



THE CORROSION BEHAVIOR AND WEAR RESISTANCE OF GRAY CAST IRON

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ABSTRACT

Gray cast iron has many applications as pipes, pumps and valve bodies where it has influenced by heat and contact with other solutions . This research has studied the corrosion behavior and Vickers hardness of gray cast iron by immersion in four strong alkaline solutions (NaOH, KOH, Ca(OH)₂, LiOH) with three concentrations (1%,2%,3%) of each solution. Dry sliding wear has carried out before and after the heat treatments (stress relief, normalizing, hardening and tempering). In this work, maximum wear strength has obtained at tempered gray cast iron and minimum corrosion rate has obtained in LiOH solution by forming protective white visible oxide layer.

KEY WORD: corrosion, treatments, hardness, wear, alkaline.

سلوك التآكل ومقاومة البلى لحديد الزهرة الرمادي

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المستخلص

يستخدم حديد الزهر الرمادي في العديد من التطبيقات مثل الانابيب و المضخات و الصمامات و يتأثر بالتسخين و عند التماس بالمحاليل الاكالة. درس هذا البحث سلوك التآكل و صلادة فيكرس لحديد الزهر الرمادي المغمور في محاليل قاعدية قلووية قوية (هيدروكسيد الصوديوم, هيدروكسيد البوتاسيوم, هيدروكسيد الكالسيوم, هيدروكسيد الليثيوم) بثلاثة تراكيز لكل محلول (1%, 2%, 3%). تم اجراء اختبار البلى الانزلاقي الجاف قبل و بعد المعاملات الحرارية (ازالة الجهود, التطبيع, الاصلاد و المراجعة). في هذا البحث تم التوصل الى ان حديد الزهر الرمادي المراجع يمتلك اعلى مقاومة للبلى و اقل معدل للتآكل تم الحصول عليه في محلول هيدروكسيد الليثيوم بتكوين طبقة اوكسيدية واقية بيضاء اللون.

1. INTRODUCTION

Gray cast iron (GCI) is traditionally chosen in many industrial applications because of its flexibility, good cast ability, low-cost (20–40% less than steel) (Hammood and Lieth, 2012). GCI is a durable and fire-resistant material that is used in the home and industry. It is a complex material with stable and meta-stable phases and has elements in the solution, which influence the extent and stability of the desirable properties not obtained by other alloys (Sherif et al., 2015). GCI has low rate of thermal expansion, high damping capability (tool machines), good stiffness, resistance to thermal fatigue, good antifriction properties, 100% recyclability and its resistance to compressive stresses 3-4 times of resistance to tensile stresses (Rajput, 2007; Black and Kohser, 2008), good thermal conductivity due to the graphite phase, which is an excellent thermal conductor (Cueva, 2003), but GCI is machinable but its machinability varies with the variation of micro constituent (Manchanda and Narang, 2011).

The structure of GCI depends on chemical composition before the casting process, and cooling conditions (Hammood and Lieth, 2012). All GCI contain flake graphite dispersed in iron matrix including silicon (Ramadan et al., 2006) where Higher silicon levels favor the formation of graphite, but lower silicon levels favor the formation of iron carbides (Decker, 2005). The properties of the GCI depend on the size, amount and distribution of the graphite flakes and the matrix structure (Ramadan et al., 2006). GCI is composed of graphite flakes in pearlitic matrix, or graphite flakes and areas of pearlite in a ferritic matrix (Sherif et al., 2015). Pearlitic matrix is a lamellar mixture of ferrite and cementite (Rajput, 2007; Black and Kohser, 2008). Graphite flakes are interconnected and disposed in the form of plates, constituting an easy path for fast heat dissipation (Cueva, 2003).

GCI applications were in flywheels, pulleys, machine frames, automobiles cylinders, pistons, machine casting, water main pipes, soil pipes, flange couplings, ingot moulds and large equipment parts that were subjected to compressive loads and vibrations (Manchanda and Narang, 2011; Black and Kohser, 2008). Castings of GCI are used widely in pressure applications such as cylinder blocks, manifolds, pipe fittings, compressors, and pumps (Zwilsky, 2005). Recently, there has been an increasing interest in cast irons as structural components in the wind power industry, rotor hubs or nacelles (Hammood and Lieth, 2012).

Alkaline solution is the substance that decreases the hydrogen ion concentration of a solution. Sodium hydroxide, potassium hydroxide, lithium hydroxide, and calcium hydroxide are strong bases because they dissolve and dissociate completely in aqueous solutions to yield hydroxide

ions (Silberbeg, 2003). NaOH, KOH, LiOH are monoacid bases and $\text{Ca}(\text{OH})_2$ is diacid base (Kumar, 2003).

