Short Communication

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Archives in Chemistry

2020
Vol. 1 ISS. 2 : sc 001

Effect of degeneracy in graphite particle aspect ratio (AR) on some mechanical properties of as-cast spheroidal graphite iron (SGI)-compacted graphite iron (CGI) cast iron series

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Statement of the Problem: Spheroidal Graphite Iron (SGI) and Compacted Graphite Iron (CGI) castings and their derivatives have proven to be the cost-effective materials of choice and/or potential alternatives to other conventional/competing materials (e.g. malleable iron, steel, aluminum, etc., castings) and manufacturing processes (forging, machining, fabrication, etc.) in many automotive and industrial applications, with either an outright improvement in service performance or lower production cost or both. A range of un-alloyed SGI-CGI iron grades were produced in a series of systematic iron-melt treatments with a special Ca-CaC2-Mg master alloy. Data sets are presented and analyzed to gauge the effect of variation in graphite particle Aspect Ratio (AR) range in an as-cast SGI-CGI iron series ranging from ASTM type I (fully spheroidal) to ASTM types II-III-IV (mixture of spheroidal and compacted/vermicular graphite forms) on some of their selected mechanical properties. Findings: It was observed that generally, properties relating to strength and ductility progressively decrease as the proportion of non-nodular graphite (AR≤0.65) increases.

Until the 19th century, cast iron was commonly defined as “scrap steel” for its low quality and workability compared to mild steel. For some time now, the cast iron is better known as a very useful and multipurpose ferrous metal alloy, characterized by a relatively high content of carbon [1]. This Fe-C alloy, also including secondary elements, presents a carbon content between 1.9% and 5.5%, up to the saturation limit of 6.67%. Its production is usually realized by a process of reduction of iron oxides by coal combustion in contact with iron inside the blast furnaces. The ore is disposed with alternating layers of coal. Coal, typically coke, has a low sulfur content. The iron in the ore, in the molten state, drains down in appropriate containers.

This cast iron is said “of first melting” or “untreated” and used to produce the “industrial” steel [2-3]. This steel is recast, either directly or after removal or addition of other elements such as silicon, manganese, sulfur, phosphorus. The material is poured into molds in foundry processes for casting metal industry (Figs. 1, 2). More broadly, the cast iron is a material hard and brittle, weak in tensile and bending, but very made-existing in compression and corrosion.

Since its high malleability, this material is not an appropriate solution when plastic deformations occur, neither hot nor cold. On the contrary, it presents a good fusibility represented by a not very high melting temperature. Adding, it has a good fluidity when melted, which leads to “healthy” and compact castings. It allows an easy realization of cast pieces even in the case of complex geometries. Furthermore, the cast irons may present physical characteristics very variable based on metal texture, shape and volume of the graphite, the production process and any heat treatment [4-5]. The levels relatively high silicon guarantee good resistance to oxidation, corrosion [6] and wear

Introduction

Compacted graphite iron (CGI) along with lamellar graphite iron and spheroidal graphite iron define the three main classes of cast iron according to morphology.CGI displays very useful properties for a range of engineering applications with the tensile strength and elastic modulus being considerably higher than grey cast irons (75% and 35% respectively).Cast iron is a family of alloys divided into several classes, defined by their graphite morphology and metallic matrix structure. There are mainly three different classes of cast irons classified by their graphite morphology; lamellar graphite iron (LGI), compacted graphite iron (CGI) and spheroidal graphite iron (SGI). LGI, commonly known as gray iron or flake graphite iron has a stable eutectic with graphite shaped as lamellas or flakes, see Figure 2a. In Figure 2c, SGI is illustrated.It is also called ductile iron or nodular cast iron and has a stable eutectic with the graphite shaped as spheroids or nodules. The third class of cast iron is CGI which has a stable eutectic with a worm-like shaped graphite, also called compacted graphite or vermicular graphite, see Figures.

Compacted graphite iron (CGI) can be considered as a prom-

Note : This work is partly presented at 31st Materials Science and Engineering Conference: Advancement & Innovationson on October 15-17, 2018 Helsinki, Finland ising engineering material which contains graphite particles in compacted (vermicular) form. CGI shows intermediate mechanical and physical properties between grey and ductile irons. For instance, it possesses 70% higher tensile strength, 35% higher elastic modulus and nearly double fatigue strength of grey cast irons.Thus it includes an optimal combination of different properties like strength, ductility and thermal conductivity which have lead to a distinctive attention during recent years. Because of these properties, CGI found a significant role in production of automotive engines, machine parts and also many different applications. Pearlite content can be chosen to suit the application, with the GJV 300 Grade being fully ferritic and the GJV 500 Grade being fully pearlitic. Flake graphite is inadmissible. As with grey iron and ductile iron, specific alloying elements can be added to enhance high temperature strength, wear resistance or other properties.A full range of heat treatments, including austempering, can also be applied. Typical chemistry ranges are provided below, although the chemical specification of CGI castings is subordinate to mechanical properties.

Materials & Methods:

Detailed description of preferred embodiments and best modes for carrying out the invention

Compositions in accordance with the invention comprise a polymer and a flake reinforcing material distributed therethrough in an effective amount to structurally reinforce the polymer. Individual flakes of the flake material a) are less than or equal to 1,000 Angstroms in thickness, b) have an aspect ratio (largest dimension/smallest dimension) greater than or equal to 100, and c) preferably are significantly randomly oriented throughout the polymer as opposed to being deliberately aligned or configured in some organized manner. It is anticipated that any of a wide variety or platy solid materials that can be ground into thin flakes can function as the flake reinforcing material. Examples of such materials include graphite, mica and talc flakes. Further examples or workable materials might include glass flakes, certain platy clays such as kaolinite, and certain platy metal ores such as MoS2 and ZnS. Actual reduction to practice at this writing has been demonstrated with graphite flakes.

Similarly, the flakes should typically not be deliberately aligned in the polymer, but rather should be significantly randomized to avoid weakness in the finished product in any one direction. As “randomness” is a matter of degree, the terminology “significantly random” is used. Thin graphite flakes less than 1,000 Angstroms in thickness and having an aspect ratio in excess of 100 could be produced by a number of different methods. Standard texts on short-fiber reinforcement usually include the concept of minimum fiber length necessary for efficient reinforcements.

impressive increase, but the final Young’s modulus was still only 290,000 psi. A rule-of-mixtures calculation indicates the modulus should have been about 11×106 psi, assuming graphite flake has a Young’s modulus of 100×106 psi. Obviously the efficiency of reinforcement was very poor and could be improved greatly.

Result:

Compacted graphite iron has an intermediate graphite morphology between lamellar graphite iron and spheroidal graphite iron. The formation of compacted graphite morphology is controlled by small changes in alloy composition. Several important factors influencing the formation of the as solidified microstructure, as well as the microstructure formation during the eutectoid transformation are also reviewed. The focus of this review is to compare mechanisms in which compacted graphite iron differs from lamellar graphite iron and spheroidal graphite iron. The effects of microstructure on some properties that are relevant in commercial applications are included in the study. Additionally the relatively few models for microstructure formation are also summarised.

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