Effects of Ceramic Fibre Insulation Thickness on Skin Formation and Nodule Characteristics of Thin Wall Ductile Iron Casting

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Abstract. Skin formation has become one of the problems in the thin wall ductile iron casting because it will reduce the mechanical properties of the materials. One of the solutions to reduce this skin formation is by using heat insulator to control the cooling rate. One of the insulators used for this purpose is ceramic fibre. In this research, the thickness of the ceramic fibre heat insulator used in the mould was varied, i.e. 50 mm on one side and 37.5 mm on the other side (A), no heat insulator (B), and 37.5 mm on both sides (C). After the casting process, the results were characterized in terms of metallography by using scanning electron microscope (SEM) and tensile test for mechanical properties. The results showed that the skin thickness formed in A is 34.21 µm, 23.38 µm in B, and 27.78 µm in C. The nodule count in A is 541.98 nodule/mm² (84.7%) with an average diameter of 15.14 µm, 590 nodule/mm² (86.7%) with an average diameter of 13.18 µm in B, and 549.73 nodule/mm² (87.2%) with an average diameter of 13.95 µm in C. The average ultimate tensile strength for A was 399 MPa, B was 314 MPa, and C was 415 MPa. Microstructural examination under SEM showed that the materials have a ductile fracture with matrix full of ferrite.

1. Introduction
In manufacturing industries, aluminium is the most preferred material for any automotive parts because of its light weight and strength. Unfortunately, aluminium has a large production cost if we compared it to iron production [1]. In term of characteristics, ductile iron can compete with aluminium but for the weight. In this instance, thin wall ductile iron (TWDI) has been developed to compete with aluminium to overcome the light weight problem.

One of the problems in thin wall ductile iron casting is the formation of the skin, which can reduce the mechanical properties of the material [2]. The main cause of this problem is due to the formation of graphite nodule in which the edge of material tends to form flakes graphite. Specifically, this problem become worse when magnesium (Mg) does not fully functioned because of rapid cooling rate at the edge of material [3].

Ceramic fibre has been known to have an excellent heat insulator that can withstand temperature even above 1000 °C [4]. By using ceramic fibre as a heat insulator inside the sand mould, it could decrease the cooling rate of the molten metal and reduce the formation of skin during the casting and hence would improve the mechanical properties of TWDI.
2. Experimental
The research was done in foundry based industry. The casting design of this research was using vertical casting design based on Stefanescu’s research [5] with some modifications. The sand used for the moulding was silica sand with furan binder. In order to examine the effect of the thickness of ceramic fibre insulator in the mould on the skin formation and nodule, the ceramic fibre was placed inside the mould before pouring the silica sand inside the casting mould.

In this research, certain variation of the thickness of ceramic fibre heat insulator was used, that is 50 mm on the left side and 37.5 mm on the right side (A), no heat insulator (B), and 37.5 mm on both sides (C). The distance between the heat insulator and the mould was 20 mm on both sides. After casting moulds were ready, the moulds were coated using graphite to smoothen the surface of material. The molten metal was poured with temperature between 1380-1410°C at maximum pouring time 10s to keep the quality of the end material. The raw materials for making the molten metal were steel scrap and return scrap. The melt was added with slag removal and carburizer before liquid treatment process for inoculation and nodulizing purposes. Before and after the liquid treatment, spectrometry test was carried out to examine the composition of the material. After the material was taken out, shot blasting was performed on the material to reduce surface roughness of the material.

The characterization included microstructural examination by using scanning electron microscope (SEM) and mechanical properties by using tensile test. The purpose of microstructural examination is to observe nodule diameter, nodule count, and thickness of the skin formation. For tensile testing, JIS Z 2241:2011 number 5 was used as a reference. This examination was to observe ultimate tensile strength (UTS) and elongation of the material, whereas SEM examination was performed to examine the fractography of the materials.

