# GNG5140 Final Prototype

# Assignment G
# Modular Ultralight eV Prototyping

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# Abstract

UO Super mileage is a student organization at the University of Ottawa that competes in the highly regarded Shell Eco-Marathon program. The aim of the club is to design and build the most energy-efficient electric vehicle possible and to provide undergraduate and graduate students with the opportunity to enhance their engineering skills through hands-on experience. Over the years, the team has taken part in the prototype car category, which involves creating smaller vehicles that only require functional components and don't have any added features. However, more recently, they have stepped up to the urban concept category, where they face new design and production challenges such as optimizing the manufacturing process to create the chassis frame adapters. The process must be robust, economical and efficient in terms of material usage, among other important factors.

Our group, which is part of the Engineering Design course (GNG5140) at the University of Ottawa, will be providing support to the UO Super mileage club in selecting the most suitable manufacturing process for their vehicles. In this report, we begin by clearly defining the design problems and presenting some examples of existing solutions for reference. Additionally, we provide comprehensive technical information on the various manufacturing processes that will be evaluated and compared in order to determine which is the best fit for the club's needs in terms of design, mechanical requirements, and budget constraints.

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# List of Tables

## List of Acronyms

| Acronym | Definition |
|---|---|
| SAE | Society of Automotive Engineers |
| CNC | Computer numerical control |
| CAD | Computer-aided design |
| FDM | Fused Deposition Modeling |
| CFRP | Carbon Fiber Reinforced Polymer |
| OD | Outer Diameter |
| MPa | Mega Pascal ($N/mm^2$) |
| | |
| | |
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| | |

# 1 Introduction

The University of Ottawa's SAE Supermileage team has constantly worked to improve its energy-efficient automobiles. We have been tasked with finding alternate ways of spare part production that are cost effective, time efficient, and simple to learn. We are focused mostly on traditional manufacturing techniques, from which we will methodically seek inspiration and work towards the needs of our Super mileage team. We gathered public materials from multiple SAE Supermileage teams and determined the processes employed, such as water jet cutting, CNC machining, Additive fabrication, and casting. Some pieces must be extremely exact, and their production will be beyond the scope of this project. We had a thorough discussion with our team members and decided to focus more on casting processes (with possible future development) and, secondly, the process of additive manufacturing. We will be able to best develop a better solution and bring about a revolutionary change in low-cost manufacturing using the information gained from the collected resource

# 2 Prototypes and Test

## 2.1 Final Prototype Drawing

This is the drawing of the revised prototype, which will be used for metal 3D printing after verification with the client. The verified drawing is available in appendix C.

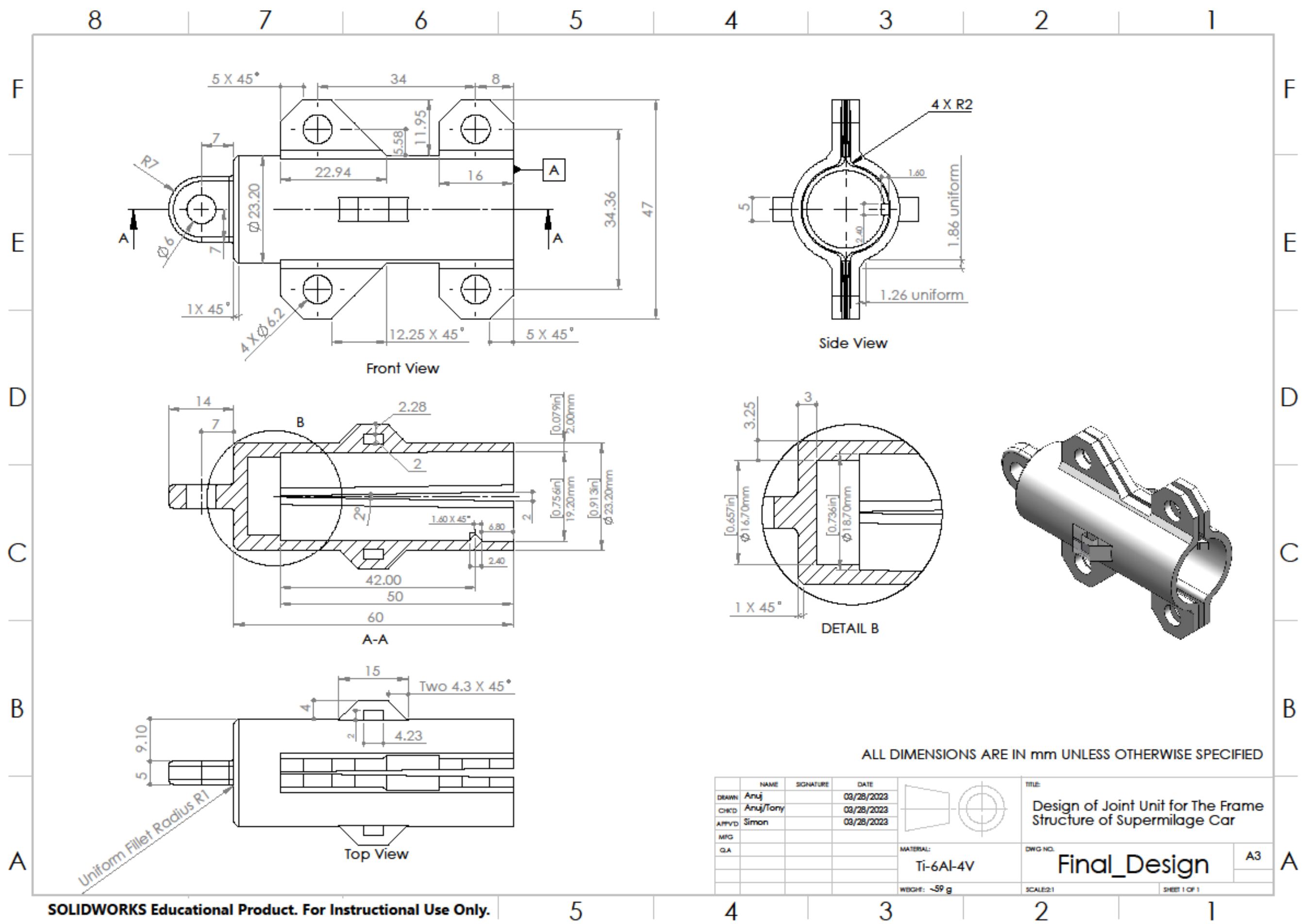



**Figure 1: Revised Prototype Drawing**

## 2.2 Final Prototypes

Final prototype is shown in figure 3, which is similar to the previous one.

