufacturing industry, common metal additive manufacturing technologies can be divided into electron beam selective melting (EBSM), selective laser melting (SLM), laser engineered net shaping (LENS), and wire arc additive manufacturing (WAAM) according to the different raw materials used in the manufacturing industry. Among them, wire arc additive manufacturing uses electric arc as heat source and filler wire as raw material, and the technology itself has the advantages of high accumulation rate, high material utilization, low cost and suitable for manufacturing large components, which is becoming a kind of development potential..

With the development of manufacturing technology, the manufacturing of various key metal components is developing in the direction of high efficiency, intelligence, and greenness. Additive manufacturing technology will be applied more and more widely to adapt to the future development trend of manufacturing industry.

2.2 Wire arc additive manufacturing

As early as 1920, the manufacturing industry had a patent for using fusible electrodes to stack metal ornaments with metal. With the advancement of science, the related technology of how to obtain a circular cross-section pressure vessel by gradually accumulating weld metal is further explained. Since then, the development of computer technology and its wide application in the manufacturing field, digital welding technology and numerical control equipment have completely changed and redefined the wire arc additive manufacturing technology. In the past ten years, the wire arc additive manufacturing technology has attracted the attention of the majority of researchers and developed rapidly due to its unique advantages. Wire arc additive manufacturing technology is suitable for the manufacture of carbon steel, aluminum alloy, titanium alloy, nickel-based alloy and memory alloy. Compared with the conventional subtractive manufacturing technology, the wire arc additive manufacturing system can reduce the manufacturing time by 40% to 60% and the post-processing time by 15% to 20%.

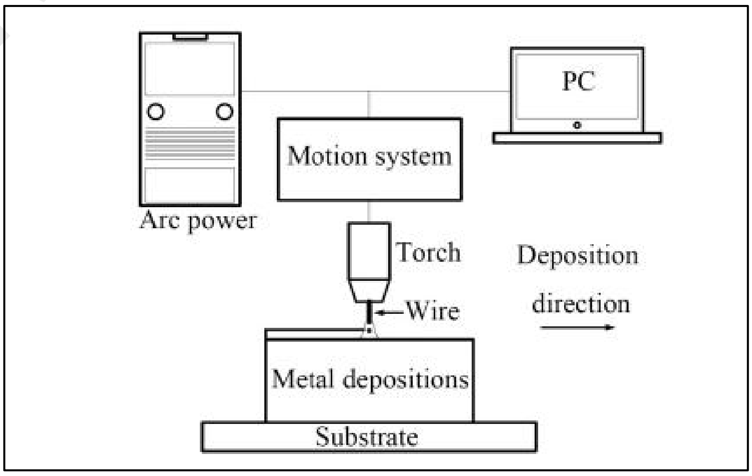


Figure 2.1: Flow chart of wire arc additive manufacturing

The wire arc additive manufacturing (WAAM) technology uses an electric arc as a heat source to heat and melt the metal wire, and the molten metal is stacked layer by layer on a path set by a computer program to realize the formation of three-dimensional solid components. Compared with laser and electron beam additive manufacturing technology, wire arc additive manufacturing technology has the following characteristics:

(1)Wire arc additive manufacturing adopts arc melting wire, and the melting efficiency of a single wire can reach 3-6 kg • h-1, with high forming efficiency and low cost.

(2)Wire arc additive manufacturing has a higher degree of freedom. The wire arc additive manufacturing drive equipment is a multi-axis robot that can achieve high-degree-of-freedom, high-flexibility, and arbitrarily complex space path manufacturing.

(3)Wire arc additive manufacturing is suitable for forming large complex components. The wire arc additive manufacturing forming environment is open, and there are no restrictions on the size of the components.

(4) Wire arc additive manufacturing is widely used in the manufacture of aluminum alloy components. Aluminum alloy has a high reflectivity to laser, so when using laser additive manufacturing to manufacture aluminum alloy components, the forming efficiency is low, and defects such as pores are prone to occur in the components. The heat source of wire arc additive manufacturing is electric arc, which can fully melt the aluminum wire, and at the same time the forming environment is open. Therefore, the high-efficiency and high-quality manufacturing of large-size aluminum alloy

components can be realized.

(5) Wire arc additive manufacturing facilitates component repair. Laser and electron beam additive manufacturing have a limited forming environment and a low degree of freedom in manufacturing. Therefore, it is difficult to repair the local damaged location of large components. The wire arc additive manufacturing technology has an open forming environment and a high degree of manufacturing freedom, and it is easy to perform accumulation repairs on any local position of large-scale components.

Due to a series of advantages of wire arc additive manufacturing technology, it has important applications in manufacturing. The research on wire arc additive manufacturing technology is very important. After the emergence of new design technologies in the future, the combination of the two will certainly produce more advanced manufacturing methods.

Figure 2.2: Wire arc additive manufacturing machine

2.3 Generative design

At present, traditional industrial design is the use of creativity by the designer, sketching and final rendering on paper or on a computer, and one or several design schemes can be drawn; while the derivative design is designed by the computer and the designer together: Input the design goals and constraint parameters into the software. The software uses artificial intelligence algorithms and cloud computing capabilities to generate hundreds of design schemes that meet the parameter conditions for users to choose. Generative design is a design method that imitates the evolution of nature. At the same time, generative design also shows another advantage of it-component integration, that is, the new component integrates the original 8 different components into one integration This will greatly shorten the product development process. The integrated parts printed by three-dimensional printing can reduce the weight of the parts by 40% and increase the strength of the parts by 20%.

The steps of generative design: (1)The designer inputs the product he wants to design, and adds constraints such as weight, cost, material, strength, etc. (2)The computer uses algorithms and AI to produce thousands of designs, and performs performance analysis and recommendations for each design at the same time. (3)The designer studies the design options given by the computer, and increases or decreases the design goals and modifies the parameters when necessary. This allows designers to enter the design iteration, where computers use AI to create pre-verified solutions. (4)Export files and generate prototypes. Designers or engineers use 3D printing or other methods to manufacture products. If they are not satisfied with the results or want to explore other options, they can repeat the third step as needed.

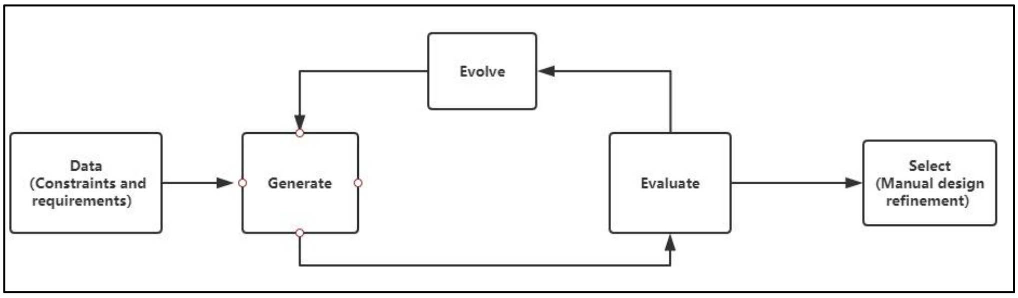


Figure 2.3: Generative design flow chart

Compared with normal designers, designers who use generative design can quickly complete the design of the first draft and even the final draft, and there is almost no problem that the design drawings cannot be realized or applied, and they have a great advantage in the completion efficiency of industrial projects. Even for projects that do not involve more complex projects, designers can be replaced by decision makers with strong aesthetic ability. Therefore, for designers who use the original design method, the impact is relatively large. In the near future, it will be necessary for them to use skillfully and explore unique design methods on this basis. For the field of industrial design, generative design brings more possibilities. Combining arc additive manufacturing technology can complete industrial projects that were difficult to complete before. Of course, in three to four years or even more than ten years, the bio-design will basically only affect the industrial fields involving high-tech, national defense and military industry, aerospace, and automobiles. The impact on other industrial design directions is almost negligible, but exploration and research in these directions can be carried out in advance.

2.4 Application of generative design

The use of generative design technology did not start in the past two years. As early as 2015, aviation giant Airbus cooperated with Autodesk to develop a large-scale "bionic" cabin isolation structure for its Airbus A320 aircraft. It is 3D printed using a new super strong and lightweight alloy material called "Scalmalloy" using direct metal laser sintering forming technology. Compared with the previous isolation structure, the new type of bionic isolation structure is composed of several different components, which is not only stronger and half the original mass, but also requires a 95% reduction in the material required for each partition. It is estimated that 3180 kg of fuel can be saved a year, and each Airbus A320 can reduce carbon emissions by 166 tons a year.

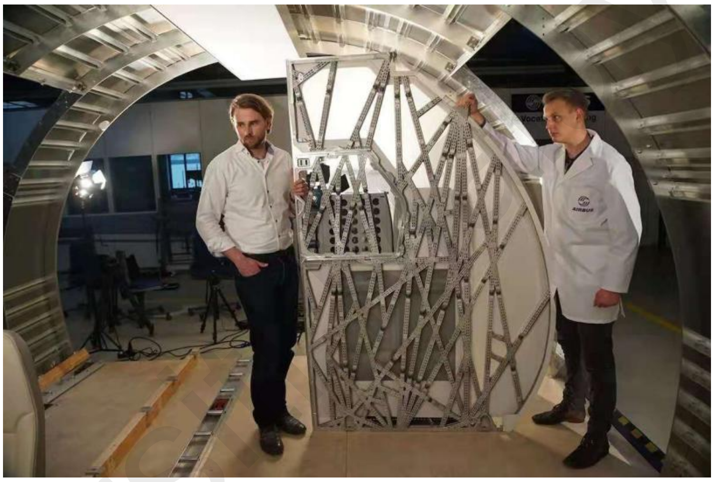


Figure2.4: Large-scale "bionic" cabin isolation structure for Airbus A320 aircraft

As the generative design technology matures, Airbus can use generative design to create a 3D printed plastic model for the partition, and then cast the components into alloys that can be used for flight. The second-generation bionic partition is as strong and light as the first-generation design, and is more suitable for mass production. Currently, Airbus is using generative design to reconsider the construction of other structural components of the aircraft, including the leading edge of the A320 vertical tail (VTP). The function of VTP is to provide directional stability and reduce aerodynamic inefficiencies caused by lateral movement.

In 2018, General Motors and Autodesk cooperated with the goal of developing future passenger cars and trucks with generative design and additive manufacturing as the core technologies, including the development of more efficient and lighter electric drive systems and zero-emission vehicles. According to GM' s vision for the future, cars and other models will reduce weight and materials, which will not only save fuel, reduce exhaust emissions, save money for car owners, but also increase the cruising range of electric vehicles and provide car owners with more spaciousness.

After Curiosity, the NASA research team set out to study the lander that can fly to Saturn and Jupiter all the time. How to reduce the weight of the lander has become a very important issue. NASA sent a research team to conduct research and development with the Autodesk research team, applied generative design, and used a variety of non-3D printing processing methods such as CNC milling and lost foam (3D printing components are not allowed in the aerospace field), which is the basis for ensuring strength The weight has been reduced by 35%. In November 2018, the landing warehouse prototype of the first version of the lander was released on-site at AU in the United States.

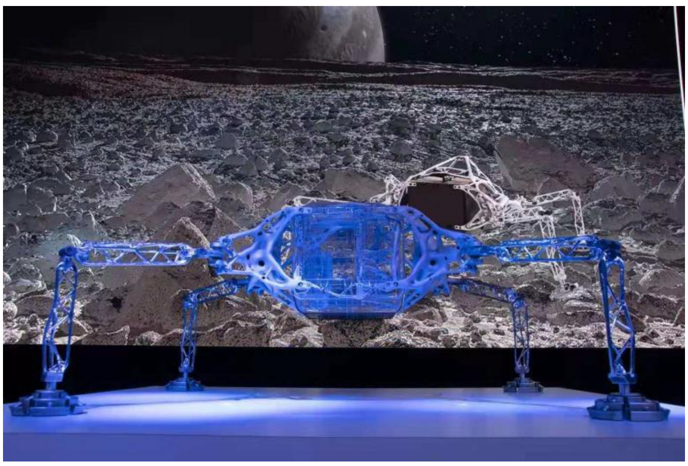


Figure2.5: Lander designed by generative design method

2.5 Research gap

In 2011, Sivam proposed an exploration method based on generative design. Construct the genotype of the design based on the parametric CAD system, and then randomly change its parameters within a predefined range to generate a set of unique designs, and finally achieve the cost-saving requirements.(Sivam,2011) In 2018,aiming at the problem of insufficient movement ability and flexibility of the biped robot, Ge used generative design methods to design a more lightweight leg structure for the purpose of lightweighting important parts of the robot, and then optimized the optimized leg structure. The structural model is simulated and analyzed.(Ge,2019) In 2020 ,a paper researched that the truck crane turntable is the core component connecting the boom and the chassis frame, and its stiffness and strength directly affect the performance of the crane. In order to realize the lightweight and innovative design of the turntable, a derivative design was carried out on the turntable of the truck crane.(Yang,2020)

In summary, the main purpose of this research is to explore the relationship between generative design and wire arc additive manufacturing technology. Generative design is a new technology, and there is very little research on it now, so there is no specific guide for the research process. Autodesk Fusion360 is also a new software. This study is going to use it to explore the process of generative design and simulation. The final result can be manufactured using wire arc additive manufacturing technology.

CHAPTER 3: METHODOLOGY

In this chapter, Fusion360 will be used for traditional design and generative design. Fusion360 is a CAD/CAE/CAM tool based on cloud computing. It has powerful functions and cloud storage of data, so it supports the team to share product data; it also has faster and simpler organic modeling and accurate solid modeling, the module can define design problems according to the target contract and generate design solutions that meet the requirements.Figure3.1 is the flow chart of the research process.

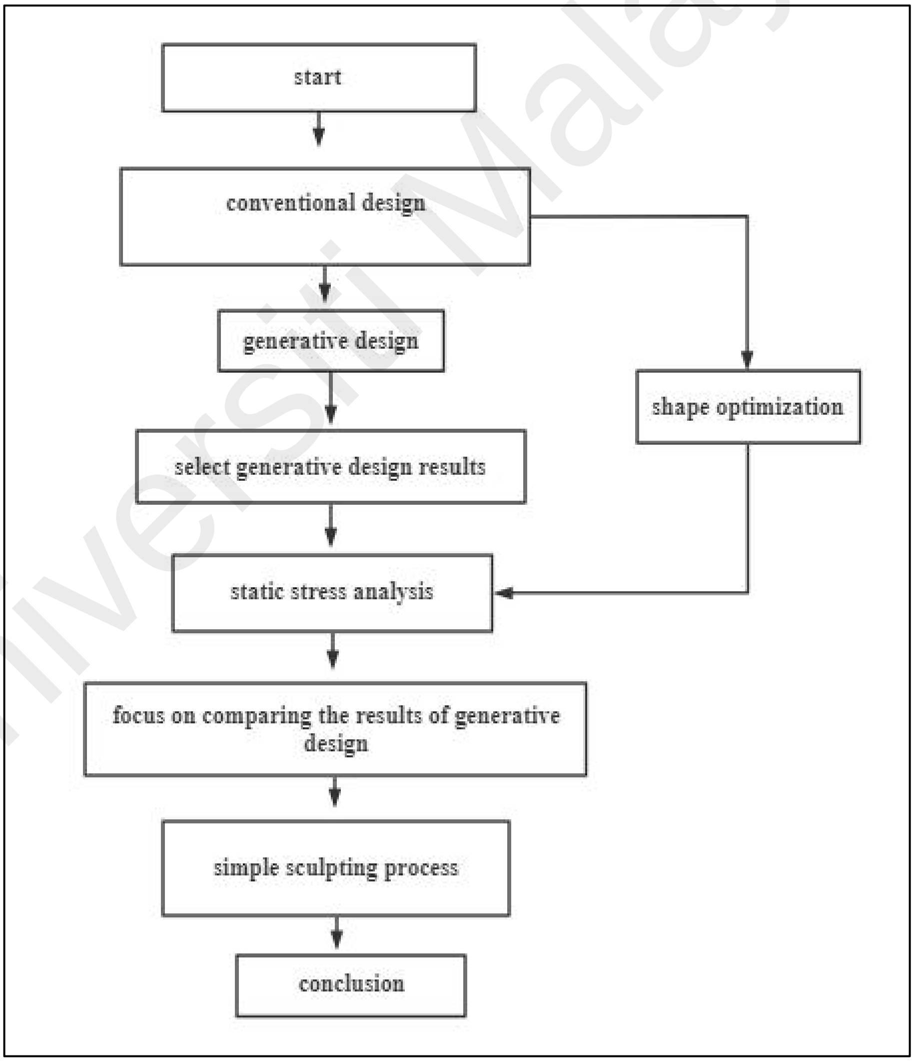


Figure3.1: Flow chart of the process

3.1 Problem identification and expected results

3.1.1 Component

motorcycle triple clamp

3.1.2 Research materials

Aluminum 6061

Al6061 is a high-quality aluminum alloy product produced by heat treatment and pre-stretching process. It has excellent processing properties, good corrosion resistance, toughness and low melting point (560-650 degrees Celsius). The wire arc additive manufacturing technology uses metal wires as raw materials and uses submerged arc welding to stack the melted materials layer by layer according to a pre-designed path, and finally solidify and shape. According to the characteristics of Al6061 and the characteristics of wire arc additive manufacturing technology, the material used in this study is Al6061.

3.1.3 Model design

First, use Fusion360's design module to design the actual shape of the component and produce its engineering drawings; then use the generative design module to perform generative design operations.

3.2 Selecting a suitable component for the project

This component belongs to a body component of a motorcycle. It is used to fix the front fork of the motorcycle and the handlebar shaft, which clamps the front fork together and connects with the frame. In terms of design, the upper and lower cams will be combined with the pure quality of the steering axle, and the upper component of the axle is locked with the upper cam to place the fork on the bottom of the frame. For the motorcycle, the front suspension system of the entire motorcycle needs to shoulder the steering function in addition to the shock absorber function. In addition to being able to move up and down to achieve the effect of shock absorption, the upper front fork of a motorcycle must also be fixed on a triangle platform, and the vehicle can be steered by turning the handlebar. Generally speaking, for this component, it must be able to support a component of the body weight and also need to have a great rigidity, can be used to achieve the function of steering, so it must not bend or warp.

Figure3.2: Motorcycle triple clamp

3.3 Conventional design process

First, modeling the component according to the parameters of the component. The component has a relatively simple structure and has many rounded corners. Therefore, special attention must be paid to the radius of each rounded corner. Fusion 360 combines industrial and mechanical design, simulation, collaboration, and processing in one software package. Therefore, we can use the design module in Fusion 360 for modeling without the need to use other modeling software.

