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EFFECT OF PLATE THICKNESS AND CASTING POSITION ON SKIN EFFECT FORMATION IN THIN WALL DUCTILE IRON PLATE

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ABSTRACT

In producing Thin Wall Ductile Iron (TWDI) plate, special notice should be taken on the skin effect formation. Skin effect is a rim of flake interdendritic graphite formed in the surface. In a normal ductile iron casting, skin effect can be removed with machining process. Unfortunately this procedure cannot be applied in TWDI due to the thickness. This paper discusses the effect of casting design to the skin effect formation. Vertical casting design is used in this work. Variations are made in the thicknesses of the plate. The T1 model is equipped with 5 plates with thicknesses of 1, 2, 3, 4, and 5 millimeters; while the T1-Mod is equipped also with 5 plates, but with the same thickness, which is 1 mm. Skin thicknesses, nodule count, and nodularity are measured by NIS Element software. The result showed that skin effect formation is determined by magnesium content and cooling rate. Skin effect thicknesses are determined by cooling rate and the interaction area of molten metal with the mould. The presence of the skin effect in similar thickness and position of plate improved nodule count. In the same thickness, without the presence of the skin effect, the nodule count tends to increase as the positions of the plates increase. In the design ranging from 1 to 5 mm plate thickness, the highest nodule count is 1284 nodule/mm^2 gained by 1 mm plate thickness in 1st position and the lowest one is 512 nodule/mm^2 gained by 5 mm plate thickness in 5th position. As for the design of all 1 mm thickness where skin effect is not formed the highest nodule count is 1689 nodule/mm^2 gained by 1 mm plate thickness in the 5th position and the lowest is 1113 nodule/mm^2 gained by 1 mm plate thickness in the 1st position (near the in gate). The highest nodule count is 90 and the smallest is 85.

Keywords: Casting design; Cooling rate; Magnesium; Skin effect; Thin Wall Ductile Iron (TWDI)

1. INTRODUCTION

Thin wall ductile iron (TWDI) contains the advantage of ductile iron properties and weight. TWDI makes ductile iron possible to compete with aluminum in terms of weight (Soedarsono et al., 2011; Soedarsono et al., 2012).The latest thickness development in TWDI has reached 1 mm for plate (Soedarsono et al., 2011) and 3 mm for components (Martinez et al., 2002). The problem connected due to its thickness is the formation of skin effect. Skin effect in TWDI is defined as a rim of flake interdendritic graphite (Ruxanda et al., 2002). The term of skin effect

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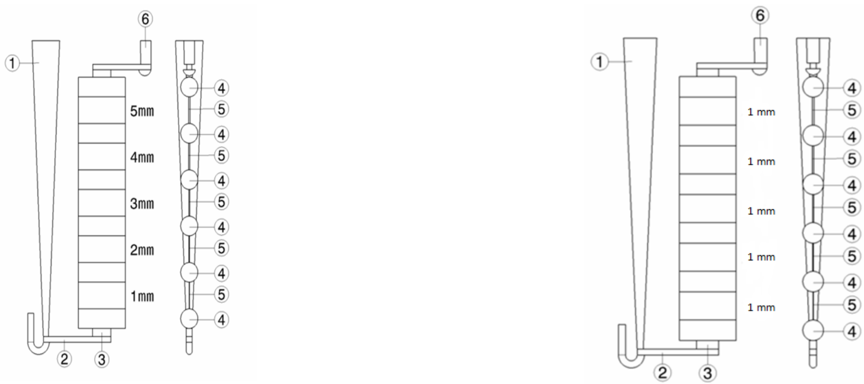
in TWDI was used by Aufderheiden et al. (2005).