The purpose of this prototypes is to ensure that the design is ready for metal printing.
The purpose of metal printed part is,

1. To conduct the pull testing
2. To use it for joining carbon fiber tubes.

Following modification were done on the previous prototype.

1. Mounting feature is added on the second side to make design symmetric and to increase the gripping.
2. Protrusion is added as shown in the figure 4, to increase the holding force of joint.

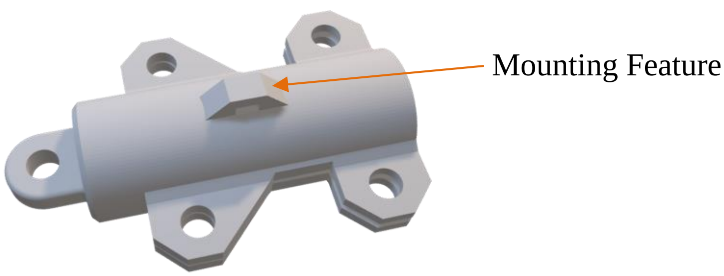



**Figure 2: Prototype with Mounting Feature**

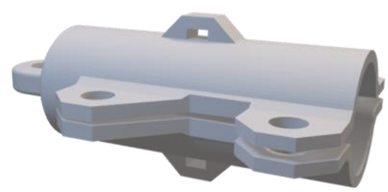


**Figure 3: Final Prototype**

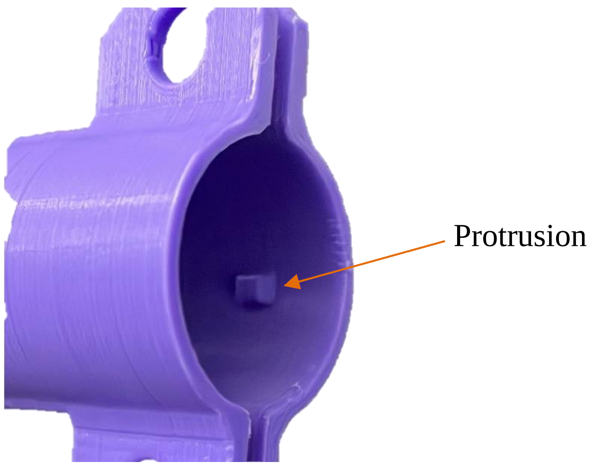



**Figure 4: Protrusion on One side**

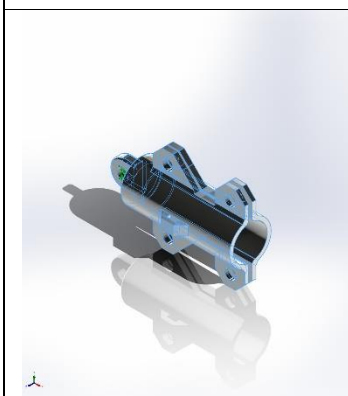
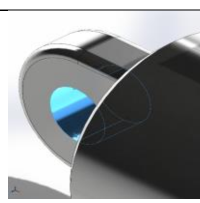
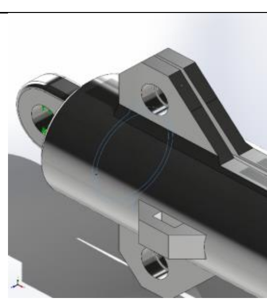
## 2.3 Testing

If the part doesn't deform or the stress is relatively small comparing to the material strength, then the part is considered pass the test, if the value is way off the strength, then it is failed the test in simulation.

### 2.3.1 Test 1

In the simulation, considering the worst-case scenario is that the impact load and the direct load are simultaneously acting on the joint, so we set the loading force as 7,000N (Appendix A).

**Table 1: Revised Prototype Test 1: Material Properties and Constraints [1]**

| Model Reference | Properties |
|---|---|
|  | Name: **TI64(3DP)**<br>Model type: **Linear Elastic Isotropic**<br>Yield strength: **7.3e+08 N/m^2**<br>Tensile strength: **8.45e+08 N/m^2**<br>Elastic modulus: **1.048e+11 N/m^2**<br>Poisson's ratio: **0.31**<br>Mass density: **4,318.06 kg/m^3**<br>Shear modulus: **3.189e+08 N/m^2** |
|  | **Entities: 1 face(s)**<br>**Type: Fixed Geometry** |
|  | **Entities: 1 face(s)**<br>**Type: Apply normal force**<br>**Value: 7,000 N** |

