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THE EFFECT OF ALLOY ELEMENTS ON FATIGUE STRENGTH OF GRAY CAST IRON AT ROOM AND HIGH TEMPERATURE

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ABSTRACT

Gray cast iron is quite poor in terms of fatigue resistance due to its typical microstructure of distributed graphite lamellas in a pearlite matrix. The objective of this research to improve mechanical properties and fatigue strength gray cast iron (GCI) at high temperature by adding the alloy elements such as: nickel (Ni), molybdenum (Mo), copper (Cu) and chromium (Cr). The mechanical characterization that has been done is tensile test and hardness tesst. The tensile test was conducted based on ASTM E8 standard. The hardess test of GCI was test by Brinell Hardness Test methods based on ASTM E10. Fatigue test was performed on continuous radius fatigue specimens based on JIS Z 2774 standard with cyclic loading frequency of 50 Hz and load ratio R = -1. The fatigue test has been done at room temperature and at temperature 300^{o}C. The results of this experiments show that alloy elements such as : nickel (Ni), molybdenum (Mo), copper (Cu) and chromium (Cr) increase the hardness and tensile strength of Gray cast iron. Nickel results finer graphite grain and improve fatigue strength of Gray cast iron at high temperature.

Keywords: *Fatigue, Gray cast iron, Alloy*

1. INTRODUCTION

Gray cast irons which are produced more than other cast alloys products in the world are one of the most usable Fe-C alloys. Gray cast iron is used in many industries. It is characterized by a flexibility of use, excellent castability, low cost, wide range of achievable mechanical properties. Due to the superior metallurgical stability behaviour, lower cost and comparatively ease of production, cast iron is often more used [1, 2]. Cast iron is commonly used as brake rotor and brake drum material. Gray cast iron with the microstructure of type A graphite flakes in a predominantly pearlitic matrix has been used for brake rotors and drums since the early stage of vehicle development [3]. Graphite flake cast iron has long been used as the material for drum brake because of its overall excellence in thermal fatigue strength, anti-squeak and anti-vibration characteristics, and wear resistance. Flake graphite also gives advantage as drum brake materials because it's anti welding properties. Graphite flake in the GCI performed that GCI has a good wear characteristic in lubricated or not lubricated friction [4].

These cast irons had limited application because of low tensile strength, especially low ductility which is caused by the presence of thick flake graphite in a pearlite matrix. Gray cast iron is also quite poor in terms of fatigue resistance [5]. Most of components are designed to operate for long lives, a method for predicting the fatigue limit of a component of arbitrary shape is desirable [6].

Braking by drum brakes consists of a process in which the brake pads are pressed against a rotating drum to convert the vehicle's kinetic energy into breaking force and thermal energy. Braking process caused thermal heat hot spot at temperatures higher than the AC1 transformation temperature. In contrast to the local temperature gradient, this surface/inside temperature gradient is a macroscopic or average temperature gradient. Repeated thermal stress caused by this average temperature gradient has an effect of propagating heat cracks. The thermal stress caused by local temperature gradients is presumed to be much greater than that caused by the average temperature gradient [7]. Jimbo et al. reported that thermal stress that was caused by thermal gradient caused heat cracks [8].

Rausch et al. developed different methods to control morphology, size and distribution of graphite shape and matrix structure to improve the mechanical properties of grey cast irons. The mechanical properties of various members of the cast iron family are influenced both by the morphology of the graphite and the characteristics of the surrounding matrix structure [9]. The graphite morphology can be manipulated in several ways. This research aim to improve strength and fatigue strength Gray cast iron at high temperature by adding the alloy element such as: nickel (Ni), molybdenum (Mo), copper (Cu) and chromium (Cr).

2. EXPERIMENTAL

Cast iron was melted in the standard line frequency induction furnace of capacity the 10 tons per hour. The iron charge contained : pig iron, steel scrap and cast iron returns. Alloy elements: FeMo, FeSi, FeCr, FeNi and Cu were added on the melting iron. The chemical composition of the cast iron was tested by spectrometer. The results of composition test were given in Table. 1. Differences in chemical composition are limited to some elements such as Cu, Cr, Ni and Mo. Based on alloying compositions carbon equivalent (CE) of the Gray cast iron was also calculated.

