Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Influence of pouring temperature on the microstructure in ductile cast iron

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It is advised to keep the melt temperature of cast iron as low as possible to avoid problems during casting. Most casting properties except mould filling is improved by keeping the temperature down. Nodule density, nodularity and ferrite increase with lower melt temperature, but this has not been quantified earlier. This paper attempts to fill this void by describing a suitable evaluation method, and using it on data from controlled experiments and foundry trials to demonstrate that nodule density increase with 0.3 - 1% per ºC pouring temperature decrease, while ferrite increased 0.2% per ºC decrease. Nodularity increased 0.2% per ºC decrease in temperature in one trial.

Keywords: *Melt temperature, nodule density, nodule count, nodularity*

1. Introduction

Foundrymen know the importance of keeping the melt temperature as low as possible, and to reduce the time from melting to solidified cast. The melt temperature should be low to control oxidation [1,2], and the treatment temperature should be kept low to keep a high and consistent magnesium yield, and by that reduce variation in residual magnesium during spheroidization treatment [3]. A high pouring temperature increase the dissolution of various elements such as hydrogen and nitrogen. These elements precipitates when the temperature drops during the cooling of the melt before and during solidification, which may cause gas porosities [4]. A high pouring temperature can also cause metal penetration into the mould and cores [5].

What is less known is the quantitative effect of the melt temperature on nodule density (ND), nodularity and matrix structure.

The ND is important since it reduce both the primary carbide formation as well as inverse chill [6,7,8]. High ND is also reported to reduce porosity [**Error! Bookmark not defined.**,9] and to improve toughness [10], although this is disputed in [11]. The nodularity is interesting since there is a direct link to mechanical properties such as Young's modulus and fracture elongation. Nodularity also affects the thermal conductivity and damping characteristics of the material [12].

2. Measurement and Method

2.1 Lab scale melting and casting process

In the experimental set up, raw material was melted in an induction furnace, an MgFeSi containing 4.6% Mg added to the pocket in a sandwich ladle and covered with steel chips. The melt was treated at 1500 ºC, followed by slag removal. The treatment ladle melt temperature was measured several times before and after it was poured into 12-14 pouring ladles with 30 s interval, each holding 33 kg of melt with 0.2% inoculant added. The pouring ladles were held 60 s each before pouring component moulds. The temperatures were measured using dip thermocouples (t.c.) or interpolated between measurements. The difference in temperature drop from inoculation to mould pouring between the pouring ladles have been computer simulated, as well as being verified by measurements in a separate trial and found to be negligible. All temperature readings were made using t.c.'s and time stamped. All pouring times were time stamped for accurate temperature interpolations.

2.2 Microstructure evaluation

The microstructure was evaluated in the centre of 10 mm thick plates from step blocks and in rod samples of 25 and 40 mm diameter. The variation in quantified microstructure within a plate was evaluated to estimate the uncertainty due to variations in the position of the cut, since it varies from the hot to the cold part of a step (1.5 nodules/mm change in position). To minimize the uncertainty of the microstructure analyses themselves, each sample was examined using 25 images totalling 14.2 mm^2 each in the carefully selected identical position within each sample. The observed range of ND, nodularity and ferrite levels were 105-212 nodules/mm^2, 70-90%, and 46-69%. The uncertainty in the measurements, expressed as 95% confidences, were 5-12 nodules/mm^2, 2-6% and 2%.

2.3 Normalization

To be able to study the effect of the temperature variation only in the trials, the results were normalized. As an example, the ND for one sample was divided by the average result of the two repetitions made per melt to get a normalized ND (NDn). This method makes it possible to compare the relative influence of only the temperature variation on the output between different melts, inoculants, etc.

3. Results

The chemical composition changed slightly between the two trial melts, C 3.6 - 3.9 %, Si 2.2 - 2.3%, P 0.015 - 0.024%, Mn 0.33 - 0.3% and Mg 0.047 - 0.040%.

The left plot in Fig 1 shows that the ND_n increase with 0.3%/ºC drop in inoculation/pouring temperature. The plot in the middle show that the ferrite level increase with 0.2%/ºC. The colours represent different melts and sample geometries, and show that the behaviour is consistent.

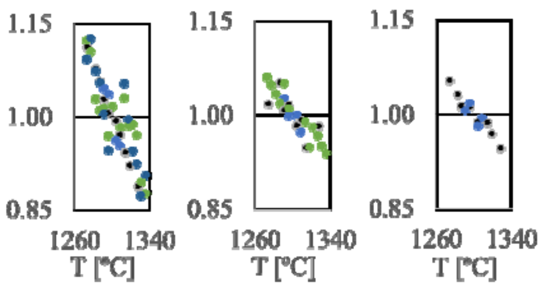

Fig. 1 Normalised ND (left), ferrite (middle) and nodularity (right) vs temperature in a lab trial.

The literature e.g. [13] describes that increased ND creates nucleation sites for austenite, which transforms to ferrite. This was confirmed in this study by the correlation between ND_n and normalized ferrite, Fig 1.

The nodularity dependence of temperature was evaluated from two trials with different results. In one trial, there was a near linear 0.2% increase in normalized nodularity per degree drop in temperature, Fig 1, while in the other there were no correlation observed.

3.1 Results from a foundry trial verification

The behaviour of the ND_n was confirmed in a foundry trial, Fig 2, that show that the behaviour of ND_n vs temperature is similar as in the lab scale trial.

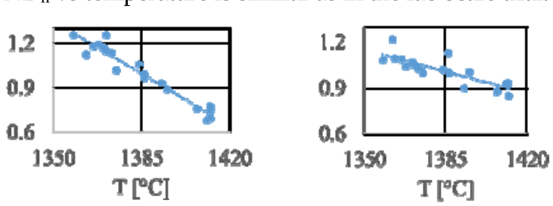

Fig. 2 ND_n, 10 mm (left) and >50 mm section (right).

The left plot is from sections of components with about 10 mm thickness, the right plot is for a thicker section of the same components equivalent to >50 mm thick, positioned near a feeder.

In the foundry trial, the variation in ND_n with temperature was more than twice as large in 10 mm sections compared to >50 mm sections. The slope was 1%/ºC and 0.4%/ºC respectively.

4. Analysis and discussion

The literature indicates that the pouring temperature [14] and section thickness (solidification rate) [15] influence ND, nodularity and matrix. This effect has not been quantified earlier. By carefully measuring the temperature during experiments and normalizing the results, it is possible to quantify this effect, and use it to compensate for the variation in temperature during the trial. This needs to be done for each individual trial for best accuracy. Adjusting for the effect of temperature can considerably improve the accuracy of the results in comparative trials. The observations made with different geometries, melts and trial location support each other despite the overlaid stochastic variations in the results.

5. Conclusion

ND, nodularity and matrix vary with the pouring temperature. This was verified for ND_n in a foundry trial. For best accuracy this effect should be evaluated, and if needed, adjusted for per trial.

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