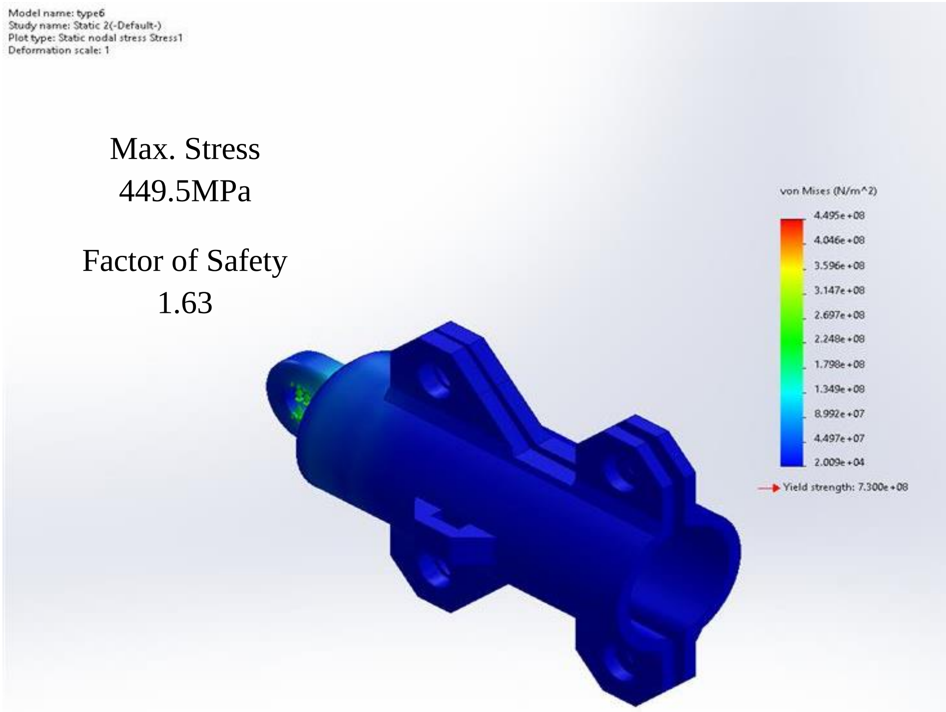



**Figure 5: Final Prototype Test 1 - Stress Result**

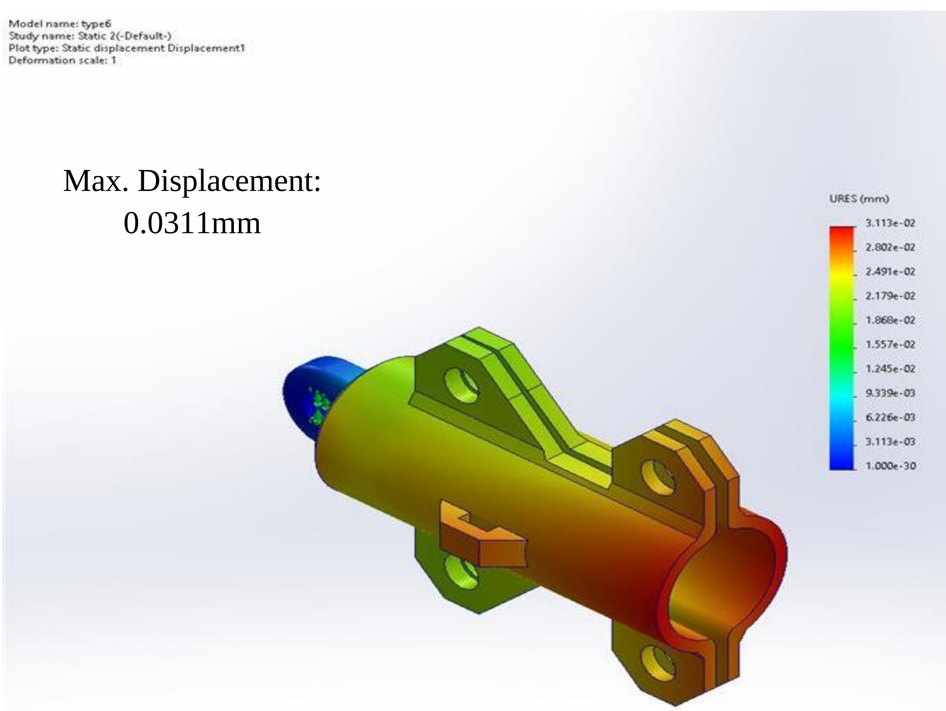
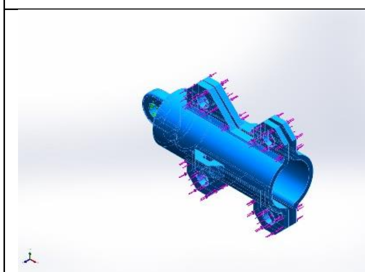
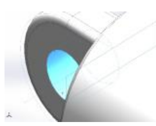
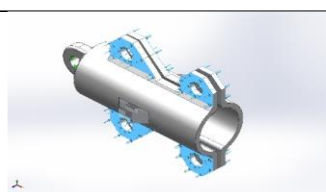
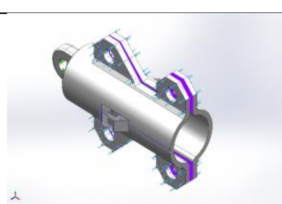



**Figure 6: Final Prototype Test 1 - Displacement Result**

### 2.3.2 Test 2

In the first iteration, we have applied the impact load and the direct load. For this next iteration, the regular working condition was considered by incorporating tightening force [2] of bolt along with the direct load of 1500N (Appendix A).
The total tightening force is divided into halve and applied from both the sides (bolt seating side and nut seating side) to simulate the actual condition.

**Table 2: Revised Prototype Test 2: Material Properties and Constraints [1]**

| Model Reference | Properties |
| --- | --- |
|  | Name: **TI64(3DP)**<br>Model type: **Linear Elastic Isotropic**<br>Yield strength: **7.3e+08 N/m^2**<br>Tensile strength: **8.45e+08 N/m^2**<br>Elastic modulus: **1.048e+11 N/m^2**<br>Poisson's ratio: **0.31**<br>Mass density: **4,318.06 kg/m^3**<br>Shear modulus: **3.189e+08 N/m^2** |
|  | **Entities:** **2 face(s)**<br>**Type:** **Fixed Geometry** |
|  | **Entities:** **8 face(s)**<br>**Type:** **Apply Normal Force**<br>**Value:** **400 N** |
|  | **Type:** **Contact interaction pair**<br>**Entities:** **4 face(s)**<br>**Advanced:** **Surface to surface** |

