# A CASE STUDY OF RAPID SAND CASTING DEFECTS

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## ABSTRACT

Rapid sand casting is quickly transforming as an established method for the production of sand moulds and cores for metal casting applications by additive manufacturing processes. The case study investigated possible sand casting defects resulting from a local implementation of rapid sand casting referred to as Rapid Casting for Tooling (RCT). Poor workmanship of the RCT process chain was found to be the root cause of sand casting defects including cold lap, gas porosity and alignment faults.

## 1. INTRODUCTION

Rapid sand casting is the application of additive manufacturing processes for the direct production of sand moulds and cores used for metal casting. As an alternative to traditional moulding and core-making processes, rapid sand casting offers several advantages to the foundryman including design freedom and the elimination of tooling creating the opportunity to save costs and reduce lead design time [1]. Examples of rapid sand casting technologies are laser sintering and three-dimensional printing [2]. The latter relies on the furan sand casting process while the former is based on the shell sand casting process [3].

Rapid Casting for Tooling (RCT) is an implementation of rapid sand casting process chain using locally available technologies, which was proposed in the literature [4]. It consists of five steps that include Computer Assisted Design (CAD), Casting Simulation, Laser Sintering, Metal Casting and Finishing Operations. RCT was conceptually developed for the production of tooling by metal casting. Potential advantages of RCT over CNC machining comprise easy learning curve, suitability for producing foundry tooling and low overall processing cost.

Few studies have been conducted to better understand the capability and performance of RCT process chain. Applying the Analytic Hierarchy Process (AHP) technique, it was found that laser sintering was superior to three-dimensional printing as additive manufacturing system for RCT when considering a set of four criteria namely manufacturing cost, manufacturing time, dimensional accuracy and surface finish [5]. An additional investigation assessed the surface finish and dimensional accuracy of RCT components [6]. It was found that mould coating contributed slightly to the improvement of the cast tool surface finish. The study also revealed that the additive manufacturing of the sand mould was the chief factor responsible for the loss of dimensional accuracy and relatively inferior surface finish. These findings suggested that minimal machining will always be required to improve the surface finish and the dimensional accuracy of cast tools in rapid prototyping sand moulds.

It is well known that the sand casting method is prone to casting defects. The general origin of defects lies in three sectors namely the casting design, the technique of manufacture (the method) and the application of the technique (the workmanship) [7]. In the case of the RCT, possible defects due to the casting design should be alleviated by the provision of the first two steps of the process chain namely CAD and Casting simulation. The impact of the method and the workmanship as they especially relate to the additive manufacturing step of the RCT process chain has not been investigated and is largely unknown at the present moment. On the other hand, casting defects due to the quality and condition of the metal and the finishing operations such as sand blasting, fettling and machining are extensively documented in the literature [8].

With the aid of a real case study, this paper attempts to understand the possible casting defects during the implementation of RCT. As such, the investigation intends to contribute an initial development of technological know-how as well as the building of knowledge management around RCT in particular and rapid sand casting in general.

## 2. METHODOLOGY AND PRELIMINARY CONSIDERATIONS

### 2.1. Case study

The case study was provided by a local sand foundry. It consisted of the manufacturing a sand casting pattern to be used on a Disamatic moulding machine. The pattern layout is shown in Appendix 1. This tool will be used as one of the two Disamatic machine plates for making greensand moulds for a steel engineering bonnet shown in figure 1. The pattern alloy material was spheroidal cast iron of grade 60.

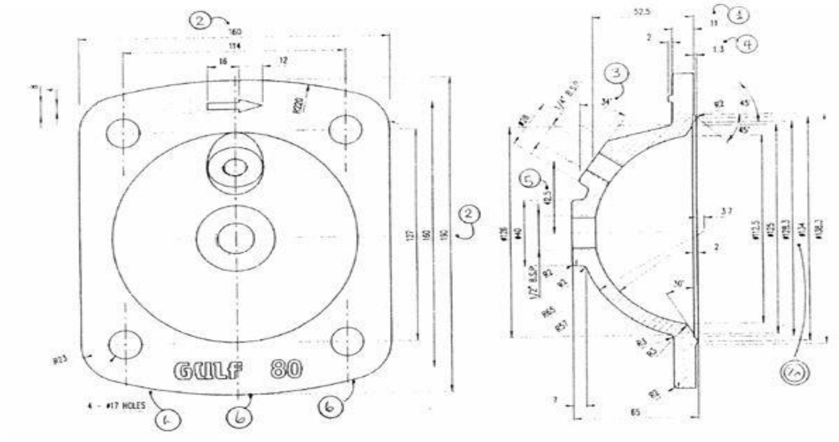


**Figure 1: Two dimensional drawing of the steel bonnet to be produced using the pattern to be manufactured by RCT**

The maximum dimension of the plate equal to 600mm was found to be too large for growing single mould components (cope and drag) on most commercial additive manufacturing systems. It required partitioning of mould components. The flat geometry of the tool also required careful design of the gating system and provision for venting to allow complete filling of the mould and escape of the gases. Finally the size and weight of the plate necessitated a strong mould to prevent mould wall movement and loss of casting dimensional accuracy.