Skin effect is a part of casting skin in cast iron. This term was introduced for the first time by Reisener (1962) to describe the reduction of carbon content. He described the casting skin as the outer layer of the casting comprising a decarburized layer and some graphite in grey cast iron. This term was also used by others researchers (Matijasevic et al., 1974; Rickard, 1976; Narasimha, 1975) and also is known as a decarburized layer, ferritic skin, or ferritic surface layer (Boonmee, 2013). Goodrich (1998) explained the formation and causes of casting skin in ductile iron. According to Goodrich, the explanation of skin effect was formed due to the sulphur contamination in the molding sand. Goodrich et al. (2002) also found that the as-cast skin on the tensile specimen reduces the ultimate tensile strength (UTS) and elongation, but this occurs only certain limits improve the yield strength. Dix et al. (2003) in their research found that the mechanical properties of fully machined TWDI are equivalent or higher than regular section ductile iron. Dix et al. (2003) also found that higher nodule count are related to higher cooling rate. Ruxanda et al. (2002) found that the thickest rim was 200 mikron. They concluded that magnesium differences between the surface and the center were the caused of skin effect formation. Ruxanda et al. (2002) also assumed that the differences happened as the result of magnesium oxidation. Aufderheiden et al. (2005) in their research tried to control the skin effect using Low Density Aluminium Silicate Ceramic (LDASC). The result showed that using LDASC improves the microstructure and mechanical properties of the inner layers, but it also improves the thickness related to the skin effect.

This paper discusses the effects of plate thickness and casting position to skin effect formation in producing TWDI plates by using one casting design with different thickness arrangements. The effect was analyzed based on skin effect thickness, nodule count and nodularity.

2. EXPERIMENTAL SETUP

The designs used in this research are modified from the design in our previous works (Soedarsono et al., 2011; Soedarsono et al., 2012; Sulamet-Ariobimo et al., 2013; Sulamet-Ariobimo et al., 2013; Sulamet-Ariobimo et al., 2012). Modification was made on the thickness of the plates. Both designs are presented in Figure 1. The dimensions of the plates were (75×150 mm) and as already mentioned, five plates were produced in each mold and all of the plates were arranged parallel to each other. In T1, the thicknesses of the plates varied from 1 to 5 mm, but in the T1-Mod all the plates were each 1 mm thick.



T1 T1-Mod

Figure 1 Casting design:
(1) down sprue; (2) runner; (3) ingate; (4) riser; (5) plate; (6) gas tunnel

The research was done on the foundry scale. The molds were made from furan sand. The metal cast was a ductile iron manufactured to grade of Ferro Casting Ductile (FCD) 450 (JIS 2000). The liquid treatment used 12 kg Fe-Si-Mg with 6% Mg as the nodularising agent in the sandwich method with a tapping temperature of 1500°C. Inoculants was placed in the ladle. The inoculant was a S70 with the composition of 1.5% Ca; 72.95% Si; 0.86% Al; 2.1% Ba. The process parameter is presented by Table 1.

Table 1 Process condition

		T1	T1-Mod.
Tapping Temperature	(°C)	1480	1410
Pouring Temperature	(°C)	1393	1312

The chemical composition used was examined before the implementation of the liquid treatment process. The metallographic examinations included formed microstructures, nodule count, nodularity and the thickness of the skin effect. The examination method was based on ASTM A427. Skin effects were measured using NIS Elements. Nodule count and nodularity were counted using NIS Elements.

First analysis will focus on the effect of different plate thickness in the 1 mm mold to the skin effect. The second analysis will focus on the influence of plates and their position in relation to the skin effect. Further analysis will focus only on a 1 mm thick plate.

3. RESULTS AND DISCUSSION

The chemical composition of both molten metal used are presented in Table 2. Chemical compositions of both molten metals are all within the standard. The major difference between both molten metals is in the magnesium content. The magnesium content of the T1-Mod is 75% higher than T1. Based on the conclusion of Ruxanda (2002) with a higher magnesium content, the skin effect in T1-Mod will be thinner than T1.

Table 2 Chemical composition –weight (%)

Element/Pouring	C	Si	Mn	P	S	Cu	Ni	Cr	Mg
T1	3.8	2.6	0.37	0.02	0.02	0.04	0.03	0.04	0.04
T1-Mod.	3.8	2.8	0.36	0.02	0.02	0.02	0.03	0.05	0.07

The un-etched microstructure of both T1 and T1-Mod. in Figure 2 showed the presence of nodule graphite. In T1 the nodule graphites are distributed evenly. The nodule diameter tends to increase as the thickness of the plate increases. Nodularity tends to decrease as the thickness of the plate increases. The nodule graphite in T1-Mod. are smaller than T1. Primary graphites are detected in almost every plates of the T1-Mod.

The etched microstructures in Figure 3 revealed that skin effects are formed in every plates. As assumed before, skin effects are not formed in T1-Mod. Most of the skin effects are lower than 200 mikron or 0.2 millimeters, as shown in Figure 4a. All the average thicknesses of the skin effects are lower than 200 mikron, except for the 3 mm plate thickness shown in Figure 4b. The skin effect of the 3 mm thick plate with i experiment. The skin effect should be thinner as the cooling rate increases, due to a shorter interaction time between molten metal and the mold.

