High strength cast irons containing vanadium annealed ductile irons and high carbon grey irons

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The inclusion of up to 0.5 per cent vanadium in annealed ferritic ductile iron produces a marked increase in tensile strength while further increases can be obtained by adding up to 2 per cent nickel to the vanadium iron. The increases occur with very little reduction in elongation and only a small increase in the notched impact ductile/brittle transformation temperature. The improvement in tensile properties is greater than can be obtained with most other alloy additions while the effects on elongation and impact properties are significantly less than produced by other alloy additions.

It is suggested that the combined addition of vanadium and nickel to annealed ferritic ductile iron should facilitate the production of irons of considerably higher strength which retain a high level of ductility well below ambient temperatures.

The tensile strength of grey iron is increased considerably by the addition of up to 0.5 per cent vanadium and irons of much higher carbon contents than normal can be produced with strengths similar to those of the current lower carbon engineering irons. The chilling tendency of the high carbon vanadium iron is low and can be reduced to a very low level by the addition of up to 1 per cent copper. Furthermore, the coarse, graphite structure associated with high carbon grey irons is refined by the vanadium.

Using a thermal cycling test rig it is shown that the high carbon irons have considerably better resistance to thermal fatigure cracking than normal engineering iron. It is suggested that the ability to produce engineering irons of adequate strength but with improved resistance to thermal fatigue might constitute a significant advantage when producing castings subjected to mechanical stress and thermal fatigue such as brake rotor castings.

Introduction

Vanadium has been used in small amounts as an alloying element in steels and cast irons since the early part of the century[1,2,3]. Vanadium is readily soluble in molten iron and, when conditions are such that it can remain in solution, like many other alloying elements used in steels, it suppresses the formation of bainite and increases the hardenability. Unlike most alloying elements however, but more like silicon, it does not suppress ferrite in steel but it does form carbides. These effects of vanadium on the transformation characteristics of iron and steel are, however, not well-known because vanadium is a very strong carbide- and nitride-former and these compounds are produced at temperatures well above the transformation temperatures involved. It is, in fact, mostly through the formation of carbides and nitrides that vanadium has its strong effects on the microstructures of steels and cast irons. In steels, high nitrogen contents, slow cooling rates and the presence of elements which lower the transformation temperatures, tend to allow these compounds to precipitate in the austenite and prevent grain growth, giving rise to fine cementite and fine pearlitic and ferritic structures.

Cast irons have much higher carbon contents and generally lower nitrogen contents than steels so the addition of vanadium results almost entirely in the formation of vanadium carbides. Vanadium also promotes the formation of eutectic iron carbide or chill in cast irons while it increases the degree of nucleation of grey irons, resulting in finer, more uniform flake graphite structures[4]. The increased chilling tendency produced by vanadium is made use of in the production of chilled cast iron rolls where, for example, an addition of 0.1 per cent vanadium has been found to increase the surface hardness from 400 HV to 610 HV and the hardness at 9.0 mm (0.38 in) depth from 300 HV to 480 HV.

Although the effects of vanadium in white cast irons are well-established little study of the influence of vanadium in ductile iron has been carried out. Eutectic carbides form in these irons when strong carbide-promoting elements are present even in small amounts but, unlike carbides produced by chromium, any eutectic carbide promoted by vanadium is readily removed by heat treatments such as annealing or normalising which are often applied to these irons. The work described in the first part of this paper was undertaken to study the effects of vanadium additions on the structures and properties of ductile irons.

In grey irons containing a small amount of phosphorus, the vanadium carbides tend to segregate with the phosphide eutectic producing a fine, uniform distribution of hard particles that enhance the sliding wear resistance. Use is made of this in castings such as large diesel cylinder liners for marine engines.

Vanadium is particularly effective for increasing the strength of grey cast irons and irons with high carbon contents can be produced with strength levels normally required by engineering castings[4]. This could confer special advantages on these irons and the second part of this paper describes experiments concerned with their development.

Tests on ductile irons

Tests have been carried out on pearlitic and ferritic ductile cast irons in the as-cast condition and after receiving a ferritising annealing treatment.

Production of the Irons. The irons were produced in the BCIRA experimental foundry from charges based on high purity oxygen-blown pig iron and appropriate ferro-alloys, which were melted in an acid-lined medium frequency induction furnace. Vanadium was added as ferrovanadium, either to the melt in the furnace or to the metal-stream as it was tapped into the ladle. The alloy dissolved readily and yields well in excess of 90 per cent were generally obtained.

The molten iron was poured at about 1420°C onto 2.5 per cent of a 5 per cent magnesium/ferrosilicon alloy to obtain nodular graphite structures and then inoculated with 0.35 to 0.5 per cent silicon as ferrosilicon.