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Chemistry and Process Control in Production of High-Alloy Graphitic Irons

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High-alloy graphitic irons include ferritic high-silicon molybdenum irons (referred to as SiMo) and austenitic high-nickel irons (referred to as Ni-resist). The high alloy contents greatly influence the eutectic carbon content and the constituents of these cast irons. This paper highlights some examples of the latest developments in SiMo and Ni-resist irons produced for automotive exhaust components with section thickness < 20 mm (3/4"). The graphite shapes of SiMo typically consist of spheroidal graphite (SG), compacted graphite (CG), and the recently-developed mixed graphite (MG) with medium graphite nodularity. MG iron constitutes a new class of cast iron that can improve manufacturability and material properties as compared to CG and SG irons.

Keywords: *SiMo, mixed graphite, carbon equivalent, Ni-resist, chunky graphite.*

1. Introduction

There are four groups of cast ferrous alloys produced for elevated-temperature service: Group 1 - ferritic high-silicon irons, e.g., SiMo; Group 2 - austenitic ductile irons, e.g., D5S; Group 3 - ferritic stainless steels, e.g., CB30 per ASTM A743; and Group 4 – austenitic stainless steels, e.g., HK per ASTM A297.

In the 1990s, the SAE Iron and Steel Castings Committee generally documented the four groups of alloys in regard to chemistry, properties, machinability, and temperature limits [1]. Recently, more comprehensive investigations of exhaust manifold materials were performed [2]. High-alloy graphitic irons from Groups 1 and 2 continue to be the material of choice for automotive exhaust components where castability, machinability and oxidation resistance become the important selection criteria.

Previous publications mainly focused on lab-scale studies. The primary objective of the present paper is to facilitate the transfer of development results from research lab to production floor for SiMo and Ni-resist iron castings.

2. SiMo irons

2.1 Mixed graphite (MG)

The graphite nodularity is typically specified as ≥80% for SG iron, ≤ 30% for CG iron, and in a range of 40% to 70% for MG iron. Historically, MG iron was treated as scrap iron (it was neither CG nor SG iron), but recently it has been intentionally developed for elevated temperature applications [3]. As both SG and CG SiMo irons are currently used for automotive exhaust components, the present work proved that MG iron can integrate the advantages of both SG and CG structures. Extensive process development and material evaluations have been performed for MG SiMo iron. Progress to date has shown that MG SiMo provides multiple benefits such as improving manufacturability and thermal durability in comparison with CG and SG SiMo. A new ASTM standard A1095, "Specification for High-Silicon Molybdenum Ferritic Iron Castings" with SG, MG, and CG structures has been recently created.

2.2 Brittleness at medium temperature (BMT)

SG SiMo irons can be susceptible to BMT where the minimum ductility occurs at temperatures between 310 °C and 490 °C. BMT is greatly influenced by the residuals of magnesium, sulfur, and phosphorus. The tensile testing results for elongation at room temperature (RT) and 425 °C are presented in Fig. 1. As the P content increased from 0.016% to 0.047% (wt. % used in this paper), the elongation at RT was in a range of 10% to 16% which is typical for SG SiMo. However, the elongation at 425 °C responded significantly as a function of P content. The baseline samples with 0.016% P exhibited pronounced BMT. When exceeding 0.025% P, BMT is suppressed. Specifications previously did not control the minimum P content and have allowed huge variations in BMT of SG iron. Therefore, the new standard ASTM A1095 specifies the P concentration from 0.02% (min.) to 0.05% (max.) in order to eliminate BMT of SG iron. MG iron was immune to BMT because of moderate magnesium content in the range studied.

