

TIME AND COST ASSESSMENT OF THE MANUFACTURING OF TOOLING BY METAL CASTING IN RAPID PROTOTYPING SAND MOULDS

K. NYEMBWE, D. DE BEER, K. VAN DER WALT AND S. BHERO

Abstract

In this paper the time and cost parameters of tooling manufacturing by metal casting in rapid prototyping sand moulds are assessed and comparison is made with alternative tool making processes such as computer numerical control machining and investment casting (Paris Process). To that end two case studies obtained from local companies were carried out. The tool manufacturing was conducted according to a five steps process chain referred to as Rapid Casting for Tooling (RCT). These steps include CAD modelling, casting simulation, rapid prototyping, metal casting and finishing operations. In particular the Rapid Prototyping (RP) step for producing the sand moulds was achieved with the aid of an EOSINT S 550 Laser Sintering machine and a Spectrum 510 Three Dimensional Printer. The results indicate that RP is the rate determining step and cost driver of the proposed tooling manufacturing technique. In addition it was found that this tool making process is faster but more expensive than machining and investment casting.

Keywords: Tooling; Metal Casting; Rapid Prototyping; CNC Machining; Laser Sintering; Three Dimensional Printing.

1. INTRODUCTION

Metal casting processes that have been used for tool and die making include shell casting and investment casting. A few applications of this process are mentioned in literature such as the production of wax pattern from aluminium dies for use with the investment casting (Paris) process and the manufacturing of steel cast dies for forging, drawing, extrusion, die casting and glass making by the Shaw process (Beeley, 2001).

The above processes generally suffer several limitations such as coarse metallurgical microstructure, segregation, inferior tool quality in terms of surface finish, dimensional accuracy and the need for a pattern that is costly and time consuming to produce. These shortcomings reduce the durability and precision of cast tools that are furthermore expensive and take long to deliver to customers. Hence the use of metal casting for tool making has traditionally been restricted in favour of CNC machining and rapid tooling processes.

New technological developments applied to the field of metal casting have allowed the alleviation of some of its limitations thus making it a feasible and competitive option for tool and die making.

One innovation worth mentioning is the direct production of sand moulds and shells by using Rapid Prototyping (RP) processes therefore completely eliminating the patternmaking requirement (Klocke et al, 2000; Ederer, 2005; Hahn et al, 2005; Lerner et al, 2005). A successful case study on the production of an injection moulding tool by casting in an RP sand mould is reported in literature (Chua, Leong & Lim, 2003).

Current RP processes for the manufacturing of sand moulds are subdivided in two categories namely Laser sintering (LS) and 3-Dimensional Printing (3DP). In the LS process a laser beam is used to selectively fuse pre-coated foundry sand particles into a solid part that will become a component of the mould or shell. In 3-DP, the principle is similar to ink printing on a piece of paper from an ink-jet printer. In this case in a layer-by-layer fashion, a printing head selectively deposits or “prints” binder fluid that fuses the powder particles together in desired areas (Palm, 2002). RP technologies locally available include the Direct Croning Laser Sintering (DCLS) process (www.actTech.com) and the Z-Corporation process (www.zcorp.com).

The use of direct RP sand moulds and shells to manufacture tooling has not been fully exploited. One possible reason is that commercial RP processes are still relatively new and costly. In addition there is apparently no available investigation relating to the impact of these technologies on metallic tooling. Stringent requirements are demanded for tooling different from ordinary castings such as delivery time and price as well as quality. In particular time and cost are important parameters of any tool manufacturing process. Time should be as short as possible in order to allow quick turnaround to market new products. Cost needs to be as low as possible so as to increase the profit margin of mass production processes of finished goods that use the tools. Time and cost determine the economic viability of a tool making processes (Altan, Blaine & Yen, 2001).

In this paper the time and cost parameters of producing metallic tooling in RP sand moulds are assessed by means of case studies. Experiments are conducted to determine the rate determining step and cost driver of this tool manufacturing method. Time and cost results are also compared to the ones of conventional tool making processes such as CNC machining and investment casting (Paris Process). As such the study intends to provide a preliminary understanding on the competitiveness of the tool manufacturing at hand. The quality of products in terms of dimensional accuracy as surface finished will be examined in future publications.