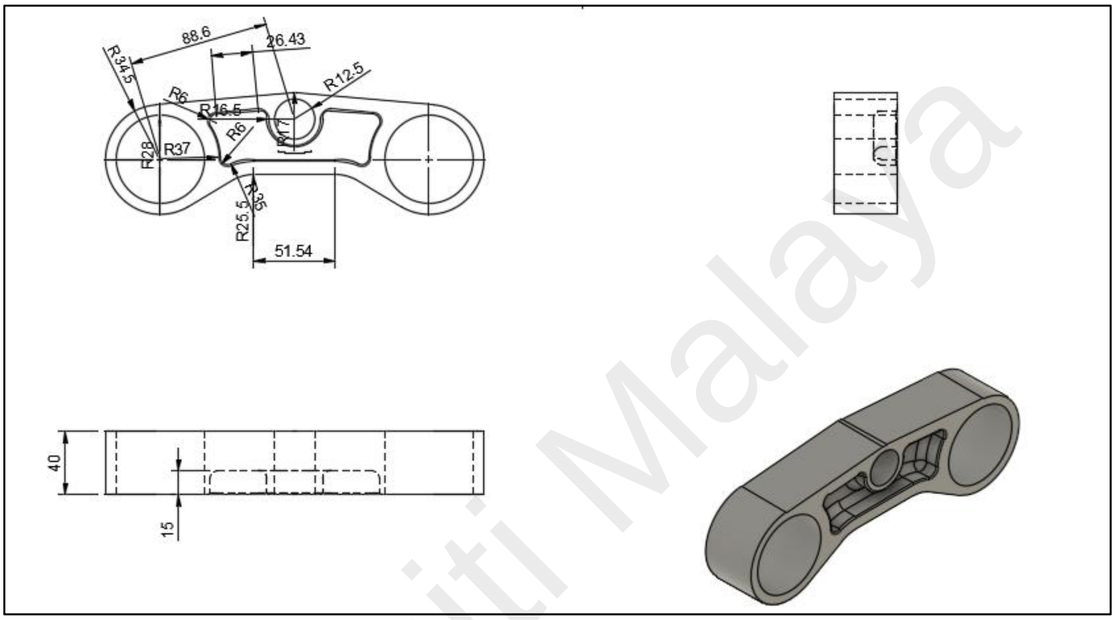


Figure3.3: Engineering drawing of component

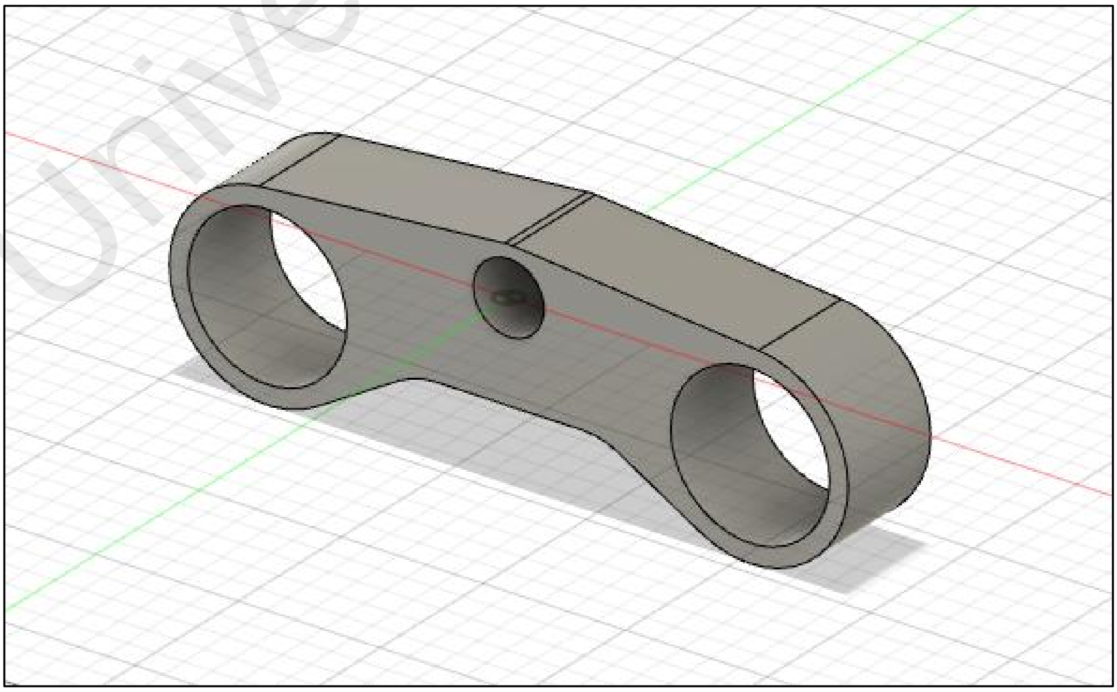


Figure3.4: The initial model of component

In the process of modeling using Fusion360 design module, each step of the operation will form a time axis, as shown in the following figure, the biggest advantage of this time axis is: if a step needs to be changed, you can directly drag the time axis and place it on the time axis;The changes will change the subsequent operations, making the modeling process more convenient.

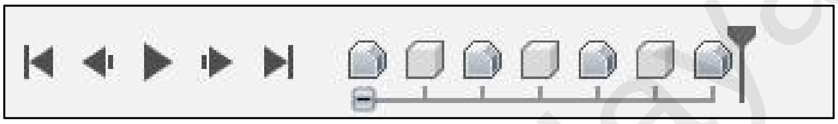


Figure3.5: Design time axis

3.4 Perform generative design

Generative design is a way of simulating biological evolution in nature. It only needs to input specific design goals, such as performance requirements, materials, and manufacturing methods. After the application program clarifies the design requirements, it evaluates whether the massively generated design meets the design requirements in the procedurally synthesized design space. The performance data of each solution in the entire design space will also be given feedback. The goals and constraints can be adjusted at any time during the real-time evaluation of the design plan to generate new results that meet the optimization definition. Choosing a satisfactory design plan to export the design to generate geometric primitives for use in other CAD programs。

According to the boundary conditions of fork upper (right and left) and triple clamp.

Define the design space in the generative design module of Fusion360. The generative design does not need to give the initial shape, and only needs to determine the retained geometric primitives and obstacle geometric primitives in the generative design according to the structure of the original design. The geometric primitives are reserved as entities designated to be included in the final shape of the design. These entities are displayed in green. Obstacle geometric primitives represent entities in blank areas where materials will not be placed in the process of generating results, and are also spaces that need to be avoided in the design. These entities are shown in red. Set the three holes as reserved geometric primitives, and other boundary conditions as obstacle geometric primitives. The specific operation procedures will be shown separately in the following.

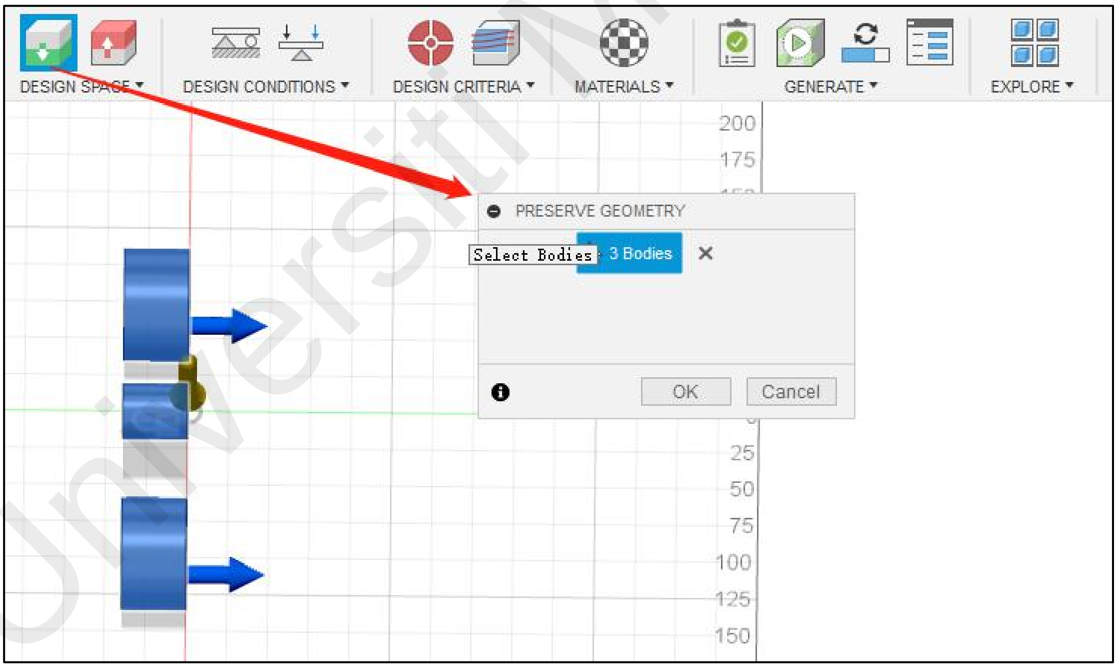


Figure3.6: Preserve geometry

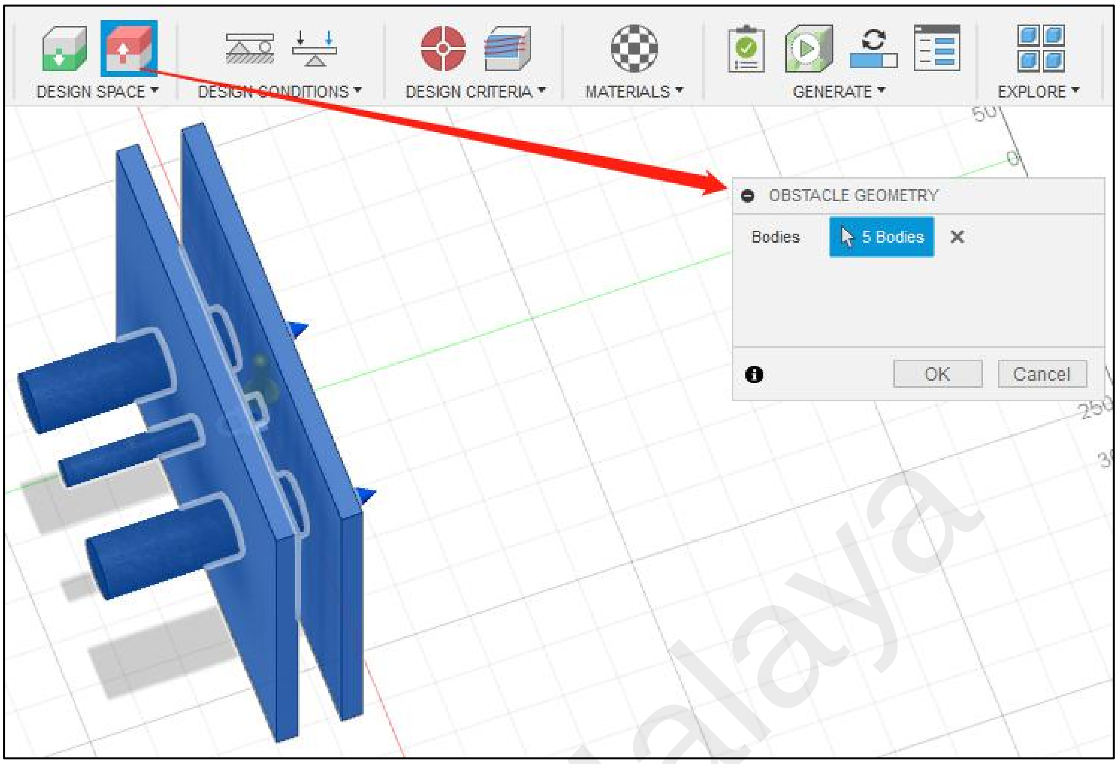


Figure3.7: Obstacle geometry

After setting the obstacle geometry element and the retained object geometry element, it is necessary to define the load of the component that will be subjected to the generative design. The load definition is to apply forces in different directions to the reserved geometric elements, which will provide data to the cloud server for AI calculation. In the process of defining loads, in order to ensure the geometric symmetry of the generative design, the loads applied by the geometric elements are kept symmetrical, that is, after defining a load, a load in the opposite direction is also defined. These setting will not only make the generated components very beautiful, but also ensure that the force of the components is relatively uniform and prolong the service life of the components.

Table 3.1:The value of the load 1

	F_x/N	F_y/N	F_z/N
Load 1	0	0	8000N/-8000N

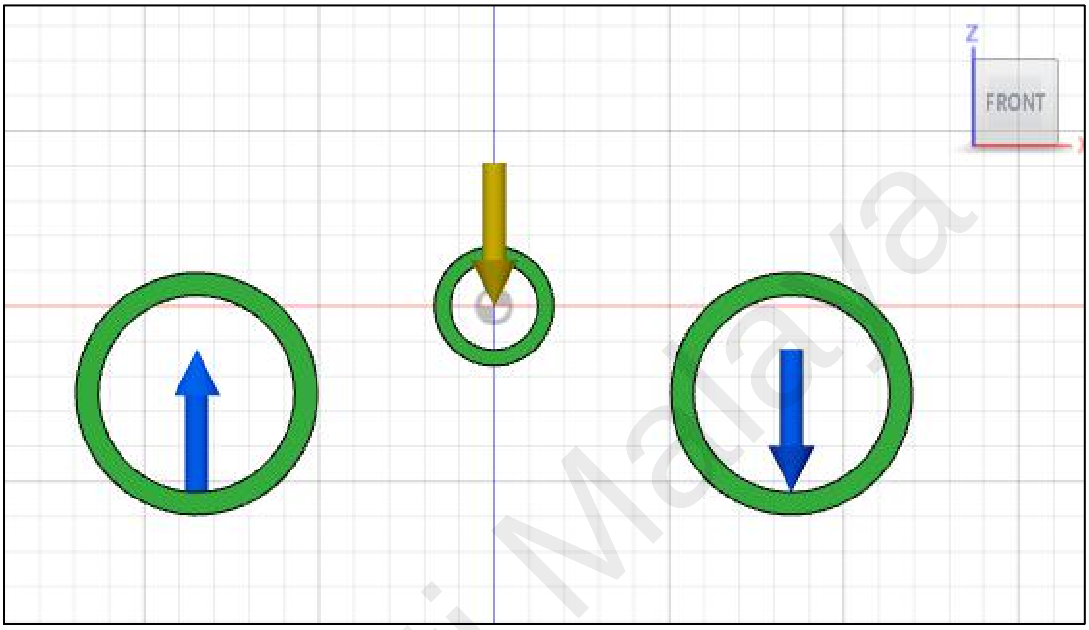


Figure3.8: Load1 along the Z axis

Table 3.2:The value of the load 2

	F_x/N	F_y/N	F_z/N
Load 2	0	0	8000N/-8000N

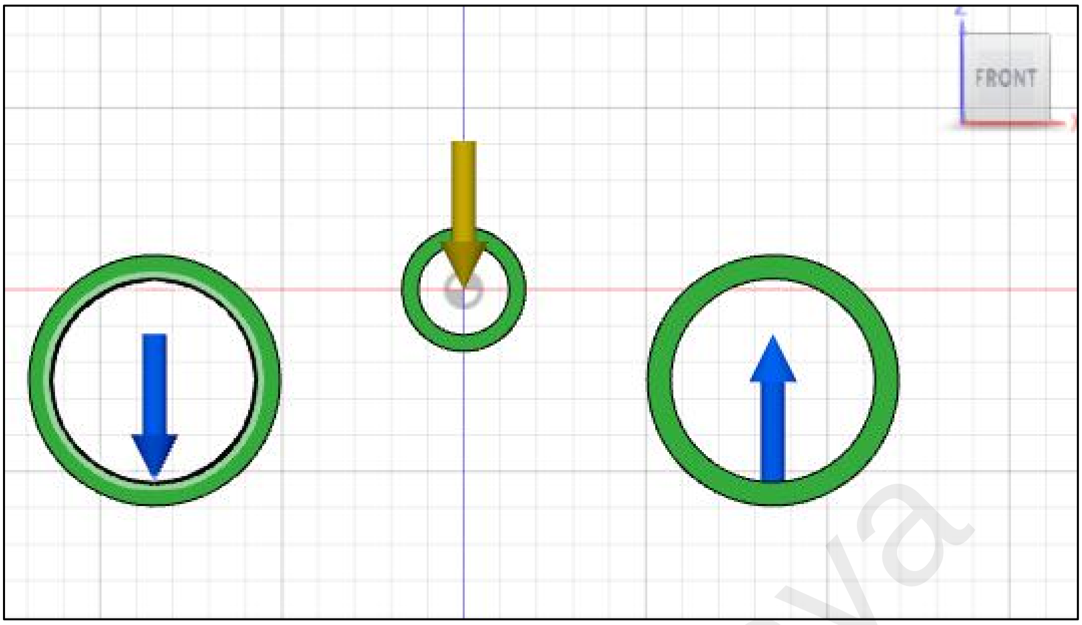


Figure3.9: Load2 along the Z axis

Table 3.3:The value of the load 3

	F_x/N	F_y/N	F_z/N
Load 3	0	4000N/-4000N	0

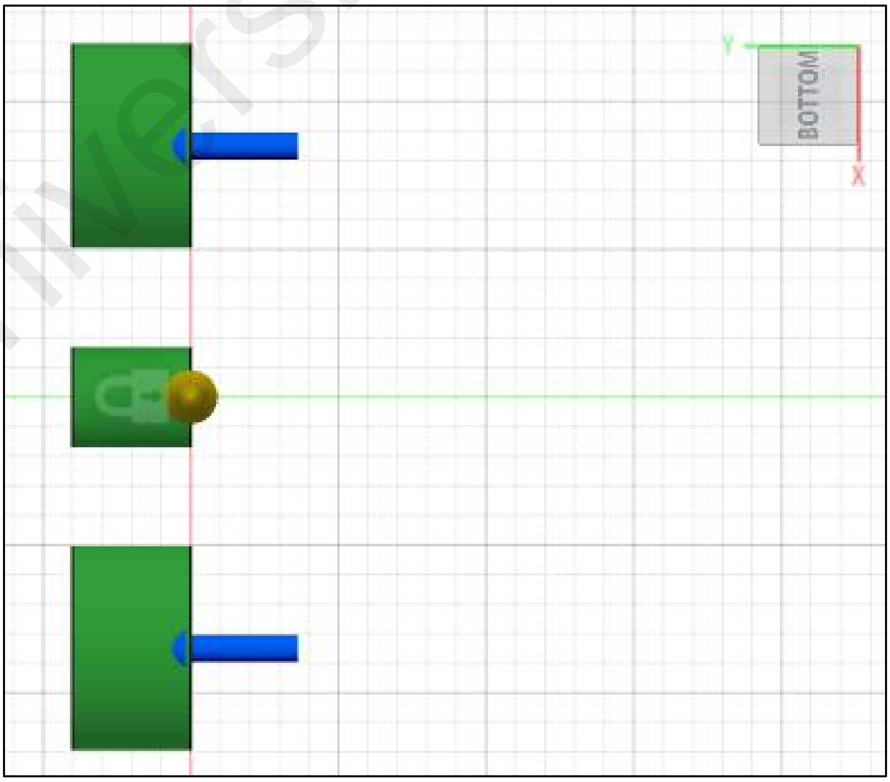


Figure3.10: Load3 along the Y axis

Table 3.4 :The value of the load 4

	F_x/N	F_y/N	F_z/N
Load 4	0	4000N/-4000N	0

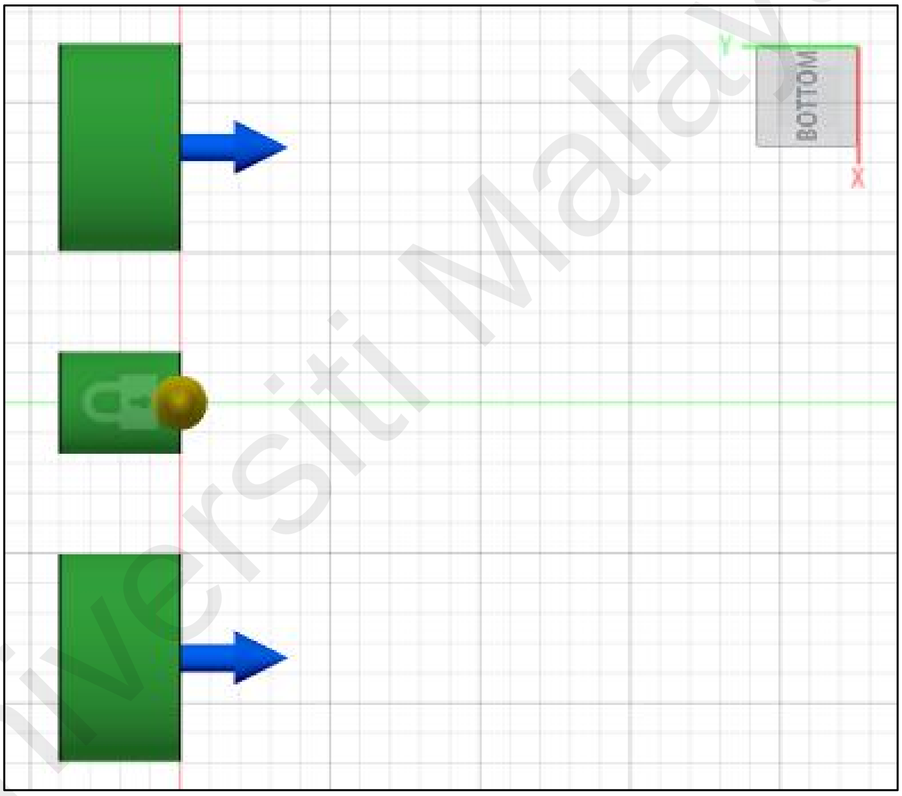


Figure3.11: Load4 along the Y axis

This report has listed the four load values in the table, it is using nearly maximum load that applied onto conventional model. These data are obtained through stress analysis of the conventional model, which belongs to the preliminary work. The focus of this research is the result of generative design, so I will not introduce too much here.The forces in this table are not divided into specific directions, and are only defined by the angle formed with a certain coordinate axis. Therefore, all the forces only need to indicate its value, as long as the symmetry condition is met, so that the generative design can be carried out later.

