THE EFFECT OF CHROMIUM ADDITIONS ON MICROSTRUCTURE AND SOME MECHANICAL PROPERTIES OF NODULAR CAST IRON

BY

S. B. HASSAN
Department of Metallurgical Engineering, Ahmadu Bello University, Zaria, Kaduna State.

ABSTRACT

The effect of chromium additions on the microstructure and some mechanical properties of Bamford nodular cast iron have been investigated. The nodular cast iron samples containing from 0.5 to 2.5%wt of chromium were produced at BAMFORD International, Jos. The mechanical properties studied include: tensile strength, hardness and percentage elongation. The results indicate that the tensile strength and hardness of the samples increased with percentage chromium additions from 449 N/mm^2 at 0% wt chromium to 543 N/mm^2 at 2.5%wt chromium and from 195BHN at 0%wt chromium to 232BHN at 2.5%wt chromium. However, the percentage elongation of the nodular cast iron samples decreased with increasing percentage chromium additions from 8% at 0%wt chromium to 1% at 2.5%wt chromium additions. This indicates the reduction in ductility of the nodular cast iron with chromium additions. The microstructure revealed an increase in degree of pearlite phase together with some precipitates of chromium carbide phase as the chromium level increased.

1.0 INTRODUCTION

For a very long time, chromium has been added to cast irons, particularly for applications requiring enhanced properties compared with those obtainable from Ordinary white, grey and nodular cast iron compositions. However, a distinction is frequently made between the small additions of chromium in order to improve particular properties in service and large additions to produce a distinct class of high chromium cast irons having characteristic properties and microstructures of their own.

At the low end of the chromium addition, small additions of up to about 1.5%wt are added to grey cast irons for solid solution hardening of the pearlite and to prevent distortion and 'growth' when utilized at high temperatures (Jackson, 1974 and Angus, 1976). In this case a simultaneous addition of nickel or silicon is frequently necessary, especially for thin section castings in order to counteract the inevitable 'whitening' effect of chromium (Jackson, 1974). Small quantities of chromium are also added to centrifugally cast piston rings and cylinder liners, to prevent the completion of malleabilising where massive carbide in a pearlitic matrix is required for optimum service properties (Angus 1976 and Bailey, 1954).

Higher additions of the order of 2 to 2.5 percent of chromium are sometimes made to white irons for roll making and other heavy section castings to maintain whiteness (Charles 1971; Dell. 1969; Roy, 1988 and William, 1990). Similarly, in martensitic white cast iron, chromium is used to counteract the 'greyness' that would otherwise result from the nickel addition required to form the martensitic matrix to the alloy (Jackson, 1974 and Morrogh, 1964). All these alloys containing these levels of chromium are essentially white cast irons solidifying with austenite dendrites surrounded by a ledeburite eutectic comprising a continuous film of hard brittle iron carbide containing rods and globules of austenite (Jackson, 1974).

The use of chromium as alloying element to nodular cast iron is not common due to the fact that chromium causes chilling effect on iron and this could adversely affect the good properties of nodular cast iron. Hence, care must be taken if used in small additions in order to control the chilling effect. In iron-carbon-chromium system, different types of Fe-C-Cr carbides are the formed in chromium alloyed cast irons and steels. The $(Fe, Cr)_3C$ carbides are the forms commonly found in low chromium contents of less than 5%. These are characteristically found in less than 2% chromium additions. The hardness of these carbides increases with the chromium content (Hassan, 2002).

The objective of the present study is to investigate the influence of small additions of chromium on the microstructure and mechanical properties of nodular cast iron produced locally.

2.0 EXPERIMENTAL PROCEDURE

2.1 MATERIALS

The experimental materials used for the study was chromium alloyed nodular cast iron which was produced at BAMFORDS International (Nigeria) Limited, Jos in the form of rods measuring 40mm diameter by 600mm length. The chemical compositions of the different nodular cast iron grades produced are given in Table 1.

All tensile tests were performed on a Hounsfield tensometer testing machine. The Brinell hardness testing machine was used for hardness measurements of the chromium nodular cast iron samples. A metallurgical microscope with an in-biult camera was uised to examine and photographically record the microstructure of the various nodular cast irons samples.

2.2 METHODS

For each of the nodular cast iron grade with respect to chromium level, a standard tensile test specimen of 5mm diameter and 20mm long were machined from a 40mm diameter and 600mm long chromium alloyed nodular cast iron rod (Aboh, 2002). The length of the specimen was chosen to be five times its diameter, in order to conform to standard size. In all, twelve chromium alloyed nodular cast iron specimens were machined out for use during the test.

The tensile tests, metallographic examinations and hardness measurements of the chromium alloyed nodular cast iron specimens were used to assess the effect of chromium on the microstructure and some mechanical properties of nodular cast irons under investigation.