Table 1. Compositions of Gray Cast Iron

Compositon	C	Si	Mn	S	P	Cr	Cu	Ni	Mo	%CE
Base GCI	3,31	2,35	0,47	0,03	0,06	0,14	0,53	0,07	0,02	4,04
GCI Alloy 1	3,22	2,37	0,52	0,03	0,06	0,19	0,69	0,17	0,15	3,95
GCI Alloy 2	3,33	2,39	0,48	0,03	0,05	0,19	0,39	0,22	0,12	4,06

Round specimens were machined by CNC turning machine from the cylindrical portions of gray cast iron cast. Standard specimen for tensile test and fatigue test geometries were used, with the exception of the grip section length. The tensile testing was performed on smooth, cylindrical specimens based on ASTM E8 standard in a Shimadzu EHF-EB 20-40 L servo-hydraulic material testing system. Rotating-bending fatigue tests with cyclic loading frequency of 50 Hz and load ratio R = -1 were performed to determine the fatigue curves of the three Gray cast irons. Fatigue test was performed on continuous radius fatigue specimens based on JIS Z 2774 standard in a Shimadzu H6 fatigue testing machine. Fatigue tests were conducted at room temperature (35^o C) and at temperature 300^o C. The hardness of Gray cast irons was tested by Brinell Hardness Test based on ASTM E10. A microstructure analysis was made by metallurgical microscope Olympus U-MSSP4. The graphite flake type, form, and size were defined by procedure described in ASTM A-247 Standard.

3. RESULTS AND DISCUSSIONS

The hardness and tensile properties of GCI, GCI alloy 1 and GCI alloy 2 are shown in Figure 1 and Figure 2. It shows that alloy element such as : nickel (Ni), molybdenum (Mo), copper (Cu) and chromium (Cr) increase the hardness and tensile strength of Gray cast iron. GCI alloy 2 has highest hardness and tensile strength. Increasing hardness and tensile strength of GCI was caused higher Ni content in GCI alloy 2 than Ni content in GCI alloy 1 or GCI. The addition of nickel in alloy iron produces a slight hardening effect [10]. The results of tensile test was comparable with results of the hardness test.

