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Control of Remote Area Shrinkage in Ductile Iron Castings

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In this investigation, the most important process parameters to reduce or eliminate the formation of remote area (un-fed) shrinkage in ductile iron castings were determined. A Taguchi designed experiment was carried out that consisted of 7 factors at two different levels. Analysis of the results from the designed experiments showed that the only significant factors affecting the shrink and surface sink were final Si content and the tap temperature in the range studied. However, the large "error" factor in the Taguchi analysis indicates strong interactive effects, showing shrinkage to be a complex multi-variable problem.

Keywords: *Ductile iron, shrinkage, process variables*

1. Introduction

Prediction of shrinkage tendency in ductile iron is a complex multi-variable problem. There are conflicting reports in the literature [1-4] regarding the effect of various process variables on shrinkage. The major factors believed to influence the shrinkage behavior of ductile iron are: mold material/mold wall movement; chemical composition; tap/pour temperature and holding time; inoculation; Mg content of the melt; and casting geometry (surface area to volume ratio). The aim of this research work was to determine the optimum metallurgical conditions which will yield the minimum shrinkage or no shrinkage in ductile iron castings. Metallurgical conditions for this investigation included: pre-treatment, alloy treatment and post treatment of the iron melts. The effect of molding factors and casting geometry were beyond the scope of this work.

2. Experiment Procedure

A total of 16 melts were made in a Taguchi designed experiment that consisted of 7 factors at two different levels as shown in Table 1. The shrinkage test castings included a boss-plate, a step-plate, and a chill wedge, produced in CO_2 bonded silica sand molds. The test mold had two identical sets of castings on either side of the sprue, with two inoculation chambers in the runner to study the effect of different in-mold inoculants. The in-mold inoculants investigated were 75%FeSi (foundry grade), 75%FeSi with Bi, 75%FeSi with Zr, and an inoculation filter containing Zr inoculant. Most of the observations on shrinkage were made on an unfed boss-plate casting produced in a CO_2 bonded silica sand mold. Shrinkage and surface sink evaluation of the boss-plate castings was done by visual comparison, titration, grid, and x-ray (selected castings) methods. Carbon content was kept constant and Si varied at two different levels.

Table 1. Taguchi design of experiment summary.

Factors	Level #	
	1	2
Tap Temperature (^oC)	1482	1538
Time after Treatment (min.)	1	10
Graphite Type	Amorphous	Crystalline
Mg Alloy Type	Standard	Special
Inoculation	0.3% ladle/ No Cover	0.1% Ladle/ 0.2% Cover
In Mold Inoculation	Yes	No
Final Silicon (%)	2.30	2.80

3. Results and Discussion

Analysis of the results from the designed experiments showed that the only significant factors affecting the shrink and surface sink were final Si content (Fig. 1) and the tap temperature (Fig. 2) in the

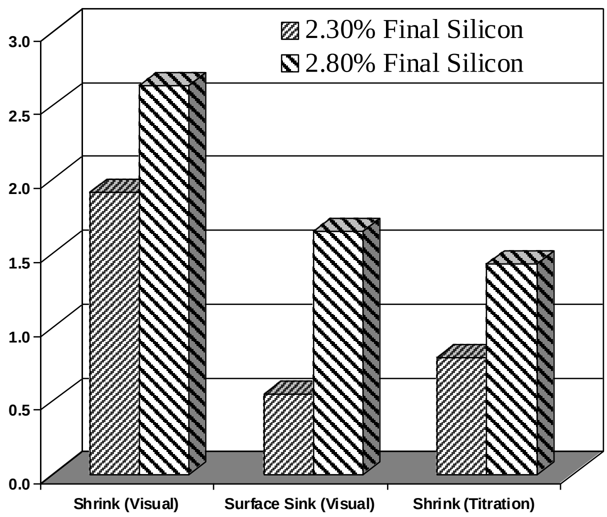

Fig. 1 Shrinkage increases with increase in Si content.

range studied. Inoculant type, holding time after Mg treatment, graphite additive type (crystalline or amorphous), Mg alloy type, and mode of ladle inoculation were all found to have little effect on shrinkage. However, the comparatively large error factor in analysis indicates extensive second order or higher order interactions, showing that the prediction of shrinkage tendency in ductile iron is a more complex multi-variable problem that cannot be so readily stated.

