

Tough Hypereutectic High Chromium White Iron – A double in-situ fibrous composite

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Abstract. A tough hypereutectic high chromium white iron has been developed by considering the alloy as a double in-situ fibrous composite and applying the principles of composite theory. The eutectic in the ternary Fe-Cr-C system solidifies as M_7C_3 carbide rods of irregular hexagonal cross section in a matrix of austenite. The carbide rods are intermittently joined together with no misorientation at the joint. The colonies (eutectic grains) of a 27%Cr alloy solidify with a flat solid – liquid interface. In hypereutectic high chromium white irons the primary carbide solidifies as single crystal rods with no branching. Depending on the thermal conditions in the mould the primary carbides are nucleated only on the mould surface, or repeatedly at the solid – liquid interface. In 27% Cr, 4.5%C hypereutectic alloys, the as-solidified microstructure is one of long parallel aligned primary carbides in a eutectic matrix of carbide rods in austenite, or short randomly orientated primary carbides in a eutectic matrix. In either case the microstructure can be described as a double in-situ fibrous composite. The application of composite theory has resulted in hypereutectic high chromium white iron castings with improved fracture toughness similar to that of heat-treated alloy steel but with superior wear resistance.

Introduction

High chromium white irons (15% to 30% by weight chromium) are used extensively in the mining and mineral processing industries in situations requiring high wear resistance but have been limited to applications where low to moderate toughness is acceptable. Due to the reduction in toughness with increasing carbon content, high chromium white iron (HCWI) castings are generally restricted to hypoeutectic to eutectic composition. Wear resistance is improved by increasing the carbon content to hypereutectic compositions, thereby increasing the carbide volume fraction (CVF), and by heat-treatment. Conventional heat-treatment destabilises the austenite matrix, secondary carbides are precipitated, and the austenite matrix transforms to martensite leading to the improved wear resistance, but does not improve the alloys' toughness. Hypereutectic HCWI, although having superior wear resistance, are too brittle for most commercial castings but can be used as weld overlays. When used as weld overlays, the poor toughness of the overlay leads to cracking commonly termed check cracking. In these instances cracking is tolerated for the improved wear resistance.

For those applications where toughness is an important consideration heat-treated low alloy steels have been used. These alloys are used for their superior toughness but have significantly poorer wear resistance. A material with the high wear resistance of hypereutectic as-cast high chromium white

irons but with the toughness of heat-treated low alloy steels has been much sought after for several decades. An as-cast HCWI with improved toughness would substantially reduce the costs associated with the heat-treatment, reduced service life and increased downtime of heat-treated low alloy steels and offers the probability of weld repair.

This short manuscript details the application of materials characterisation and composite theory to the development of an as-cast hypereutectic HCWI.

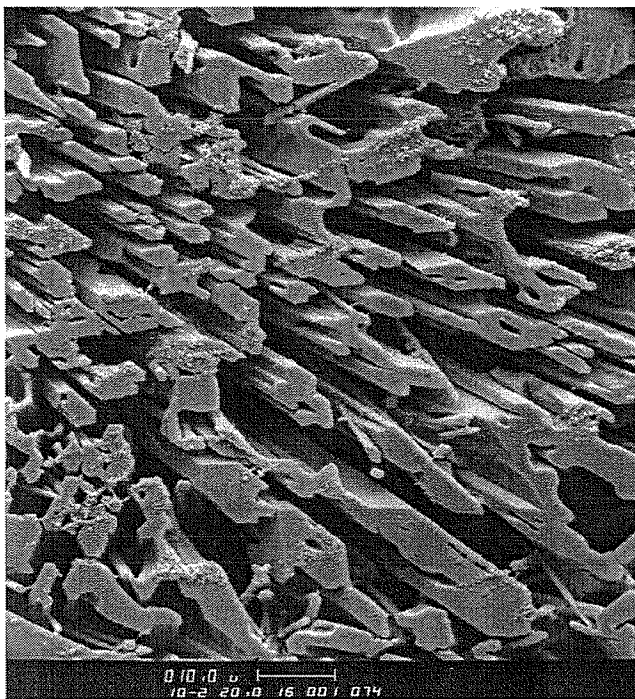
Procedure

Sections were carefully taken from castings and weld overlays using a water-cooled cut-off wheel. The sections were mounted and polished using standard metallographic techniques. For optical metallography the etchant was either Vilella's reagent or acid ferric chloride. Deep etched samples were prepared using acid ferric chloride, flowing to prevent the deposition of a colloidal silicon compound, or aqua regia. These samples were also examined using scanning electron microscopy (SEM) and analysed using electron back scattered diffraction (EBSD) and electron probe microanalysis (EPMA).