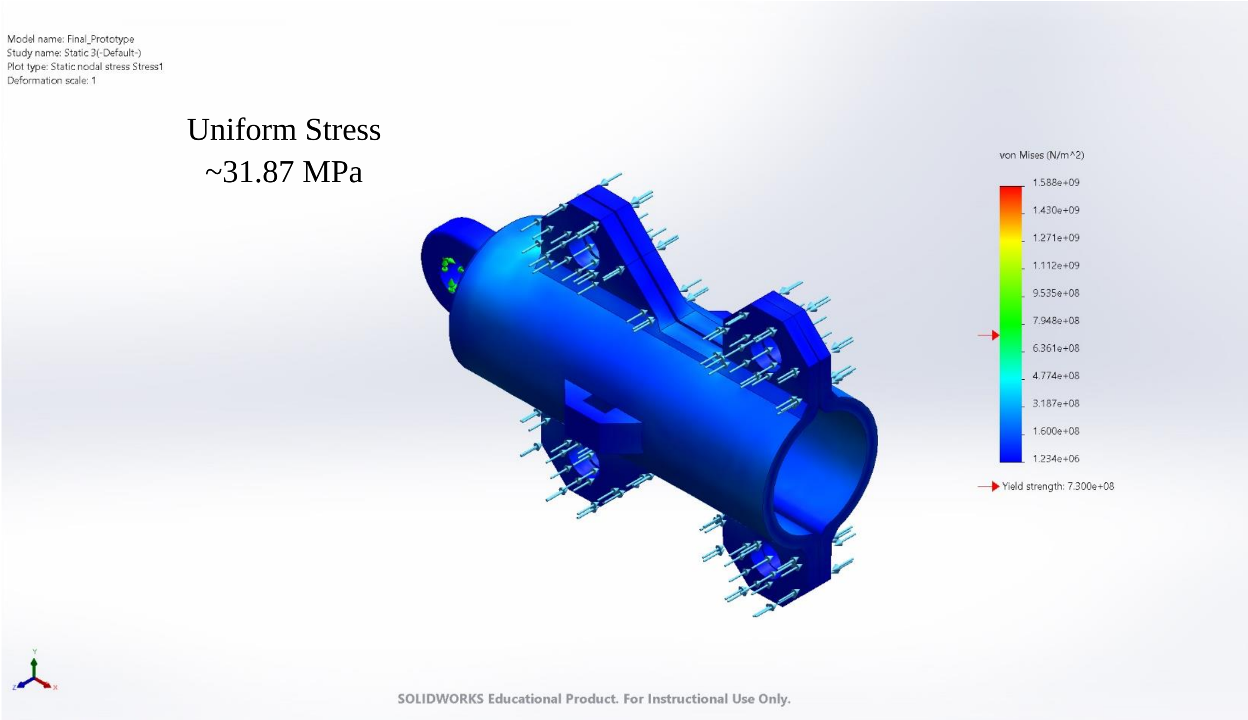



**Figure 7: Final Prototype Test 2 - Stress Result**

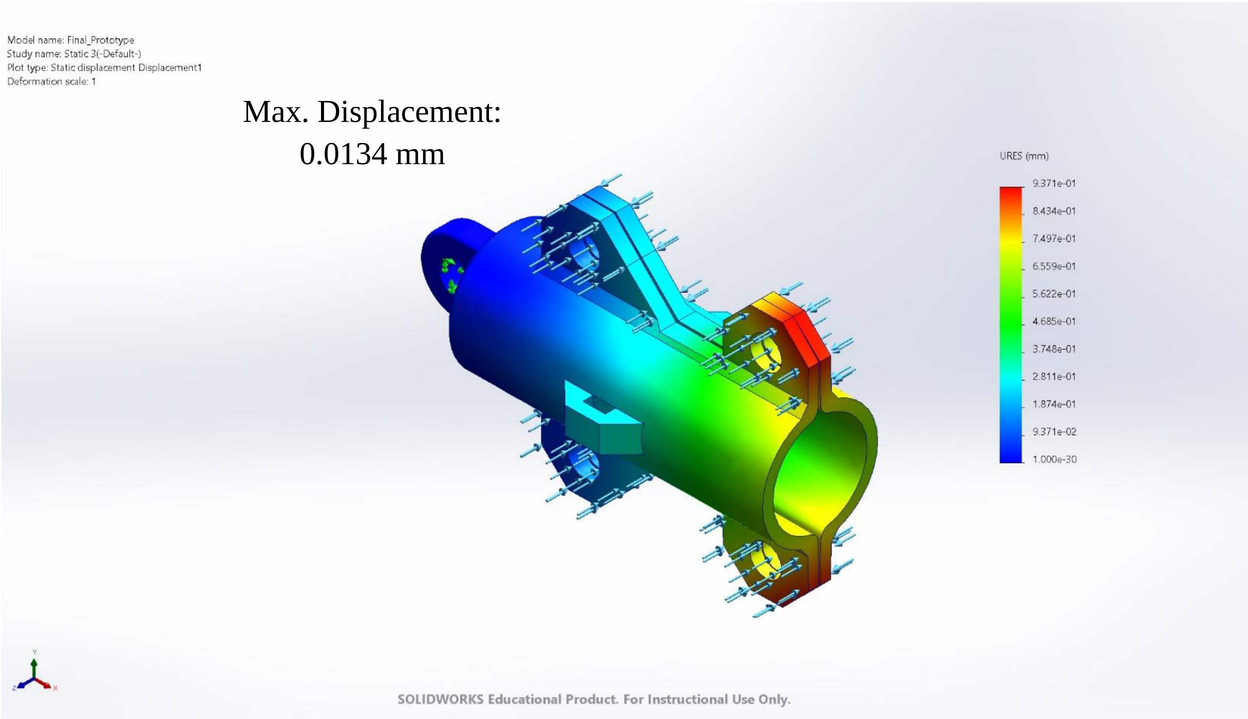



**Figure 8: Final Prototype Test 2 - Displacement Result**

### 2.3.3 Pull Test

This test is performed by pulling two side of assembly as shown in figure 9 and measuring the result. One side is tube and other side is the scale which is connected to the joint. We are able to create pulling force equivalent to 30Kg (~300N), which meets our expectations even though this is not made from titanium.

**Figure 9: Pull Testing**

### 2.3.4 Comparison Between Expected and Actual Results

**Table 3: Comparison Between Expected and Actual Result**

| | | Expected Result | Actual Result |
|---|---|---|---|
| 1 | Strength | > 580 MPa | 780 MPa |
| 2 | Diameter of The Tube to be Join | 1/2", 5/8" | 1/2” |
| 3 | Max Speed | 45 Km/h | Safe to Impact Loading |
| 4 | Weight of Vehicle | 300 Kg | Safe to Direct Loading |
| 5 | Recommended Weight of Vehicle | 100 Kg | Safe to Direct Loading |
| 6 | Maximum No of tubes at joint | < 8 | Not done |
| 7 | Corrosion Resistance | ✓ | ✓ |
| 8 | Fit | Transition | ✓ |
| 9 | Zip Tie Testing | Zip pass through mounting feature | ✓ |
| 10 | Pull Test with PLA Prototype | 20 Kg (Client Requirement) | >30 Kg |

The following conclusion and recommendation are drawn from the results,

1. In the first test our design is passed with the factor of safety of 1.63.
2. In the second test, we have applied the tightening force and observed that the uniform stress is acting on the part with value of around 318.7 MPa, which less than the yield strength of titanium.
3. Also, there is a stress value of 1588 MPa value and that is happening below the clamping surfaces in the inner side as shown in figure 9. In the actual situation, CFRP tube is inside the joint unit and support that area by preventing it to bend, so, this will not affect performance.
4. Our FEA model may not accurate enough since the area of the highest stress value is too small and it is possible that in the actual situation, there will not be that high amount of stress acting on that small area.