Casting experiments are carried out according to a five step process chain referred to as Rapid Casting for Tooling (RCT). It is an adaptation of the traditional casting production flowsheet shown in Figure 1 where the patternmaking step is eliminated and replaced by the RP of a sand mould.

RCT is further refined by the use of modern CAD modelling and casting stimulation computer programs during the design stage. RCT was specifically developed in order to minimise the incidence of casting defects in the metallic tool. It is described in detail in the next section on the methodology.

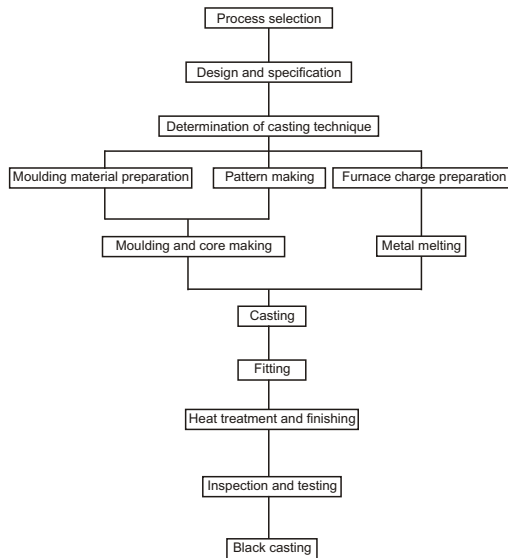


Figure 1: Flow diagram of casting production (Beeley, 2001)

2. METHODOLOGY

The methodology followed in this investigation was made up of the following tasks :

- Obtaining suitable case studies
- Conducting casting trials using RCT
- Recording manufacturing time and cost

Details of each task are provided below.

2.1 Case studies

The case studies consisted of the replication of existing tools using the route of casting in RP sand moulds. It would then be possible to compare experimental cost and time parameters with the actual ones. Case studies were selected on technical grounds including the size, the minimum wall thickness, the shape complexity and the material specifications of the tool (Table 1) that had to be compatible with the available RP machines and the gravity sand casting possibilities. The shape complexity is calculated taking into account the volume, the surface area and number of cores required. Details of the mathematical expression and explanation can be found in literature (Ravi, 2005).

Two case studies were obtained from local foundries. The first case study deals with the manufacturing of an aluminium die for investment casting wax patterns and the second case study was the production of a cast iron sand casting pattern for a Disamatic moulding machine.

2.1.1 Wax pattern die

This tool is used for the production of wax pattern for the investment casting of a steel automotive bracket (Appendix 1). The production die was manufactured by CNC machining in a local tool room. Its actual manufacturing time and cost provided by the foundry are respectively 40 hours and 14 000 Rands. The cheapest local quotation obtained to produce the same tool by investment casting (Paris process) was 10 000 Rands in 120 hours.

2.1.2 Sand Casting plate

The pattern is used for the production of sand moulds on a Disamatic moulding machine for the casting of a steel engineering bonnet (Appendix 2). The production plate was manufactured by CNC machining and assembly at the foundry. The actual manufacturing time is 80 hours at a cost of 20 000 Rand. The cheapest local quotation to manufacture this plate by investment casting (Paris process) was 8 000 Rand in 240 hours.

Table 1 Technical characteristics of tool used for the case studies

		Material specifications	Minimum thickness [mm]	Maximum dimension [mm]	Complexity [-]
Wax die	pattern	Al 6082	4.6	203	0.11
Sand plate	casting	SG 60	7.8	600	0.25

2.2 RCT casting trials

The tool manufacturing trials were carried out according to a process chain referred to as Rapid Casting for Tooling (RCT) that comprises five sequential steps described below:

- CAD modelling: Conversion of 2D design drawings of tools into 3D models. The tool model is further modified to include filleting and contractions. From the tool model, the 3D models of the sand mould parts are designed and constitute the outcomes of this step.