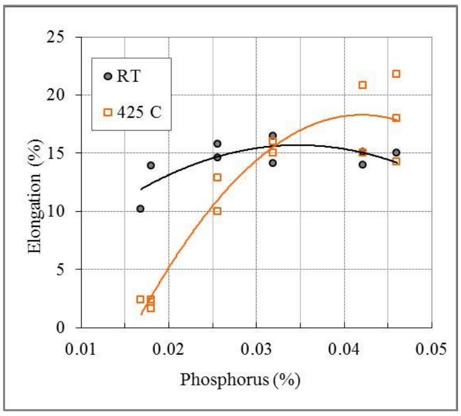

Fig. 1 Results of tensile testing at RT and 425 °C of SG SiMo samples containing 0.010% S [3].

2.3 Carbon equivalent (CE)

It has been proven that CE (C+1/3Si) can alter the microstructure and quality of castings. Controlling CE with C and Si contents would be a great advantage for foundries; they could optimize microstructure, mechanicals, and yield of their castings. Figure 2 is an example of a nomogram to provide guidance on an optimum CE from 4.50 to 4.75 for SG SiMo. Slightly lower CE is recommended for CG and MG irons.

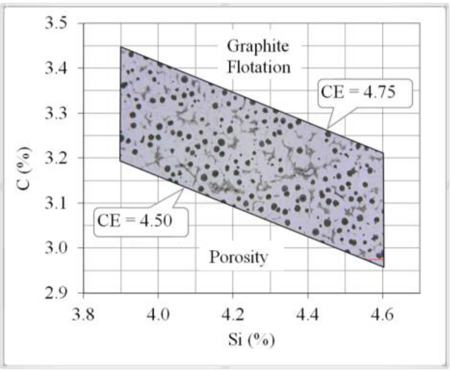

Fig. 2 Carbon, silicon, and optimum CE (micrograph zone) ranges for SG SiMo irons.

3. Ni-resist irons

3.1 Chemistry control

Three grades of Ni-resist are commonly produced for use at high temperatures: D2S (25% Ni), D4A (30% Ni) and D5S (35% Ni) per ASTM A439. Ni-resist chemistry control ranges, especially C and CE must be tighter than ferritic SiMo irons. The CE of Ni-resist iron is calculated by Eq. 1 [4]. The optimum CE was found between 4.20 and 4.40 to achieve uniform microstructure (Fig. 3a). Castings are prone to shrinkage or porosity if CE < 4.20. Degenerated graphite structures occur if CE > 4.40.

$$CE = C + 0.33Si + 0.047Ni - 0.0055Si \times Ni \quad (1)$$

3.2 Chunky Graphite

Lower nickel D2S iron alleviated susceptibility to chunky graphite as compared to D5S. A very small amount of rare earth metals increased the graphite nucleation undercooling and thus caused massive chunky graphite in D5S iron as shown in Fig. 3b. Over inoculation, e.g., double inoculation in both ladle and mold, augmented the propensity to chunky graphite, especially when the melt is treated with Fe-Si-Mg instead of Ni-Mg nodularizer. Chunky graphite could happen in thick sections (20 mm), as well as thin sections (4 mm) of castings. Formation of chunky graphite in Ni-resist irons can reduce the tensile testing results, especially the elongation.

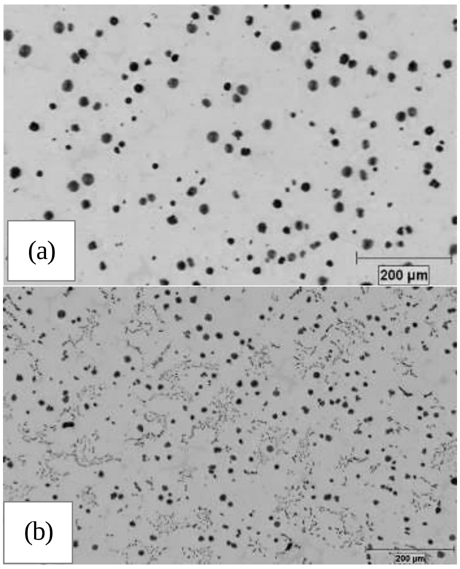

Fig. 3 Micrographs of D5S samples: (a) normal, and (b) chunky graphite observed when 80 ppm La added.

Acknowledgements

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