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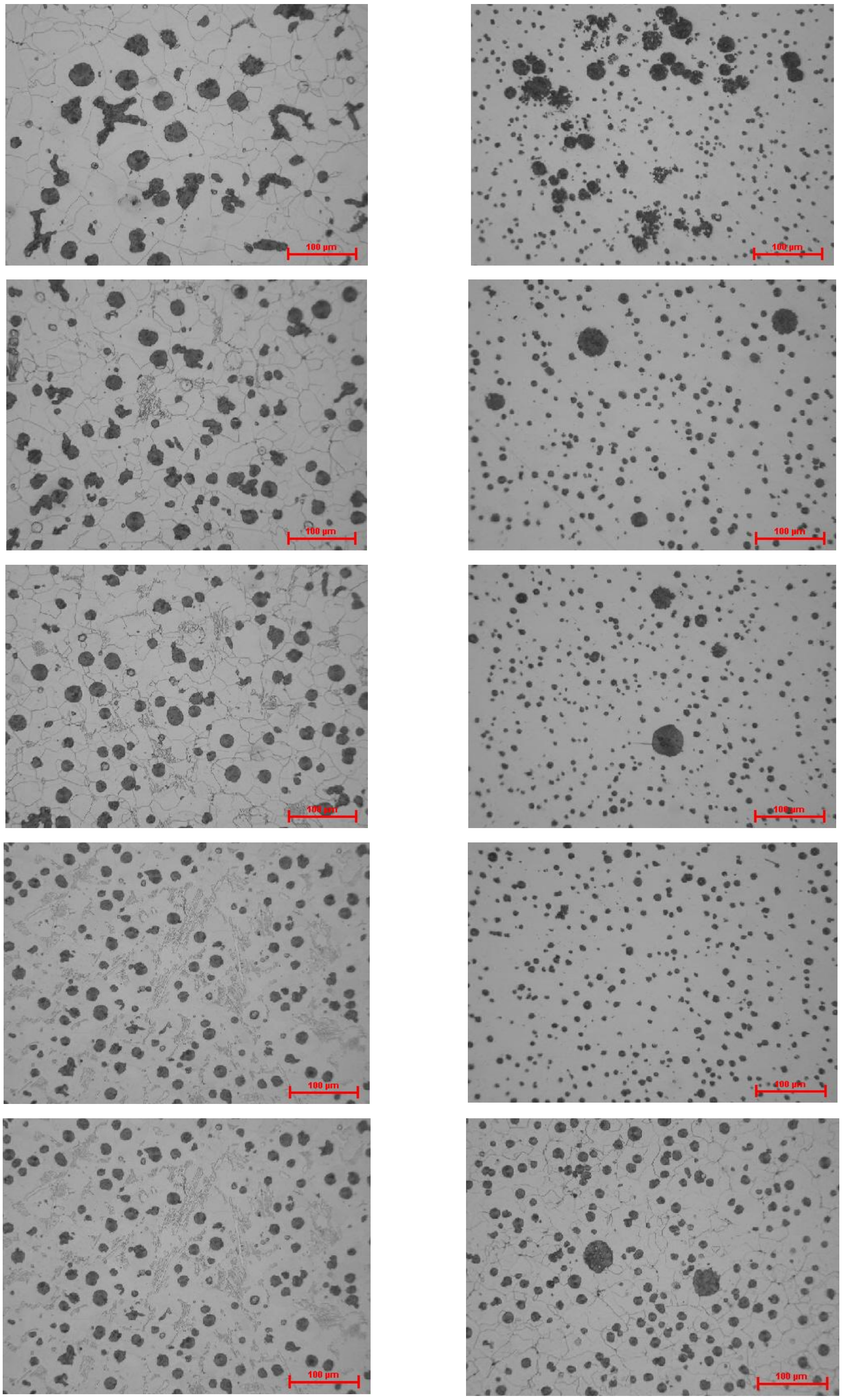

T1 T1-Mod

Figure 2 Un-etched microstructures

The un-etched microstructure reveals the presence of nodular graphite for both designs. It is also reveals the presence of primary nodular graphite in almost of the T1-Mod and unfinished nodule graphite in the 5 mm plate thickness of T1.

