Manufacture Report – Group 21B

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1. Introduction

This report outlines the manufacturing process for a single rotational link used in the convertible roof mechanism, labelled as Link CDF as shown in Figure 1.1 below, as this component is an essential part of the mechanism and it is not a standard component that can be purchased from a supplier. The selected component experiences a rotational motion during operation of the roof and must withstand external loads including self-weight and torque from the rotating mechanism. A variety of metals and alloys were compared and screened on the Edupack software (Ansys, 2020) against several constraints and objectives. The constraints used to screen the materials are strength and stiffness. The objectives are to minimise mass and cost, embodied energy, and CO2 footprint.

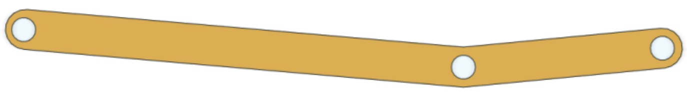

Figure 1.1: Link CDF

1. Production Quantity Estimation

To start, the production quantity for the component was first estimated using the total annual sales figures for the Fiat Abarth 500 series (Car Sales Base, 2022).From the figures, an average of 185,000 Fiat 500 cars were sold annually in Europe, where the majority of the Fiat market is, from 2017 to 2019. From that number, approximately 19,500 were Abarth 500 models. These figures also show that the average number of Fiat 500 cars sold annually stays relatively within the same range with minor deviations each year. Assuming this trend stays true and that the current proposed convertible design will only be implemented in the Abarth models, a minimum of 39,000 units of the component must be made annually for the 19,500 cars that will be produced every year as each car will require two of the same selected component.

2. Manufacturing Process

2.1. Selecting and Developing a Suitable Process

Different materials have varying processabilities. As seen in section 4.4 of the Design report, ductile cast iron was used to manufacture the component. It is generally recommended for ductile cast iron to undergo casting processes to manufacture it into the desired shape before proceeding with treatment and it is not recommended for it to undergo forming processes, unlike carbon steels (Ansys, 2020). From a selection of different casting processes as seen in chapter 3 of the Manufacturing Process Selection Handbook (Swift, 2013), investment casting, sand casting, and shell moulding were three potentially feasible processes selected based on the component's geometry and use of a ferrous material.

The first process, investment casting, allowed the casting of ferrous metals to a very high degree of precision. In fact, it is too precise and time consuming for a relatively simple component, as this process involves many steps and is more often used in smaller batch production lines with much more complex geometries. The ceramic/wax needed for the cases would also increase the cost significantly. Sand casting, which was another potential process, was a much cheaper and faster, but less precise option. It had a lead time of a few days but a relatively low production rate of 1 to 50 components per hour depending on the size. It also produces a relatively poor surface finish and requires secondary processing such as machining to improve tolerances which will significantly improve the overall manufacturing cost. As a result, it is more economical for low production runs.

The final and most likely process to be used is shell moulding. It has a higher production rate of 5 to 200 components per hour and higher material utilisation compared to sand casting. It is can also provide a better surface finish of about 0.8 to 12.5 μm Ra and is more precise compared to sand casting. In most cases, it does not require a secondary process to improve the tolerances of the component produced. Shell moulding is better suited for high volume productions and is widely regarded as the best low-cost casting method for large quantities of components. To determine the tolerances for the component's dimensions, a tolerancing graph shown in the same chapter of the handbook was used and can be seen in Figure 4.1 of the appendix. Based on the dimensions of the component, tolerances of 0.5mm to 2.1mm were needed depending on the dimension which can be seen from the component part drawings,

2.2. Costings

To estimate the cost of manufacturing the component with the selected process, the cost estimation method found in chapter 12 of the Manufacturing Process Selection Handbook (Swift, 2013), was used. A single process model for the cost can be formulated in the equation below:

$$M_i = V \cdot C_{mt} + R_c \cdot P_c \qquad (1)$$

Where M_i is the manufacturing cost; V is the volume of material required; C_{mt} is the cost of the material per unit volume; R_c is the relative cost coefficient of the component; and P_c is the basic processing cost of the component

The basic processing cost, P_c, considers factors such as equipment, operating and tooling costs, as well as processing times and component demand. A graph of P_c, against annual production quantity found in chapter 12 of the handbook was used to give a value of 10 for P_c and can be seen in Figure 4.2 of the appendix.