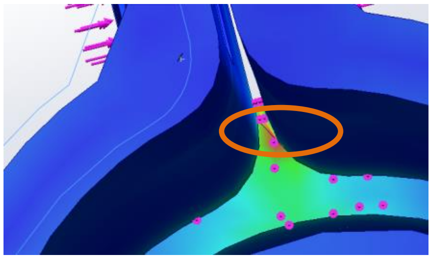


**Figure 10: Highest Stress Location**

# 3 Scalability

This joint design could find application in different structures, and it might be required in large numbers.

For the mass manufacturing, the production process selection is one of the important aspects. Here, the process is selected based on the charts provided in the Material selection by M.F Ashby [3] (Appendix B).

The appropriate processes for manufacturing for producing 500 components are,

1) Investment casting
2) Electro Machining
3) Conventional Machining

Also, the material used for manufacturing is titanium, alternative material can be used, which will provide the similar performance by just changing the thickness of the joint and also ease the material handling and hence, the overall cost.

Different structure joint has different requirements regarding the orientation of the tubes. Based on the relative axis orientation the portion shown in the figure 10 can be oriented differently.

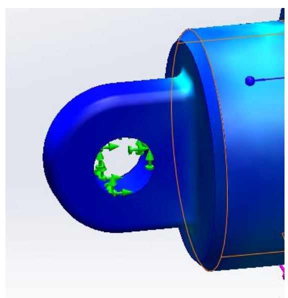


**Figure 11: Main Connection (between two units)**

Like, if the two axis are coincide to each other or at an offset to each other.

# 4 Quality

The quality of the joint depends on Quality of Design and Quality of Manufacturing.

## 4.1 Quality of Design

In the previous section the testing and its results shows that the design is safe means that the quality of design is acceptable.

Also, design for manufacturing aspect is being considered while designing.

1) To avoid the need of support material chamfer is provided instead of straight line as shown in figure 11.

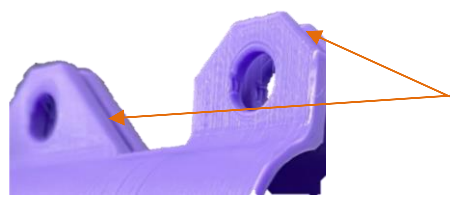



**Figure 12: Chamfer Instead of Straight Line**

## 4.2 Quality of Manufacturing

Quality of manufacturing will depend upon the parameters of 3D printing: Layer height, Nozzle Size, Printing Speed etc.

For example, layer height is directly related to the surface finish of the printed part.

As shown in the section of the scalability, if more numbers of parts need to be produce one of the methods is investment casting,
This design doesn't contain any sharp edges so there will be a less chances of cracking during the casting process.

## 4.3 Improvement in Quality

The unit of the joint is in at the end of development process.

Using the Kaizen process, the joint quality can be improved by studying the result of metal printed part and incorporating any changes need to be done.

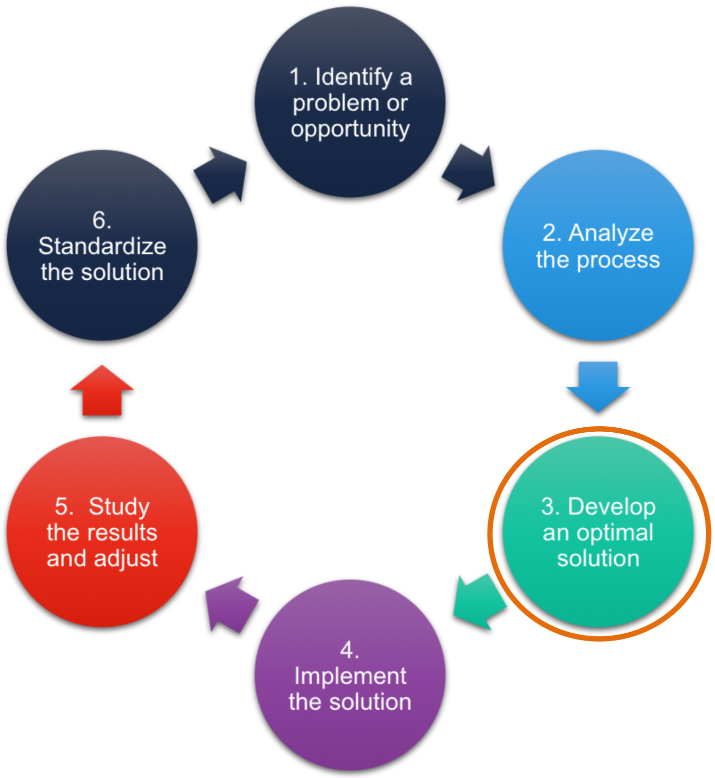



**Figure 13: Kaizen Process**

# 5 Sustainability

## 5.1 Social Aspect

This joint is providing alternative solution to welding process for joining number of tubes together. If this joint is used, then it will protect the welder from the harmful rays of being radiated.

This harmful UV rays can cause the diseases related to the eye and skin of the person [4].

## 5.2 Economical Aspect

The designed joint is semi-permanent joint, which facilitate easy maintenance and repair. Also, this joint design is versatile and numbers of tubes to be joined won't affect the design. Moreover, the design can accommodate various relative orientation by changing the orientation of the main connection.

## 5.3 Environmental Aspect

The benchmarked design of the provided joint design uses the anodized aluminum for producing the joint. The material used here is titanium alloy and the manufacturing method is 3D metal printing.

The aluminum sector produces 1.1 billion tons of $CO_2$ over a year [5]. Currently, 55 Kg of $CO_2$ is being produced while extracting 1 Kg of titanium alloy [6]. But innovation in smelting process for making pure titanium leads to no carbon emission [7].

Also, the additive manufacturing process has the lower carbon footprint compared to the conventional subtractive manufacturing process. The waste created during the 3D printing is much less than the conventional manufacturing process. Furthermore, heavy carbon supply chain is associated with the conventional manufacturing process, which is not the case with 3D printing [8].

# 6 Usability

As mentioned earlier the design of the joint changes marginally for different orientation of tubes and hence, it is easy for user to locate the mounting unit related to the given tube.
Also, the assembly of the tube with the unit does not need any special operations except drilling and skilled person is not required to perform assembly.