The most important step for generative design is to set the design objective. This information must be entered before the AI calculation, so that the subsequent generation process will be filtered according to the set information. In this study, under the condition of meeting the structural strength and rigidity, the mass is minimized, in order to achieve the objective of lightweight, and be more green and environmentally friendly. The accuracy of the analysis results of the generative design parts is guaranteed by setting the safety factor in Fusion360. The determination of the safety factor needs to consider the load, the mechanical properties of the material, the difference between the test value and the design value and the actual value, and the calculation mode. In this research, the safety factor is set to 2.0.

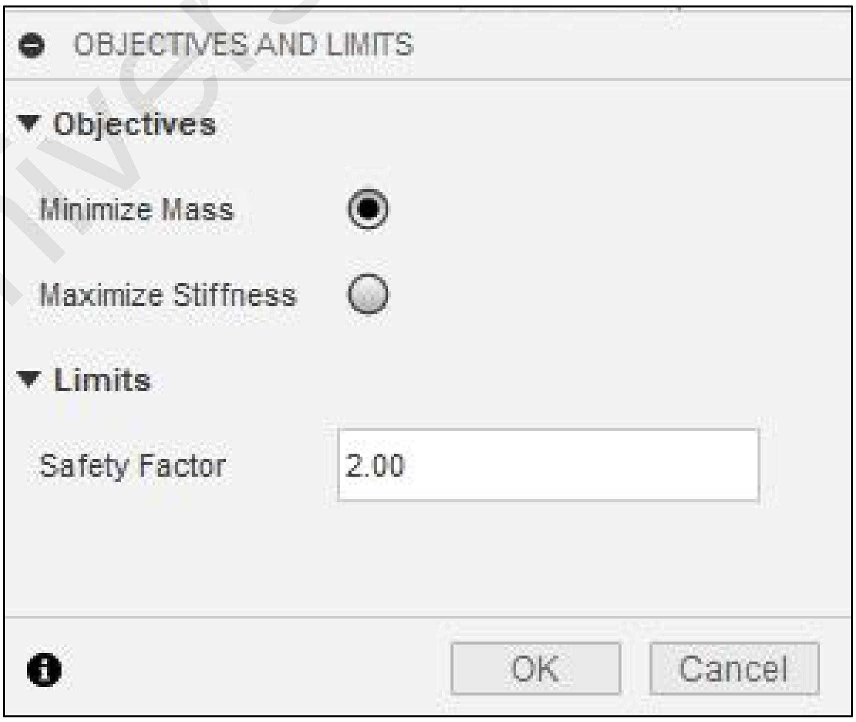


Figure 3.12: Objectives and limits

After setting the design objective, the next step is to select the materials of the component under study. The component selected in this study is a part of a motorcycle, so there is no need for a very high-strength alloy. Al6061 belongs to the Al-Mg-Si series alloy, with medium strength, good plasticity and excellent corrosion resistance. In particular, it has no stress corrosion cracking tendency, its weldability is excellent, corrosion resistance and cold workability are good. It contains a small amount of Cu, so the strength is higher than that of Al6063.After extrusion, air quenching cannot be achieved. Re-solution treatment and quenching aging are required to obtain higher strength. Therefore, the material is selected as Al6061. In the actual generative design process, six materials were selected for design at the same time, which can be used to compare the results of different materials.

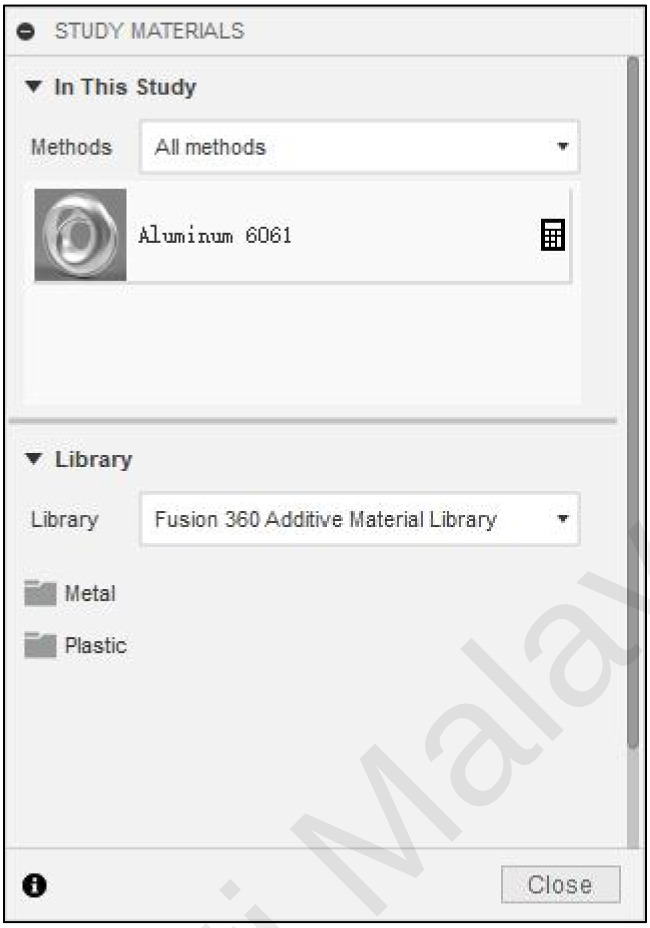


Figure3.13: Select the study materials

"Pre-check" can be performed after all the settings of the Fusion360 generative design module are completed. This function can quickly check out any mistakes or missing steps. Then, you can use "Previewer" to generate preliminary design animations, so as to roughly know the shape of the generative design results. After setting all the information, when there is no red warning in "Pre-check", the final operation of generative design can be carried out to generate.

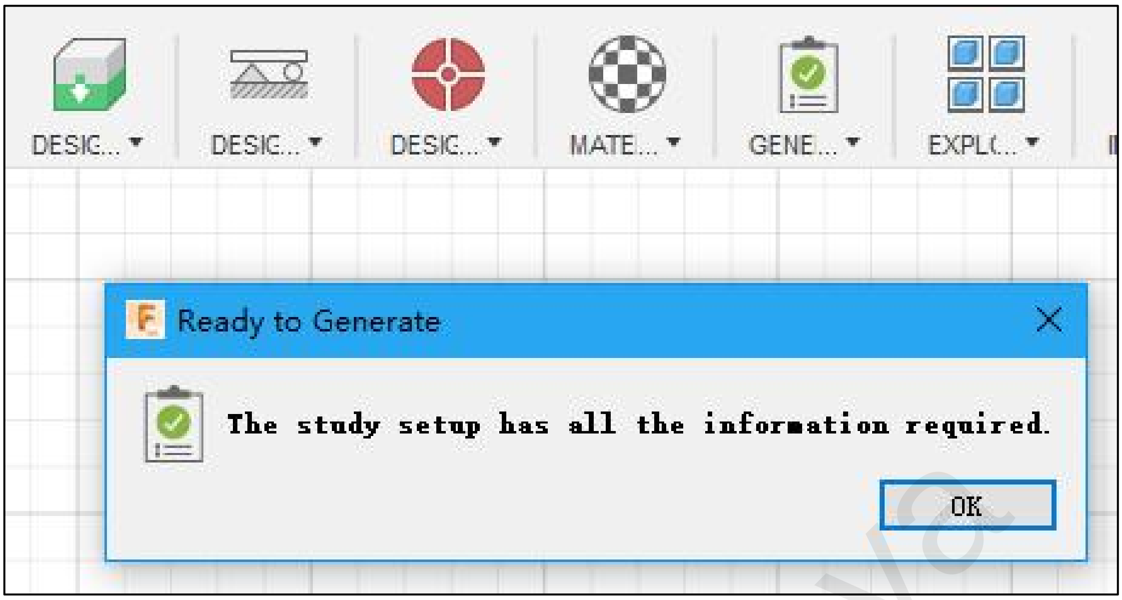
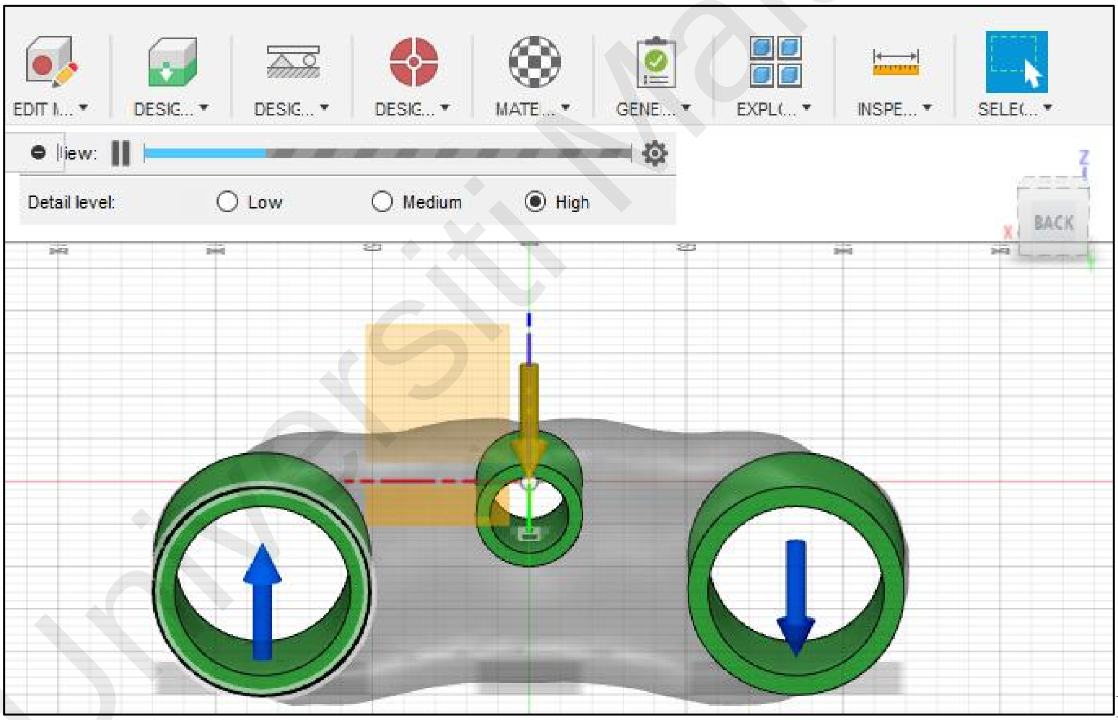


Figure3.14: "Pre-check" is ok



F

igure3.15: The process of previewer

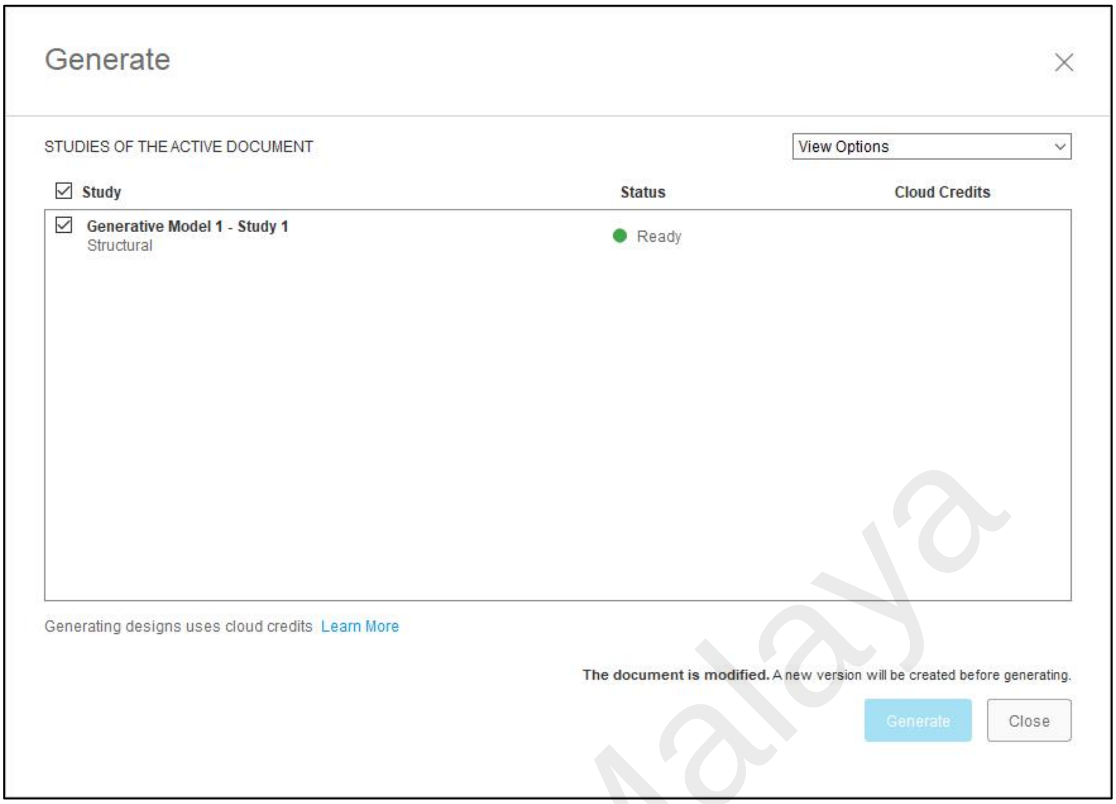


Figure3.16: Ready to generate

This part is the introduction of the main steps in the Fusion360 generative design process. For different components, each step needs to be set differently, and it needs to be set according to the actual use environment and force of the components.

3.5 Simulation analysis process

The generative design calculation takes a lot of time to filter out designs that meet the set conditions. Although the design results obtained meet the set conditions, the specific structural strength of each component of the different design results is not known, so simulation analysis is required. Learn more about the specific force of the software. There are many simulation software available, but this research will focus on the use of Fusion360. This study will use the simulation module in Fusion360 for analysis, static stress analysis and shape optimization analysis, in order to analyze the force of the design results, and to study the difference between the model design after the shape optimization and the generative design model.

3.5.1 Shape optimization analysis

In this study, simulation analysis of shape optimization will be carried out first to make the original components more lightweight. After the shape optimization is completed, the static stress analysis is performed to check whether the shape optimized model meets the requirements of strength and rigidity. For the simulation analysis of this module, the goal set in the generative design is to minimize the quality under the condition of ensuring the stiffness and strength. Therefore, this step of the simulation analysis is also to make the given components lighter. The shape optimization design is just for comparison with the generative design. The shape it designs is relatively regular, not as imaginative as the generative design, so the shape optimization design is not the main research content.

First, select the shape optimization module in Fusion360 simulation analysis, import the model of the initial component into the shape optimization module, and prepare to set the parameters of shape optimization.

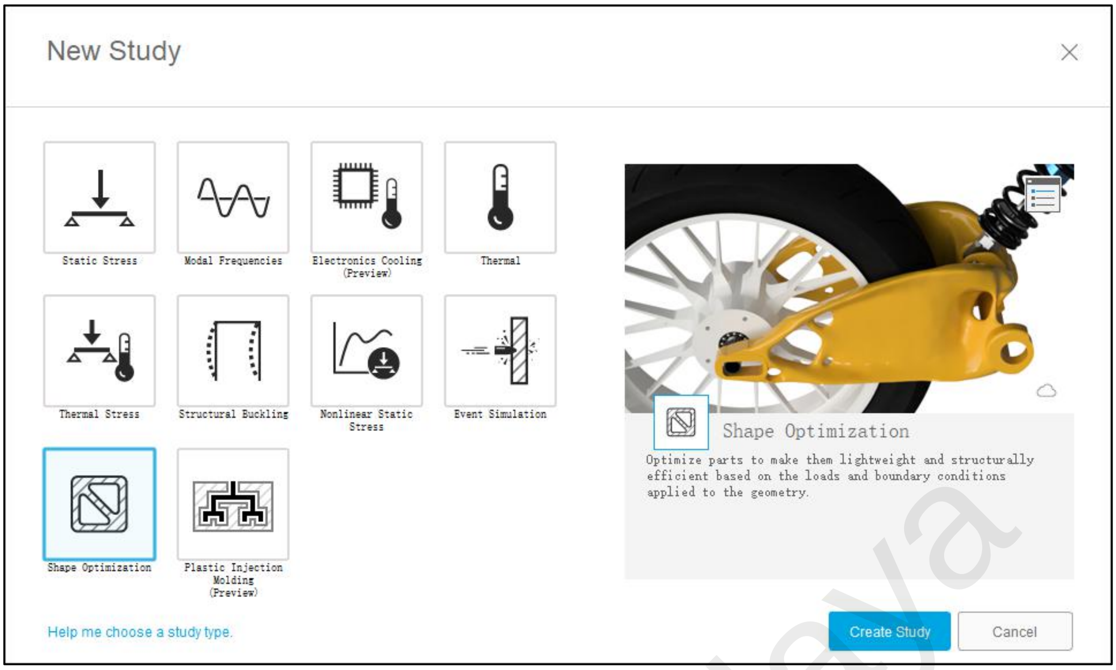


Figure3.17: Simulation function interface

Then, the first step of shape optimization analysis is to select the analysis material. According to the material set in the generative design process, the Al6061 material is also selected in the static stress setting. According to the use environment of the components in this study, the yield strength is selected in Safety factor (and tensile strength is also available). The yield strength is the yield limit of the metal material when the yield phenomenon occurs, the stress that resists a small amount of plastic deformation. An external force greater than this limit will permanently invalidate the components and cannot be restored. Therefore, the yield strength is more suitable as a criterion for the availability of components.