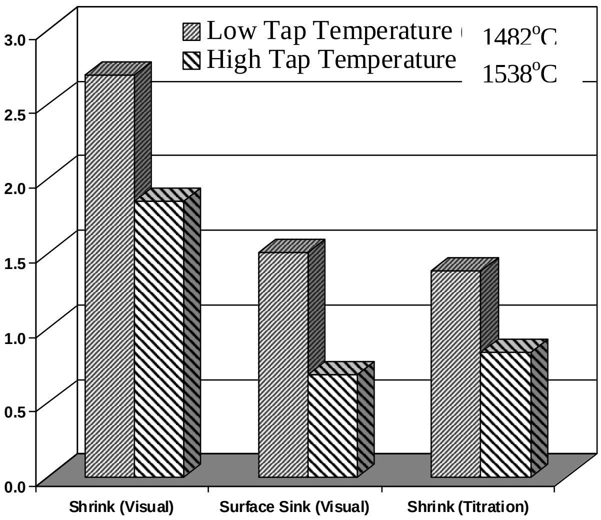

Fig. 2 Shrinkage decreases with increase in tap temp.

Of the 'non-Taguchi' variables, higher residual Mg and high nodule counts led to increased shrinkage. Shrinkage and surface sink increased with an increase in Si content from 2.3 to 2.8%. The wider mushy zone at high silicon content results in a thin or weak casting wall that cannot resist the internal pull and collapses to compensate for the shrinkage/porosity in the later stage of solidification resulting in the surface sink. The wider mushy zone at high silicon content also results in more intense intercellular segregation in the last to freeze areas, leading to increased shrinkage/porosity. The effect of high tap temperatures in reducing the shrinkage may be related to the fact that high tap temperatures lower the residual Mg level in the iron due to more rapid Mg fade after treatment and also lower the Mg recovery. The current finding that lower Mg content leads to less shrinkage is in accord with earlier work [3,4]. Also, superheating and holding the melt above 1538°C reduces its nucleation potential and so leads to lower nodule counts (low nodule counts were associated with decreased shrinkage tendency in this work).

In past work on nodule count effects, conflicting results have been presented [1-4]. The observed lower shrinkage at low nodule counts must be taken in context. The great majority of the nodule counts in this work would be considered satisfactory in normal practice, and many exceed what is normally obtained in commercial castings. The main recommendations coming from this work for reducing shrinkage in ductile iron castings are to keep the Si and Mg contents at the low end of their normal ranges, and use sufficient inoculation to avoid carbides and maintain a reasonable nodule count. If shrinkage problems appear, and nodule counts are high, it may be helpful to reduce the inoculation, *but only if other aspects of metal quality can be maintained*.

4. Conclusions

Of the variables investigated, the only ones shown by the Taguchi analysis to have a significant effect on shrinkage/surface sink were Si content and tap temperature. There was more shrinkage at the higher Si level, and less at the higher tap temperature. The large "error" factor in the Taguchi analysis indicates strong interactive effects, showing shrinkage to be a complex multi-variable phenomenon. Inoculant type, holding time after Mg treatment, graphite additive type (crystalline or amorphous), Mg alloy type, and mode of ladle inoculation were all found to have little effect on shrinkage. The increase in Si content from 2.30% to 2.80% had a particularly marked effect in increasing the shrinkage and surface sink. Of the 'non-Taguchi' variables, higher residual Mg and high nodule counts led to increased shrinkage.

Acknowledgements

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