

IMPROVEMENT IN PROPERTIES OF GREY IRON AFTER BORON ADDITIONS

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ABSTRACT

Boron extends the usefulness of grey iron by producing uniformly distributed mottle. Although it is a strong carbide former it acts differently from other carbide forming metals such as chromium and distributes the hard particles of cementite uniformly throughout the soft matrix of grey iron even in certain types of chilled castings. This fine dispersion of cementite (carbide) gives outstanding wear resistance and machinability along with increase in mechanical properties. An examination was undertaken of the effect of small additions of boron to grey iron through a number of practical experiments. The micro and macro structures of the irons treated with boron in the range 0.003-0.04% were analysed. Examination of the castings, test bars and step bars revealed that with increasing boron content the fineness and uniformity of the cementite dispersion increased. A step bar section which was chilled with less than 0.003% boron addition was uniformly mottled throughout the section with an addition of 0.015% boron. Pearlite Lamellae spacing became finer with increasing boron upto 0.02%. An addition of boron above 0.02% generated type D and E flake graphite. The cell count was also found to increase with upto 0.02% boron addition, after which it remained constant with increasing boron content. The hardness of the step bars indicated appreciable reductions in section sensitivity with the addition of boron.

INTRODUCTION

Boron has been shown to be powerful carbide stabiliser and as such it is capable of producing a uniformly distributed mottle in many types of castings and in certain types of chilled castings. It may increase the depth of chill and chill plus mottle. This effect gives excellent wear resistance and mechanical properties to the castings, in addition to small increase in hardness and tensile strength. In any given section, the tendency is for the casting to be white at the cast surface and grey at the centre of the section with a graded degree of mottling from edge to centre. Similarly, in any given casting, the thin section will tend to be white, the thick section grey and only the intermediate section will be mottled and then not uniform in distribution. In fact, mottle zones are occasionally produced in irons intended to be completely white and in irons intended to be completely grey. This paper shows the possibility of producing consistently, and at will a uniform distribution of fine or heavy mottle in wide range of sections in a given casting.

An important difference in the mottling characteristics of boron compared with other carbide forming metals such as chromium is that boron distributes the mottle uniformly throughout the section while the other carbide formers have a much greater tendency to produce a chilled structure at the edge of the castings. This increases as the amount of carbide stabiliser increases and the section size decreases. Boron containing irons are much less sensitive to the effect of section size.

The uniform dispersion of hard particles of iron carbide (cementite) in the usual grey iron matrix imparts excellent wear resistance. However, while the material is wear resistant, it will still be machineable. This is clearly an advantage in certain applications such as piston rings and liners, brake drums, machine tool slides, camshafts etc.

The possibility of producing an indefinite chill structure by boron addition is of potential commercial importance as an alternative to the usual method for the production of those structures by nickel and chromium addition. The properties of indefinite chill structure in a roll obtained by boron addition and those obtained in a roll of similar size in which the indefinite chill structure was produced by addition of 1% nickel and 1% chromium have been compared previously. The distribution of mottle in the boron-containing roll was almost uniform throughout the cross-section whilst in the nickel-chromium roll the amount of carbide was greater near the edge of the roll than at the centre.

The use of boron to produce indefinite chill structures appears to be attractive particularly when rolls having deep passes are to be produced. There are however, a number of limitations. The structure at the centre of the boron-containing roll contains a considerable amount of carbide, while the pearlite which is often surrounded by a narrow area of ferrite is relatively coarse. At the centre of a nickel-chromium roll, the carbide is less prone to mechanical failure than a roll having a structure similar to that produced by 0.01% boron addition. It is possible that the structure of the boron-containing roll could be improved by a nickel addition. However, the use of boron is economically attractive only if the addition of Nickel can be avoided.

It is also possible that boron could be used as a substitute for chromium in the production of small chilled castings such as automobile tapes and camshafts where wear resistance and the possibility of local hardening are important. While the micro hardness of the carbides in the boron-containing irons is at least as great as those in the chromium containing irons, the thermal stability at 875°C of the boron-containing iron is inferior to that of chromium irons. Heat treatment for seven hours at this temperature causes no breakdown in the chromium irons, but in the boron-containing irons there is an initial breakdown of small amount of carbide to give secondary graphite. The amount of break down after heat treatment for one hour is insufficient to affect the BHN hardness of the material, if the boron-containing iron is heat treated at 875°C for eight hours the amount of graphite will be sufficient to cause a small reduction in BHN hardness.

EXPERIMENTAL

The experiments, testing and trials were carried out in a reputed foundry. Boron was added in the form of Ferroboron having 20% recovery along with ferrosilicon and ferrochrome having 70% and 60% recovery respectively. The amounts of silicon and chromium were fixed to be 0.1% and 0.15%, respectively, and boron was varied from 0.003% to 0.04%.