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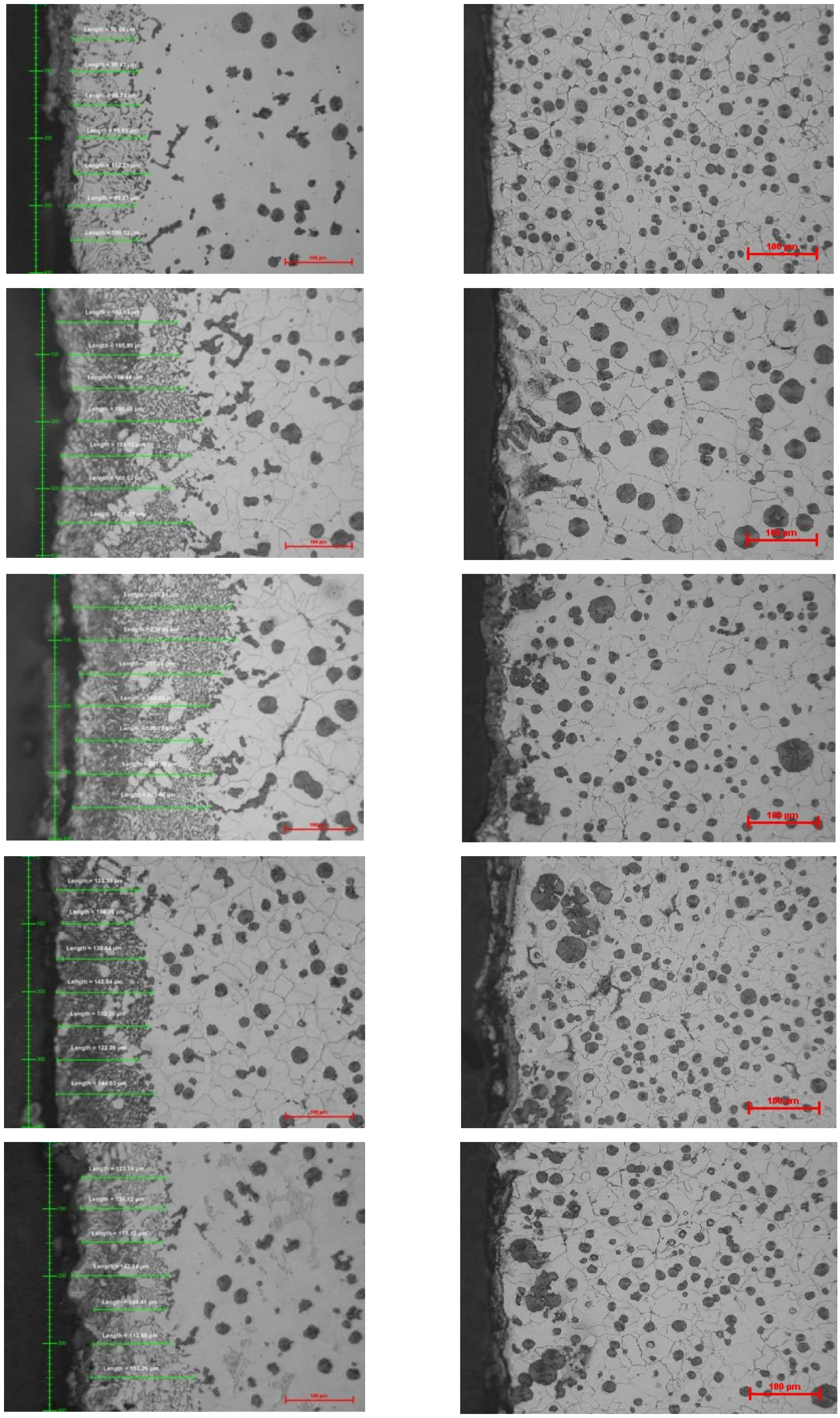
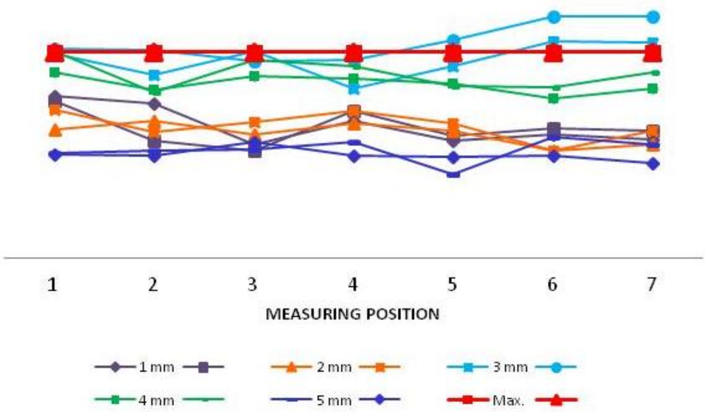