- Casting simulation: Dimensioning and positioning of the gating and feeding system of the casting. The objectives of the casting simulation depend on the case studies and include minimisation of oxidation, elimination of shrinkage defects and complete mould filling.
- RP: Production of sand moulds by AM from CAD files generated in step 1.
- Metal casting: Melting of the tool alloy followed by pouring of the metal in the mould produced in step 4.
- Finishing operations: Cleaning of the casting by sand blasting followed by minimal machining.

Local companies assisted in conducting the various steps of the casting experiments. These companies were selected on the basis of the cheapest price and shortest time to execute a task. The best proposal was in the case of CAD, casting and finishing operation selected from three quotations. For the casting simulation step only one quote was obtained because the market is still monopolistic in South Africa dominated by Magmasoft. The Metal Casting Technology Station at the University of Johannesburg and the Centre for Rapid Prototyping and Manufacturing at the Central University of Technology, Free State are the only two institutions offering RP technologies in 3DP and LS respectively.

In total three casting experiments were conducted. The first two produced the aluminium dies using two different RP technologies: 3DP and LS. The third experiment produced the plate by casting in a LS RP mould. Additional experimental conditions are summarised in Table 2.

Table 2 Technical characteristics of RCT steps during tooling manufacturing trials

RCT Steps	Experimental conditions
CAD Modelling (Pro Engineering software: wildfire II)	<ul style="list-style-type: none"> - Filleting of designs - AI and SG contractions added - 1mm machining allowance added
Casting simulation (Magmasoft software: Frontier)	<ul style="list-style-type: none"> - <u>Aluminium die:</u> - Objectives: minimise shrinkage and oxidation during filling - Iterations: 5 - <u>DiSA plate:</u> - Objectives: complete filling of mould - Iterations: 3
Rapid prototyping (LS EOSINT S 550 and 3DP Spectrum 510 RP machines)	<ul style="list-style-type: none"> - <u>EOSINT S 550:</u> - Standard operating parameters - Curing of mould parts at 75⁰ C? - Shell sand (silica) - <u>Spectrum 510:</u> - Standard operating parameters - No curing of moulds - Synthetic sand
Metal Casting (Gravity casting)	<ul style="list-style-type: none"> - <u>Aluminium die:</u> - Charge: LM 4 - Resistance furnace - Nitrogen degassing - Pouring temperature: 750⁰ C - Kalpur direct pouring device - <u>DiSA plate:</u> - Charge: Pig iron + steel scrap - Induction melting - George Fisher inoculation - Pouring temperature: 1400⁰ C - Kalpur direct pouring device
Finishing operation	<ul style="list-style-type: none"> - Use of sand paper Grit () for die - Sand blasting followed by fettling for the plate

2.3 Manufacturing time and cost

The manufacturing time is the actual working time devoted to a specific step and recorded during the execution. The manufacturing cost is the invoiced price a particular step provided at its completion.

3. RESULTS

The manufacturing time and cost results of RCT steps for the three experiments are respectively shown in Table 3 and Table 4.

Proportions in percentage of the total time and cost of the manufacturing time and cost of each RCT step are shown in Figures 2 and 3. It can straight away be seen from these tables and Figures the importance of the RP step with regard to its contribution to the total time and cost.

Table 3 Experimental manufacturing time results

Casting Experiments	CAD Modelling	Casting Simulation	RP	Casting	Finishing Operation	Total [hour]
Wax Pattern Die (SLS)	5.5	5	24	1	1	36.5
Wax Patter Die (3DP)	5.5	5	16	1	1	28.5
Sand Casting Plate	6.5	9	48	2	2	67.5

Table 4 Experimental manufacturing cost

Casting Experiments	CAD Modelling	Casting Simulation	RP	Casting	Total [Rand]
Wax Pattern Die (SLS)	790	2280	12000	2000	17070
Wax Patter Die (3DP)	790	2280	8000	2000	13070
Sand Casting Pattern	910	5700	40000	3032	49642