As our design is just a universal joint design for half an inch CFRP tube and it can be easily adopted by other user to use it, if they need to use other diameters tube then they just need to simply change the inner diameter (indicated in figure 13) of the design to match them.

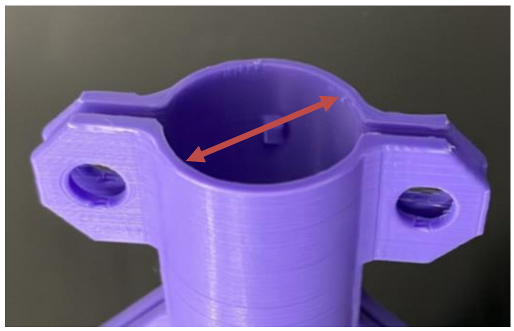


**Figure 14: Design Driving Diameter**

Improvements can be done by providing the video of assembly to reduce the unnecessary steps and hence, the time of assembly.

# 7 Conclusion and Recommendations

The report provides the details about the final prototype and testing result along with scalability, quality, sustainability, and usability aspects.

1) The joint is versatile and joint design is adaptive to change in orientation.
2) The protrusion add the additional holding force for the tube, which can be seen by the result of pull testing.
3) The joint and the tube assembly can be done easily by the semi skill person.
4) In the worst-case scenario (direct loading, impact loading & tightening force due to tightening torque), joint will fail, which is advantageous as it will save the high cost components for automobile.
5) It is advisable to print the holes without any support materials, otherwise it will be difficult to remove that afterwards.
6) It is recommended to use the process selection charts provided in the appendix B to select the manufacturing process according to the number of parts to be produced and design parameters.

# 8 Bibliography


[1] "Desktop Metal," [Online]. Available: https://www.desktopmetal.com/uploads/BMD-MDS-Ti64-210803.

[2] "The Engineering ToolBox," [Online]. Available: https://www.engineeringtoolbox.com/bolt-torque-load-calculator-d_2065.html.

[3] M. Ashby, Materials Selection In Mechanical Design, Butterworth-Heinemann.

[4] "Canadian Centre for Occupational Health and Safety," [Online]. Available: https://www.ccohs.ca/oshanswers/safety_haz/welding/eyes.html.

[5] "World Economic Forum," [Online]. Available: https://www.weforum.org/agenda/2020/11/the-aluminium-industry-s-carbon-footprint-is-higher-than-most-consumers-expect-heres-what-we-must-do-next/.

[6] "3DPrint.com," [Online]. Available: https://3dprint.com/283678/low-carbon-titanium-for-metal-3d-printing-explored-by-eos/.

[7] "nature portfolio," Toho Titanium, [Online]. Available: https://www.nature.com/articles/d42473-021-00166-8.

[8] "Makerforged," [Online]. Available: https://markforged.com/resources/blog/3d-printing-and-the-environmental-impact-of-manufacturing.

# 9 Appendix A

Direct loading

Weight 300Kg

Gravity takes 10

And we take half as a safety measure.

Direct loading

$$F_{direct} = mg$$
$$\text{m = 300 kg}$$
$$g = 10\,ms^2$$
$$F_{direct} = \frac{300\ \times 10}{2}$$
$$F_{direct} = 1{,}500\ N$$

Impact

45km/h- to 5 km/h in to sec

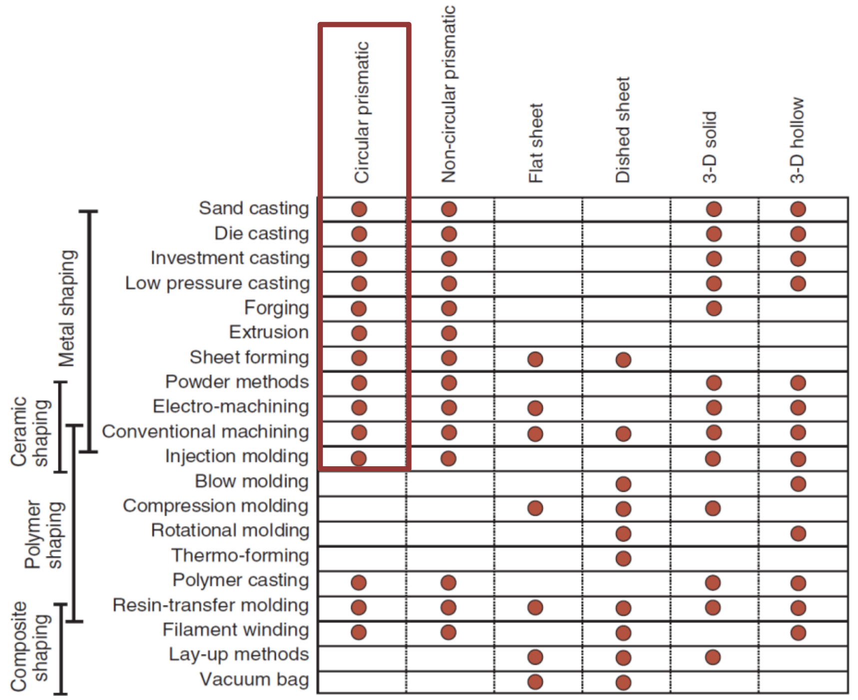
Weight is 300 including driver

$$F_{impact} = m\frac{v-u}{t}$$
$$m = 300kg$$
$$v = 45km/h$$
$$u = 10km/h$$
$$t = 2s$$
$$F_{impact} = 300\frac{45-10}{2}$$
$$F_{impact} = 5250N$$
$$F_{total} = \ F_{direct} + \ F_{impact}$$
$$F_{total} = 6750N \approx 7000N$$

