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Critical Solid Fraction Point Analysis: Case Study on Cement Mill Machine Diaphragm

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ABSTRACT

During the solidification process, metal liquids turn into solid geometry units including the riser and gating system. The disruption in the liquid flow often causes shrinkage in the object. Critical Solid Fraction Point is a critical point where the continuous liquid supply turned solid and unable to pour to some sections. Simulation software can predict the critical solid fraction time of an object and the liquid supply behavior. The simulation helps the designer in the casting design. The application of low steel alloys in the cement industry, e.g., the Diaphragm, needs development to minimize the shrinkage. This research aimed to analyze the critical solid fraction point in the diaphragm steel casting products. The primary objective of this research was to predict the critical solid fraction point during solidification, started from the longest time in the riser/feeder using SOLIDCast 8.1.1 casting software and provided improvement recommendation to minimize the shrinkage.

Keywords: *Critical fraction solid time, diafragm, shrinkage*

I. Introduction

The Diaphragm is a component in cement mill machine that functioned as a filter and sorter of the raw material. The component is assembled to a geometrical unit that shaped like a ring into the machine. The component will be rotated and experiences continuous friction with the processed raw material and ball mill component. The component generally made from wear-resistant casting steel. The component's replacement already relies on the domestic supply with a relatively lower service life compared to the foreign supplies.

The previous simulation of the Diaphragm design predicted that the shrinkage occurred in the riser. However, it was also predicted that the disrupted liquid supply path in some sections of the product. This occurrence indicated that a complex geometrical shape in the Diaphragm product also made a relatively complex liquid flow path from the riser [1].

During solidification, liquid from the riser flows through a path that passes the sections up to a section that requires faster supply or faster solidification [2]. The effective duration to

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supply the liquid correlates with the time the object reaches the critical solid fraction point. When a section reaches the critical solid fraction point, the liquid unable to flow through the section. This research aimed to predict the critical solid fraction time of the Diaphragm casting object during solidification, started from the longest time in the riser/feeder using SOLIDCast 8.1.1 casting software and provided improvement recommendation to minimize the shrinkage [3].

II. Method

Fig. 1. depicts the methods used in this research to obtain the timing prediction of the critical solid fraction point in the Diaphragm casting sections [4], [5]. This research only used a computer/laptop with a licensed SOLIDCast 8.1.1 software in each casting simulation.