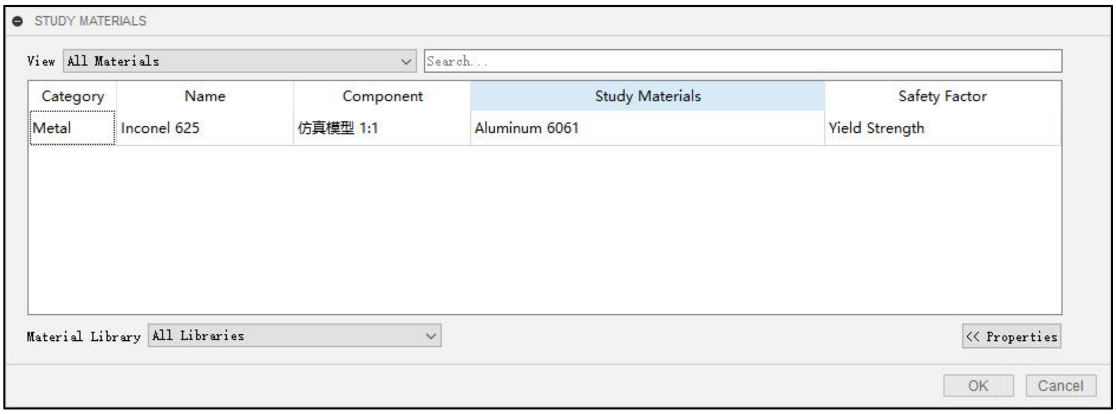


Figure3.18: Select study materials

After selecting the analysis material, the next step will be to apply constraints and loads to the component. In this shape optimization analysis, the three internal surfaces of the component are constrained, and static stress is applied at the same time. The magnitude of the static stress is the same as the previous stress in the generative design, and the position where the static stress is applied is the same as the previous setting, and the initial design conditions need to be met, that is, the same as the load required in the generative design.

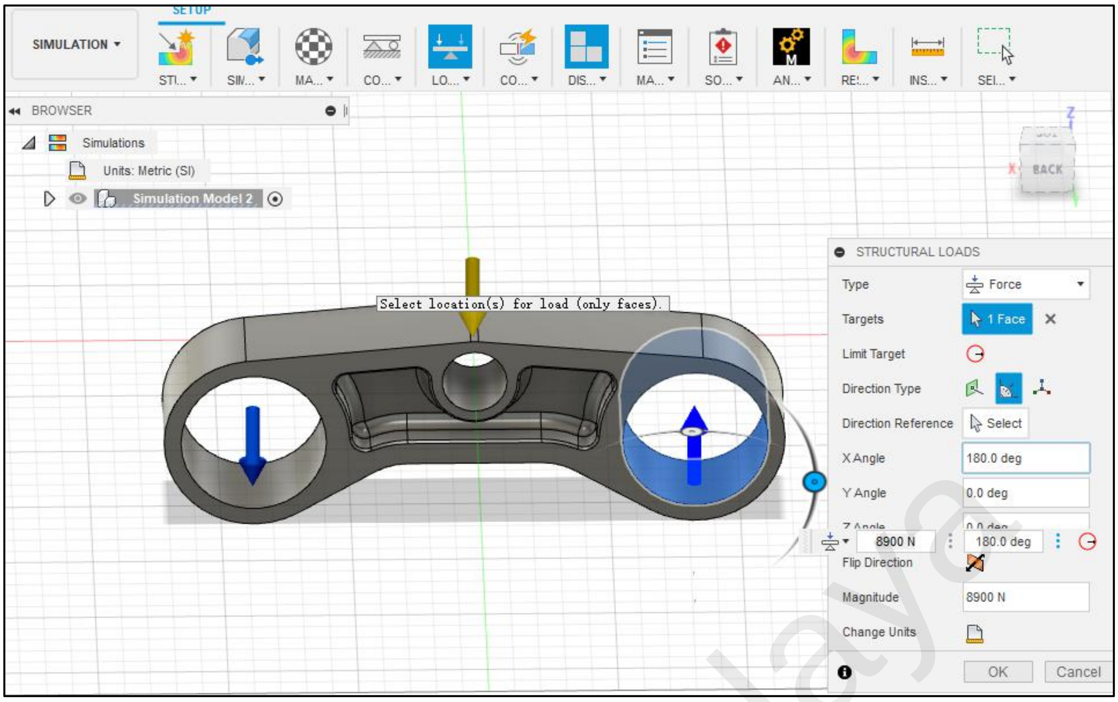


Figure3.19: Structural loads

After setting the constraints and loads, in order to achieve the shape optimization design, you need to set the target quality, that is, how much you want to reduce the quality of the original component. Since the mass of the components themselves is relatively small, the shape optimization of this study reduced the mass by at least 15% on the initial basis.

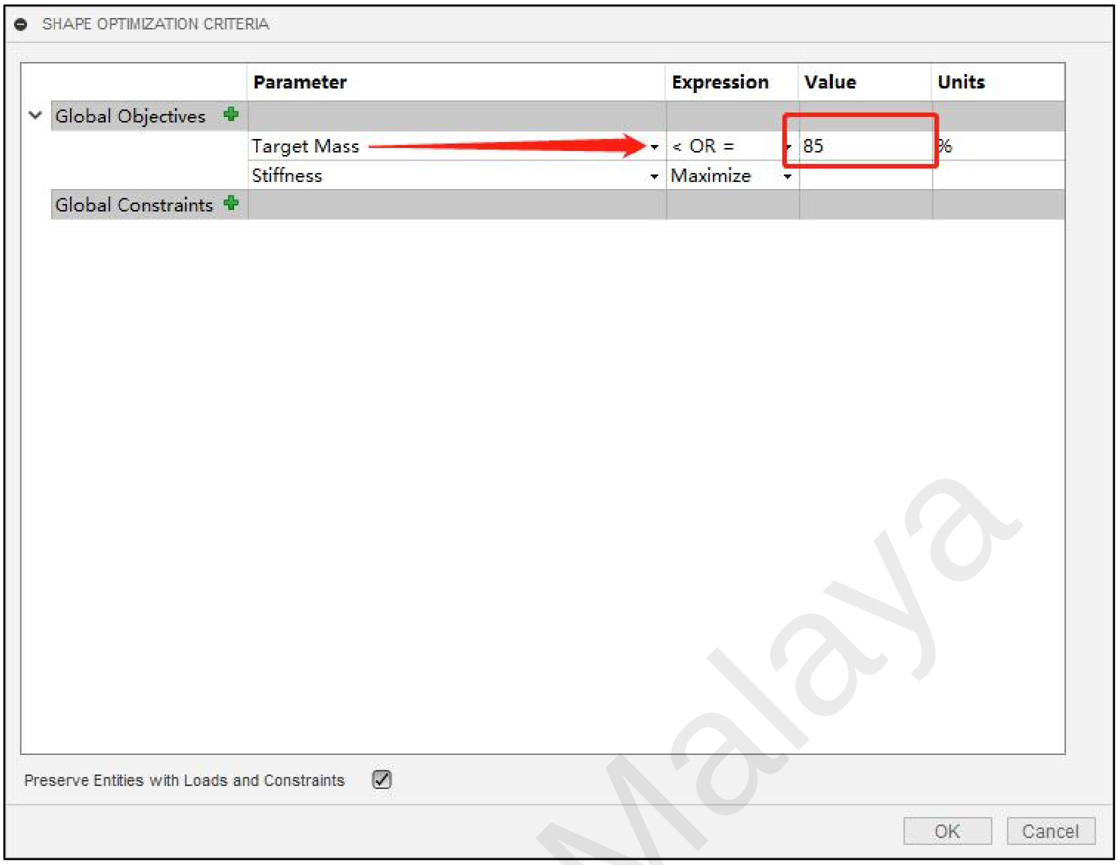


Figure3.20: Shape optimization criteria

For Fusion360 shape optimization simulation function, it can perform shape optimization simulation after all parameters are set. The simulation requires a lot of calculations, which can only be performed through the cloud server, so after the "Pre-check"shows that there are no other problems, the calculations can finally be performed.

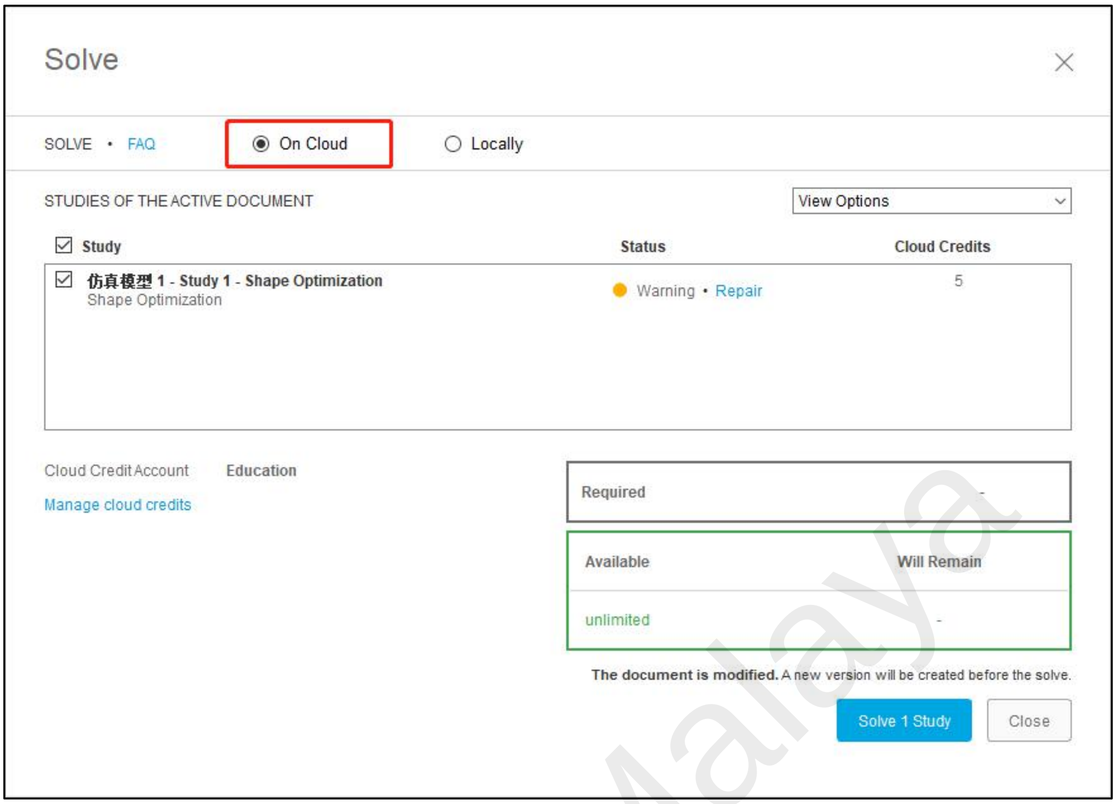


Figure3.21: Solve on cloud

As an emerging software in the past two years, Fusion360 has very powerful functions and can be designed and simulated at the same time, similar to the ANSYS software package. Therefore, in the shape optimization process, the shape optimization function of ANSYS is not used. Many problems were encountered in this process, but in the end a simple shape optimization is carried out. After the shape optimization simulation is completed, the static stress analysis of the model after the shape optimization will be performed next.

3.5.2 Static stress analysis

Static stress analysis is used to determine the structural rigidity of the design result, and a fixed stress value is set to check the force condition of each component of the design result. This kind of analysis is a very important operation in the component design process, and it is an important analysis to check the size of the load that can be applied to the design result. The following will show how to analyze the static stress.

First select the static stress simulation of the Fusion360 , import the results of the generative design into the simulation module, and then set each parameter to prepare for the subsequent simulation analysis.

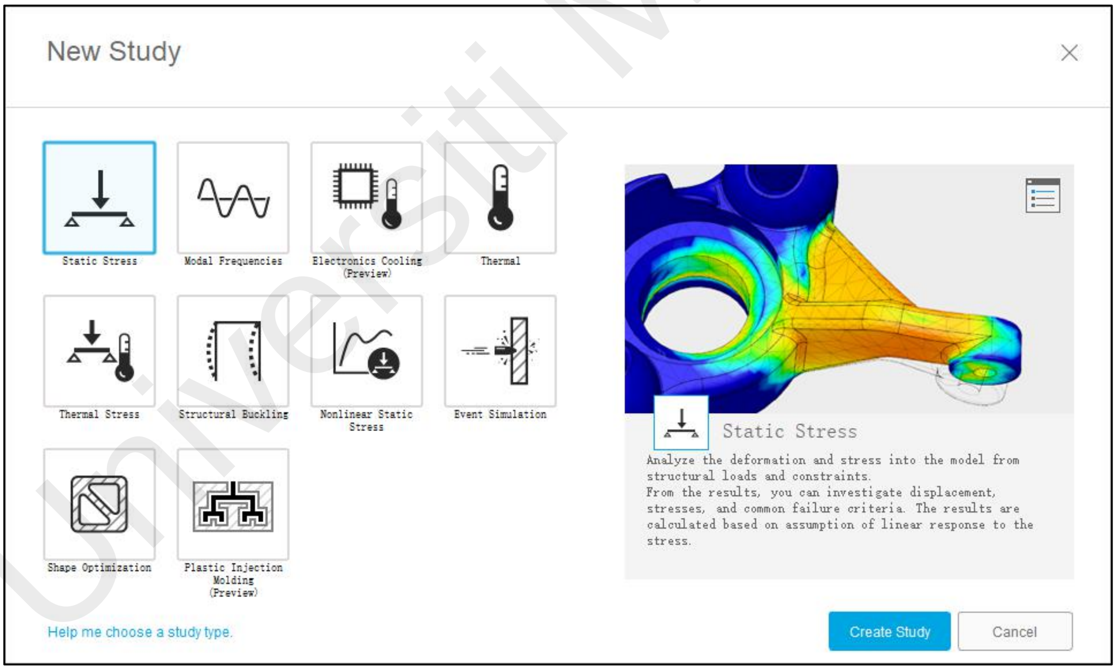


Figure3.22: Simulation function interface

Then, the first step of static stress analysis is to select the analysis material. According to the material set in the generative design process, the Al6061 material is also selected in the static stress setting. According to the use environment of the components in this study, select the yield strength in "Safety factor" (at the same time there is also tensile strength to choose). The yield strength is the yield limit of the metal material when the yield phenomenon occurs. It is resistant to slight plastic deformation. An external force greater than this limit will cause permanent failure of the component and cannot be restored.

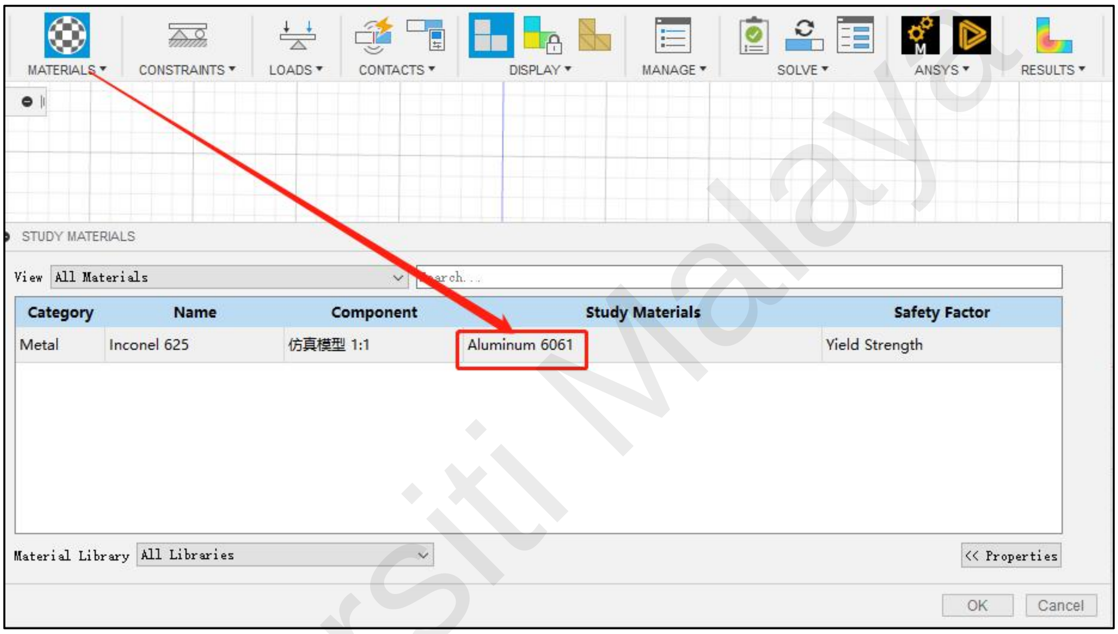


Figure3.23: Study materials

After selecting the analysis material, the next step is to constrain the components and apply loads. In this static stress analysis, the three internal surfaces of the component are constrained and static stress is applied at the same time. The magnitude of the static stress is the same as the previous stress in the generative design, and the position where the force static stress is applied is also the same as the previous setting, so the explanation will not be repeated in this operation.