## 2.2. Experimental procedure

The experimental procedure followed in the casting trial of the sand casting pattern is summarized in Table 1. Casting simulation was conducted using Magmasoft software to make sure that the pattern could be produced free of defects such as shrinkage porosity and sand inclusion. Figure 2 and 3 show the casting simulation results in terms of methoding design and fluid flow. An inclination of 15 degree was recommended. Vents were also included in the casting design. Additional simulation results on air entrapment, shrinkage and hardness are shown in Appendix 2 predicting a final casting meeting specifications.

**Table 1 Software, Equipment and Casting parameters used in the casting trial of the sand casting pattern**

| RCT Steps | Experimental parameters |
|---|---|
| ***CAD Modelling***<br>(Pro Engineering software: wildfire II) | - Filleting of designs (default setting of the casting toolbox software)<br>- Shrinkage allowance factor: 1.10<br>- 10mm machining allowance added |
| ***Casting simulation*** | - Objectives: complete filling of the mould and escape |

| | |
|---|---|
| (Magmasoft software) | of air during pouring<br>- Iterations: 3 |
| ***Rapid prototyping***<br>(SLS EOSINT S 700 machine) | - Standard operating parameters<br>- Curing of mould parts at 75$^0$ C<br>- Shell sand (silica) |
| ***Metal Casting***<br>(Gravity casting) | - Charge: Pig iron + steel scrap (Appendix 3)<br>- Induction melting<br>- George Fisher inoculation (Magnesium treatment)<br>- Pouring temperature: 1400$^0$ C |
| ***Finishing operation*** | - Sand blasting followed by fettling for the plate |

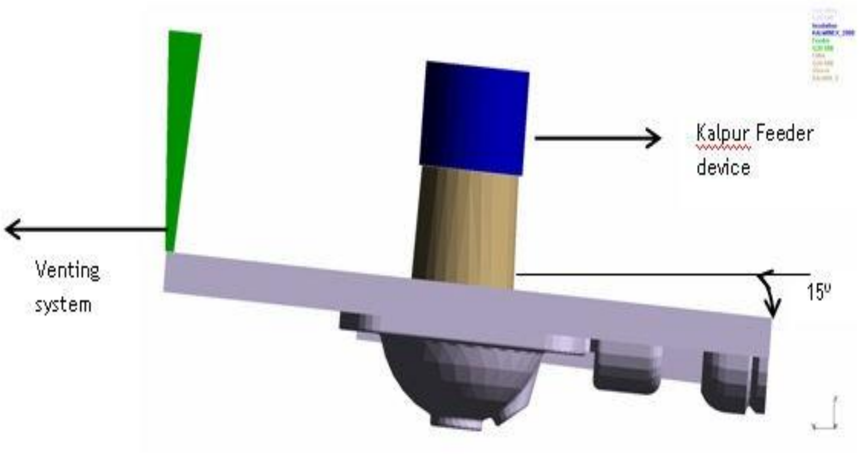
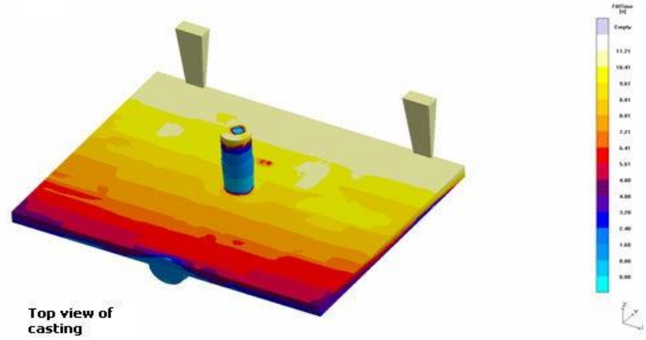
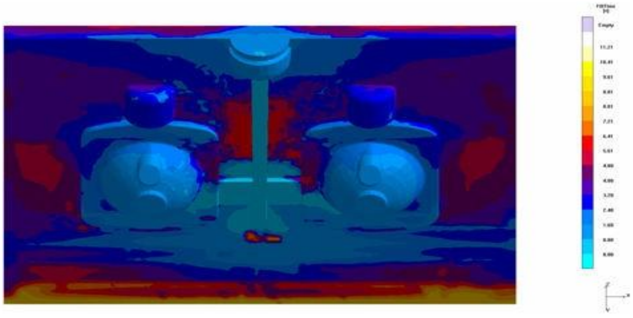