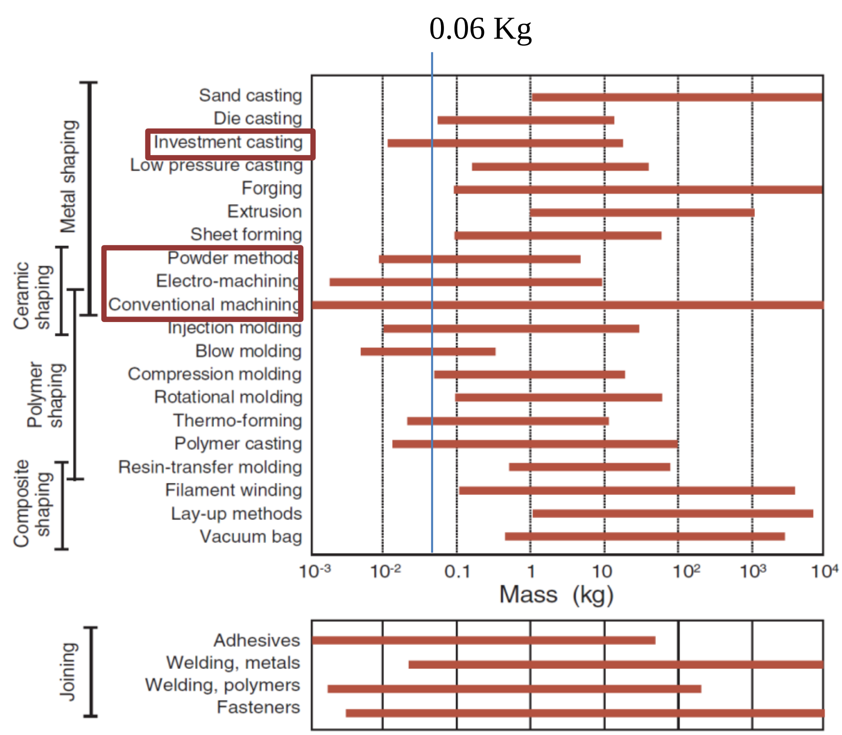
# 10 Appendix B

| | | Metals, ferrous | Metals, non-ferrous | Ceramics | Glasses | Elastomers | Thermoplastics | Thermosets | Polymer foams | Composites |
|---|---|---|---|---|---|---|---|---|---|---|
| Shaping | Sand casting | ● | ● | | | | | | | |
| | Die casting | ● | ● | | | | | | | |
| | Investment casting | ● | ● | | | | | | | |
| | Low pressure casting | | ● | | | | | | | |
| | Forging | ● | ● | | | | | | | |
| | Extrusion | | ● | | | | | | | |
| | Sheet forming | ● | ● | | | | | | | |
| | Powder methods | ● | ● | ● | | | | | | |
| | Electro-machining | ● | ● | ● | | | | | | |
| | Conventional machining | ● | ● | ● | ● | ● | ● | ● | ● | |
| | Injection molding | | | | ● | ● | ● | ● | ● | |
| | Blow molding | | | | ● | | ● | | | |
| | Compression molding | | | | ● | ● | ● | ● | | |
| | Rotational molding | | | | | ● | ● | ● | ● | |
| | Thermo-forming | | | | | ● | ● | ● | | |
| | Polymer casting | | | | | ● | ● | ● | ● | |
| | Resin-transfer molding | | | | | | ● | ● | ● | ● |
| | Filament winding | | | | | | | | | ● |
| | Lay-up methods | | | | | | | | | ● |
| | Vacuum bag | | | | | | | | | ● |
| Joining | Adhesives | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | Welding, metals | ● | ● | | | | | | | |
| | Welding, polymers | | | | | ● | ● | ● | ● | |
| | Fasteners | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Finishing | Precision machining | ● | ● | | | | ● | ● | | ● |
| | Grinding | ● | ● | ● | ● | | | | | ● |
| | Lapping | ● | ● | ● | ● | | | | | ● |
| | Polishing | ● | ● | ● | ● | | ● | ● | | ● |

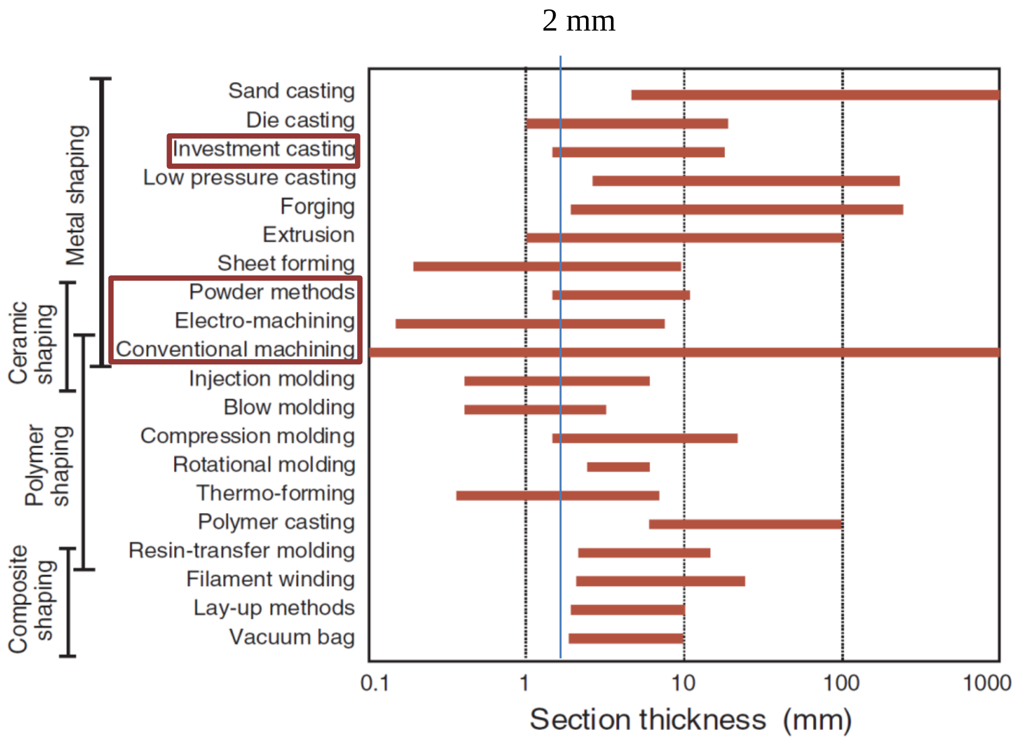
The process–material matrix. A red dot indicates that the pair are compatible.