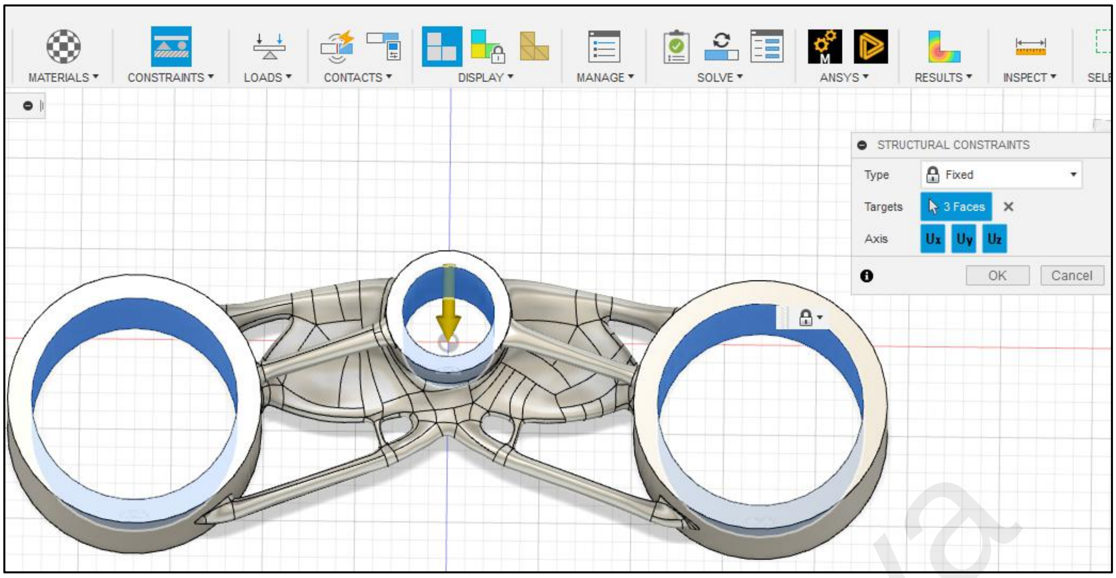


Figure3.24: Structural loads

The above are the operations that must be performed before the analysis, mainly material selection and load application. After completing all the preliminary settings, you can perform a "Pre-check" to prevent some important settings from missing or wrong. Under the "Slove" menu, you can generate meshes for the components you want to analyze to observe the mesh density during stress analysis. If the mesh density is too small, the results of the stress analysis may be inaccurate. If the mesh density is too large, the calculation time will be too long. Therefore, the mesh density can be changed from small to large for many times.

Finally, after the "Pre-check" shows that there is no problem, the design results can be simulated and analyzed. For static stress analysis, since the amount of calculation is not very large, you can choose to perform simulation analysis on a cloud server or a local computer. Because the server is located abroad, this calculation process will be very slow when performing simulation calculations in China, and even often fails. This study chose to perform simulation calculations on a local computer.

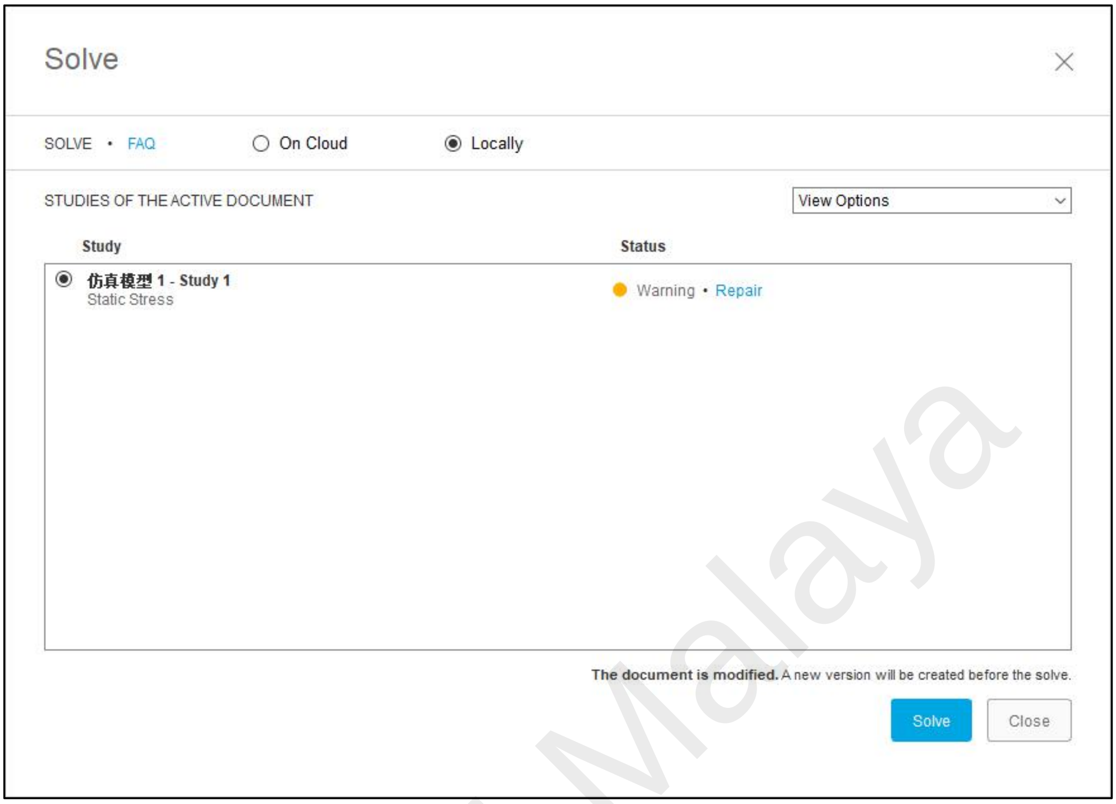


Figure3.25: Solve locally

The above is the analysis process of static stress on the results of generative design. This process can be used as a guide for reference. Generative design is still in its infancy, so there is not a lot of research on generative design in the reference literature. The operation process of static stress analysis in this study is just an attempt, which will continue to study generative design in the future. provide help.

3.6 Sculpting process

After completing the simulation of the stress analysis, according to the results of the simulation of the stress analysis, when the selected model does not meet the minimum requirements of the safety factor and stress, we need to carry out a manual modification process. We can use the functions in the Fusion360 software to modify the components, such as adding and deleting sharp parts, subdividing and flattening certain parts of the part. There are no specific requirements for this process. Different designers handle this process differently, and this process cannot be completed in a short time. This process may need to be repeated many times. After each modification, the stress analysis simulation can be continued, and then modified according to the analysis results. The engraving process begins to modify the most critical area with high edges until it becomes smooth and not so sharp, to minimize the occurrence of stress concentration, and to protect the service life of the part.Due to the semester time, this report will only use some analysis methods for simple processing.

CHAPTER 4:RESULTS AND DISCUSSION

All the work of this research uses Fusion360, and the research process and the work done by the research have been roughly displayed. The overall process is not complicated, and the selected components are relatively simple, but this is also a research process for completely new concepts in a special semester. Generally speaking, the results obtained in this research are quite satisfactory, basically satisfying an exploration and practice process for emerging concepts, and generally formulating a set of basic design guidelines. The following will show the obtained design results and simulation results, and conduct a comparative discussion.

4.1 Conventional design model

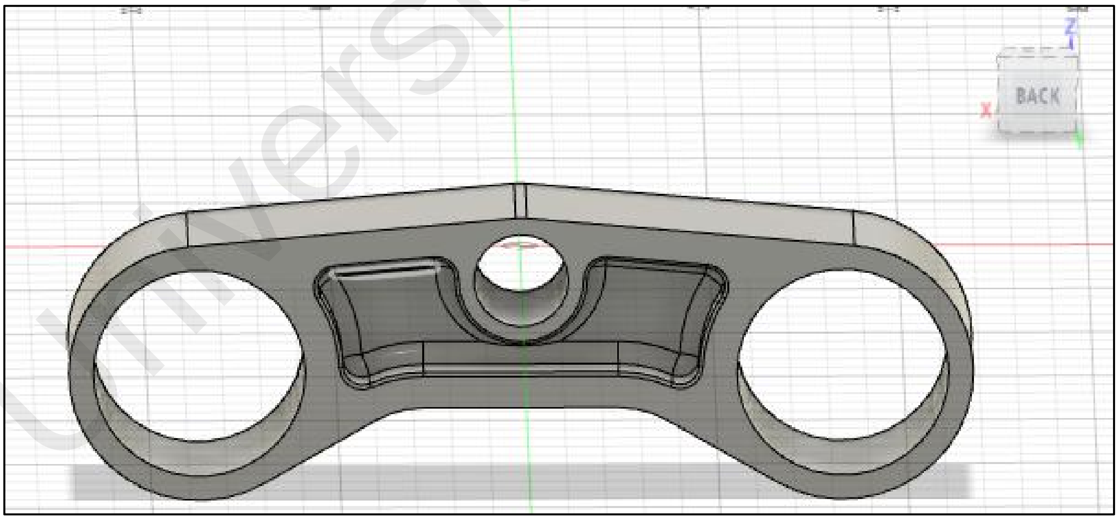


Figure4.1: Conventional design model

In 3.3, the engineering drawing of the component has been shown. This time the modeling did not use other modeling software, such as Solidworks, UG, etc. The component was modeled according to the given data. The shape of the component model is relatively simple and can be mass-produced on a lathe during the manufacturing process.

The purpose of this research is to do the generative design. At the same time, they must have good structural strength and rigidity. Finally, a guideline on additive manufacturing and generative design has been formulated. Lightweight parts can reduce the materials used to manufacture components, achieve more environmental protection and reduce production costs. In the manufacturing process, the additive manufacturing method (wire arc additive manufacturing) can be used to print parts of various shapes, and the residual stress and safety factor can be checked before it is mass-produced.

4.2 Results of generative design

Through the method of generative design, a lot of design results can be produced, which is more convenient and quicker than conventional modeling methods, and the shapes designed are also very innovative. The generative design results of this study are not only the Al6061 material model, but also the design results of five other materials such as Al7075 and stainless steel 361L. This will facilitate the comparison of the advantages and disadvantages of different materials as manufacturing materials. For the selection of the final material, this research focuses on the performance of Al6061 as an additive manufacturing material.

According to the catalog map of the generated model results, we can find that after Fusion360 processes our set parameters, it generates a lot of different types of model results through cloud server calculations. The results of these models are not only additive manufacturing methods, but also models suitable for traditional processing methods such as milling. According to the right side of the result graph, we can filter different models by setting different parameter ranges, which greatly facilitates our search for ideal models. The catalog diagram is a display of all design results. After clicking on it, you can see the specific parameters of the model.

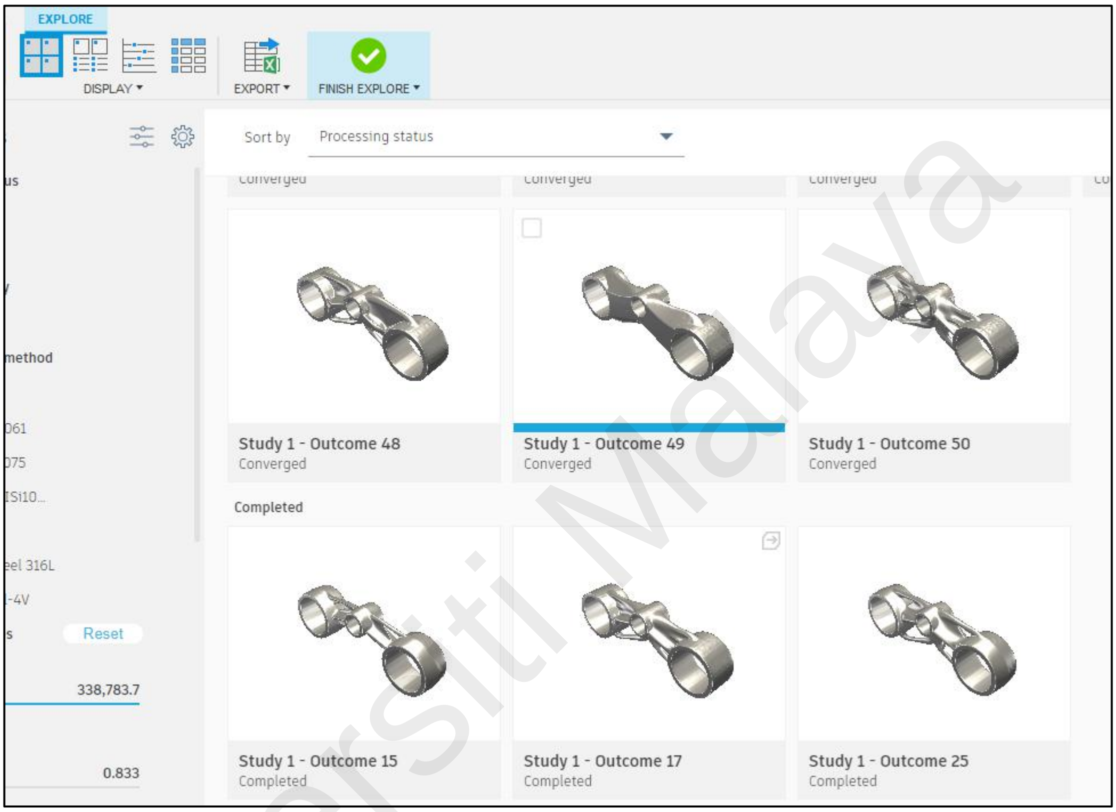


Figure4.2 The catalog map of the generated model results

In the upper left corner of the results page of generative design, we can find scatter plots of all design results.

For the scatter plot of the design result distribution, we can view the model result distribution under different standards by changing the meaning of the two axes of the coordinate system. Generally, the minimum safety factor is selected for the abscissa, because any screening criteria must be based on the structural strength and rigidity of the generative design model to meet the requirements, or it can be said that the components must not fail during use. In addition, for the points on the scatter chart, which model results it represents can be determined in Fusion360. The screenshots cannot reflect the specific results. Therefore, in the analysis below, we will analyze a certain area more, and finally screen and confirm.

In the case of taking the cost of parts as a consideration standard, when observing the distribution of model results, we need to change the ordinate of the parts to "Piece part cost", and the abscissa is still the minimum safety factor. From the chart, we can see that most of the parts made of Titanium 6Al-4V as a material have a relatively high safety factor, and the safety factor meets the requirements of close to or greater than 2.0. When the generative design shape is relatively special, there is a very high possibility that the manufactured parts will fail. Based on the consideration of manufacturing cost, if there is no material restriction, according to the result distribution in the image, we can see that the lower right corner part is more suitable, which not only meets the low cost but also has a qualified safety factor. Finally, select the model made of Al6061 material in this area from Fusion360, and the final screening results will be listed after the analysis is completed.

Table4.1:Filter results based on cost

Model	Outcome19	Outcome25	Outcome13	Outcome26	Outcome31
Materials	Al6061	Al7075	Titanium 6Al-4V	Al6061	Stainless steel 316L

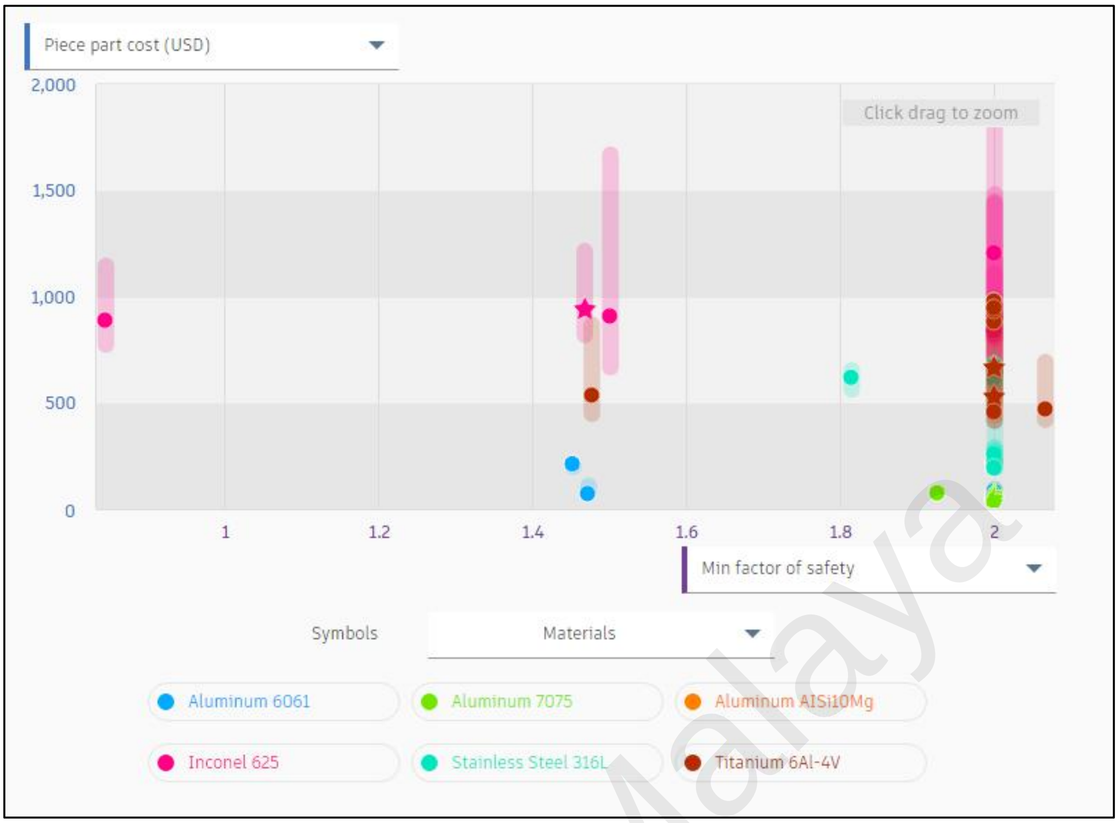


Figure4.3: Scatter plots for per cost

In the case of taking the quality of the parts as the reference standard, to observe the scatter point distribution of the model results, we need to change the ordinate of the scatter chart to "Mass", and the abscissa is still the minimum safety factor. According to the distribution of all the results in the image, we can still find that the Inconel 625 material has a failure condition. If this material is selected as the manufacturing material, the special shape model must be deleted, and the model with the safety factor of 2 should be selected as far as possible; for others materials, we observe that when the safety factor is 2.0, the individual parts of stainless steel have the largest mass, followed by Inconel 625, and finally Titanium 6Al-4V and aluminum alloy materials. When the parts need to meet the requirements of safety factor and quality as small as possible at the same time, we can choose from the lower right corner area when we choose the generative design result. The final selection result will be listed after the image is analyzed.