The composition of the base metal was in the following range:
C%= 3.30-3.40, Si%=1.80-1.90, Mn%=0.85-0.95, P%=0.07 Max., S%= 0.06 Max. and Cr%= 0.10 Max.

The metal was superheated to 1450°C. Ladle addition of 0.0003%, 0.01%, 0.015%, 0.02%, 0.03% and 0.04% boron as Ferro boron were made simultaneously with addition of 0.10% silicon and 0.15% chromium. One ladle was treated with only 0.10% Si and 0.15% Cr and no boron was added. The slag was skimmed off and the tensile test bars, step bars, flat chill test bars and fly wheel castings were poured at 1380-1400°C. Silicon was added to obtain an inoculation effect and chromium was added to improve the corrosion resistance, hardness and tensile strength of the castings.

For each set of experiments, two tensile test bars, one step bar, two chill test bars and one fly wheel casting were produced.

RESULTS

The slices cut from the fly wheel castings were used for chemical analysis after measuring the hardness. The chemical analyses of the irons treated with different percentages of boron are given in Table 1.

MICROSTRUCTURE

The samples for microstructural examination were cut from 35mm thick edges of the flywheel castings. To see the mottling clearly the samples were etched with ammonium persulphate solution. Microstructures were examined at the lowest magnification available (x16).

The examination of the etched samples revealed that without boron addition the iron was grey in the sample and no cementite distribution was visible through out the section, as shown in Fig.1.

The iron which was treated with 0.003% boron also did not show much cementite, as shown in Fig. 2. Figure 3 reveals that the addition of 0.010% boron produced a uniform mottle structure throughout the section. As the amount of boron increased to 0.04% the mottling increased in uniformity and fineness. Increases within boron content increased the amount of carbide (cementite) in the structure. This is revealed with the help of Figs. 4-7, which show the structure of irons treated with 0.015%, 0.02%, 0.03% and 0.04% boron, respectively. The sample with 0.02% boron (Fig.5) did not show clear mottling because of defective sampling.

Examination of microstructures of the 1/8" (3mm) section of the step bar revealed a predominantly white (chilled) structure due to the very thin section. This was observed without boron and with 0.003% boron, and the microstructure is shown at a magnification of x40 in Fig.8. The microstructure of the step bar treated with 0.01% boron did not show much section-sensitivity. The 1/8" section of the step bar was mottled uniformly when treated with 0.015% boron, as shown in the Fig. 9. The clarity of the mottling is less compared with that of the fly wheel castings because of the higher magnification used.

Microstructures of the flywheel castings and tensile test bars were also examined at x225 magnification using Nital as etchant. Figures 10-12 show the micro- structures of the flywheel castings which were treated with 0%, 0.015% and 0.04% boron, respectively. The figures shows that the pearlite lamellae became finer with increasing boron. Free cementites were clearly visible in the microstructure of the flywheel castings treated with 0.04% boron. No changes in the flake size and the distribution (type) were revealed.

The structure of the test bar samples treated with 0.01%, 0.03% and 0.04% boron were quite comparable and reproducible. Increasing boron content refined the structure and resulted in a change in flake type, as shown in Figs. 13-15. Addition of 0.03% and 0.04% boron induced type D and E graphite whereas 0.01% boron produced predominantly type A graphite. Excessive cementites/carbides are seen in the structure of samples treated with 0.03% and 0.04% boron.

CELL COUNTS

The same samples of flywheel castings were polished with coarse alumina powder and washed with water and alcohol. After drying in hot air these samples were immersed in a solution of Stead's Reagent for about 15 minutes. They were then washed with alcohol and dried. The eutectic cells appeared dark and were outlined by a white network. The etchant (Stead's Reagent) had the following composition: cupric chloride 10 g, magnesium chloride 40g, hydrochloric acid (conc.) 20cm³, ethyl alcohol 100 cm³. The salts were dissolved in the minimum quantity of cold water (about 10% of their weight) and then alcohol was added along with acid. The etched samples were examined under low magnification (x3.5). The cell sizes were identified and number of cells were counted. The ASTM designation was used for classification of the eutectic cell size at x3.5 magnification. The cell sizes and the cell counts for different boron percentages are shown in Table-2.

A plot of boron contents against cell counts is shown in Fig. 16. This shows that boron increased the cell count and refined the grains. However, at 0.02% boron, the number of cell counts became almost constant and there was no beneficial effect on cell count with increasing boron content above 0.02%.