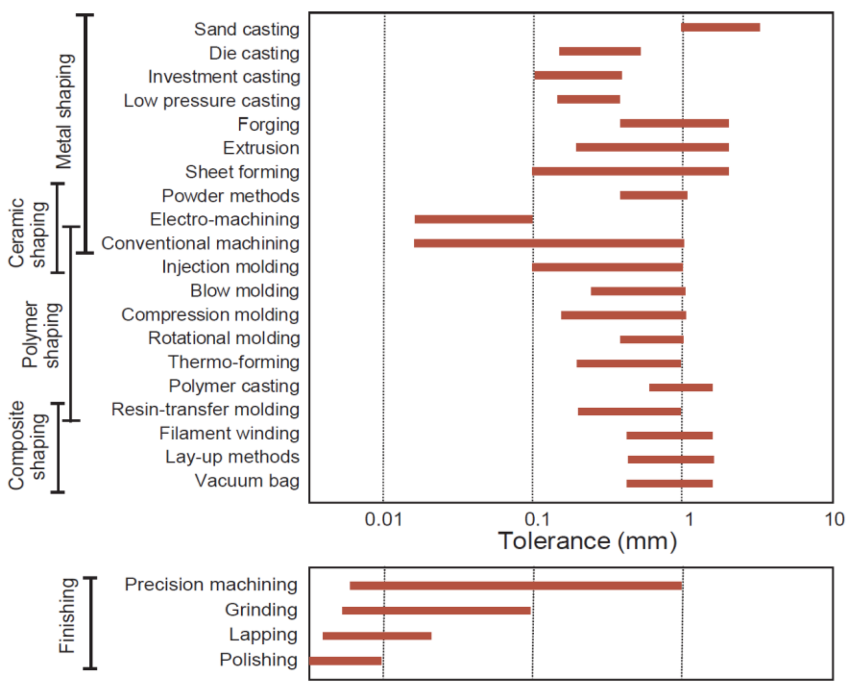

The process–shape matrix. Information about material compatibility is included at the extreme left.



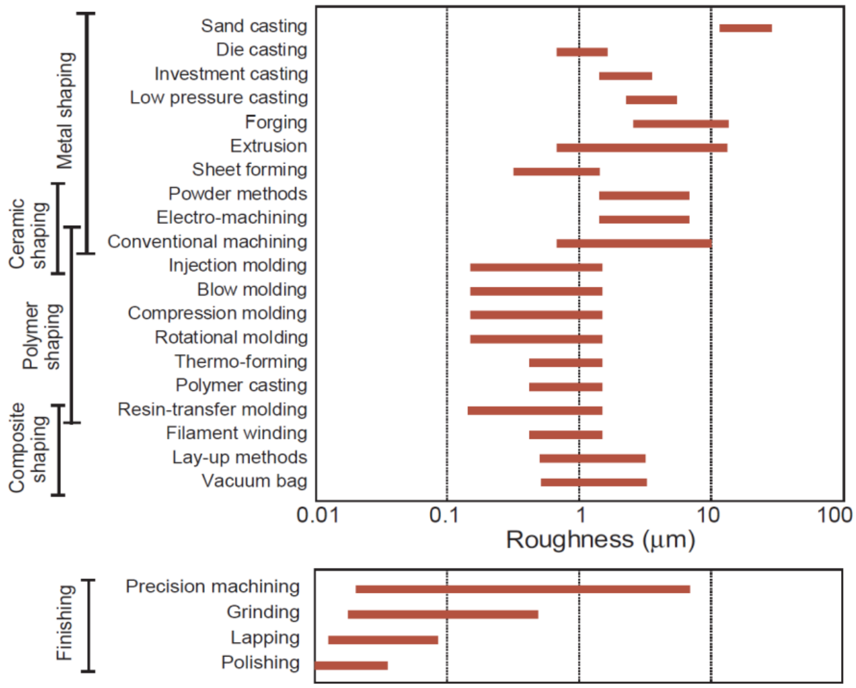

The process — mass-range chart. The inclusion of joining allows simple process chains to be explored.



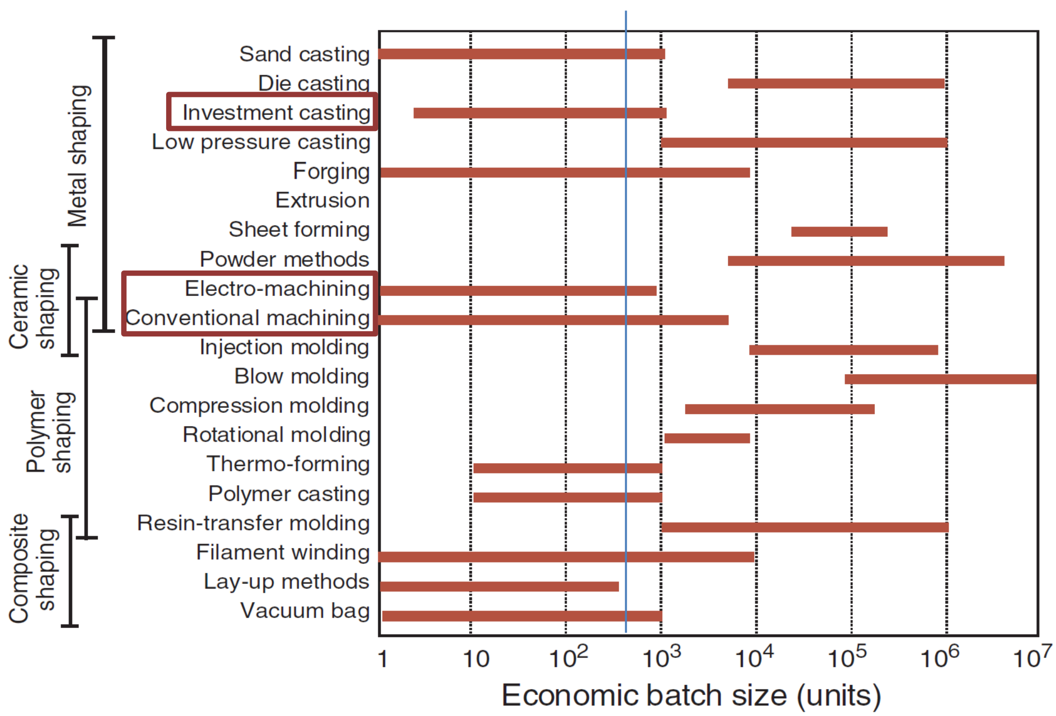

The process — section thickness chart.




The process — tolerance chart. The inclusion of finishing processes allows simple process chains to be explored.




The process — surface roughness chart. The inclusion of finishing processes allows simple process chains to be explored.




The economic batch-size chart.

# 11 Appendix C