Effect of Mould Coating on Skin Formation and Nodule Characteristics of Thin Wall Ductile Iron Casting

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Abstract. Thin wall ductile iron (TWDI) has the potential alternative for lightweight aluminium use in automotive parts. The main problem in TWDI, however, is the formation of skin during the casting, which may reduce its mechanical properties. This casting skin is formed by the decomposition of nodular graphite at the mould interface during the casting process. One of the ways to work around this problem is by using mould coating to control the cooling process. In this work, three variables of mould coatings were used, i.e. graphite, MgO, and MgO/graphite double layers. The results showed that the average casting skin thickness in double layer coating was the lowest (30.41 µm), 57% lower than that of in MgO (71.46 µm) and 60% lower than that of graphite (74.44 µm). The reduction of casting skin thickness increased the mechanical properties of TWDI (346 MPa), 69% higher than that of MgO (223 MPa) and 26% higher than that of graphite (297 MPa). The same is true for ductility (2.7%), which was higher than that of MgO (1.43%) and that of graphite (1.43%).

1. Introduction

Thin wall ductile iron (TWDI) is produced due to the need for a light weight material but with low cost consideration. In this case, the thin wall casting method makes the possibility for ductile iron to compete with the light weight of aluminium [1]. Compared with aluminium, the ductile iron has several advantages of high yield strength, low production energy and thus low production cost [2].

The appropriate technology in making automotive parts using TWDI is by using thin wall casting method. The TWDI casting only needs simple production process and tools, which are affordable for low budget manufacturers, however, the casting thickness standard for this thin wall casting has not been established. The main problem frequently found in TWDI is the formation of skin during the casting process, which significantly reduces the mechanical properties of TWDI [3].

Casting skin is a graphitic layer found at the TWDI surface. This phenomenon is caused by several factors, i.e. inadequate processing temperature, inappropriate carbon equivalent value, and inefficient liquid treatment during the casting process [4]. This skin formation is formed in regular cast iron and is normally eliminated by machining process, however, this machining process would not be possible when the casting product is very thin of only 1 to 10 mm thickness.

In this work, the effect of mould coating on the formation of casting skin and nodule characteristics of thin wall ductile iron by using three variables of mould coatings, i.e. graphite, MgO, and MgO/graphite double layers is reported and discussed.

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2. Experimental

The casting method used in this work was based on the previous work [5]. The plate design was 150 x 75 mm with 1 mm thickness, as can be seen schematically in Figure 1. The mould was made of furan sand and the metal cast was 1400 kg of ductile iron grade FCD 45 scrap.

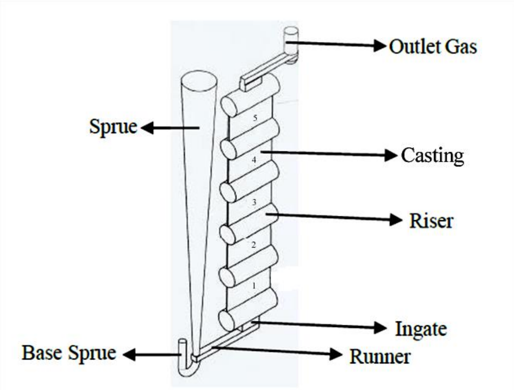


Figure 1. Schematic of the mould template

Mould coatings preparation began with the mixing of coating materials with ethanol, specific gravity measurement, manual brush of the mould, and solvent evaporation. The coating substance was poured into a bucket contained ethanol and mixed to achieve a value of 55 in Baume scale. The mix was applied on the mould surface using a manual brush after the furan sand cured perfectly. The applied coating was then heated to vaporize the solvent from the mixture and the coating would attach perfectly on the mould surface. These steps were applied on all samples. Slightly different with sample C, which has double-layer coating, MgO coating was firstly applied on the mould surface. After the MgO was set in, graphite coating was then applied on top of the MgO layer using the same method. Figure 2 shows the grey coloured of the graphite coating layer was firmly attached on top of creamy coloured of MgO coating layer.

Chemical composition check was conducted before and after liquid treatment. Nodulizing agent was 7.7 kg of FeMgSi-6% with some amount of S70-type inoculant in the liquid treatment process. Different mould coatings were used, i.e. graphite (Sample A), MgO (sample B), and double-layer of graphite/MgO (sample C).