The relative cost coefficient, R_c, is a scaling factor to determine the actual processing cost compared to the ideal design depending on the geometrical complexities. It is calculated using the equation below:

$$R_c = C_{mp} \cdot C_c \cdot C_s \cdot C_{ft} \qquad (2)$$

Where R_c is the relative cost coefficient; C_{mp} is the material to process suitability coefficient; C_c is the shape complexity coefficient; C_s is the section coefficient; and C_{ft} is the larger value between the tolerance and surface finish coefficients.

Values of every coefficient can be seen in Table 4.1 below, which was then used to calculate a value of 1.5 for R_c using equation 2. Each value was determined directly from figures and tables given in chapter 12 of the handbook and can be found in Figures 4.3, 4.4, 4.5, 4.6, 4.7 and 4.8 of the appendix.

Table 2.1: Cost Coefficients

Name	**Symbol**	**Value**
Material to Process Suitability Coefficient	C_{mp}	1
Shape Complexity Coefficient	C_c	1
Section Coefficient	C_s	1.5
Tolerance Coefficient	C_t	1
Surface Finish Coefficient	C_f	1

A material cost, C_{mt}, of £ 0.217/kg (Ansys, 2020), which translated to 0.0001555 pence/mm^3 was assumed. The final volume of the component was then determined to be 3.81×10^5 mm^3 in Fusion 360 but did not consider any wasted materials during the manufacturing process. The waste coefficient, W_c, of 1.1 was determined from a table showing shape complexity classification against different processes found in chapter 12 of the handbook, shown in Figure 4.9 of the appendix. The volume of material needed to manufacture the component was determined from the equation below:

$$V = V_f \cdot W_c \tag{3}$$

Where V is the volume of material needed; V_f is the final volume of the component; and W_c is the waste coefficient

Putting all the numbers together into equation 1, the cost to purchase and manufacture the material into one unit of the component is £157. Since one car requires two units of the component, it would cost £ 314 to manufacture the components required for one car.

3. Manufacturing Output and Further Considerations

When choosing the material for the component, it is a good idea to consider other environmental impacts aside from CO2 footprint. This can include potentially harmful substances that manufacturing using said material would produce, or how recyclable the material is.

From the available manufacturing process options, shell moulding was found to be the most suitable process for the desired geometry of the component, material and quantity produced. From the FEA as mentioned in section 4.4 of the Design Report, the system appears to be over engineered with a minimum safety factor of 10. This could mean that the links are too thick for the proposed mechanism. Designing them to be thinner would result in less material being used per component produced which would result in a lower overall material and manufacturing cost. It is also important to consider that most metallic components are usually heat treated several ways, depending on the material, before used to improve its properties such as strength and wear-resistance. A post-manufacturing anti-rust spray could also be used to coat the metal and prevent it from rusting if it has poor anti-rust properties. However, doing all this would increase the cost of the component.