Table4.2:Filter results based on mass

Model	Outcome19	Outcome17	Outcome49	Outcome47	Outcome14
Materials	Al6061	Al7075	Titanium 6Al-4V	Al6061	Stainless steel 316L

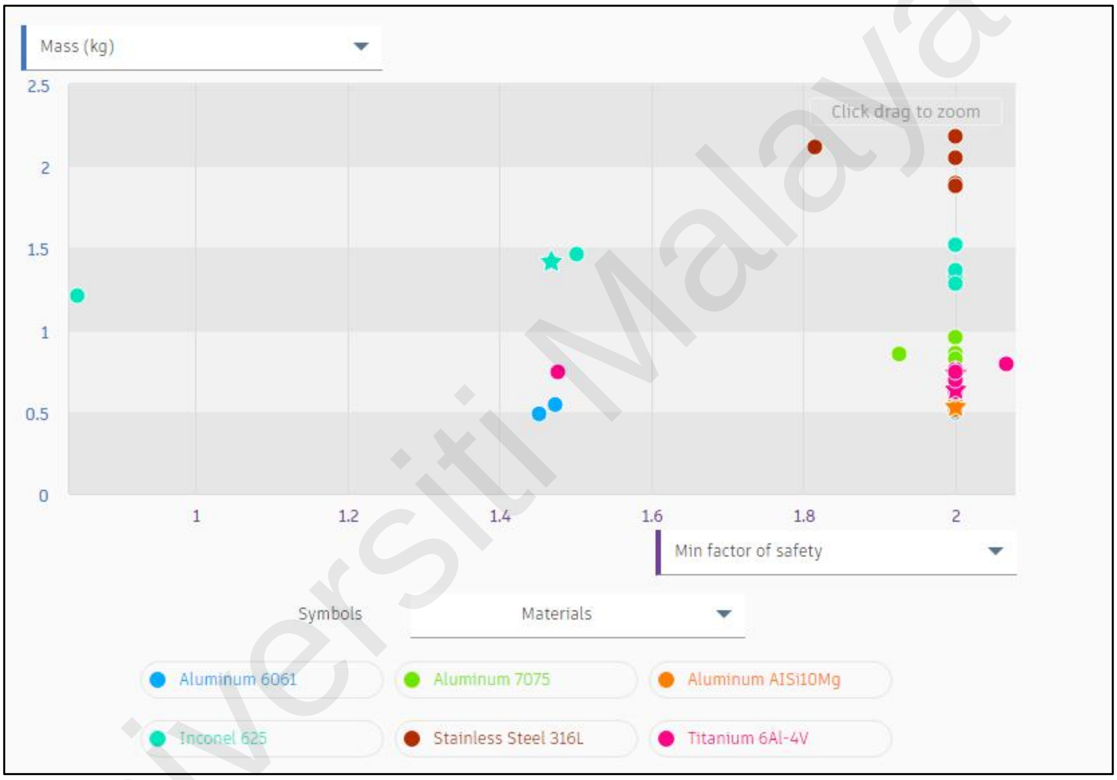


Figure4.4: Scatter plots for mass

In the distribution map of Fusion360 generative design results, we can also observe the relationship between Mises stress and safety factor of different materials and shape models. Set the ordinate of the result distribution graph to "Max von Mises stress", the abscissa is still the minimum safety factor, we directly observe from the minimum safety of 2. It can be seen from the image that when the minimum safety factor is 2, the maximum equivalent yield stress that different materials can withstand is from largest to smallest, Titanium 6Al-4V, Inconel 625, Al6061, AlSi10Mg, Stainless Steel 316L, and

Al7075. For Al6016 material, its strength meets the requirements of parts, and other materials will continue to be studied in the future.

Table4.3:Filter results based on Max von Mises stress

Model	Outcome19	Outcome17	Outcome48	Outcome5	Outcome31
Materials	Al6061	Al6061	AlSi10Mg	Al7075	Stainless steel 316L

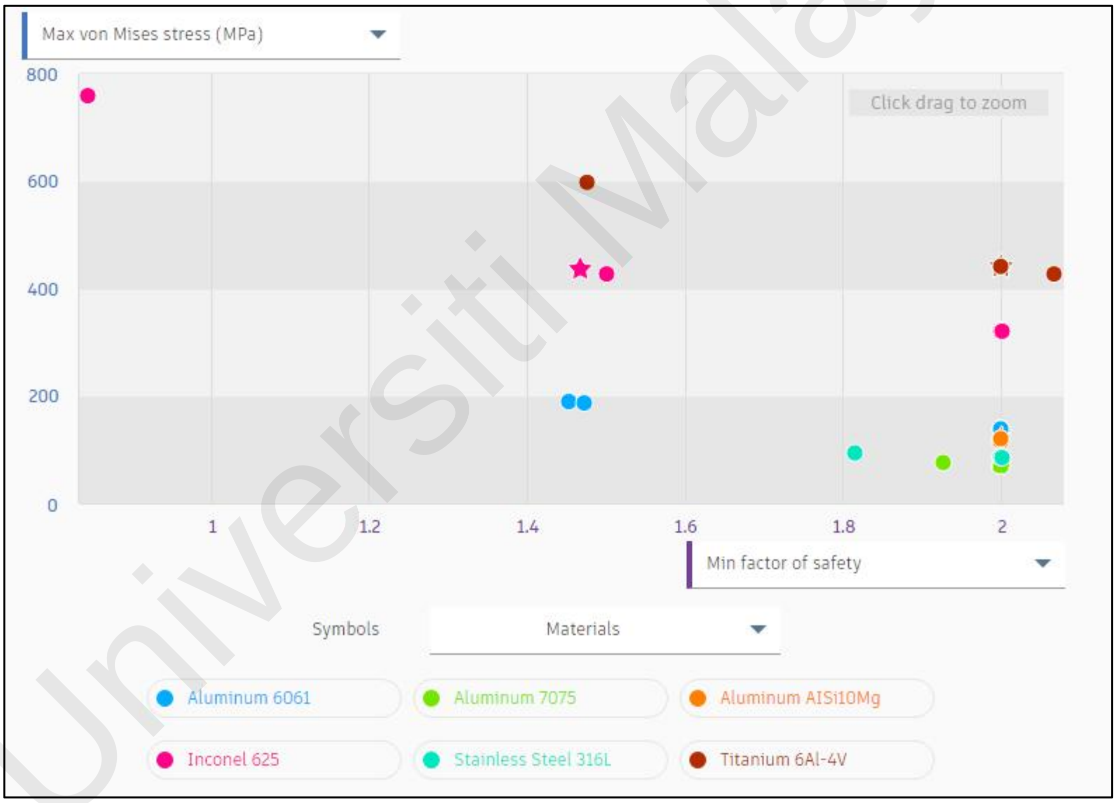


Figure4.5: Scatter plots for max von Mises stress

The research time is limited, and all materials will have a very large workload, so the selected material is Al6061. Comprehensive analysis of all images, as well as the analysis of specific generative design results parameters, will select models from the generative design results of Al6061. When selecting a model, it is also necessary to consider whether the shape of the designed model is generally symmetrical, because the asymmetry of the shape will make the parts receive uneven force during use, which is likely to cause the failure of the parts. In addition, when selecting the results of generative design, you need to observe the number of iterations of the model. The more iterations, the greater the amount of calculation in the generation process, and the better the performance of all aspects of the model. The following are two generative design models made of Al6061 material determined by selection, namely outcome 17 and outcome 19, which have gone through more than 20 iterations and can be used for analysis and use.

For the maximum Mises equivalent stress that can be borne by outcome17, its value is 187.5Mpa, and the theoretical mass of the model is 0.535Kg; for the maximum Mises equivalent stress that can be borne by outcome19, its value is 177.5Mpa, and the theoretical mass of the model is 0.573 Kg. The maximum stress that they can withstand will be used in the static stress analysis stage and compared with the results of the static stress analysis.

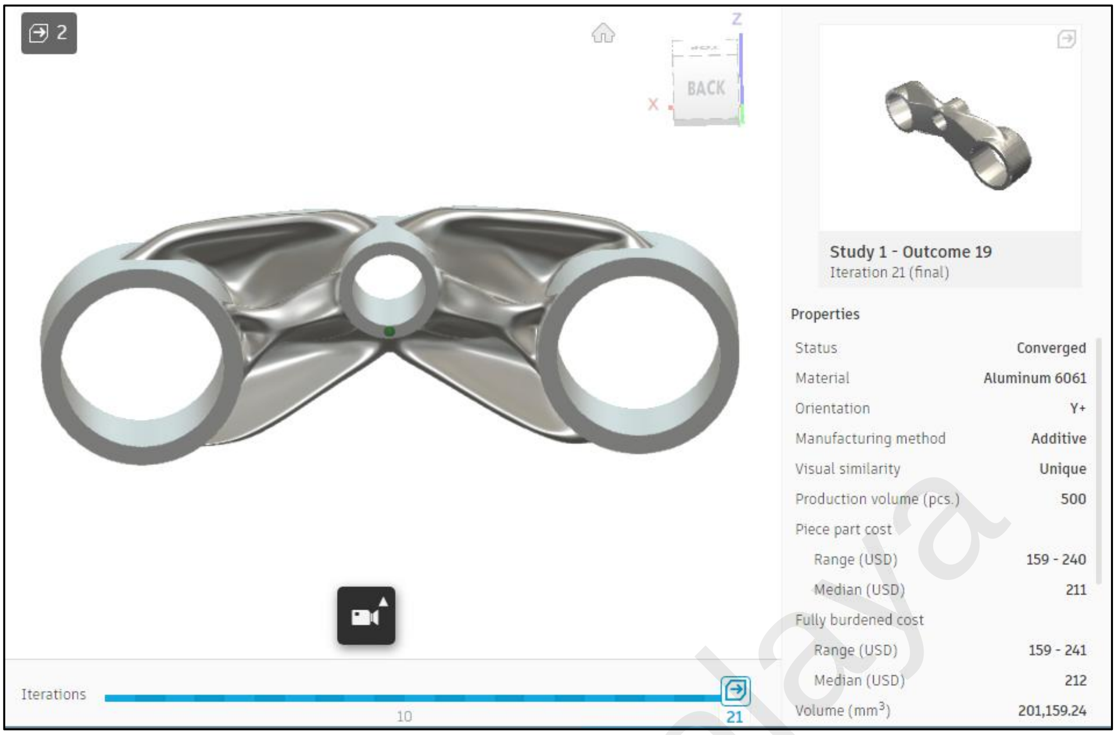


Figure4.6: The model of outcome 19

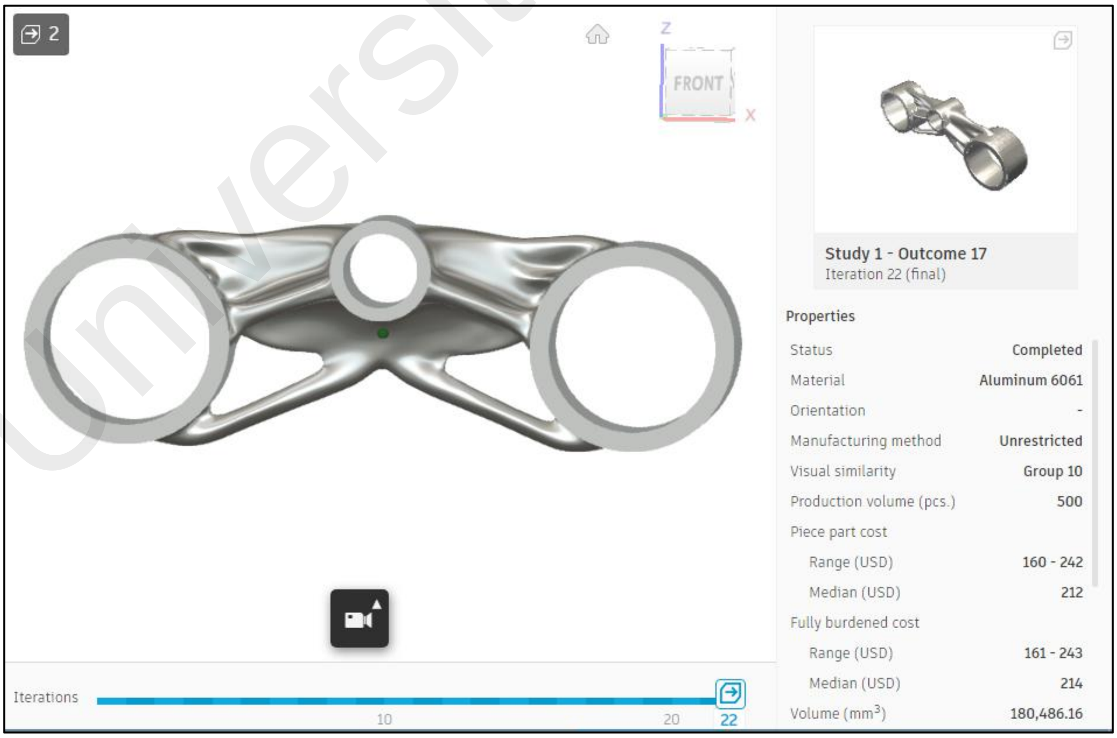


Figure4.7 :The model of outcome 17

4.3 Results of shape optimization design

For the shape optimization design of parts, it is based on the application of geometric primitive loads and boundary conditions to achieve lightweight and structural efficiency of parts. The operation of shape optimization simulation is similar to generative design, but its shape is always regular. The lightweight target required by this research is only 85% of the original mass.

After the shape optimization, the mass of the model is 0.635Kg, the volume is 165305.4mm3, the minimum safety factor is 2, and the maximum Mises equivalent stress that can withstand is 378.3Mpa. Finally, it will be subjected to static stress analysis.

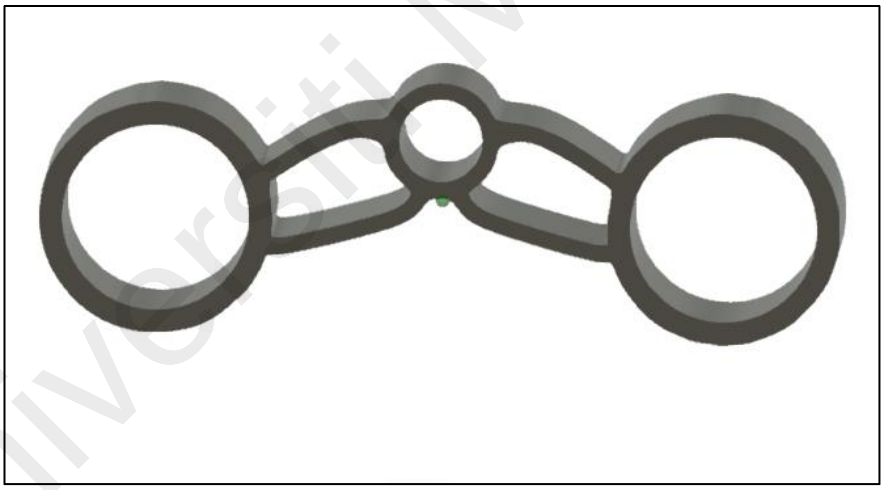


Figure4.8: The model of the shape optimization

4.4 Results of static stress analysis

4.4.1 The static stress of components with generative design

In 4.2, through analysis and comparison, two generative design models with roughly symmetrical shape pairs have been selected, namely outcome17 and outcome19.

For the model of outcome19, according to the results of static stress analysis, there are two groups of loads whose direction is parallel to the Z axis. The effects of these two groups of loads on components are similar, so one group can be analyzed. We can find that when the load parallel to the Z axis actually acts on the component, the minimum safety factor of the component is 1.974, which is less than the minimum theoretical value of 2.0, but it is very close. According to the comparison between the theoretical value and the actual value, it shows that this design can basically guarantee that the parts will not fail when the actual load acting on the Z axis is applied. optimize.

For loads whose direction is parallel to the Y-axis, they also have two groups. Their influence on the components is similar, but the direction of action is opposite. Therefore, one group is also selected for analysis. Through the analysis results, we can find that when it actually acts on the component, the minimum safety factor of the component is 3.069, which shows that the structure of all parts of the component of this design is safe when bearing the load in the Y-axis direction, so the subsequent optimization work does not need to adjust the load in the Y-axis direction.

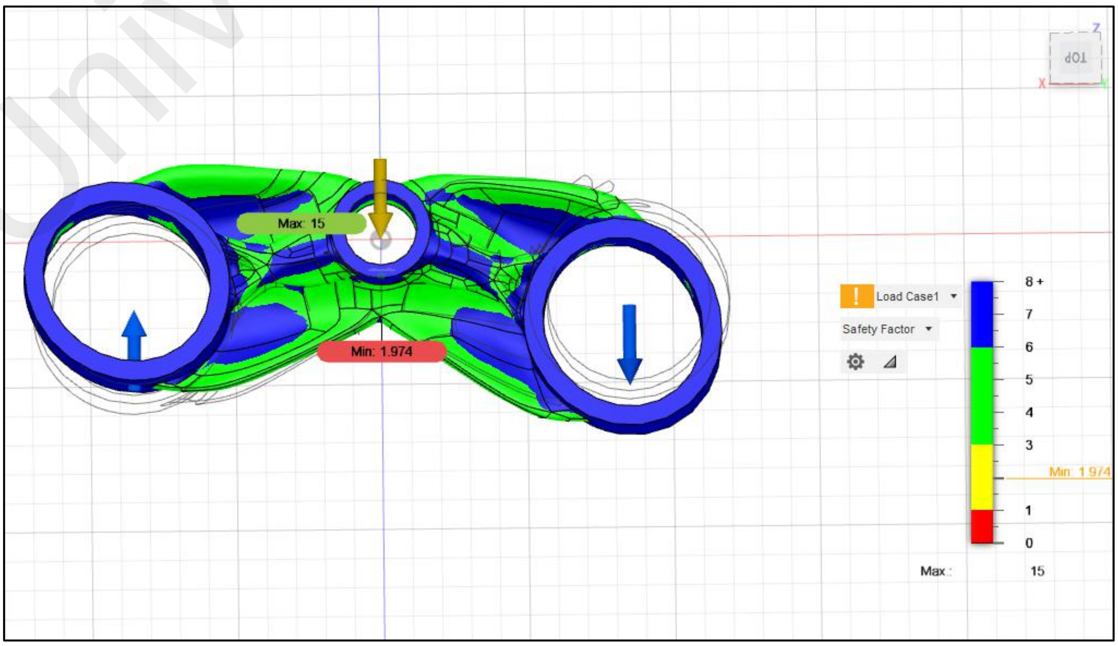


Figure4.9: The static stress result for the outcome19's safety factor(Z-axis)

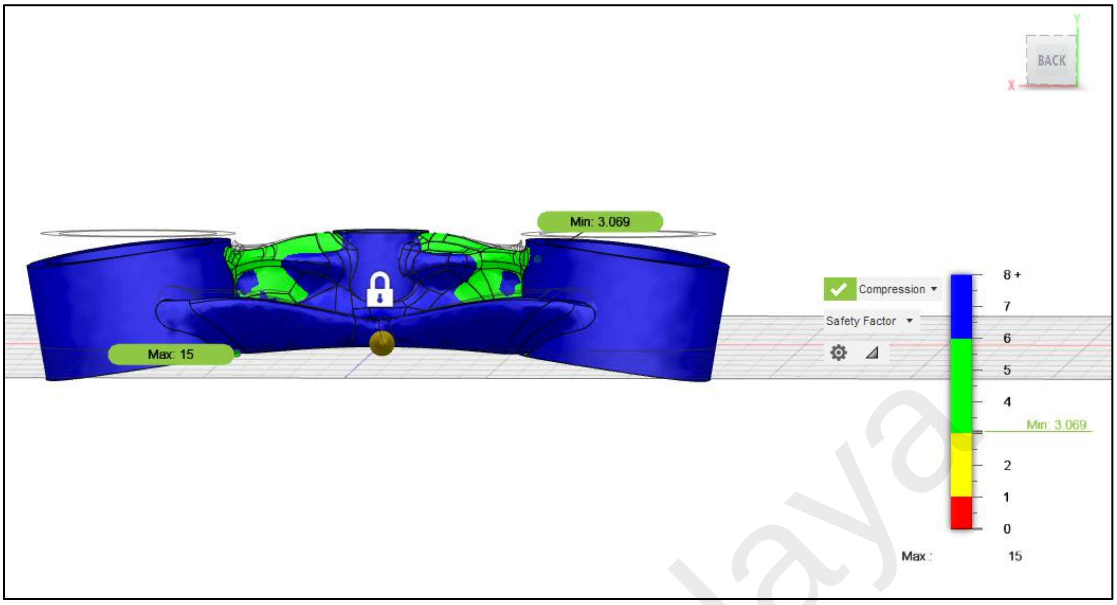


Figure4.10: The static stress result for the outcome19's safety factor(Y-axis)

After the analysis of the actual safety factor of the outcome19 parts is completed, the force situation of the parts when the actual load is applied will be analyzed. The four different loads used in this study can be divided into two groups for analysis, because the two different loads in each group are of the same magnitude and the direction of force is opposite, and the static stress analysis results show that the same group of loads has the effect of the components is similar. We can find that when the load parallel to the Z axis actually acts on the components, the components will have stress concentration in the relatively small parts, and the Mises equivalent stress of the maximum stress concentration part is 139.3Mpa. In the model obtained by generative design, the theoretical maximum Mises equivalent stress value is 177.5Mpa, and the theoretical value is greater than the actual value.