Figure 2. Visualization of the mould after the application of double-layer coating

3. Results and Discussion

Chemical composition of the molten metal examined by using spectrometry is given in Table 1. Based on this composition, the carbon equivalent before and after liquid treatment was calculated to be 4.1625 and 4.4683, respectively, whereas holding and pouring time of the molten metal into the mould is given in Table 2. The pouring process was at 1406 °C performed in sequence started from sample C, sample B, and sample A. The FCD 45 metal was poured and was used as the same source as of liquid treatment batch to eliminate the difference in chemical composition and carbon equivalent (CE). There was an occurrence of the pouring time in sample B in which after the pouring of molten metal had finished and the molten metal was seen filled the mould perfectly, while the mould A was still in pouring condition the molten metal level in mould B dropped down. The molten metal in mould B was then refilled after the pouring process of mould A had finished. The holding and pouring time for all the samples are given in Table 2.

Table 1. Chemical composition of the molten metal before and after liquid treatment

Element	Before	After	Standard
C	3.6933	3.6964	3.50 – 3.90
Si	1.6294	2.6003	2.40 – 2.80
Mg	0.0000	0.0841	0.03 min
Mn	0.4866	0.4214	0.30 – 0.50
P	0.0085	0.0098	0.03 max
S	0.0232	0.0200	0.02 max
Cu	0.3732	0.1413	0.15 max
Cr	0.0042	0.0142	0.15 max
Ni	0.0022	0.0032	0.15 max
Al	0.0033	0.0106	0.03 max

Table 2. Holding and pouring time

Sample	Holding Time	Pouring Time
A	163 seconds	11 seconds
B (unfinished)	142 seconds	12 seconds
B (refilled)	185 seconds	7 seconds
C	115 seconds	15 seconds

Figure 3 shows layer of the mould coating schematically. In this figure, the double-layer coating is used in sample C. As can be seen in the figure, the compound in the layer will react with the sulphur existed in the sand at the mould surface, and hence reducing the sulphur content on the mould interface. Meanwhile, the graphite coating layer, which is in direct contact with the molten metal, would function as local carburizer without any interruption from the sulphur at the molten metal interface and could prevent graphite depletion phenomenon, and thus reducing the casting skin thickness.

Figure 4 shows that the double layer coating method in sample C has proven to reduce casting skin thickness of up to 60% when compared to that of sample A, which used standard graphite coating only. At the same time, it is seen that sample B, which used single layer MgO coating only, seems to have the most skin formation. The anomaly of casting thickness in sample B is expected to be due to the pouring method described previously. The delayed solidification in sample B could make the inoculant in the molten metal faded away and thus causing severe skin formation.

Figure 5 shows the nodule count formed in each sample. The highest nodule count was found in sample C followed by sample B and sample A with the least nodule count. There is a trend that this nodule count is pertinent to the thickness of casting skin formation. As can be seen in the figure, the thicker the casting skin, the less the nodule count. Sample C has an average 2014 nodule count per mm^2, followed by B with 1900 and A with 1671 nodule count. The 60% difference of casting skin thickness of sample C from sample A shows that reduced casting skin of sample C is related to the increase of nodule count in sample C 20% more than nodule count of sample A. In this instance, the use of mould coating affects the nodule count as the mould coating helps to reduce the casting skin formation, which correlated to the number of nodules formed in the metal.