4. Appendix

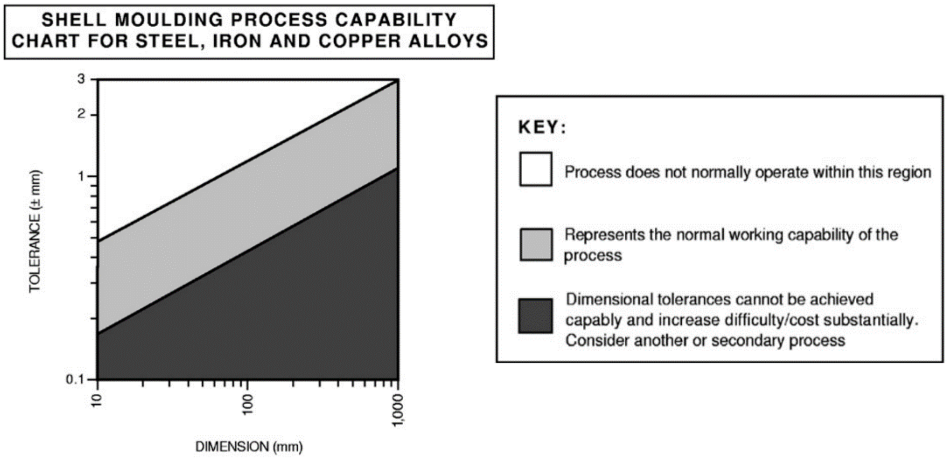

Figure 4.1: Shell Moulding Tolerance Capability

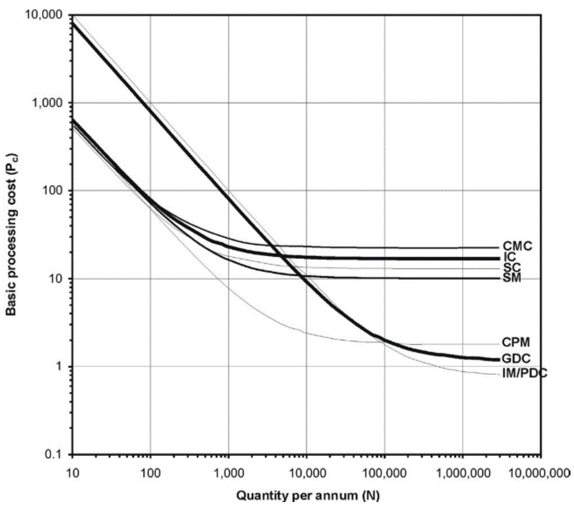

Figure 4.2: Basic Processing Cost Against Annual Production

	Process																					
Material	AM	CCEM	CDF	CEP	CF	CH	C.M2.5	CM5	CMC	CNC	CPM	GDC	HCEM	IC	IM	MM	PDC	PM	SM	SC	SMW	VF
Cast iron	1.2						1	1	1	1.2				1		1.2		1.6	1	1		
Low carbon steel	1.4	1.3	1		1.3	1.3	1	1	1.2	1.4			1.3	1		1.4		1.2	1.2	1.2	1.2	
Alloy steel	2.5	2	2		2	2	1	1	1.3	2.5			2	1		2.5		1.1	1.3	1.3	1.5	
Stainless steel	4	2	2		2	2	1	1	1.5	4			2	1		4		1.1	1.5	1.5	1.5	
Copper alloy	1.1	1.1	1		1	1			1	1.1			1	1		1.1	3	1	1	1	1	
Aluminium alloy	1	1.1	1		1	1			1	1		1.5	1.1	1		1	1.5	1	1	1	1	
Zinc alloy	1.1	1	1		1	1			1	1.1		1.2	1	1		1.1	1.2	1	1	1	1	
Thermoplastic	1.1			1						1.1	1.2				1	1.1						1
Thermoset	1.2			1.2						1.2	1				1	1.2						
Elastomer	1.1			1.5						1.1	1.5				1.5	1.1						