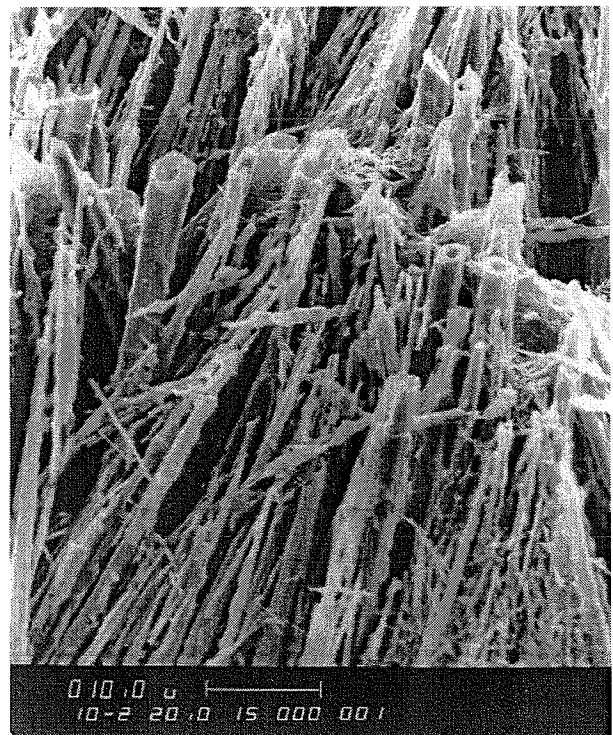
Foils for examination using transmission electron microscopy were prepared with difficulty using a twin jet electropolisher. The foils were examined in an analytical transmission electron microscope (AEM) operating at 200kV.

Results and Discussion

The metallographic samples were deep etched to remove the matrix and reveal the three dimensional morphology of the carbides. The samples were examined using SEM which provides an increased depth of field and higher magnifications than optical microscopy.



(a)



(b)

Fig. 1. The image on the left (a), is a SEM micrograph of a deep etched sample showing the eutectic M_7C_3 carbide fibres in a HCWI casting [1] and the image on the right (b) is a SEM micrograph of M_7C_3 carbide fibres from a HCWI weld overlay [2].

Fig. 1(a) and Fig. 1(b) are SEM micrographs of deep etched samples of a HCWI casting and a HCWI weld overlay respectively. The M_7C_3 carbide fibres have a hexagonal cross section consistent with the pseudo hexagonal (strictly trigonal) crystal structure of M_7C_3 carbide. Electron back scattered diffraction showed that adjacent carbide fibres had the same crystallographic orientation. The faster cooling rate of the weld overlay has resulted in much finer fibres than are found in the casting.

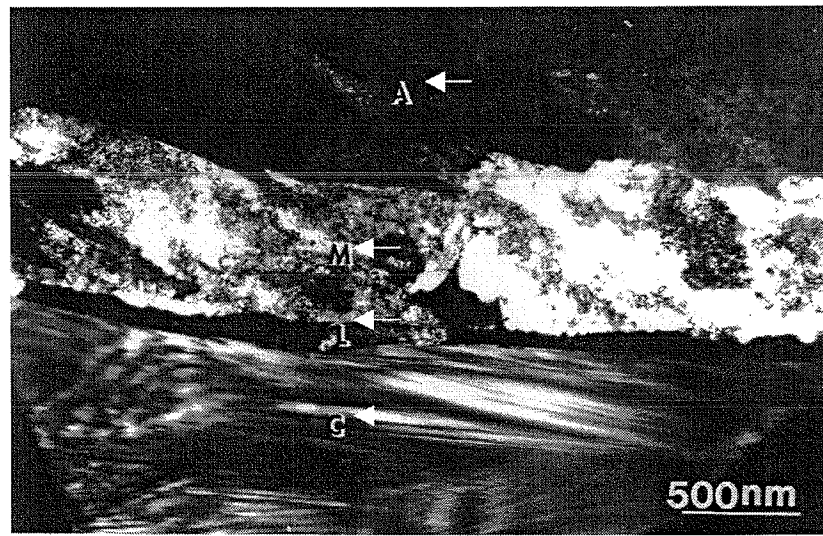


Fig. 2. An AEM image of the layers surrounding a carbide fibre. The carbide fibre is identified as C, two martensite layers as L and M and the austenite matrix as A.