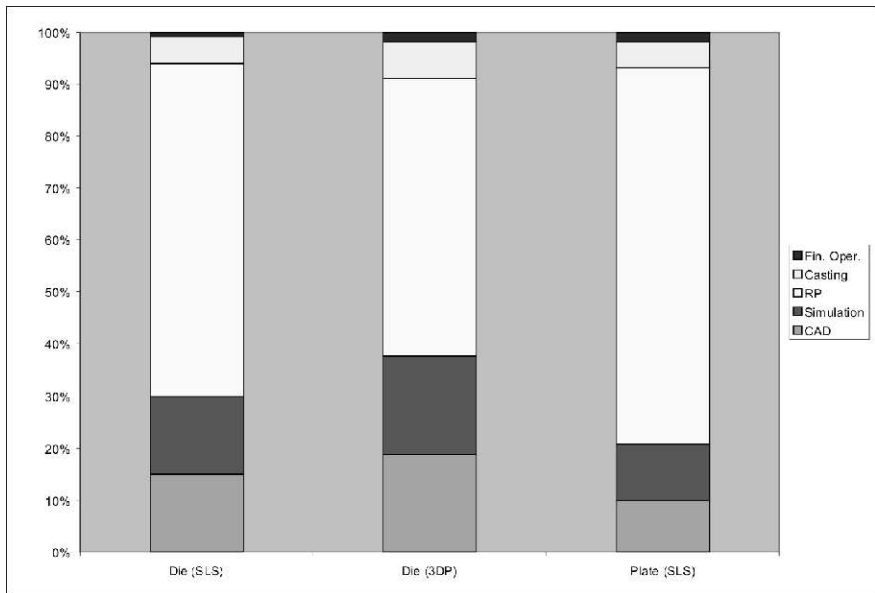


Figure 2 Contribution of RCT steps to the final manufacturing time

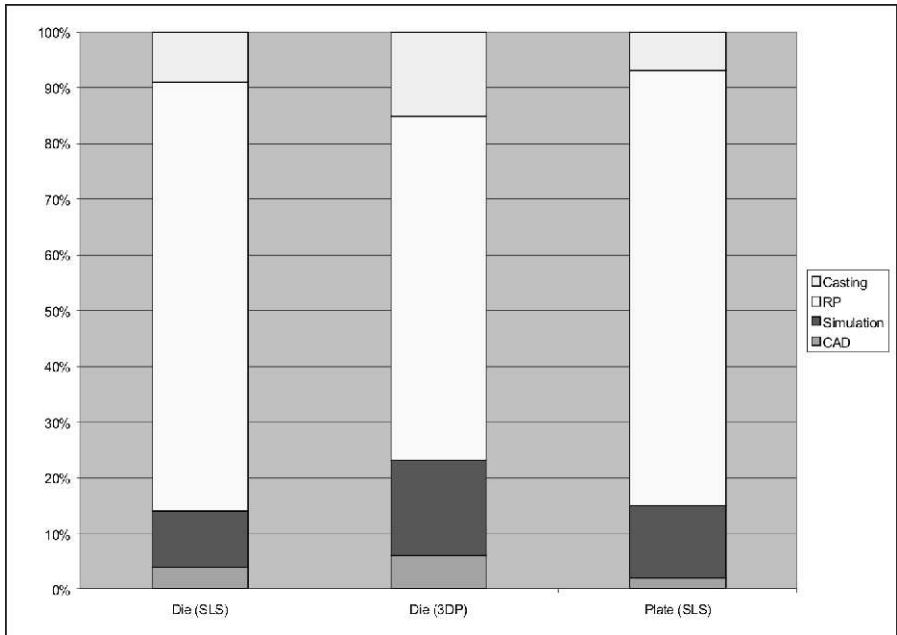


Figure 3 Contribution of RCT steps to the final manufacturing cost

4. DISCUSSION

4.1 RCT manufacturing time and cost

The growing of the sand mould by RP is the slowest step and therefore RCT rate determining step (Figure 2). This step contributed 54% to 73% of the total RCT time respectively for the die manufacturing using the Spectrum 510 printer and the sand casting plate using the EOSINT LS machine. In the case studies conducted layer-by-layer manufacturing is slower possibly because of the process technical limitations.