Figure 4.3: Relative Cost Data for Material Processing Suitability

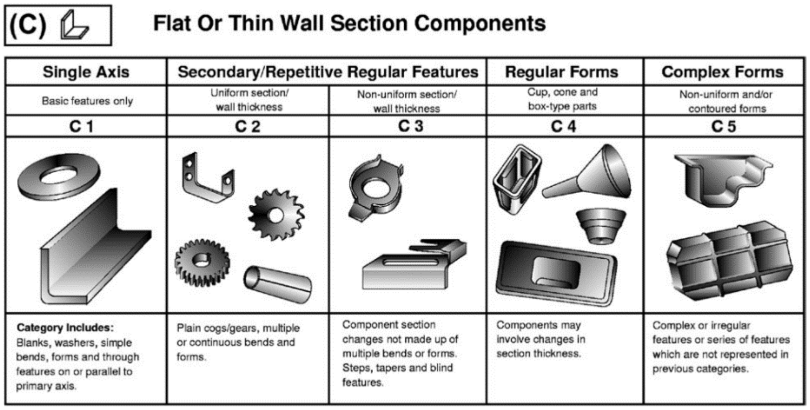

Figure 4.4: Shape Classification Categories used to Determine Cc

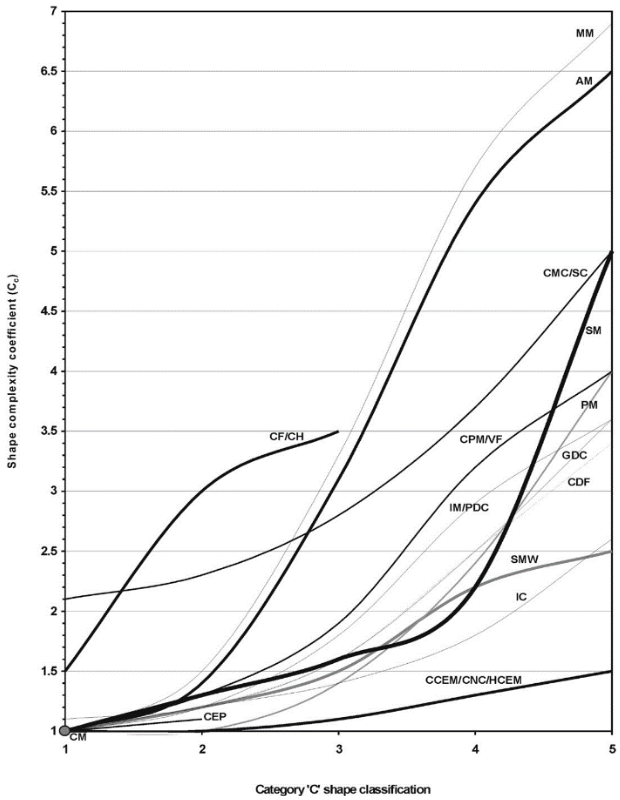

Figure 4.5: Chart to Determine Shape Complexity Coefficient Cc

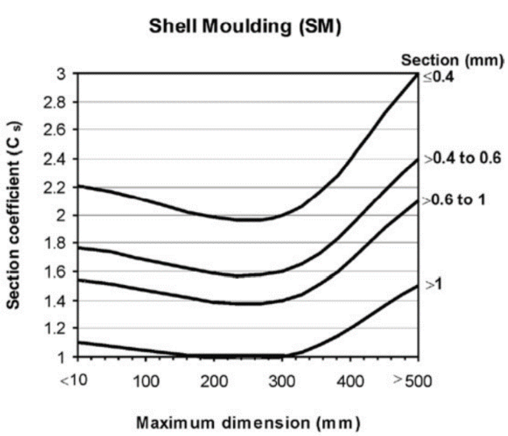

Figure 4.6: Chart to Determine Section Coefficient, Cs for Shell

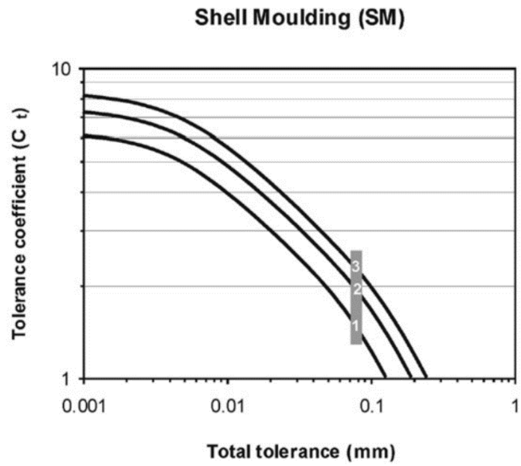

Figure 4.7: Chart to Determine Tolerance Coefficient, Ct for Shell

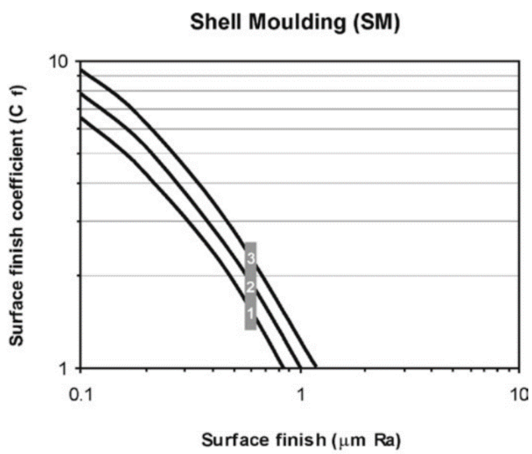

Figure 4.8: Chart to Determine Surface Finsih Coefficient, Cf for Shell

	Process																			
Shape Classification	AM	CCEM	CDF	CEP	CF	CH	CMC	CNC	CPM	GDC	HCEM	IC	IM	MM	PDC	PM	SM	SC	SMW	VF
A1	1.6	1	1.1	1	1	1	1.1	1.6	1	1	1	1	1.1	1.6	1	1	1	1.1		1
A2	2	1	1.1	1.1	1	1	1.1	2	1.1	1.1	1	1	1.1	2	1.1	1	1.1	1.1		1.1
A3	2.5	1.5	1.2		1	1	1.2	2.5	1.1	1.1	1.5	1.1	1.1	2.5	1.1	1	1.1	1.2		1.1
A4	3	2	1.2				1.3	3	1.2	1.2	2	1.1	1.1	3	1.2	1	1.2	1.3		1.2
A5	4	3	1.3				1.4	4	1.3	1.3	3	1.2	1.2	4	1.3	1.2	1.3	1.4		1.3