**Figure 2: Casting methoding design suggested after simulation**

The entire mould was made of four sand parts that were grown on an EOSINT S700 laser sintering machine at the Centre for Rapid Prototyping Manufacturing (CRPM) at the Central University of Technology in Bloemfontein [9]. The various sand parts were glued together to form the cope and the drag. The internal cavity of the mould was spray coated with graphite paint to improve the surface finish of the final casting (Figure 4). Before pouring the molten metal, the mould was placed in a frame filled with backing sand and weights were placed on top as shown in Figure 5 in order to make it able the withstand the metallostatic pressure of the liquid metal. Gravity casting using a ladle operated manually was employed to cast the mould.



Top view of casting



Bottom view of casting

Figure 3: Mould filling results

Figure 4: Drag component of the mould with the internal cavity of the tool to be cast.

**Figure 5: Assembled mould with weights and required inclination (see magnetic angle finder tool) ready to be poured.**

## 3. RESULTS AND DISCUSSION

Figure 6 shows the front picture of final sand casting plate. The finishing operations included sand blasting and fettling to remove the casting runners. No machining of the cast pattern was performed.

The final casting picture revealed evidence of noticeable defects including:
1. Cold lap mainly visible in the top half of the casting
2. Gas porosity in top right region
3. Vertical alignment fault in the middle of the casting

Cold lap defects are generally due to poor metal fluidity. Low pouring temperature is usually the main culprit for low metal fluidity. Mould factors related to thermal properties, surface effects and air pressure could also cause inadequate effective fluidity of the cast alloy [7] resulting in cold lap defects. Gas porosity defects are mainly due to sub-optimal mould permeability to allow gas escape during casting [8]. Finally, misalignment is generally due to inadequate jointing of the mould components to produce the final casting cavity. Figure 6 also revealed a general loss of dimensional accuracy.

It is the opinion of authors that the casting defects experienced in this case study could be chiefly attributed to the workmanship of manipulating laser sintered sand moulds. The jointing of the moulds components were not done correctly. Backing sand was used to increase the strength of the mould but had inadequate green strength and permeability. As a result of this incorrect application of the sand technique, a mould leak occurred during the casting trial. Thus the top section of the casting was subsequently filled with cold metal resulting in the occurence of cold lap defect. The feeding system reservoirs could not be adequately filled with molten metal thus the apparition of shrinkage and porosity defects. Finally the poor joining of the sand mould components was solely responsible for the vertical alignment fault.

**Figure 6: Final casting exhibiting some defects: 1: cold lap; 2: porosity; 3: Alignment fault**

The casting defects suffered in this casting trial were unlikely to occur had traditional moulding methods be used with minimal requirements for joining mould components and elimination of backing sand use. Foundryman are well familiar with these traditional moulding methods. Fortunately, the casting defects were not dimmed to be deleterious enough to be scrapped the final casting. This casting could be salvaged by machining to produce a useful sand pattern.

## 4. CONCLUSIONS AND RECOMMENDATIONS

Rapid sand casting offers an alternative to traditional sand casting methods. This case study investigates possible challenges that are encountered when working with additive manufacturing sand moulds in order to produce defect free castings. The study shows that laser sintered sand moulds in particular require to be handled with appropriate care to avoid casting defects such as cold lap, gas porosity and alignment fault. Additional case studies employing alternative additive manufacturing technologies such as three- dimensional printing need to be conducted in order to fully understand the potential and limitations of rapid sand casting applications.