3. Results and Discussion
Samples codes and information are given in Table 1. Casting process data containing information on holding time, pouring temperature, pouring time during casting process, and visual information of the sample are given in Table 2, whereas composition of the sample is given in Table 3.
Table 1. Sample Codes and Information

| Sample | Information |
|--------|-------------|
| A      | First pouring order; Mould was using ceramic fibre insulator with thickness 50 mm on left side and 37.5 mm on right side |
| B      | Second pouring order; Mould did not use any insulator |
| C      | Third pouring order; Mould was using ceramic fibre insulator with thickness 37.5 mm on left and right side |

Table 2. Casting Process Data

| Sample | Holding Time | Pouring Temperature | Pouring Time | Plate Thickness |
|--------|--------------|---------------------|--------------|-----------------|
| A      | 5 min 55 s   | 1445°C to 1420°C and last at 1406°C | 9.00 s    | 2.18 mm         |
| B      | 6 min 4 s    | 1395-1390°C         | 11.75 s     | 2.08 mm         |
| C      | 6 min 14 s   | 1385-1380°C         | 9.40 s      | 2.32 mm         |

Table 3. Composition of the Metal

| Element | Before Liquid Treatment | After Liquid Treatment | Factory Standard |
|---------|-------------------------|------------------------|-------------------|
| C       | 3.97                    | 3.78                   | 3.90 – 4.00       |
| Si      | 1.601                   | 2.67                   | 1.5 – 1.7         |
| Mn      | 0.496                   | 0.51                   | 0.30 – 0.50       |
| P       | 0.007                   | 0.0069                 | 0.03 max          |
| S       | 0.019                   | 0.0171                 | 0.02 max          |
| Cu      | 0.0421                  | 0.0428                 | 0.15 max          |
| Ni      | 0.0073                  | 0.0077                 | 0.15 max          |
| Cr      | 0.0007                  | 0.0027                 | 0.15 max          |
| Mo      | 0.0084                  | 0.0084                 | -                 |
| Mg      | 0                       | 0.0572                 | 0.03 min          |
| Sn      | 0.008                   | 0.0080                 | -                 |

As can be seen from Table 3, Si content after liquid treatment is much higher than that of the factory standard. This phenomenon is expected because Si helps cast iron to grow more graphite. On the contrary, Cu, Ni, Sn, and Mo are pearlite stabilizers [5], but it can be solved by giving more silicon to promote more ferrite phase. In this instance, the composition of sulphur and manganese need to be controlled because they will reduce the mechanical strength of thin wall ductile iron.

Figure 2 shows that the cooling rate of the material can affect nodule count, percentage of the nodular (nodularity) and nodule diameter. It can be seen that Sample B has the highest count of nodule compared to the others. This can be understood since sample B has the highest cooling rate as the mould lacks of the heat insulation. On the contrary, sample A has the lowest nodule count as compared to the others samples. This is because sample A has the slowest cooling rate from all of samples. Percentage of the nodule in sample C is the highest among all the samples, because sample C
has the best cooling rate as compared to the other samples; it is neither too slow nor too fast. Sample A has the biggest nodule diameter among all the other samples due to the slowest cooling rate. In terms thickness of the skin formation, sample B has the thinnest skin formation because it has the highest cooling rate among all other samples. On the contrary, A has the thickest skin formation because it has the slowest cooling rate. The slower the cooling rate the thicker the skin.

Figure 3 shows nodule diameter distribution in terms of the homogeneity of the samples. As can be seen from the figure, the uniformity in nodule size is quite scattered in the range of 5 to 25 μm. Figure 4 shows the microstructure of the samples from optical microscope. From the figure, it can be seen that sample B has the most carbide on the surface compared to the other samples. This can be understood since sample B has the highest cooling rate among all other samples. The more the cooling rate the more carbide layer on the surface of the material.

Figure 5 shows the average mechanical properties of samples A, B, and C in terms of strength and elongation. As can be seen in the figure, the strength of sample C is the highest among the three despite the fact that B has the lowest skin formation. It seems that the number of nodules and percentage of nodularity cannot be related to this mechanical property. The opposite is true for nodule diameter and the skin thickness.

Figure 6 shows secondary electron images of samples fractography. From the figure, it can be seen that sample C has better fractography in terms of dimple as an indication of ductile fracture as compared to those of the other two samples. Thus, even other factor could play important role in determining the mechanical properties, in this work, nodule diameter seems to has a profound effect.
Figure 3. Nodule diameter distribution

Figure 4. Optical microstructure of samples A, B, and C showing carbides on the surface

Figure 5. Mechanical properties of samples A, B, and C in terms of strength and elongation
Conclusion

The use of ceramic fibre heat insulator has the effect on cooling rate of thin wall ductile iron casting. The slower the cooling rate, the bigger nodule diameter, the lower the nodule count, and the thicker the skin layer formation. On the contrary, the higher the cooling rate, the smaller the nodule diameter, the higher the nodule count, and the thinner the skin formation.

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Figure 6. Secondary electron image of the fractography of samples A, B, and C, each with a scale bar of 100 \( \mu \text{m} \).