T1 T1-Mod

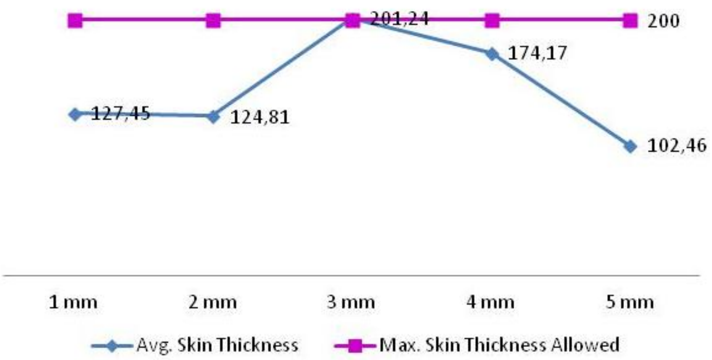
Figure 3 Etched Microstructures

The etched microstructure reveals the presence of a ferritic matrix for both designs.It is also revealed the presence of the skin effect in T1 design which does not form in T1-Mod.

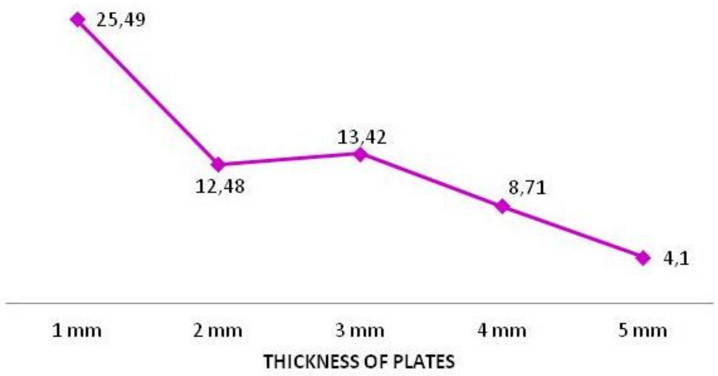
Simulation results show that the solidification sequences for T1 begins with a 1 mm thick plate, followed by 2 mm, 5 mm, 4 mm and 3 mm, respectively. Based on this finding, the skin effect in the 1 mm thick plate should be the thinnest, followed by 2 mm, 5 mm, 4 mm, and 3 mm, respectively. The results showed that the thinnest skin effect formation is found in 5 mm thick plate and the thickest is found in 3 mm thick plate. This happened because of the interaction between molten metal with the mold, which also determined the skin effect formation. In the 1mm thick plate, the interaction happened in almost all sides. While, in the 5 mm thick plates, although the interaction is similar, there was still an area in-between the sides, which was due to its thickness.



(a) Thickness of Skin Effect. This figure shows the measuring result conducted in the etched microstructure (green line)



(b) Average Skin Thickness. The average of skin thickness is calculated from all the measuring data

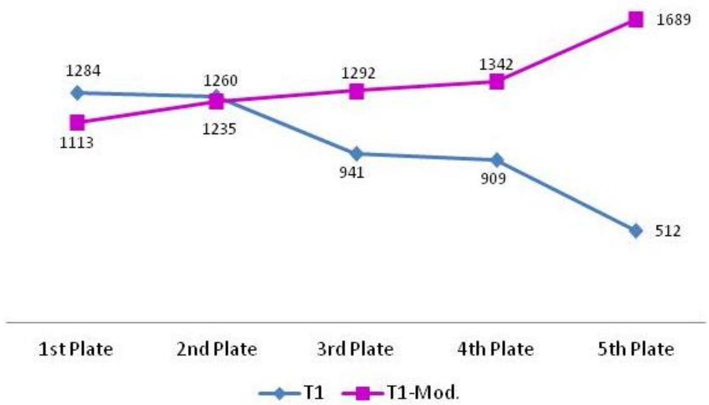


(c) Percentage of Skin to Plate Thickness. The percentage of skin effect is the ratio of average skin thickness to plate thickness