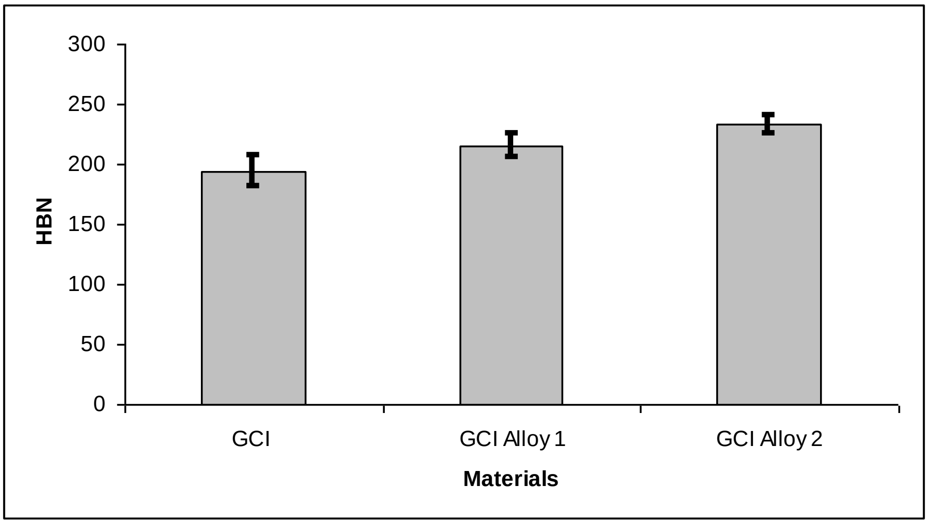


Figure 1. Effect of alloy on the hardness of GCI

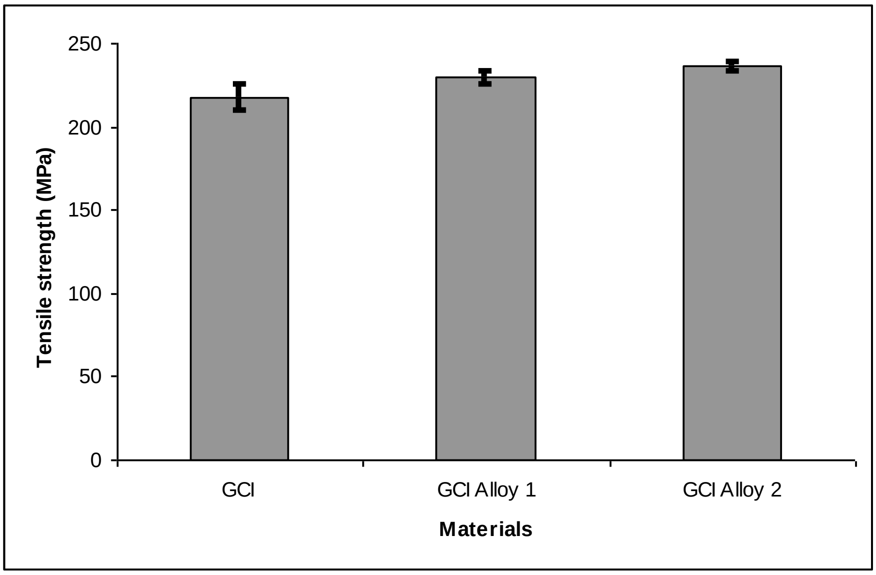


Figure 2. Effect of alloy on the tensile strength of GCI

Figure 3(a) and Figure 3(b) show the effect of alloying element on fatigue properties of GCI at room temperature (35^{o} C) and at temperature 300^{o} C. At same temperature test, alloying element didn't give significant difference in fatigue strength. This phenomena caused that GCI has graphite flake. During fatigue test the graphite flake act as initial crack. A crack initiated first at the graphite matrix interface instead of at the matrix, ahead of graphite tip suggests that the stress concentration at the graphite tip is much lower than the middle part. The crack then propagate at the tip of graphite flake.

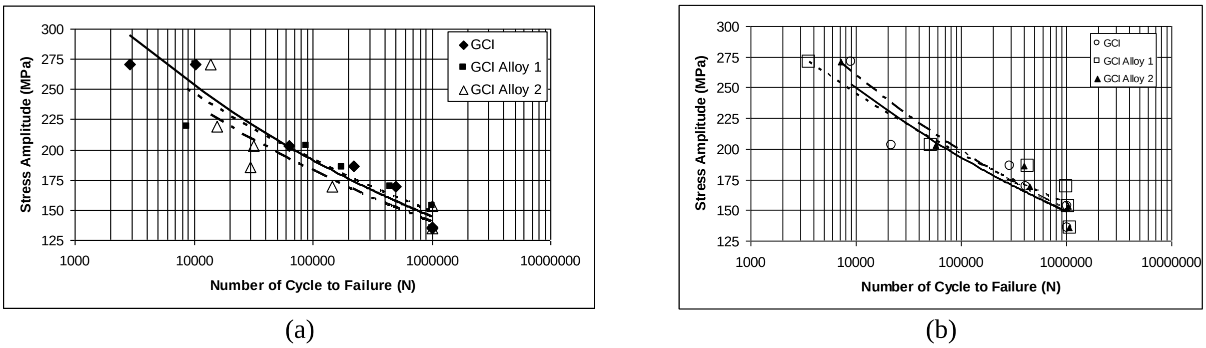
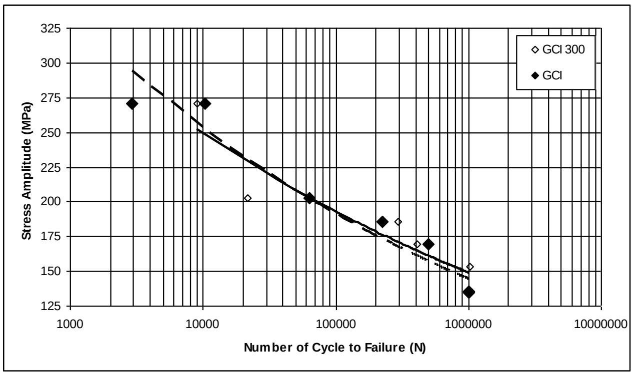
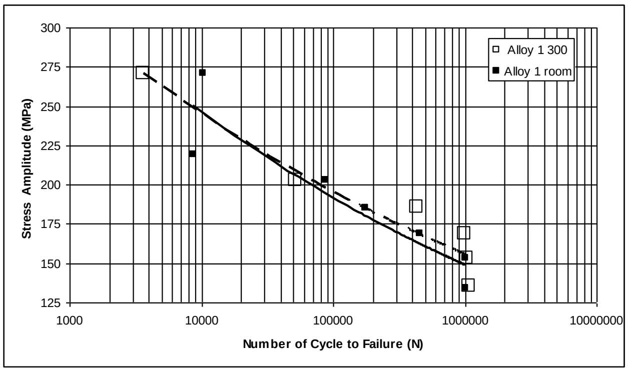


Figure 3. Effect of alloy on the fatigue strength of GCI
a. at room temperature (35^{o} C), b. at temperature 300^{o} C