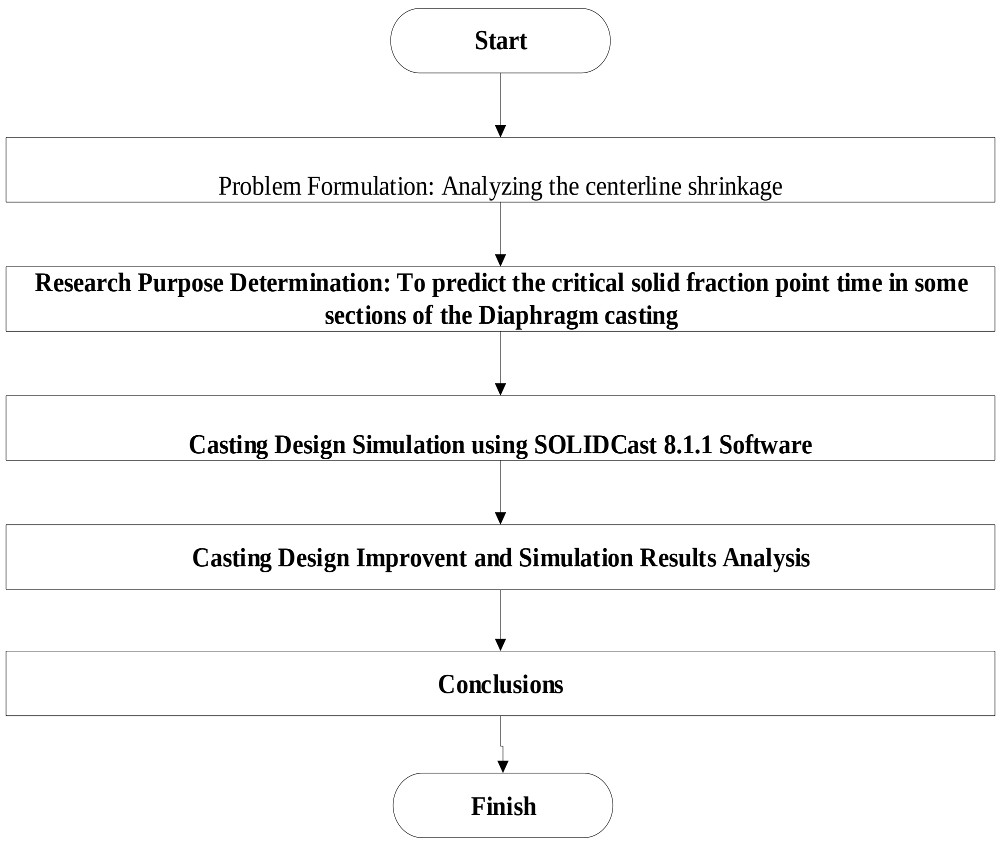

Fig. 1. Research flow chart

III. Results and Discussion

This research choose the Diaphragm casting product as the object since it has a complex geometry. The Diaphragm casting product was made from AISI 4041 chrome-molybdenum low steel alloys. Table 1 displays the chemical compositions of the object.

Figure 2 presents the disrupted supply flow from the previous Diaphragm casting design [6]. This occurrence indicated that some sections reached the critical solid fraction point first in the middle of the flow during solidification [7]. With some sections reached the critical solid fraction point, the liquid supply from the riser stop flowing through the section. As a result, other sections start from the solid section up to the end need sequent supply and separate from the direct supply [8].

Table. 1 AISI 4041 Steel Chemical Compositions

AISI 4140	
%C	0.36 – 0.43
%Mn	0.75 – 1.00
%Si	0.15 – 0.30
%P	Max 0.025
%S	Max 0.025
%Cr	0.80 – 1.10
%Mo	0.15 – 0.25

Fig. 2. The disrupted supply flow of the diaphragm casting design simulation in the previous research

Sections without direct supply from the riser take the supply from other sections which contain the remaining disrupted liquid. As a result, the last section to solidify do not receive any supply and causes shrinkage [9]. The critical solid fraction time and solidification modulus are similar where both represent the solidification time. However, both are different in the percentage of the solidification section. Solidification modulus represents the solidification time up to 100% solid, whereas the critical solid fraction time represents the solidification time up to x% solid (where x<100%). Therefore, there is some residual ((100-x)%) that unable to flow to other sections [10] optimally.

Due to the above problem, this data collecting and the critical solid fraction time analysis simulation needed an initial simulation of casting only material before the additional riser and chill. The result helped to position the riser or chiller in the casting design [11], [12]. Figure 3 shows the predicted critical solid fraction time in each Diaphragm casting object from the initial casting only simulation. Based on the complex geometrical shape of the Diaphragm casting object and the critical solid fraction point in each section, Figure 3 also displays the five areas with natural supply flow as circled in blue.

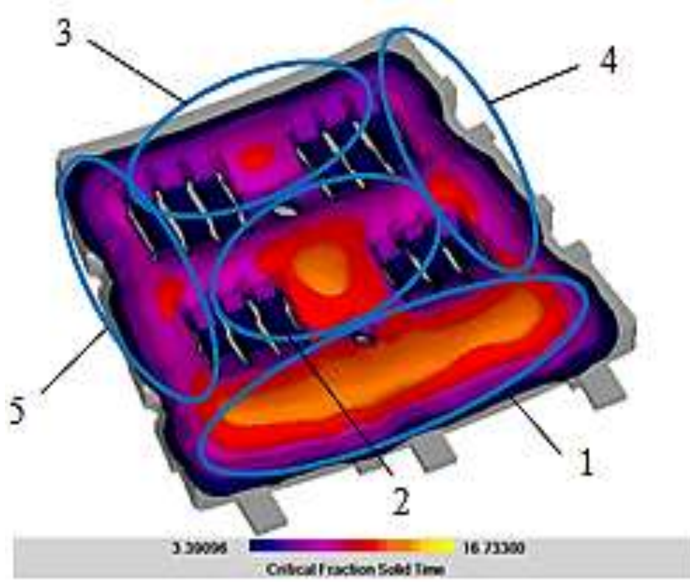

Fig. 3. The critical solid fraction point differences in the casting object sections from the initial casting only simulation

Sections circled in blue indicate sections with the fastest critical solid fraction time; in this research it is 3.39 minutes. The color that gradually turned into yellow means that the sections had the slowest critical solid fraction time, and in this research, it is 16.7 minutes. Sections with the slowest critical solid fraction point timing were the sections that needed risers.