The heat treatment of GCI can considerably alter the matrix microstructure with little or no effect on the size and shape of the graphite achieved during casting. The matrix microstructures resulting from heat treatment can vary from ferrite-pearlite to tempered martensite. Although the size of the graphite flakes in gray irons is unaffected by heat treatment, the size does have a marked influence on the carbon kinetics during heat treating. Chemical composition is another important parameter influencing the heat treatment of gray cast irons (Copley, 2005; Ateia, 2010).

Lunarska, (1996) has studied the corrosion and electrochemical tests of grey cast iron in phosphoric acid solution. Corrosion process has accompanied by the hydrogen evolution and lead to the formation of hydrogen which induced cracks at the sharp edges of the graphite particles. In vermicular cast iron, hydrogen cracks form the spatial network causing the falling off some parts of metal and thus accelerating the degradation of this material under the corrosion-erosion conditions (Lunarska, 1996).

Cueva, (2003) studied the wear resistance of three different types of gray cast iron (gray iron grade 250, high-carbon gray iron and titanium alloyed gray iron) used in brake disc rotors, and compared with the results obtained with a compact graphite iron (CGI). The wear tests were carried out in a pin-on-disc wear-testing machine, the pin being manufactured from friction material usually used in light truck brake pads. The rotating discs (500 rpm) were subjected to cyclical pressures of 0.7, 2 and 4MPa and forced cooled. The results showed that compact graphite iron reached higher maximum temperatures and friction forces as well as greater mass losses than the three gray irons at any pressure applied (Cueva, 2003).

Ateia, (2010) studied the effect of heat treatment on thermal conductivity and mechanical properties of gray cast iron used in the manufacturing of brake rotor in automotive industry. He concluded mechanical properties of gray cast iron depend mainly on the microstructure type of matrix and also to the distribution of graphite flakes. During normalizing heat treatment, the decomposition process of carbon on the graphite flakes is less than annealing process. The increased amount of Pearlite in the matrix that accompanied with the refinement of the grain structure lead to an improvement of mechanical properties. Thermal conductivity which is the prime requirements in brake rotor applications also improved according to the microstructure evolution (Ateia, 2010).

Mohebbi et al., (2011) have studied the long-term corrosion behavior of cast iron pipes in the absence of historical data. A comprehensive experimental program is presented in which the corrosion behavior of three ex-service pipes was thoroughly examined in three simulated service environments. It has been found that localized corrosion is the primary form of corrosion of cast iron water pipes. It has also been found that the microstructure of cast irons is a key factor that affects the corrosion behavior of cast iron pipes. They concluded that long-term tests on corrosion behavior of cast iron pipes can help develop models for corrosion-induced deterioration of the pipes for use in predicting the remaining service life of the pipes (Mohebbi and Li, 2011).

Seidu et al., (2015) was investigated the effect of copper additions on the corrosion behavior of grey cast iron in (3.5 wt% NaCl, 0.3M H₂SO₄, and 0.1M NaOH) respectively. Grey cast iron samples containing 3.0%, 2.5%, 2.0%, and 1.5% weight percent of copper were produced. The results reveal that the samples containing 2.0% and 1.5% weight percent of copper show an excellent corrosion resistance while samples containing 3.0% and 2.5% weight percent of copper show good corrosion behavior all in salt water and basic environments but poorly in acidic environment (Seidu et al., 2015).

Sherif et al., (2015) studied the corrosion of cast iron in freely aerated stagnant Arabian Gulf seawater (AGS) at room temperature were reported. The study was carried out using weight-loss .Weight loss experiments between two and 10 days' immersion in the test electrolyte indicated that the weight-loss the cast iron increases with increasing the time of immersion (Sherif et al., 2015).

Mashloosh, (2015) was studied the wear characteristics of different cast iron types which might be used as mould materials in glass blow molding. Three types of gray cast iron with different chemical compositions were cast and heat treated, as well as samples taken (for comparison) from another two existing mould already being in use. Cast iron with (2.98% C, 5.117% Si, and 1.39% Cu) showed the highest hardness in its as cast condition compared to the other types. It showed the best wear resistance after heat treatment (stress relief annealing. Results also showed that some of the tested materials gave a good wear resistance at low temperature (up to 600 °C) but they lost their resistance at high temperature (up to 800 °C). It was concluded that hardness is not the only parameter that controls the wear resistance at high temperature (Mashloosh, 2015).

Various studies have been carried out for determination of corrosion behavior of cast iron in acids, aqueous solutions at high concentration of salts as well as in water supply systems. The

aim of this research is to study the effect of different alkaline solutions with different concentrations, wear resistance and heat treatments on GCI.