When a load parallel to the Y axis acts on a component, stress concentration occurs in several parts of the component, but the range of stress concentration is very small.

The Mises equivalent stress of the maximum stress concentration position is 89.6Mpa, and the theoretical maximum Mises equivalent stress value of the model obtained by the generative design is 177.5Mpa. Integrating the actual load conditions in the Y-axis and Z-axis directions, the design results of the outcome19 model basically meet the needs of actual use.

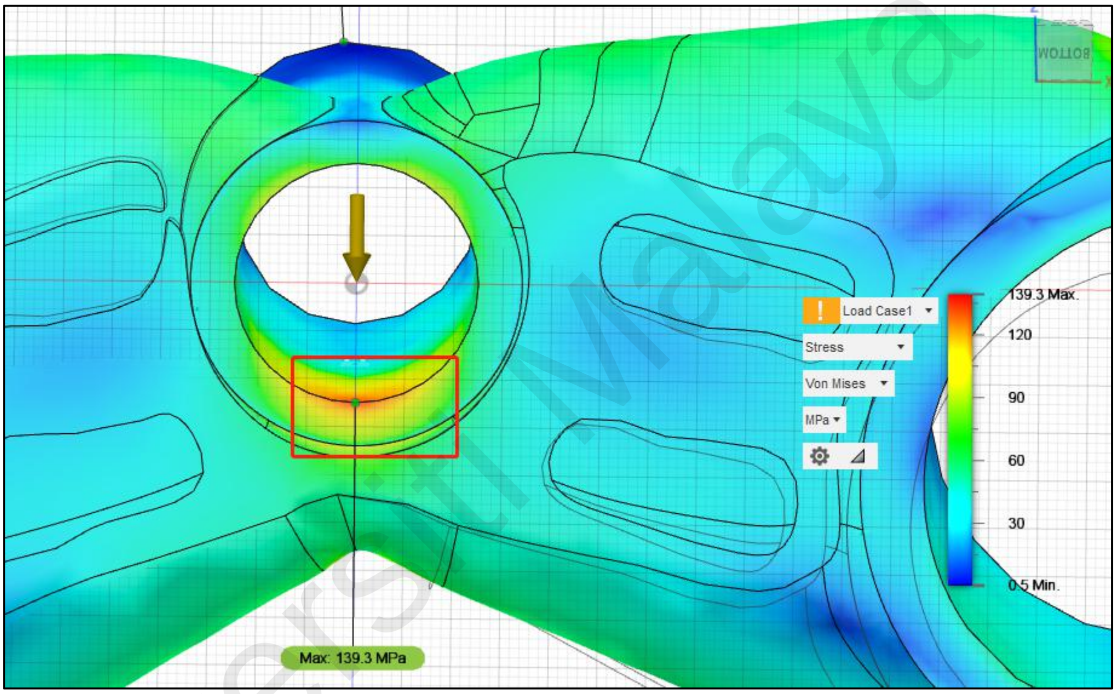


Figure4.11: The static stress result for the outcome19's stress(Z-axis)

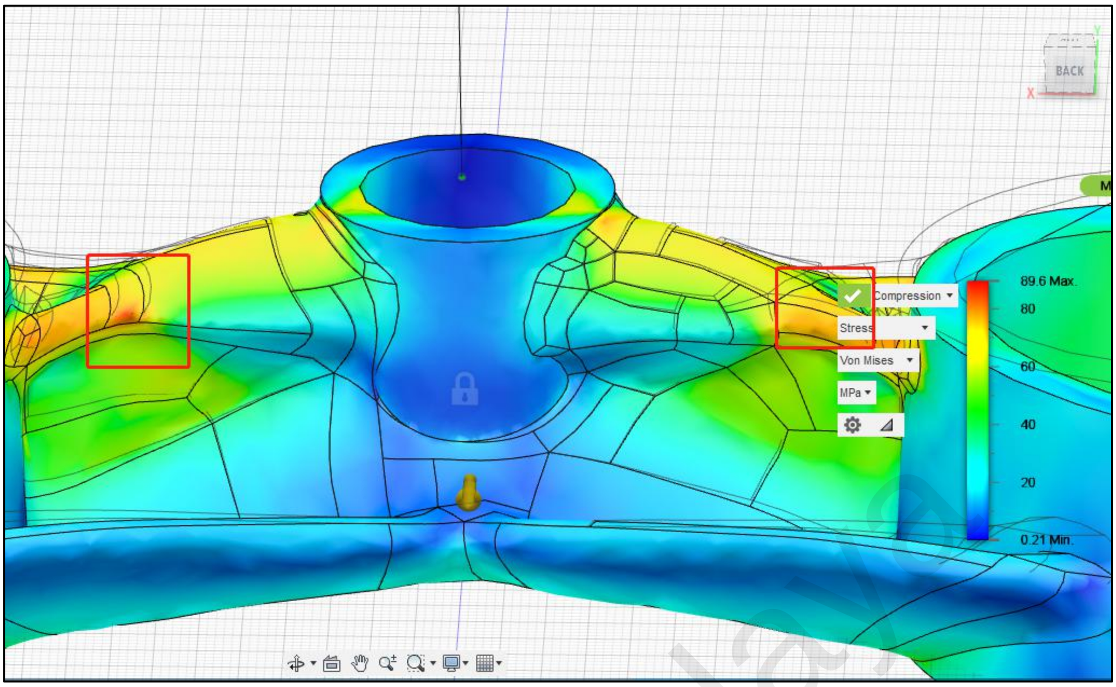


Figure4.12: The static stress result for the outcome19's stress(Y-axis)

For the model of outcome17, according to the results of static stress analysis, the effects of loads in different coordinate axis directions on components are different. There are two sets of loads whose direction is parallel to the Z axis. The effects of these two sets of loads on components are similar, so one set can be analyzed. We can find that when the load parallel to the Z axis actually acts on the parts, the minimum safety factor of the parts is 1.372, which is less than the minimum theoretical value of 2.0. It shows that this design is in a dangerous state when it is subjected to the actual load acting on the Z axis, and the design is not sufficient, and some external factors may cause it to bend or break during actual use.

Similarly, for loads whose direction is parallel to the Y-axis, they also have two groups. Their effects on components are similar, but the direction of action is opposite. Therefore, one group is also selected for analysis. Through the analysis results, we can find that when it actually acts on the parts, the minimum safety factor of the parts is

1.825, indicating that certain parts of the parts of this design are in a critical state and need to be structurally optimized.

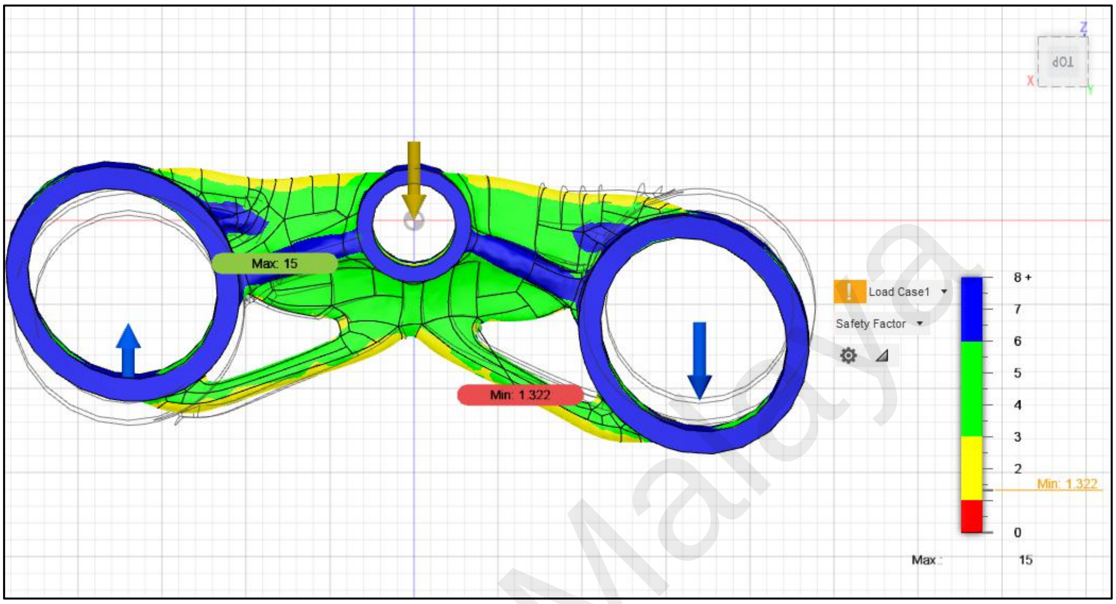


Figure4.13 The static stress result for the outcome17's safety factor(Z-axis)

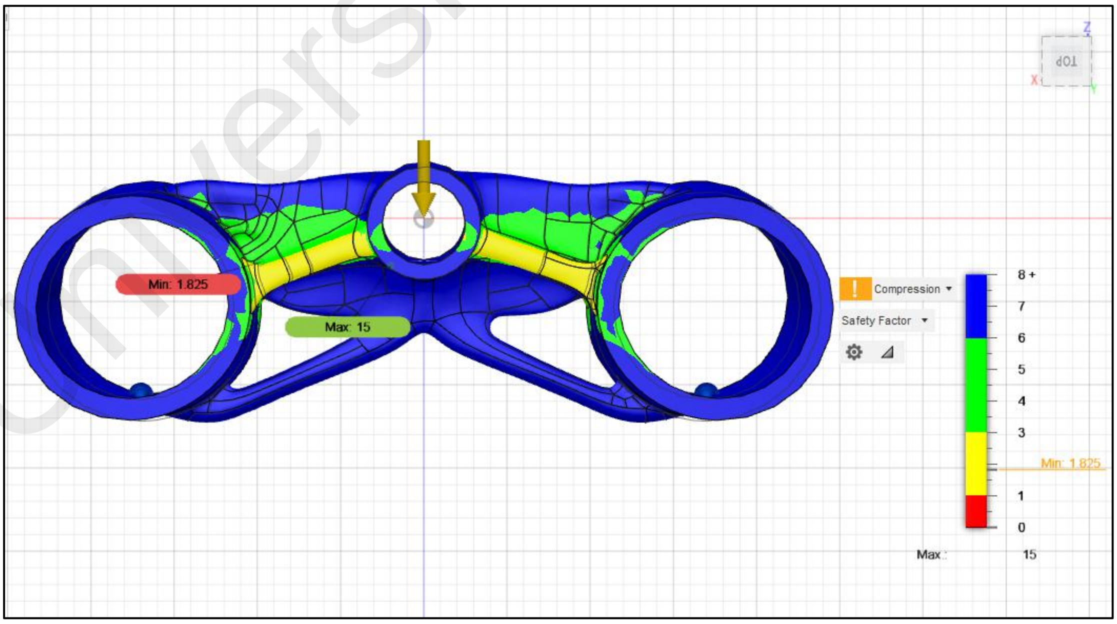


Figure4.14: The static stress result for the outcome17's safety factor(Y-axis)

After the analysis of the actual safety factor of the outcome17 parts is completed, the force situation of the parts when the actual load is applied will be analyzed. The four different loads used in this study can be divided into two groups for analysis, because the two different loads in each group are of the same magnitude and the direction of force is opposite, and the static stress analysis results show that the same group of loads has the effect of the components is the same. We can find that when the load parallel to the Z axis actually acts on the parts, the parts will have stress concentration in the relatively small parts, and the Mises equivalent stress of the parts with the largest stress concentration will be 208.2Mpa. In the model obtained by generative design, the theoretical maximum Mises equivalent stress value is 187.5Mpa, and the theoretical value is smaller than the actual value. The theoretical value is relatively close to the actual value, but in actual use, the phenomenon of component fracture and failure may occur.

When a load parallel to the Y axis acts on a component, stress concentration occurs in several parts of the component, but the range of stress concentration is very small. The Mises equivalent stress of the maximum stress concentration position is 150.6Mpa, and the theoretical maximum Mises equivalent stress value of the model obtained by the generative design is 187.5Mpa, so there may be parts failure phenomenon in actual use.

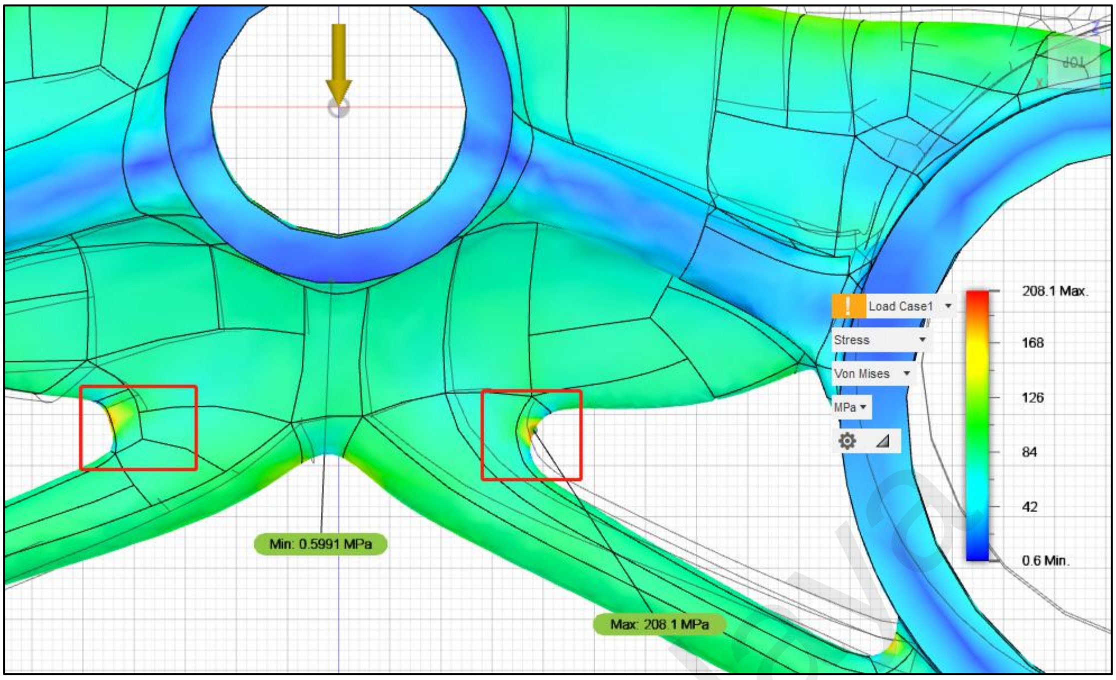


Figure4.15: The static stress result for the outcome17's stress(Z-axis)

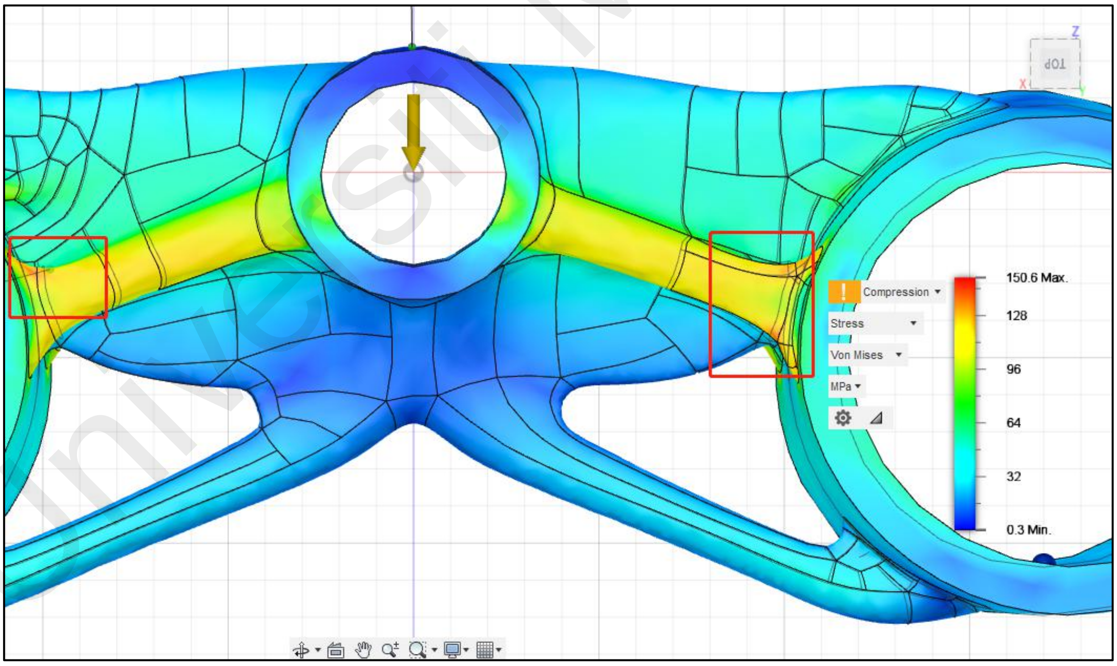


Figure4.16: The static stress result for the outcome17's stress(Y-axis)

4.4.2 The static stress of the parts with shape optimization design

According to the results of static stress analysis, the effects of loads in different directions on components are different. There are two sets of loads whose direction is parallel to the Z axis. The effects of these two sets of loads on the components are the same, so one set can be analyzed. We can find that when the load parallel to the Z axis actually acts on the parts, the minimum safety factor of the part is 2.746, which is greater than the set minimum safety factor, so the conditions are met, but the design is still in a critical state. The design may be sufficient, but external factors can cause it to bend or break. Because for some special design applications, the minimum safety factor is usually 3.0. If you continue to optimize in the future, you can change the minimum safety factor setting.

Similarly, for loads whose direction is parallel to the Y-axis, they also have two groups. Their effects on components are similar, but the direction of action is opposite. Therefore, one group is also selected for analysis. Through the analysis of the results, we can find that when it actually acts on the parts, the minimum safety factor of the parts is 3.867, indicating that this design satisfies the conditions very well. For current design standards, the design should not bend or break, and the safety factor target meets company, application, and industry standards.