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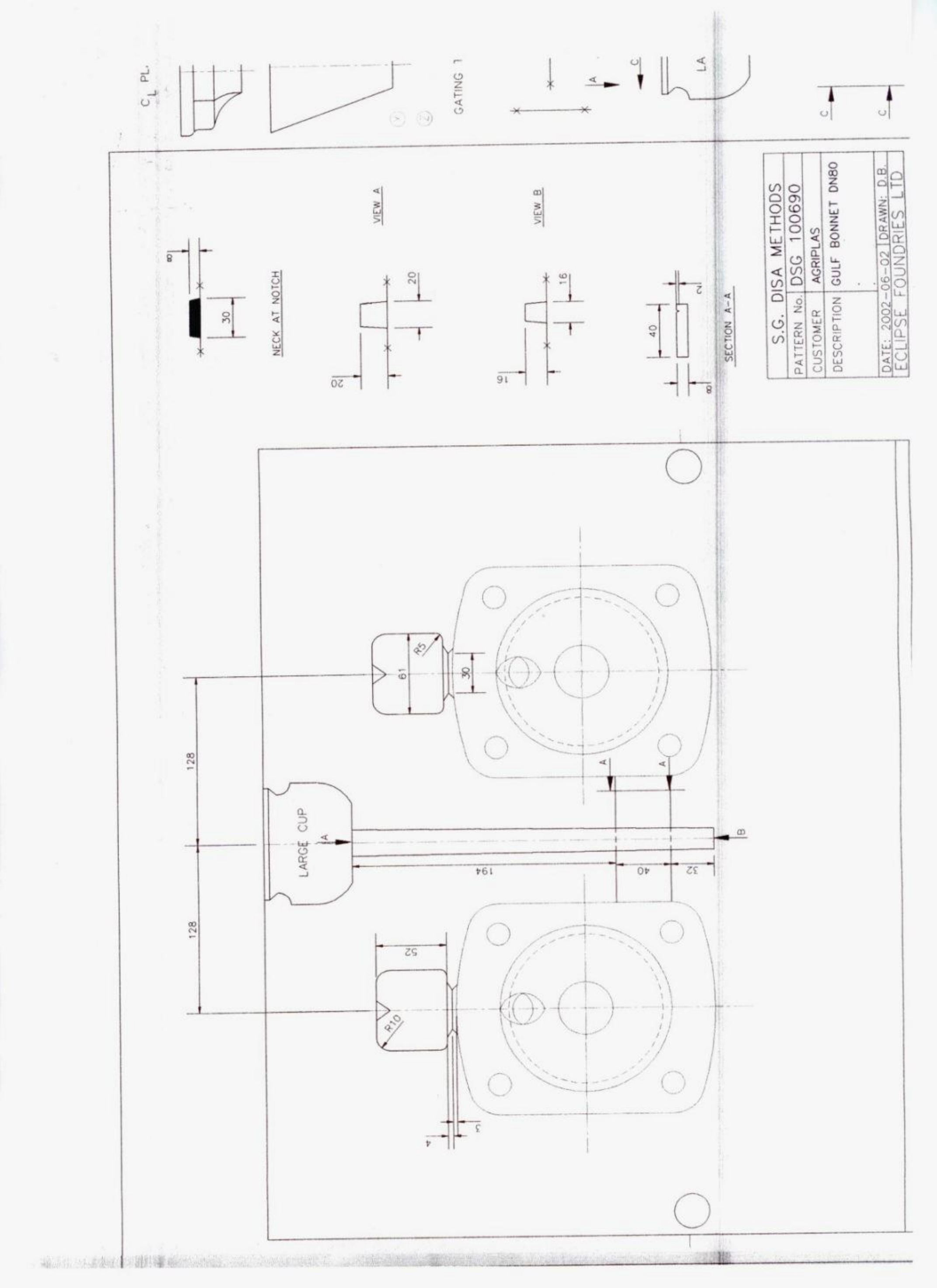
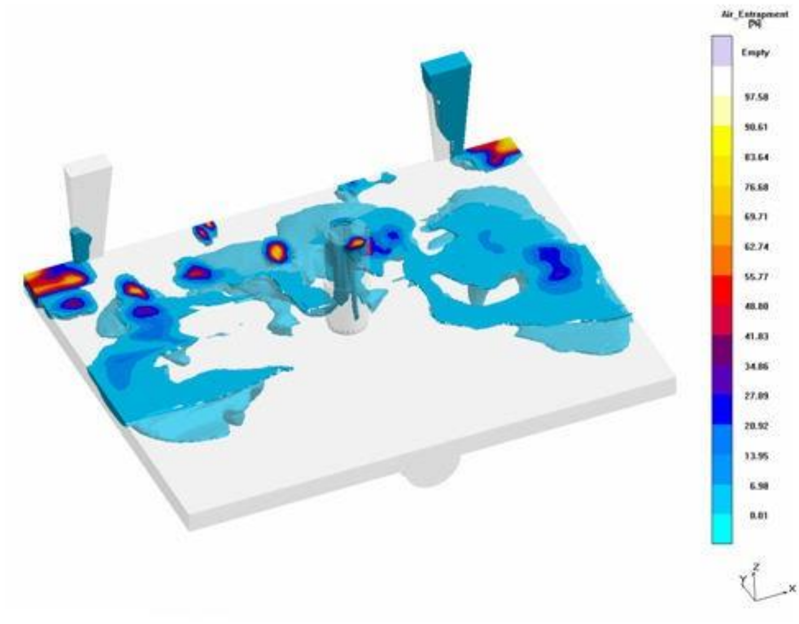
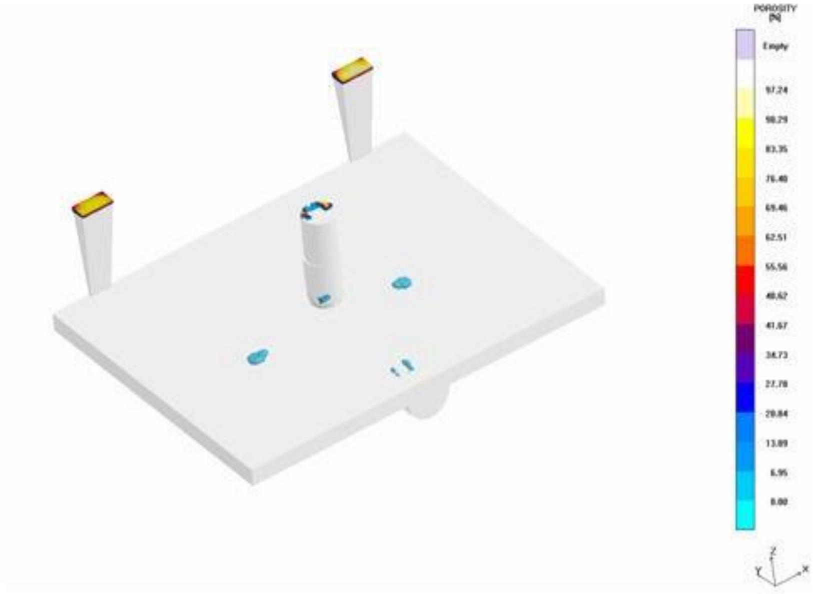
## APPENDIX 1: LAYOUT OF THE PLATE TO BE CAST



