Quality Investigation of Austenitic Manganese Steel Blades

Anicia. Dipale and Xiaowei. Pan

Abstract—Poor quality and low yield are major challenges to the South African foundry industry. An inspection of the process routes was conducted, and the defects occurring within the blades were investigated and characterized according to the type, size, shape and location on the castings.

The presence of shrinkage porosity, gas entrapment and inclusions in the austenitic manganese scraper blades are a major concern as they result in high rejection rate, additional melting of metal and increased labour energy.

This study seeks to optimize the casting process of the blades using casting simulation to visualize the filling and solidification processes of the molten metal inside the mould cavity. This will give a clear indication of the resultant casting, allowing for modification of the process in the design stages and determination of the castability. The trial and error methods will be eliminated thereby reducing operating costs and improving the overall yield.

Keywords—Casting simulation, defects characterization, quality improvement, yield improvement.

I. INTRODUCTION

When scrap and rework costs of a company are more than the profit, the company has to increase the selling price and subsequently loses the market share. For this reason, quality no longer becomes a technical issue, but a business issue. It has been a known fact from the accent times that quality is important; metrology, specifications and inspections all goes back to many centuries before the Christian era [1]. It is most critical that the casting designer specifies the true design needs. Poor casting design can interfere with the ability of the foundry to use the best techniques to produce reliable castings. The multitude of process variables, such as moulding mediums, binder, gating and risering, melting and ladle practice, pouring technique, and heat treatment must be controlled. The attention to detail necessary to make good castings can reduce the total cost of a manufactured part by significantly reducing machining, repair, and fit problems later in the assembly [2]. This study outlines how the problem areas within the castings may be remedied with the use of casting simulation at a minimum cost.

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II. CASTING SIMULATION

Looking ahead to the year 2000, the metal casting industry will continue to explore new technologies in the interests of achieving higher-quality castings that can meet the critical performance standards being imposed. This is demonstrated by the history of metal casting and by the striking fact that the industry has advanced further in the last 50 years [1]. Solidification simulation has been applied for over ten years as a support tool for casting runner design. The casting simulation programs hold an important role in analyzing what would be the outcome of the casting and gating system designs during the casting process. By visualizing the entire casting process in a virtual environment, problems associated with fluid flow, solidification and part distortion become apparent to the designer and foundry engineer. Simulation also helps to minimize the amount of material cast and, thereby, the amount of energy needed for the melting process [3].

III. METHODOLOGY

A. Casting trial

Casting trials were conducted with no changes to the suppliers casting parameters. Six boxes were cast, each with 8 castings. During the pouring process, temperature was checked and recorded for each box as well as the time it was taking to fill the box.

B. Visual inspection

Each casting from the six boxes was carefully examined upon shakeout for observation of the surface finish as well as the surface defects. The defects were categorized according to their type, size, shape, location on the casting.

C. CAD design

A foundry model of the blades was drawn using the Pro-Engineer CAD design software. The design was drawn according to the dimensions that were obtained from the pattern-shop at the foundry.

D. Simulation

The model was transferred to the simulation software in the stereolithography (stl) format for simulation. The data input was similar to that used during casting at the foundry floor.
**E. Chemical analysis**

A chemical analysis was performed on the samples in order to observe if the percentage of aluminium present is sufficient for deoxidizing purposes.

**F. Scanning electron microscope (SEM) analysis**

The samples were analyzed using a SEM on the blowhole defects in order to determine the oxygen content as well as the phases present.

**G. CAD model modification**

After comparing the simulation and the casting trial results, the defects that occurred within the castings were identified and their possible causes. This data was then used to modify the CAD model.

**H. Simulation of the modified model**

The drawing was then simulated under different conditions so as to obtain the parameters that give optimum results

**IV. RESULTS AND DISCUSSION**

**A. Casting temperature profile**

Presented in Fig. 2 below are the temperatures that were recorded when pouring into each box during the casting process. The tapping temperature is indicated above as 1482°C while 1468°C is the ladle temperature. Temperatures from 1427°C up to 1404°C were recorded while filling the different boxes, mould box 1 to 6 respectively. The temperature drop when casting the different boxes is not significantly different.

![Temperature Profile](image1)

Fig. 1 The temperatures as captured during pouring into each box

The casting temperature for the blades was lower than the recommended temperature of 1500 to 1510°C for manganese steel [4]. The lower pouring temperature may result in defects within the castings as the metal may freeze prematurely.

**B. Chemical composition**

Table I above is a representation of the chemical results. The expected elements are within the specified limits except for aluminium which was 0.01% below the expected value of 0.04%. According to literature, the effective amount of aluminium for deoxidizing purposes ranges between 0.03 to 0.09%. The lower value of aluminium may suggest that the metal will react with oxygen, and therefore form gas related defects.

**C. Macro examination**

Each casting from the six boxes was carefully examined upon shakeout for observation of the surface finish. One box was isolated for further investigation, and the results are represented in Fig. 3 below. The gas defects known as surface blows were observed on the castings. These are spherical, flattened or elongated cavities present inside the casting or on the surface. These defects are caused by the moisture left in the mould and the core. Due to heat of the molten metal the moisture is converted into steam, part of which when entrapped in the casting ends up as blowhole or ends up as open blow when it reaches the surface [5].