Following the consideration, it was ideal for applying five risers so that the five detected areas had their liquid supply. However, the complex geometrical shape became the next obstacle because there were two areas (area 4 and 5) that unable to receive side or top risers. Therefore, improving the casting design required four side chillers in area 4 and 5 and three top exothermic risers in area 1, 2, and 3. Chillers in the area 4 and 5 made the section reached the critical solid fraction faster and caused the liquid supply from the top exothermic risers in area 2 and 3 able to reach both areas. Figure 4**.** shows the casting design of the above simulation.

Figure 5 displays the improved casting design with different critical solid fraction points between the sections. Blue sections show the sections with the slowest critical solid fraction time that is 3 minutes. As stated before, the color that gradually turned into yellow meant that the sections reached the slowest critical solid fraction time with the prediction up to 35 minutes in area 2 with the top exothermic riser.

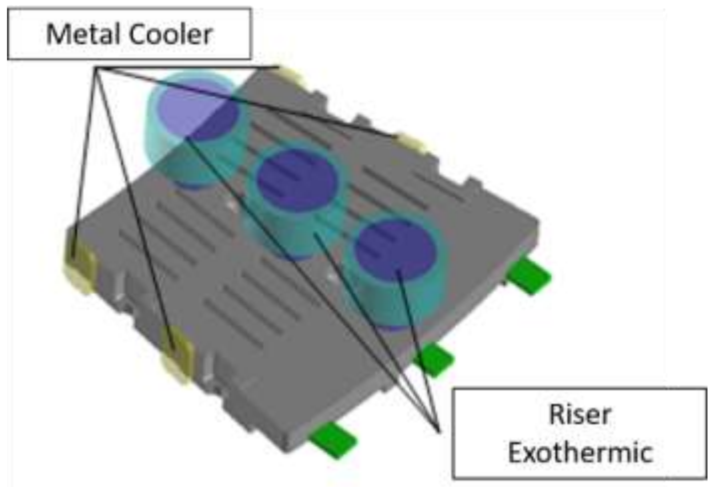

Fig. 4. Casting design with three top exothermic risers and four side chills

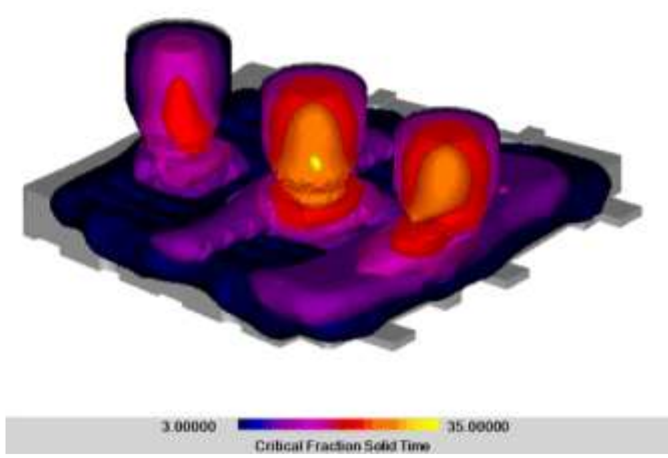

Fig. 5. The differences in the critical solid fraction times between sections from the simulation with top exothermic riser and four side chills

Additionally, it can be observed that there were no sections in the middle of the supply path with faster critical solid fraction point compared to the clamped sections, as observed from the color gradation. In conclusion, the improvement of this simulation was deemed effective to produce the Diaphragm casting object without shrinkage [13].

IV. Conclusion

Based on the simulation results of the castings using SOLIDCast 8.1.1, the application of three exothermic top risers and four side chillers made the sections reached the critical solid fraction point in sequential solidification process until the longest time was found in the riser. Additionally, the chance of shrinkage in the Diaphragm casting product was relatively small due to the improvement in this research.

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