Furthermore in all cases the manufacturing of sand moulds by RP is the most expensive step therefore RCT cost driver. This step contributed 61% to 78% of the total RCT cost respectively for the die manufacturing using the Spectrum 510 printer and the sand casting plate using the EOSINT LS machine. A possible reason for the expensiveness of the RP step is the newness of the AM processes and the lack of competition with regards to providing RP services locally.

4.2 Comparison of RCT with casting and machining

Figure 4 shows the comparison in terms of manufacturing time of RCT process chain versus machining and metal casting for the case studies conducted.

RCT is the fastest process chain. A manufacturing time improvement of 68% to 72% can be obtained compared to metal casting and 6% to 18% versus machining. Casting was the slowest process chain because of the required manufacture of a pattern prior to casting. On the other hand machining was slower than RCT possibly because of the intricacy of the case study tools.

Figure 5 shows the comparison in terms of manufacturing cost of RCT process chain versus machining and metal casting for the case studies conducted. It can be seen that RCT is the most expensive compared to casting and machining. RCT was respectively 124% to 453% and 60% to 176% more expensive compared to metal casting and machining. The possible reason for this finding is the expensiveness of RP processes as mentioned. Manufacturing of tooling by metal casting appeared to be extremely undervalued.

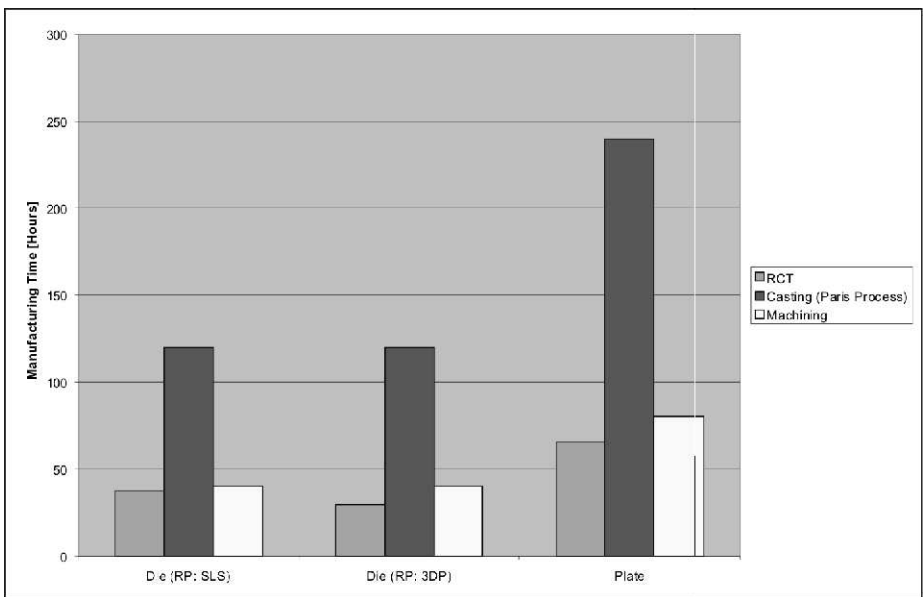


Figure 4 Manufacturing time comparison between RCT and other tool manufacturing processes