HARDNESS

The hardness of the surfaces and cross-sections of the flywheel castings, tensile test bars and step bars were measured. The hardness increased with increasing boron content upto 0.04%. This is due to the fact that the number of carbide particles increases with increasing boron content. Figure 17 reveals the increasing hardness of the flywheel castings and test bars. The hardness of the test bar (30 mm) was greater than that of the flywheel casting (35 mm). The results are shown in Table-3.

The hardness of surfaces and cross-sections of the step bars was also measured. The results obtained confirmed that the hardness increased with increasing boron content. Especially, the surface of the ½" (12.7 mm) section size, as shown in Fig. 18. However, for the 1/8" section size the hardness decreased with increasing boron content, as shown in Fig.19. This is because boron distributes the cementite throughout the matrix. Without boron treatment the section was completely chilled and the hardness at the surface was high. But as the boron content is increased the cementite at the surface is decreased comparatively and it is distributed uniformly throughout the section. The inside cross-section hardness of the 1 / 8" step bar section treated with upto 0.01% boron could not be taken inside the surface as sectioning was difficult because of the chilling. However, the step bars treated with 0.01% boron or above were subjected to hardness testing by sectioning. The results for the step bars treated with various amounts of boron are shown in Table-4. The results reveal that as the amount of boron increased the section sensitivity decreased, as shown in Figs 20 and 21.

CHILL TEST

A chill test was conducted for each set of experiments and the results are shown in Table-5. Chill depth (the white region of the fracture surface) increased with increasing boron content, as shown in Fig.22. Chill depths in the experiments in which 0.030% and 0.040% boron had been added were too high (16 and 17 mm). The excessive chill depth indicated that the castings was solidified with more cementite. This is why more cementite was seen in the corresponding micro structures.

TENSILE STRENGTH

Tensile tests were also carried out on the tensile test bars in order to measure the effect of boron addition. The results are shown in Table-6 and revealed that the tensile strength increased slightly with boron additions upto 0.02% and then decreased at a boron contents above this owing to excessive carbides and type D and E graphite. Figure 23 shows this effect in graphical form.

DISCUSSION

The mechanism by which mottle structures are generated by addition of boron to grey iron has been studied previously. It has been proposed that grey iron cells start forming after austenite dendrite formation has occurred across the complete section. The cells begin to form in the cast surface, but nucleation quickly spreads to the other parts of the section. The difference with boron-containing iron is that the graphite flakes protruding from the solid cell to the liquid appear to protrude further than has been observed in the case of ordinary flake graphite iron. At the same time, the outline of the growing cell is much more irregular. At a later stage in the eutectic solidification process, when the cells touch each other, small pockets of liquid are left in the area between them. The carbides formed in these pockets are the special characteristic of boron-containing iron. The final structure consists of a very fine distribution of mottle where the carbide is closely associated with grey iron. It is in this respect that boron-containing irons differ from other mottled irons.

Cast iron melts saturated with nitrogen are reported to promote the formation of the eutectic graphite with boron addition. The effect is explained in terms of the nucleation of graphite by particles of boron nitrides which precipitate from the melt above the eutectic temperature. It is suggested that the beneficial effect of boron addition to malleable iron may also be due to the precipitation of boron nitrides which would promote graphitisation during annealing. This effect is significant only in the presence of a sufficient amount of nitrogen to promote segregation of boron nitride in the melt. It can be postulated that boron annuls the negative effect of nitrogen on the graphitisation rate in the second stage of the malleabilising cycle. The optimum boron content is that which correspond stoichiometrically. Above that content boron acts as a carbide stabiliser as excess boron is available after saturation with nitrogen and will form carbides.

Thus, boron plays the dual role of carbide former and a graphitiser. However, in this investigation nitrogen content is assumed to be negligible. Some investigators have reported that a very small amount of boron in malleable iron promoted graphitisation at the second stage, whereas a boron addition of the order of 0.04% produced the usual carbides. The promotion of graphite may be attributed to the fact that aluminium is present (about 5.4%) in the Ferroboration and it is a strong graphitiser. But a larger boron addition nullifies the effect of aluminium.

CONCLUSIONS

The results of this investigation lead to the following conclusions:

1. Boron is strong carbide stabiliser if added to grey iron even in small quantity (such as 0.003%) and increases the wear and abrasion resistance of the castings.
2. Distributes the hard particles of carbides uniformly throughout the soft matrix of grey iron resulting in excellent machinability.
3. The amount, fineness and uniformity of carbide dispersion increases with increasing boron in the range of 0.003-0.04%.
4. The addition of boron also refines the eutectic cells and pearlitic lamellae upto 0.02% boron content.
5. Above a 0.02% boron content type D and E graphite are produced and no additional advantage of grain refinement is observed.
6. Section sensitivity decreases with increase in boron addition, as revealed by hardness testing.

Further Reading

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