The tensile tests were carried out on a Hounsfield tensometer using the machined cylindrical tensile test specimens of 5mm in diameter and a guage length of 20mm. Two samples were tested for each grade of the nodular cast iron (Aboh, 2002). The maximum strength and percentage elongation were determined. The result is shown in Figures 1 and 3 and Table 2 (the appendix)

Before subjecting the specimens to hardness testing, they were mounted on fused Bakelite powder for easy handling and surface preparation was carried out by grinding to obtain a smooth surface. The Brinell hardness testing machine was used to determine the hardness values across the traverse section of the nodular iron samples. Hardness values were taken at least at three different points to obtain an average hardness result shown in Figure 2 and Table 2 (appendix).

Microstructural examination of specimens cut from the fractured chromium alloyed nodular cast iron was carried out. Each specimen was carefully ground and polished. The surface of the polished specimen was etched in 5 percent Nital by swabbing the surface with cotton wool soaked in the etchant. The microstructural examination of the etched surface of the specimen was made under optical metallurgical microscope with an in-built camera through which the resulting microstructures were all photographically recorded. The micrographs are shown in Plates 1 – 6.

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

Table 1 shows the chemical composition of the nodular cast iron used in this investigation. The various microstructures resulted from addition of chromium to nodular cast iron are shown in Plates 1- 6. The effect of chromium additions on some mechanical properties of nodular cast iron produced at BAMFORDS International Jos is entered in Table 2 (appendix) and the graph of the variation of these mechanical properties with chromium additions is presented in Figures 1 – 3.

3.2 DISCUSSION

The chemical compositions of the nodular cast irons used in this investigation were found to fall within the normal composition for the standard nodular cast iron. The hardness, tensile strength and percent elongation were used as major criteria in assessing each of the nodular cast iron grades under investigation. The microstructure of specimens representative of each chromium level were examined and all had good nodular graphites structures.

The micrographs of the chromium nodular cast iron specimens were used to correlate the mechanical properties values obtained. The typical microstructures for the various chromium additions are shown in Plates 1 to 6.

The microstructure of the unalloyed nodular cast iron is composed of a mixture of graphite nodules and pearlite matrix as expected (see Plate 1). The proportion of pearlite matrix was observed to increase and become finer as the chromium additions increased. The microstructure obtained for various chromium levels between 1.5 to 2.5%wt shows a highly fine pearlite phase matrix with graphite nodules surrounded by ferrite shell (see Plates 4 to 6). These uniformly distributed hard pearlite matrices also contributed to the increase in hardness value of the nodular cast iron as the chromium addition increases.

This structure is expected to contribute to a better wear resistance of the chromium nodular cast iron as compared to unalloyed nodular cast iron. Essentially, all the microstructures observed were ferrite, pearlite, ledeburitic carbide and graphite nodules.

The mechanical properties obtained for various levels of chromium additions to nodular cast iron is summarized in Table 2 (appendix) and shown in Figures 1 to 3. The results show that the hardness values and tensile strength increased with the percentage chromium additions while the percent elongation decreased with chromium levels (see Figures 1 to 3).

The increased pearlite content and fineness of the pearlite structure as well as the presence of the solid solution of chromium and carbide of chromium in the matrix of the chromium nodular cast iron resulted in increased tensile strength and therefore better wear resistance. However, there is a general reduction in ductility of these nodular cast iron grades with chromium addition as reflected in the percentage elongation values (see Figure 3). It is noteworthy to observe that higher tensile strength values were developed as the chromium level increases up to 2.5 percent chromium and probably this trend may continue even above this level.

In this study, the high hardness values obtained in these nodular cast iron specimens as the percentage chromium addition increased could therefore be attributed to the carbide formation and stability characteristics of chromium as alloying element in ferrous metals.

4.0 CONCLUSION

The effectiveness of chromium additions on the microstructure and mechanical properties of nodular cast irons produced from BAMFORD International, Nigeria has been assessed using hardness values, tensile strength and percent elongation.

From the experimental results obtained, it can be concluded that: The mechanical properties of the nodular cast iron can be enhanced by the addition of chromium up to 2.5 percent by weight level without embrittling the nodular cast iron. The improved mechanical properties (tensile strength and hardness) are due to the presence of chromium carbide phase that is formed in the microstructure of the nodular cast iron. This low level of chromium addition to a greater degree, is considered to account for the result obtained in this study and therefore develops a material with better wear resistance.