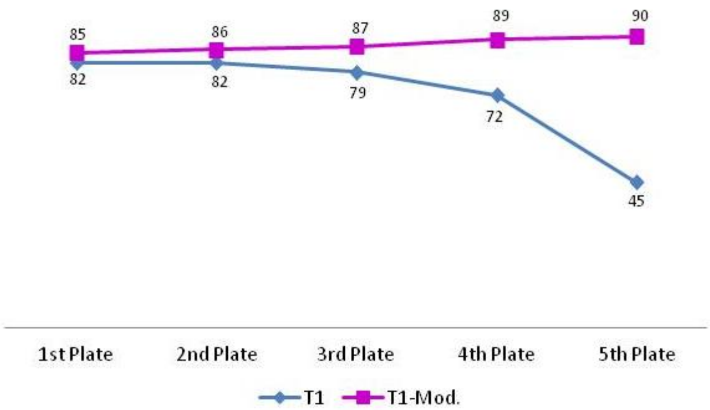
Figure 4 Analysis of skin effect

When the skin effect is analyzed on the plate thickness, the result is present in Figure 4c. The skin effect tends to decrease as the thickness of the plate increases. This is the reason skin effect should be avoided in TWDI. In regular ductile iron casting, skin effects can be removed with a machining process, but this procedure cannot be applied in TWDI.

The skin effect does not form in the T1-Mod. Analysis carried out on both process parameters showed only two major differences, these are the magnesium content and the process temperarature for both tapping and pouring. As discussed previously, the magnesium content in the T1-Mod is 75% higher than T1. The magnesium content will act as a reserve for magnesium supply when needed. This means the T1-Mod has a higher magnesium reserve than T1. As mentioned by Goodrich (1998) and Ruxanda (2002), magnesium is responsible for promotion of the skin effect.



(a) Nodule Count (in nodule/mm^2)



(b) Nodularity (in percentage)

Figure 5 Nodule graphite characteristic

As for process temperatures, the tapping and pouring temperature of the T1-Mod is lower than T1. The T1-Mod tapping temperature is 5% below T1. Tapping temperature is linked with liquid treatment process. As for the pouring temperature, the T1-Mod pouring temperature is 6% below T1. Although the T1-Mod has lower temperatures, the T1-Mod has higher temperature differences than T1. This differences is related to cooling rate. The temperature differences of T1-Mod is 98^o, while T1 is 87^o. The T1-Mod is 13% higher than T1. With the same holding time, the T1-Mod will have a higher cooling rate than T1. Furthermore, the casting volume of T1-Mod is smaller than T1 because all the plates have the same 1mm thickness.

Nodule count and nodularity in the T1-Mod tends to increase as the plate position increases as shown in Figure 5. Nodule count is associated with cooling rate as mentioned by Dix et al., (2003). Based on this data, the cooling rate increases as the plate position moves further from the in gate as shown in Figure 5a. Although nodularity has the tendancy to trigger nodule counts, but the differences are not as much as the nodule count. Comparing nodule counts of the first plate position in the T1-Mod to the same position in T1, which also has the same thickness, reveals that skin effect increases nodule count, but decreases nodularity. Nodule count in the T1-Mod is 13% lower than T1, while the T1-Mod nodularity is 4% higher than T1.

4. CONCLUSION

All data and analysis showed that skin effect is formed due to the lack of magnesium and cooling rates. The skin effect in a certain way improves nodule count and degrades nodularity. The thickness of the skin effect is determined by cooling rate and the interaction area of mold-molten metals. Nodule count tends to decrease as the thickness of the plate increases with the presence of skin effect. The highest nodule count is 1284 nodule/mm^2 gained by the 1 mm plate thickness in the 1st position and the lowest one is 512 nodule/mm^2 gained by the 5 mm plate thickness in the 5th position

When in one mold, all the plate thickness is the same and skin effect is not formed, nodule count and nodularity will increase as the plate position increases. The highest nodule count is 1689 nodule/mm^2, gained by 1 mm thick plate in the 5th position. While the lowest is 1113 nodule/mm^2 gained by 1 mm thick plate in the 1st position (near the in gate). The highest nodule count is 90 and the smallest is 85.

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