Fig. 2 is an AEM image of the layers surrounding a carbide fibre. The carbide fibre, identified as C is separated from the austenite matrix A by two martensite layers L and M. Layer L, the thin layer adjacent to the carbide was identified by selected area electron diffraction as high carbon martensite [3]. High carbon martensite is extremely brittle and has been identified as the crack path [4] in HCWI castings and weld overlays. Layer M is tougher low carbon lath martensite.

As stated in Askeland [5], “The strength of a fibre reinforced composite depends on both the strength of the raw fibre and bonding between the fibres and the matrix”. In accordance with this theory the high carbon martensite was seen to provide a brittle interfacial layer between the high strength carbide fibres and the tougher matrix which led to debonding resulting in cracking as discussed in the previous paragraph. Analysis of the structure led to the modification of the composition to eliminate the interfacial high carbon martensite layer which led to a tougher and more wear resistant as-cast hypereutectic HCWI with a CVF of 50% [6].

Depending on the thermal gradient the carbide fibres can be aligned perpendicular to the surface of a casting or weld deposit as shown in Fig. 3(a) or through careful control of the thermal gradient it is possible to produce a HCWI casting with randomly oriented carbide fibres Fig. 3(b). Randomly oriented fibres further increase the toughness.

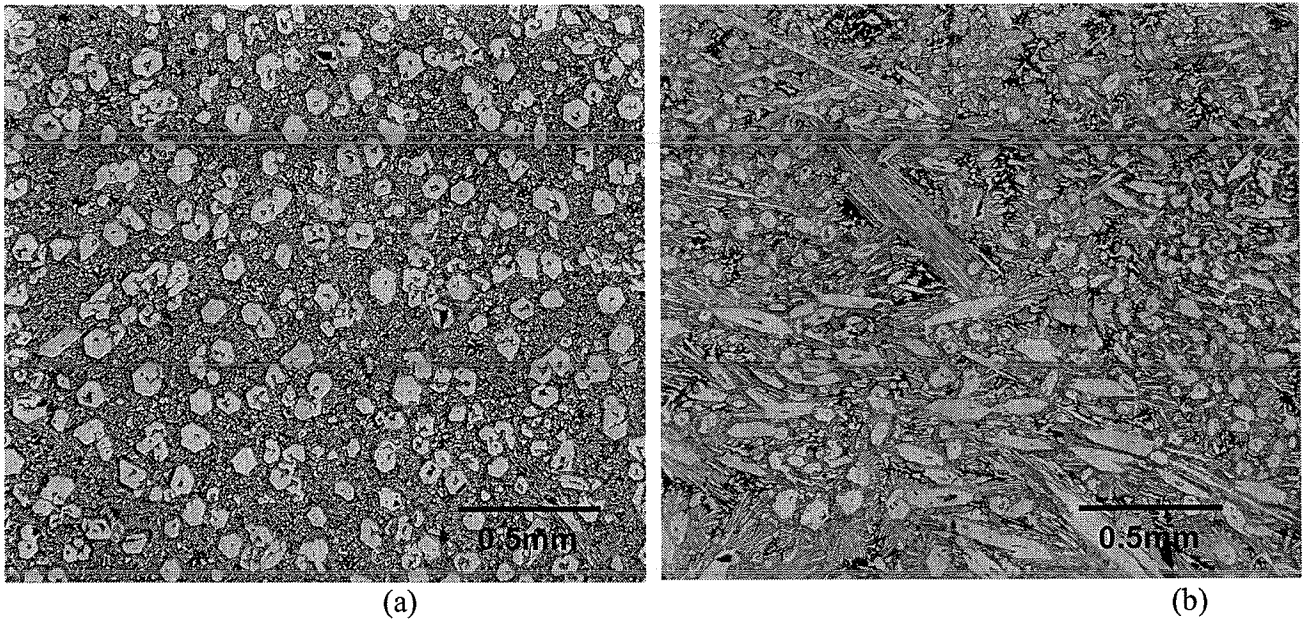


Fig. 3. Carbide fibres aligned perpendicular to the surface of a casting (a) and randomly oriented carbide fibres (b). Etchant acid ferric chloride

Conclusion

An as-cast hypereutectic high chromium white iron with a 50% carbide volume fraction has been developed with the toughness of heat-treated alloy steel and superior wear resistance. This has been achieved through analysing the microstructure as a fibrous composite and improving the bond between the strong fibres and the matrix through alloy modification. Both the primary carbides and the eutectic carbides are fibrous and constitute a double in-situ fibrous composite.

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