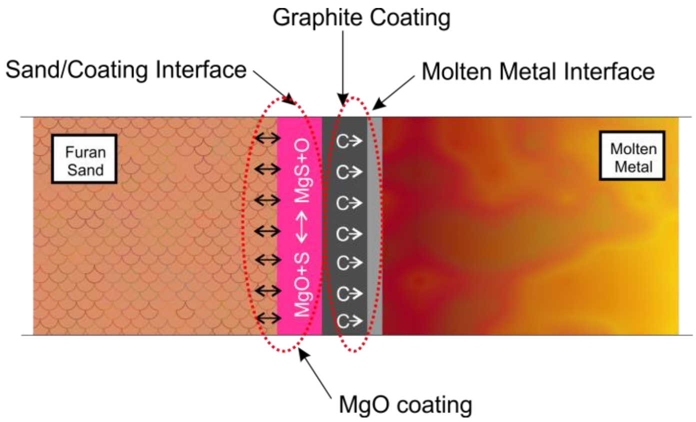


Figure 3. Schematic of double layer mould coating mechanism

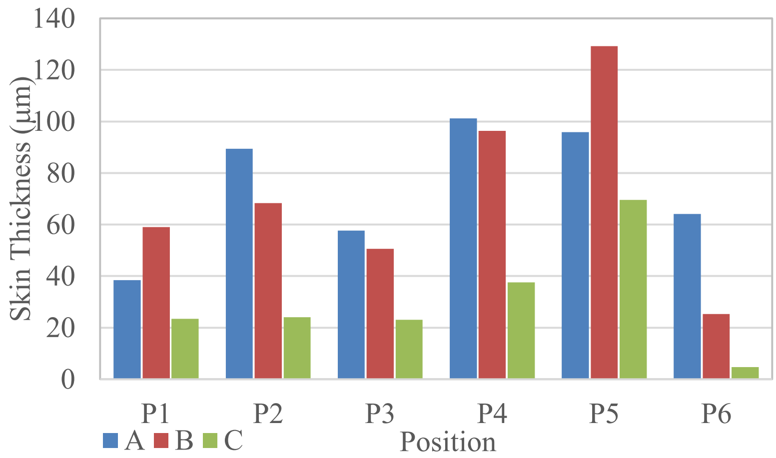


Figure 4. Skin thickness formation at different casting positions

Figure 6 shows the nodularity of each specimen. Sample B has the highest nodularity, followed by sample C and sample A with the lowest nodularity. In average, nodularity in sample B has the highest value because the single layer mould coating of MgO directly functions as a late nodulizer [3]. The MgO coating at the molten metal interface will react with the molten metal as a nodulizer, which take place inside the mould. This will then make the nodule to form by increasing the residual amount of Mg content in molten metal during solidification process. Sample C also has the MgO coating, however, the MgO in sample C cannot react directly with the molten metal, instead it will function as sulphur reducer at sand/coating interface, making the nodularity in sample C is slightly lower than that of sample B.
Table 3 shows the tensile test results of the TWDI samples of three variables. The ultimate tensile strength of sample C has the highest value, 26% higher than that of sample A and 69% higher than that of sample B. The same is true for the elongation, in which sample C is 93% higher than that of sample A and sample B.

These results were supported by the secondary electron images of the fracture area in every sample as can be seen in Figure 7. All samples show dimple fractures on the surface as an indication of ductile characteristic. The characteristic differences among these samples are in nodule count, nodule size and shape, and distribution of the nodules.

Surface fracture in sample A shows the characteristics of a dimple indicating a ductile fracture. The nodules distribute evenly, but some nodules formed in sample A looks larger than the other two samples. The size of the nodules is about 50 micrometres, and is of a primary graphite form. The number of nodules formed in the sample A are fewer compared to that of in the sample B and sample C.