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Table 1: Chemical Compositions of Nodular Cast Iron Produced

%C	%Si	%Mn	%S	%P	%Cr
3.00	2.00	0.46	0.031	0.13	0.0
3.25	2.03	0.67	0.031	0.02	0.5
3.15	2.20	0.44	0.020	0.38	1.0
3.31	2.10	0.41	0.070	0.39	1.5
3.42	2.44	0.56	0.060	0.42	2.0
3.42	2.44	0.56	0.060	0.42	2.5

Appendix

Table 2: Mechanical Properties of As-cast Chromium Alloyed Nodular Cast Iron

%Cr	Tensile Strength (N/mm^2)	Hardness (BHN)	Elongation
0.0	449	195	8.0
0.5	459	205	3.5
1.0	480	214	3.0
1.5	500	218	2.5
2.0	520	227	2.0
2.5	543	232	1.0

Micrographs of Nodular Cast Irons with chromium additions.

Plate 1: As-cast structure of plain nodular cast iron

Plate 2: As-cast structure of 0.5%Cr nodular cast iron

Plate 3: As-cast structure of 1.0%Cr nodular cast iron

Plate 4: As-cast structure of 1.5%Cr nodular cast iron

Plate 5: As-cast structure of 2.0%Cr nodular cast iron

Plate 6: As-cast structure of 2.5%Cr nodular cast iron

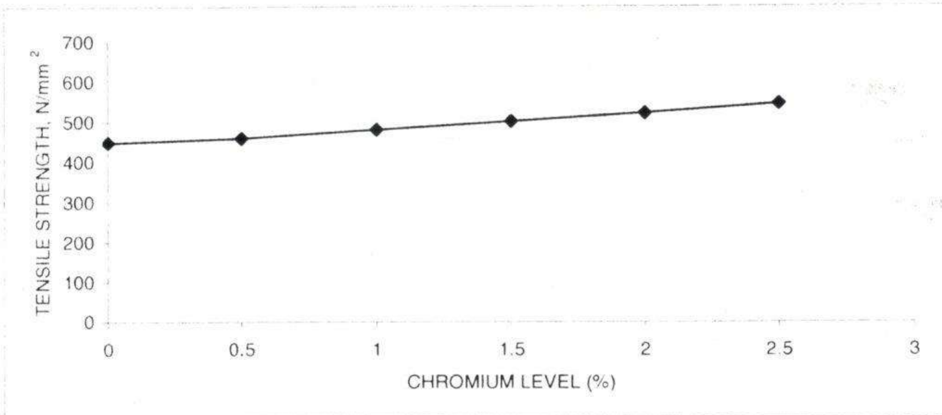

Figure 1: Variation of tensile strength with percentage chromium addition

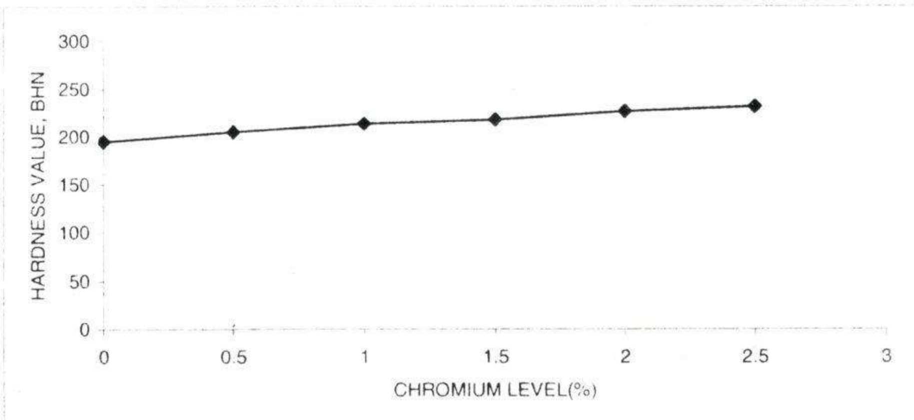

Figure 2: Variation of hardness value with percentage chromium addition

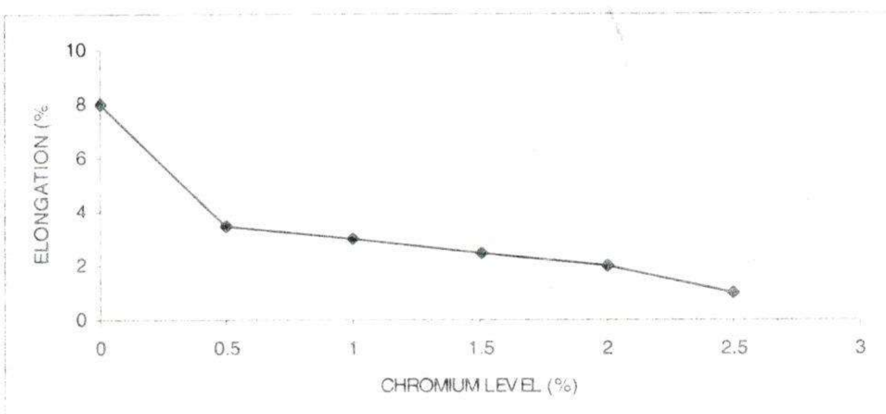

Figure 3: Variation of percent elongation with percentage chromium.