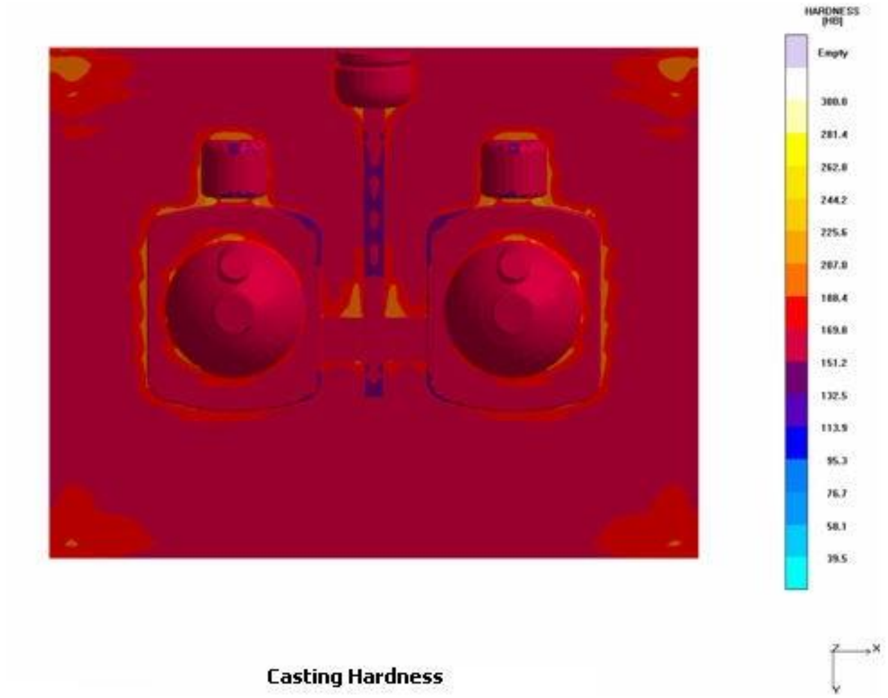
## APPENDIX 2: SELECTED RESULTS OF CASTING SOLIDIFICATION SIMULATION



Air entrapment at 100% filled, 1 % upwards



1% shrinkage and upward



Casting Hardness