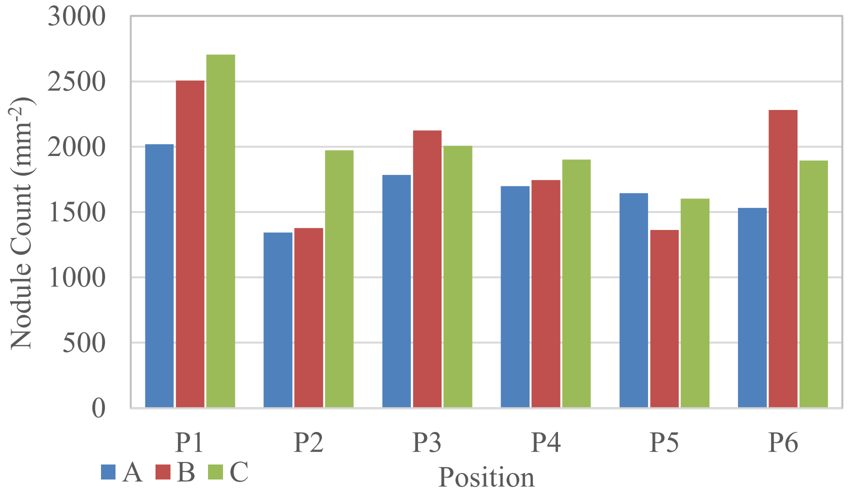


Figure 5. Nodule count at different casting positions

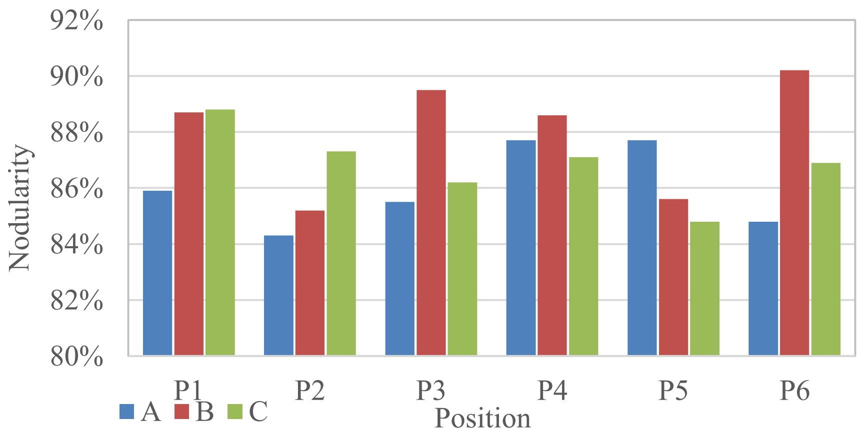


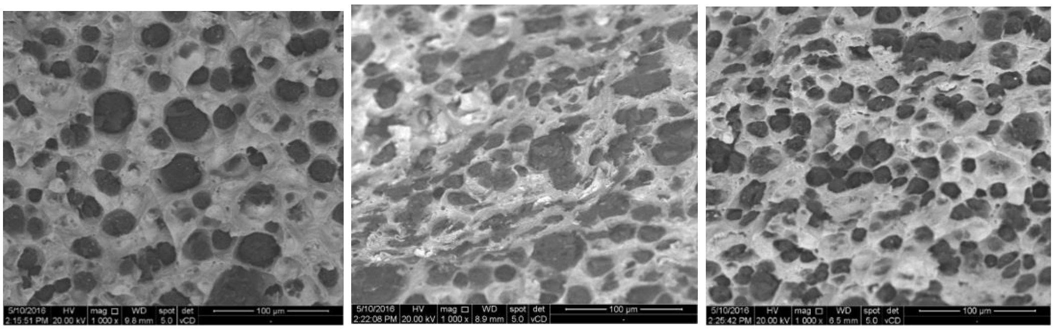
Figure 6. Nodularity at different casting positions

Table 3. Tensile test results

Sample	Strength (MPa)	Elongation (%)
A	297	1.43
B	223	1.43
C	376	2.76

More nodules are found in B compared to that of in sample A. Nodules overall diameter in sample B is larger than that of sample A. The nodules in sample B has much irregularities in shapes, which could be caused by the less amount of residual inoculant that affected the nodule characteristics. This is consistent with quantitative observations nodule diameter discussed earlier.

In sample C, surface fracture has a dimple characteristic and the nodules spread evenly. There are more number of nodules found in C compared to that of in the sample A and sample B but smaller in size. These characteristics are the optimum preferences for thin wall ductile iron. This finding is also in agreement with the qualitative and quantitative data discussed earlier. This fact is also supported by the data from ultimate tensile strength (UTS). Referring to JIS standard of elongation of ferritic ductile iron, the above results are certainly still very far from the standard elongation of 10%. This is due to the persistence of the skin layer contained in the casting, the anomalies graphite such as graphite primer and exploded graphite, carbide formation.



(a) (b) (c)

Figure 7. Secondary electron image from tensile test fracture surface (a) sample A, (b) sample B, and (c) sample C. Bar scale is 100 microns

4. Conclusion

In this work, the casting skin thickness in double-layer coating of MgO and graphite is of 30.41 μm, 57% thinner than that of using single-layer of graphite only (71.46 μm) and 60% thinner than that of single-layer of MgO only (74.44 μm). Double-layer mould coating efficiently reduces casting skin thickness by reducing sulphur content at the mould surface and stabilized the carbon content of the molten metal inside the mould. The nodule count was high when the casting thickness was formed at the lower value. Nodularity of the sample with single-layer of MgO only was the highest (87.97%), compared with the sample with single-layer of graphite only (85.98%) and double-layer of MgO and graphite (86.85%), indicating that the MgO directly functions as late nodulizer. Tensile strength of the sample from mould coating with double-layer was the highest (376 Mpa), 69% higher than that of sample with single-layer MgO only (223 MPa) and 26% higher than that of the sample with single-layer of graphite only (297 MPa). Elongation of the sample with double-layer (2.76%) was higher than that of the sample with single layer of graphite only (1.43%) and the sample with single layer of MgO only (1.43%).

Acknowledgement

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