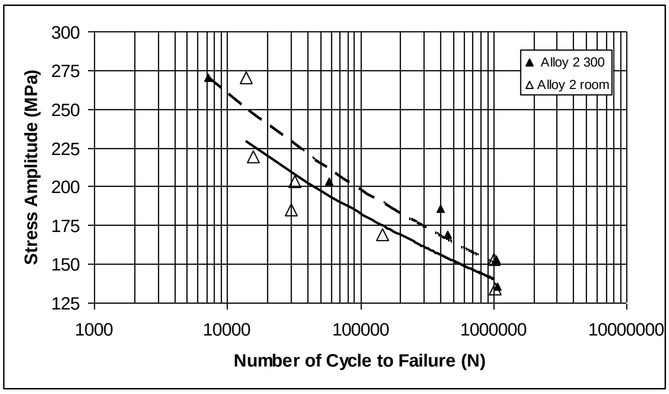
Figure 4(a), 4(b) and 4(c) show the fatigue strength characteristic of GCI, GCI alloy 1 and GCI alloy 2 at room temperature and at temperature test 300 ^{o}C. Figure 4(a) shows that fatigue strength of GCI at room temperature and at temperature test 300 ^{o}C has same characteristic. Figure 4(b) and 4(c) show that at temperature 300 ^{o}C alloy 1 and alloy 2 have a higher fatigue strength than at room temperature. It can be concluded that alloying elements (Cu, Ni, Mo and Cr) improve fatigue strength of GCI at high temperature (300^{o} C) and Ni has dominant role to improve fatigue strength of GCI at high temperature. Fatigue strength of Gray cats iron depend on graphite morphology and graphite size [11]. Finer graphite grains in the current material presumably result from the graphite refining effect of Ni. Ni (0.1-1.5%) are commonly used pearlite stabilizers. Traditionally, the graphite in GCI could be viewed as a void, and the cracks initiate at the tip of the graphite flakes due to the micronotch stress concentration [10]. The mechanism of initiation and propagation of a macroscopic crack in GCI is the result of the coalescence of micro-cracks originating from the tips of the graphite lamellas, the amount of graphite is critical, and more important than the length of the lamellas, to determine the mutual micro-cracks influence and a crack initiation condition. The values of the mean length of graphite lamellas show a good correlation with the fatigue limit of the material [12]. The as-cast microstructures are strongly dependent on the alloying elements. Ferrite matrix provides highly ductile cast iron while pearlite provides highly strong cast iron [13].



(a)



(b)



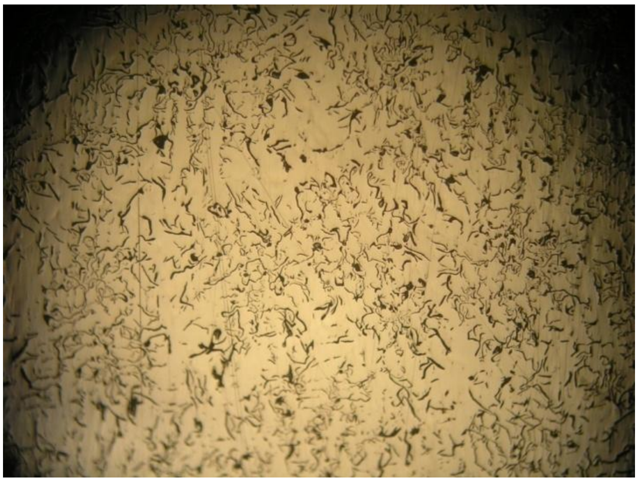
(c)

Figure 4. Fatigue strength of GCI at room temperature (35^{o}C) and at high temperature (300^{o}C)
(a). Fatigue strength GCI at room temperature (35^{o}C) and high temperature (300^{o}C)
(b). Fatigue strength GCI alloy 1 at room temperature (35^{o}C) and high temperature (300^{o}C)
(c). Fatigue strength GCI alloy 2 at room temperature (35^{o}C) and high temperature (300^{o}C)

The distribution and the size of lamellar graphite, i.e. Figure.5a, 5b and 5c were evaluated on non etched specimens and found to be uniform and similar for all specimen. The microstructures of all the sample materials comprise A-type graphite distributed in a pearlite matrix. There is a difference in the length of lamellar graphite with regard to the microstructure. GCI (Figure.5a) is classified as number 2 based on ASTM A-247-67. GCI alloy 1 (Figure.5b) is classified as number 3, and GCI alloy 2 (Figure.5c) is classified as number 4 [14]. Nickel is effective in promoting the formation of pearlite and others are more effective in refining and stabilizing pearlite [10]. Mo and Cr are classified as carbide stabilizers since they retard graphite precipitation and increase the tendency to form iron carbides. Some of these carbide stabilizers such as Mo play a dual role and act as pearlite refiners, with Mo being a pearlite refiner up to 0.8% and thereafter acting as a carbide stabilizer [15].

(a)

(b)



(c)

Figure 5. Microstructure of non etching of Gray cast iron (100 x)
(a).GCI (b).GCI alloy 1 (c).GCI alloy 2

4. CONCLUSIONS

1) Alloy element such as : nickel (Ni), molybdenum (Mo), copper (Cu) and chromium (Cr) increase the hardness and tensile strength of Gray cast iron.
2) Fatigue strength GCI with alloy elements at temperature test 300 ^oC are higher than fatigue strength at room temperature, Ni play as role for improving fatigue strength of CGI.
3) Nickel results finer graphite grain and improve fatigue strength of Gray cast iron at high temperature.

5. ACKNOWLEDGMENT

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