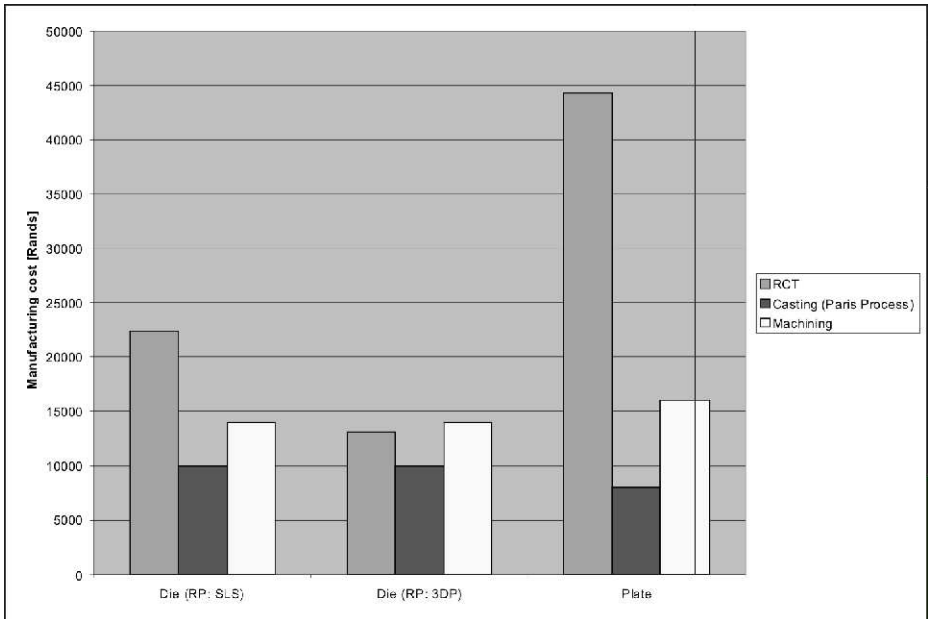


Figure 5 Manufacturing cost comparison between RCT and other tool manufacturing processes

5. CONCLUSION

In this investigation, three casting trials were carried out to understand the manufacturing time and cost of producing metallic tooling in RP sand moulds. Two main findings were obtained from these experiments using locally available technologies:

- 1) The manufacturing of sand moulds by RP was found to be the rate determining and cost driver step.
- 2) The proposed tooling manufacturing was found to be faster than machining and metal casting (Paris process) but more expensive.

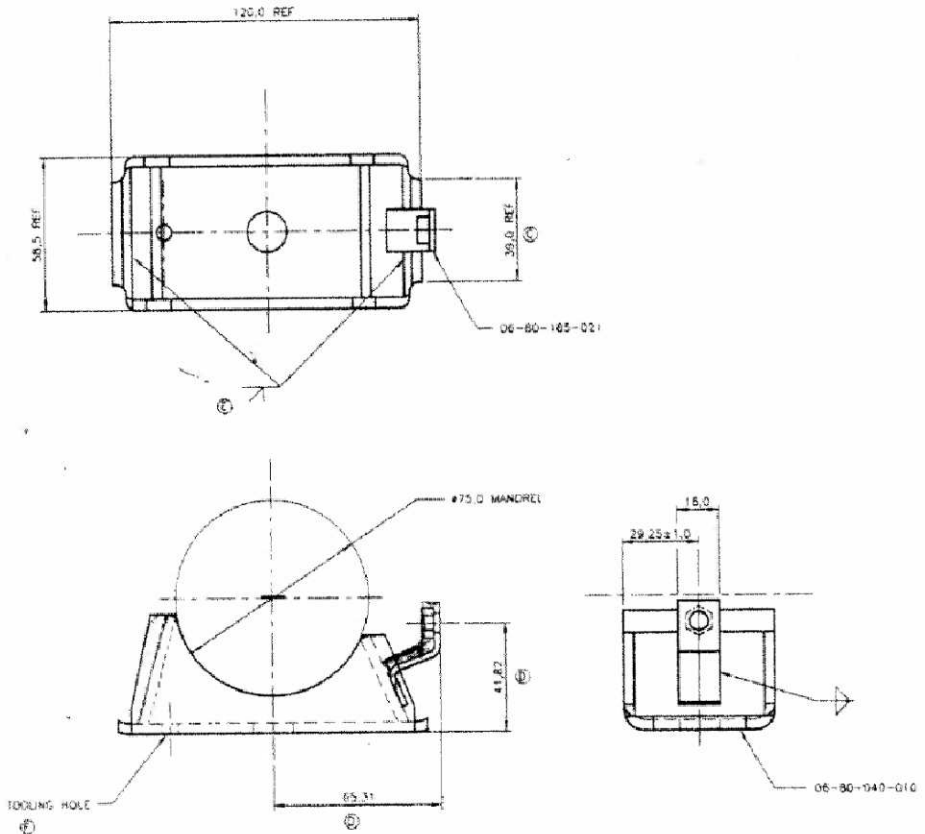
In the present situation these results are important for future optimisation work to make the manufacturing of tooling in sand moulds produced by RP processes faster and cheaper than other tool manufacturing processes such as machining. This will be achieved by concentrating the effort to minimise the cost and time of the AM of sand mould step as it is the one that has been identified as strongly controlling the cost and delivery time of the final tool.