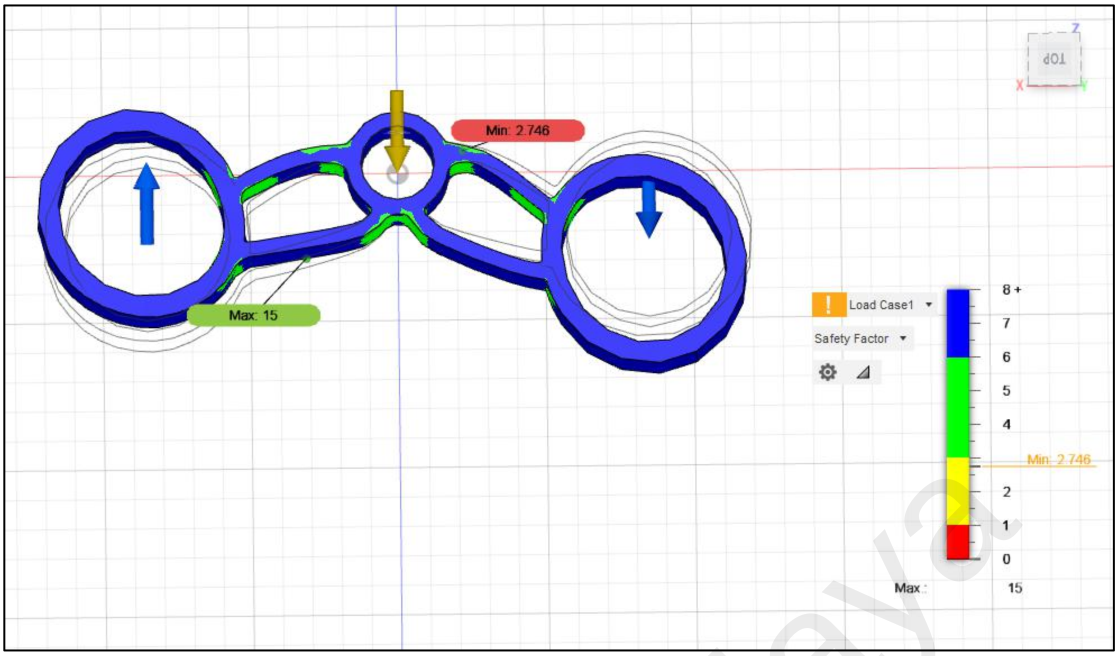


Figure4.17: The static stress result for shape optimization's safety factor(Z-axis)

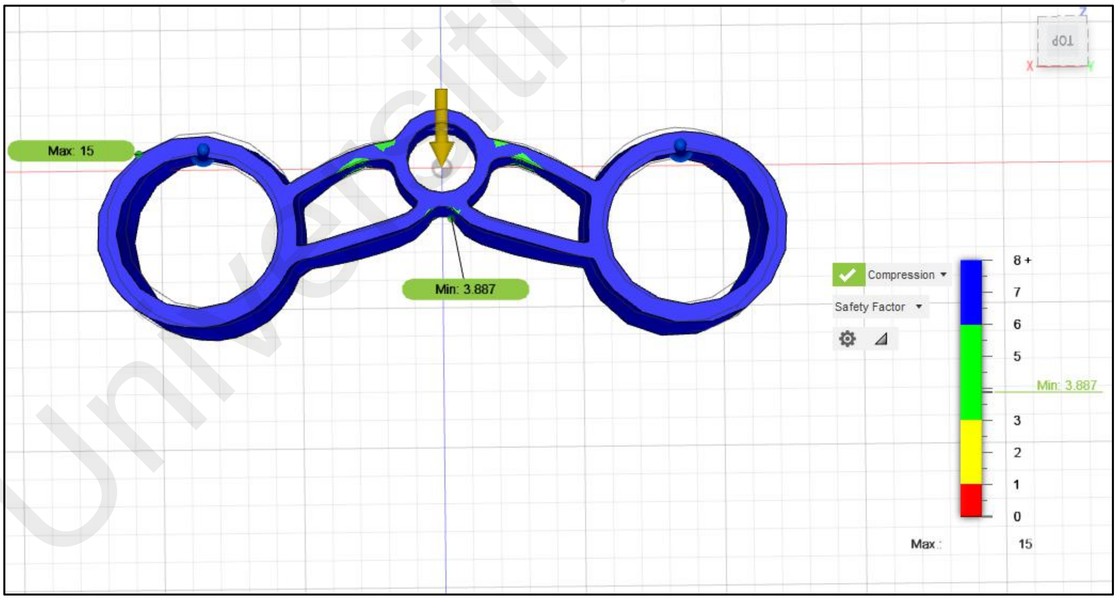


Figure4.18: The static stress result for shape optimization's safety factor(Y-axis)

After the analysis of the actual safety factor of the parts is completed, the force situation of the parts when the actual load is applied will be analyzed. Similarly, the four different loads used in this study can be divided into two groups for analysis, because the two different loads in each group are of the same magnitude and the direction of force is opposite. We can find that when the load parallel to the Z axis actually acts on the parts, there will be multiple stress concentrations in the parts. The Mises equivalent stress of the most concentrated part is 321.3Mpa. After the previous shape optimization, the theoretical maximum Mises equivalent stress that the component can withstand is 378.3Mpa, so the design is qualified. In view of the stress concentration of components, these two aspects can be studied in the subsequent optimization work: (1) Strengthen the design in the weakest area by adding materials or artificial optimization, and then use a more rigid shape ;(2) When selecting materials for parts and components, materials with higher yield and ultimate strength can be selected.

Then analyze the loads whose direction is parallel to the Y-axis. They also have two groups. Their influence on the components is similar, but the direction of action is opposite. Therefore, one group is also selected for analysis. Through the analysis results, we can find that when it actually acts on the parts, the parts will also have stress concentration. The Mises equivalent stress of the part with the largest stress concentration is 227Mpa, which is far less than the theoretical maximum of the part after the shape optimization. Mises equivalent stress. Therefore, the magnitude of the load acting in the Z-axis direction of the component is appropriate and does not need to be changed.

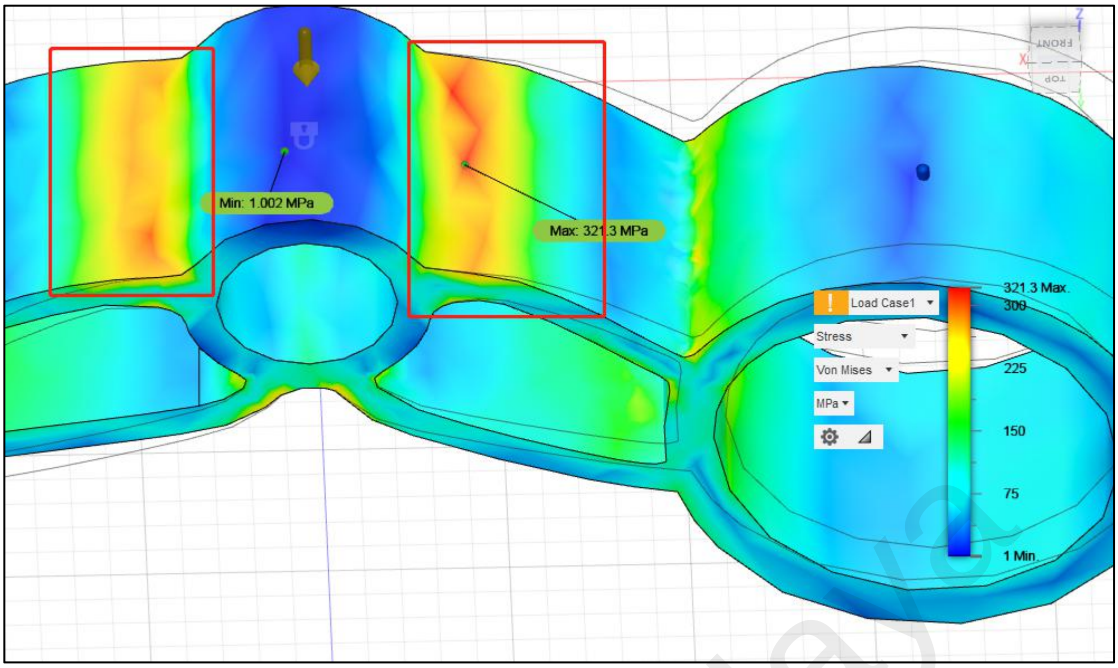


Figure4.19: The static stress result for shape optimization's stress(Z-axis)

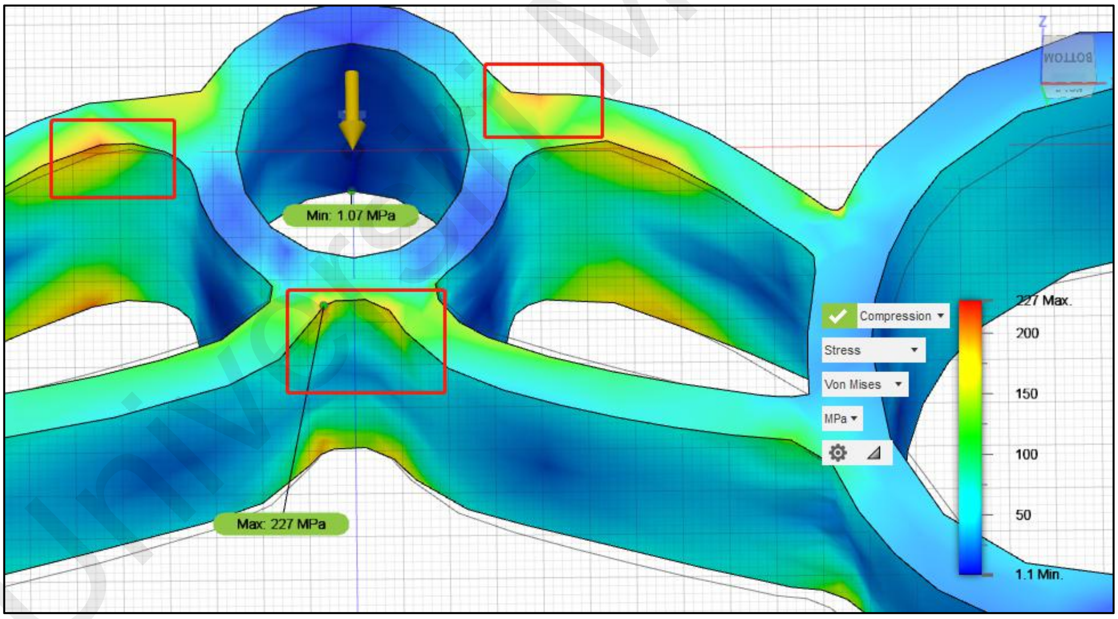


Figure4.20: The static stress result for shape optimization's stress(Y-axis)

4.5 Discussion

According to the analysis results in 4.4, the stress distribution of the model under different stress conditions has been specifically analyzed and discussed in 4.4, and suggestions for future research are given for the situations where component fracture and failure may occur, so the three models will be compared. In general, outcome19 performs well in the results of static stress analysis. It is only when the load in the Z-axis direction is applied that the actual minimum safety factor of the parts is slightly smaller than the theoretical minimum safety factor, so the parts of this model can be directly used in actual application, or it can be manufactured with stronger materials; for the static stress analysis results of outcome17, its overall performance does not meet the conditions of use, not only the actual minimum safety factor is much smaller than the theoretical minimum safety factor, but also there is a serious stress concentration phenomenon. The actual Mises equivalent stress value at the maximum stress concentration is even greater than the theoretical maximum Mises equivalent stress value, which may cause the parts to fail in actual use. Generally speaking, the two models selected for generative design, the outcome19 model can better adapt to actual usage conditions than the outcome17 model. If you want to use the outcome17 model, you can choose stronger materials for manufacturing.

In order to compare with the generative design model, this study also specifically studied the static stress distribution of the model after the shape optimization analysis. Its shape is relatively regular, and it can not only use additive manufacturing but also traditional manufacturing methods. This study did not pursue light weight excessively. From the results of static stress analysis, its static stress analysis results are more suitable for practical application conditions, but it can continue to be lighter to make its shape more efficient.

4.6 The result of sculpting process

According to the results of stress analysis and discussion, as designers, we will choose outcome19 for the sculpting process, because its stress analysis results are better than outcome17 stress analysis and have a higher safety factor. Import the model of outcome19 into the design module of Fusion360. For the area where the stress is concentrated in the stress analysis result, we can use the T-Spline tool to edit the created design. For sharp edges, if round corners can be designed, then round corners can be designed directly, which can eliminate the phenomenon of stress concentration, just like the edges in Figure 4.21. If it is a generative design that produces an edge connecting two faces, we can also delete it directly, and the two faces can become smooth. Therefore, the sculpting process is carried out according to the designer's own ideas. In Figure 4.22, by measuring the curvature of the two connecting edges, we can see the curvature changes after zooming in. The directions of their changes are opposite, so stress concentration occurs at the connection. The designer can add or delete materials on the two surfaces according to the change in curvature.

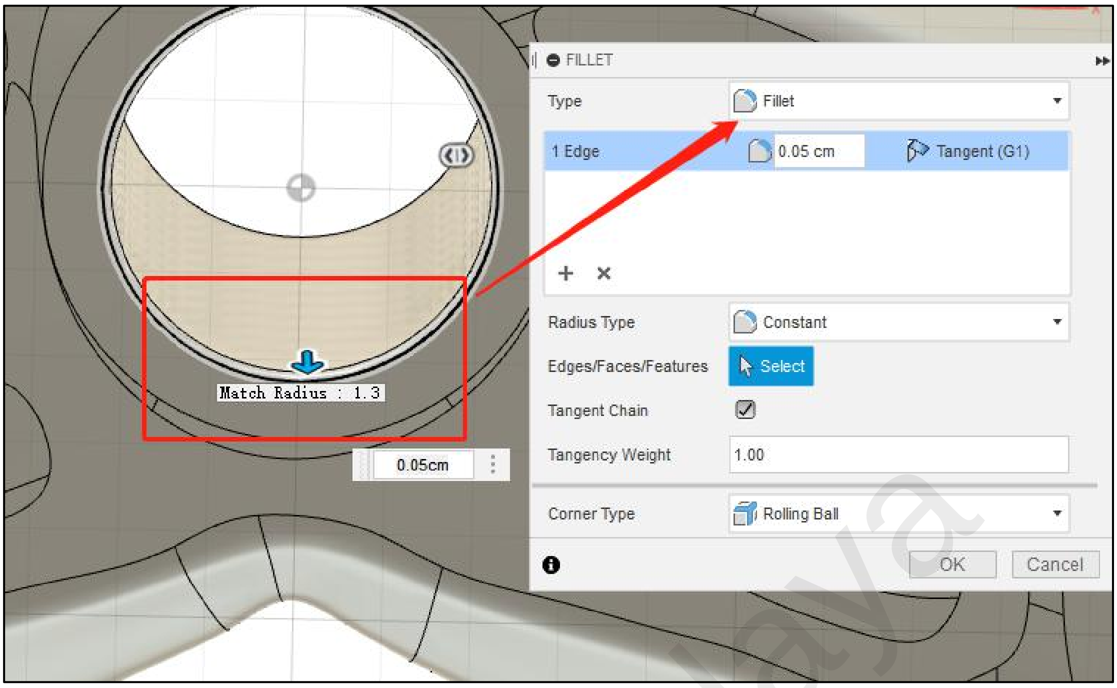


Figure4.21: Round sharp edges

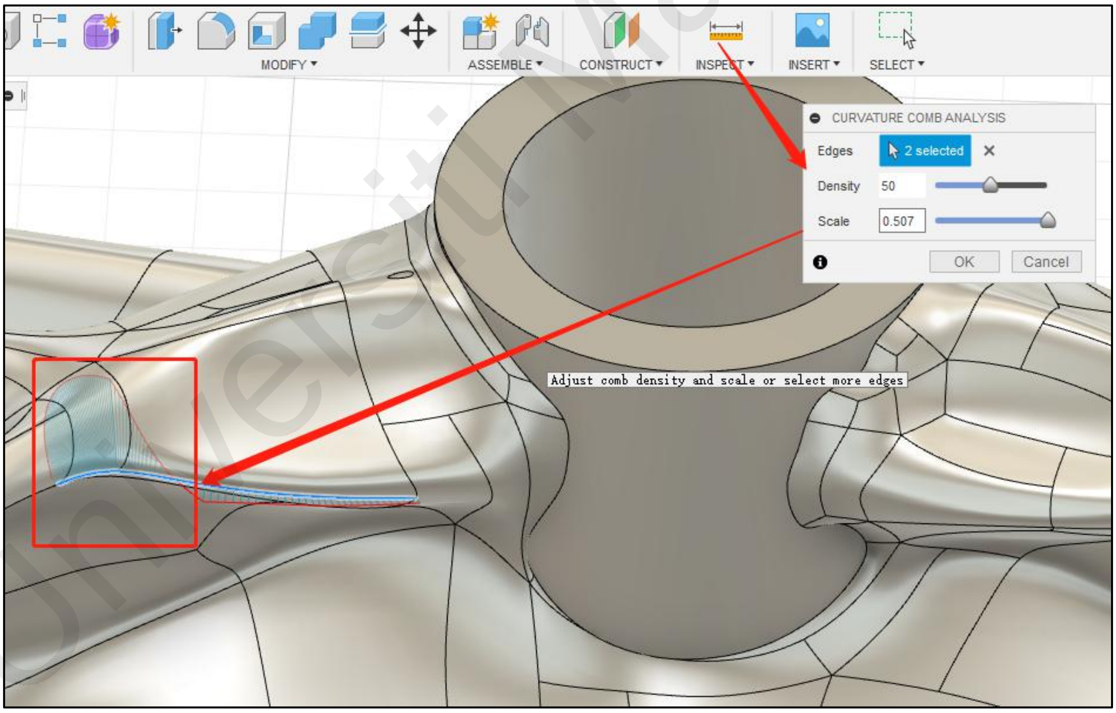


Figure4.22: Curvature changes of the two sides of the stress concentration area

CHAPTER 5:CONCLUSION AND FUTURE WORK

Fusion360 is used in all the work of this research, which can carry out generative design and has very powerful functions. This research successfully explored the use of the generative design function of Fusion360, and summarized some conclusions through static stress analysis: Not all results can be used in the generative design, and the theoretical situation is different from the actual situation; the model safety factor after the shape optimization design is higher, but its quality is greater, so a generative design model was chosen. In general, the exploratory experiments conducted in this research basically achieved the original research content and research goals, and also tried to use the shape optimization function to design and compare traditional modeling, making the research more perfect.

Wire arc additive manufacturing is a kind of integrated physical welding, thermomechanical engineering, material science and mechatronics technology. Different materials, different shapes and specifications of the parts used in the process are quite different. As a new design method developed with Al calculation, generative design is still relatively small in the literature on the connection between generative design and additive manufacturing. The method design and operation process of the entire research are explored in failure. Due to the very short time of the special semester and the epidemic, it is impossible to enter the laboratory to make the model, and all the work is carried out by simulation research. The characteristics and process of wire arc additive manufacturing technology have been described in detail in this report, and the model selected at the end of this study can be manufactured with this technology.

5.1 Future work

1. Try to use other generative design software to formulate design guidelines;
2. Try to explore more optimization methods to optimize the design of some unqualified parts of the model;
3. Choose more complex parts for generative design and analyze the results;
4. If there is an chance manufacturing models and use material analysis methods to analyze its structure, the research will be better ,these tasks need to be completed in the laboratory.

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