![Fig. 2 Samples inspected for surface defects](image2)

The blowholes, when present in castings locate themselves on the cope in poorly vented pockets or undercuts [5]. On the castings examined, the blowholes were located on the cope side of the mould and their positions on the castings varied. The pouring temperature for these castings was lower than the recommended values.

![Fig. 3 Elephant skin and a gas related defect on the surface](image3)

The surface finish of the castings showed some elephant skin which is evidence that the metal was already cold when poured into the mould cavity. The density of the molten metal had already increased, and the fluidity had decreased therefore...
resulting in these lines forming which are known as the elephant skin.

D. Micro examination

The micrographs below were obtained while analyzing the chemical composition of the different phases observed on samples using the SEM. Table II and Fig. 5b below show the chemical composition of the phase presented in Fig. 5a. The composition has high oxygen, manganese and iron. Since this test was done to enable one to make a deduction about the cause of the blowholes, the high oxygen content is evidence that these are gas related defects.

ii. Solidification time

The results indicated in Fig. 9 below illustrate the solidification time of the castings when the temperature had dropped to 500°C. The castings have the lowest solidification time on the edges which are close to the mould wall and remained the hottest at the centre. The lower solidification time at the casting and mould interface indicates that the castings start cooling from edges towards the centre.

![Fig. 6 Solidification time of the castings in seconds](image)

Evidence to support this fact can also be seen in Fig. 8, where the castings have the lowest modulus on the edges and the highest at the centre. Noted also is that the different layout of the castings on the runner bar gives different cooling characteristics.

iii. Shrinkage defects

![Fig. 10 Shrinkage defects on the sprue and the runner bar](image)

Fig. 10 above indicates the shrinkage defects that occurred within the castings after solidification had been completed. The sprue has experienced almost 100% shrinkage. This means that the sprue feed the castings until it was exhausted and could not supply anymore feed metal. This type of shrinkage occurs due insufficient feed metal and is known as primary shrinkage pipe [6]. From these results it can be deduced that this sprue was not sufficient to provide the feed metal for these castings and compensate for the shrinkage.

The degree of shrinkage within the castings with different layout on the runner bar was evaluated in Fig. 11 below. Assessed as well will be the degree of shrinkage within the castings that are closer to the sprue and those further.In Fig. 11 below, it can be comprehended that the castings located further from the sprue as well as the feeder since it was performing both functions have a higher percentage of shrinkage. The orientated parallel to the gating system seems to have a higher shrinkage percentage than those orientated vertically. The higher shrinkage defects on these castings were already predicted in Figs. 8 and 9 where both the solidification time and the thermal modulus were higher. This is evidence of different feeding and heat transfer characteristic between these castings.

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**TABLE II**

**Chemical Composition of Spectrum 1**

<table>
<thead>
<tr>
<th>Weight percentage (%) of elements observed</th>
<th>O</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Mn</th>
<th>Fe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>O 27</td>
<td>4.5</td>
<td>2.06</td>
<td>0.52</td>
<td>0.29</td>
<td>9.11</td>
<td>56.4</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

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E. Simulation results

i. Thermal modulus

Illustrated in Fig. 8 below is the thermal modulus of the castings as indicated by the casting simulation. According to Chvorinov’s rule, the sections of a casting which have a higher modulus will freeze last, while those sections with a lower modulus value will freeze earlier [5].

![Fig. 5 The thermal modulus of the castings as indicated by the simulation](image)

In the Fig. 8 above, the areas with the highest modulus are at the center of the castings on the thickest sections, (indicated in red). These sections have a tendency towards shrinkage as they freeze last.
V. CONCLUSIONS

Highlighted below are the conclusions from the results of research.

Shrinkage defects
1. The shrinkage defects observed were due to insufficient feed metal.
2. The shrinkage defects observed on the castings were not distributed evenly due to different layout of the castings on the runner bar which led to different feeding characteristics.
3. The favorable placement of the sprue has an influence on the feeding characteristics and therefore the occurrence of the shrinkage defects on the castings.
4. The modification of the gating and feeding system has proved to reduce the shrinkage defects as well as the gas related defects; the castings solidify by directional solidification.

Gas defects
1. The Al content for this steel was 0.03% after sparking, which means it had an effect as a deoxidizer. However, it was not sufficient to completely deoxidize the Hadfield steel as the expected minimum value should be 0.04%.
2. The blowholes found in the castings were due to the low casting temperature and insufficient venting.
3. According to the SEM test results the blowholes are gas related defects, the high oxygen content is evidence that that supports this fact.

VI. RECOMMENDATIONS

The following recommendations are made:
1. The recommended pouring temperature of 1500°C should be observed to minimize the gas entrapment and premature freezing.
2. Lean manufacturing in the foundry floor may be considered to improve plant lay-out.
3. Same layout of castings in the box should ensure uniform flow of feed metal. Equal number of castings should be placed on either side of the runner bar.
4. Feeders should be introduced to compensate for shrinkage defects and promote directional solidification.
5. Sufficient venting of the moulds will prevent entrapment of gases.

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REFERENCES