6. ACKNOWLEDGMENTS

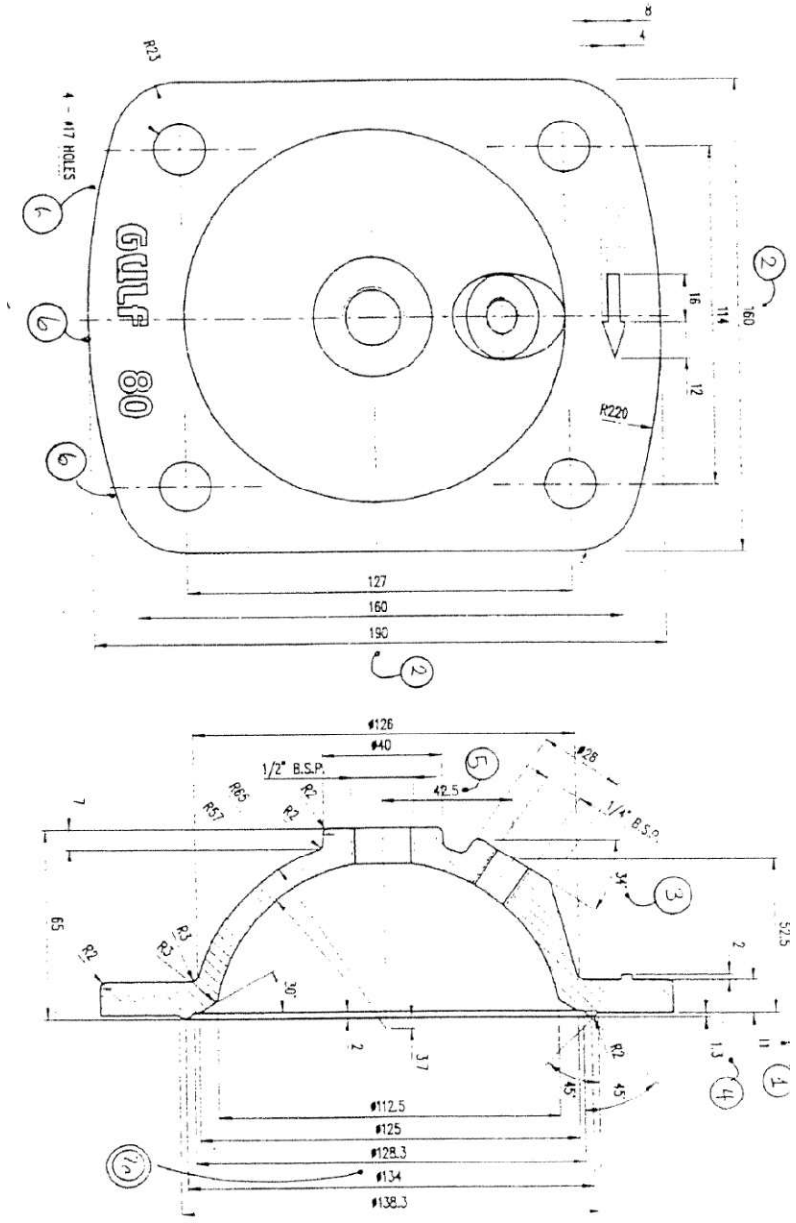
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- 3) The following foundries:
 - a. Precision Casting Pattern
 - b. Guestro
 - c. Ozz
 - d. Relay Precision Castings Appendices

Appendix 1: 2D drawing of steel bracket



Appendix 2: 2D drawing of steel bonnet



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