B1	1.7	1	1.1	1	1	1	1.1	1.7	1	1	1	1	1.1	1.7	1	1	1	1.1		1
B2	2.2	1	1.1	1.1	1	1	1.1	2.2	1.1	1.1	1	1	1.1	2.2	1.1	1	1.1	1.1		1.1
B3	2.8	1.5	1.2		1	1	1.2	2.8	1.1	1.1	1.5	1.1	1.1	2.8	1.1	1	1.1	1.2		1.1
B4	4	2	1.2				1.3	4	1.1	1.2	2	1.1	1.1	4	1.2	1	1.2	1.3		1.1
B5	6	3	1.3				1.4	6	1.2	1.3	3	1.2	1.2	6	1.3	1.2	1.3	1.4		1.2
C1	1.8	1	1.1	1	1	1	1.1	1.8	1	1	1	1	1.1	1.8	1.1	1	1.1	1.1	1.2	1
C2	2.4	1	1.1	1.1	1	1	1.2	2.4	1.1	1.1	1	1	1.1	2.4	1.1	1	1.1	1.2	1.2	1.1
C3	4	2	1.1		1	1	1.3	4	1.1	1.1	2	1.1	1.1	4	1.1	1	1.1	1.3	1.4	1.1
C4	6	3	1.2				1.4	6	1.1	1.2	3	1.1	1.2	6	1.2	1	1.2	1.4	1.5	1.1
C5	8	4	1.3				1.6	8	1.2	1.3	4	1.2	1.3	8	1.3	1.2	1.3	1.6	1.6	1.2

Figure 4.9: Waste Coefficient for Sample Processes Relative to Shape Classification

5. References

1. Ansys. (2020). Granta Edupack.
2. Car Sales Base. (2022). *Fiat 500 Europe Auto Sales Figures*. Retrieved April 16, 2022, from https://carsalesbase.com/europe-fiat-500/
3. Swift, K. a. (2013). *Manufacturing Process Selection Handbook.* Oxford: Butterworth-Heinemann.