2. MATERIALS AND METHODS

In this research, 12 circular specimens were of GCI used with diameter 33mm and thickness 5mm and 4 cylindrical specimens of (10mm) in diameter and (8mm) in height according to ASTM (G99-04). Grinding operation was carried out to produce a flat smooth surface and free from surface contaminations. The specimen was ground on a series of silicon carbide papers of increasing fineness. Fine scratches were removed from the surface of the specimen with the aid of a universal polishing machine. After polishing, the specimens were washed with water and Nital etchant to react with the surface of specimens to be ready to the light microscope. The micro-structure of the specimens was observed by using a computer aided light optical microscope before and after the heat treatment. After grinding and polishing, 12 samples of GCI were immersed in four alkaline solutions (NaOH, KOH, Ca(OH)₂, LiOH) at 3 concentrations (1%, 2%, 3%) for each solution.

3. HEAT TREATMENTS

3.1. Stress Relieving:

GCI in the as-cast condition contains residual stresses because cooling (and therefore contraction) proceeds at different rates in various sections of a casting. Temperature of stress relieving is usually below the range for the transformation of pearlite to austenite. Critical transformation temperature T₁ (A₁) can be calculated depending on manganese and silicon percentage as:

$$^{\circ}\text{C}: 730 + 28.0 (\% \text{ Si}) - 25.0 (\% \text{ Mn}) \quad 1 \text{ (Copley, 2005)}$$

In this work, The heating of GCI specimen has occurred into 600°C for one hour and following by very slow cooling (in furnace).

3.2. Normalizing

Gray cast iron has normalized by being heated to a temperature above the transformation range, held at this temperature for a period of about 1 h per inch of maximum section thickness, and cooled in still air to room temperature. In this work, the heating of GCI specimen into 900 °C for one hour and then cooling in air has occurred.

3.3. Hardening and tempering

Gray cast irons are hardened and tempered to improve their mechanical properties. In hardening gray cast iron (austenitizing) the casting is heated to a temperature high enough to promote the

formation of austenite, held at that temperature until the desired amount of carbon has been dissolved, and then quenched at a suitable rate. The temperature to which a casting must be heated is determined by the transformation range of the particular gray iron of which it is made. The transformation range can extend more than 55 °C above A1 (the transformation-start temperature) .After quenching, castings are usually tempered at temperatures well below the transformation range. In this work, heating of GCI specimen into 900°C and quenching in water after that tempering into 360 °C has occurred.

4. EQUIPMENT

1. Chemical composition analysis for the GCI was carried out using Metal analysis by SPECTRO model (SPECTROMAXx) .The results are shown in [Table 1](#).
2. Sensitive electric balance model (M254A) with +0.0001 accuracy.
3. Chemical hood for decreasing odors from the reaction between gray cast iron and alkaline solution.
4. Grinding and polishing operations were done using polishing machine model (MP-2B grinder polisher). Then, the specimens were polished using diamond paste to produce flat, scratch free, mirror like surface.
5. Optical microscope with camera ,main power 80v-256v/50-60Hz, 60/20w.
6. Wear tester device type (MT-4003, version 10.0). The tested specimens were set as a pin against standard rotating steel disk with a hardness of (850 HV).
7. Digital display micro hardness tester modelHVS-1000.

Table 1. Chemical composition of GCI.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	V	Fe
Wt%	3.57	1.41	0.332	0.135	0.196	0.071	0.007	0.06	0.011	0.014	0.213	0.022	Bal.

5. RESULTS AND DISSCUSION

[Fig. 1](#) represents the corrosion behavior of gray cast iron against the immersion time in days at three concentrations of (NaOH) in aqueous solutions. The corrosion rate has been high in the first days and has decreased with the continuation of immersion in (NaOH) solution. The gray cast iron has corroded rapidly after two days because iron behaves as anode and graphite flakes as cathode. By increasing the concentration the corrosion rate increasing because the increasing

the concentration of caustic soda increasing the corrosion rate (Decker, 2005). But increasing time of immersion the corrosion rate decreasing because one form of graphitic corrosion occurs on the surface. Just the surface of GCI graphitizes forming a graphitic coating on the exterior (Lunarska, 1996) as in this research.

Fig. 2 represents the corrosion rate versus immersion time of gray cast iron in (KOH) solution with three concentration (1%, 2%, 3%). The corrosion rate at the concentrations (1% & 2%) has been in the negative part which indicate to increasing in the weight by formation an oxide shell. In 3% of (KOH) solution there are high negative values of corrosion rate. These negative values are referred to increasing in weight and formation of oxide film. There is continuous decreasing in weight with increasing the immersion time according to dissolving of oxide film. This belongs to changing of a chemically active state of a metal to a much less reactive state and this agrees with the passivation (Decker, 2005).

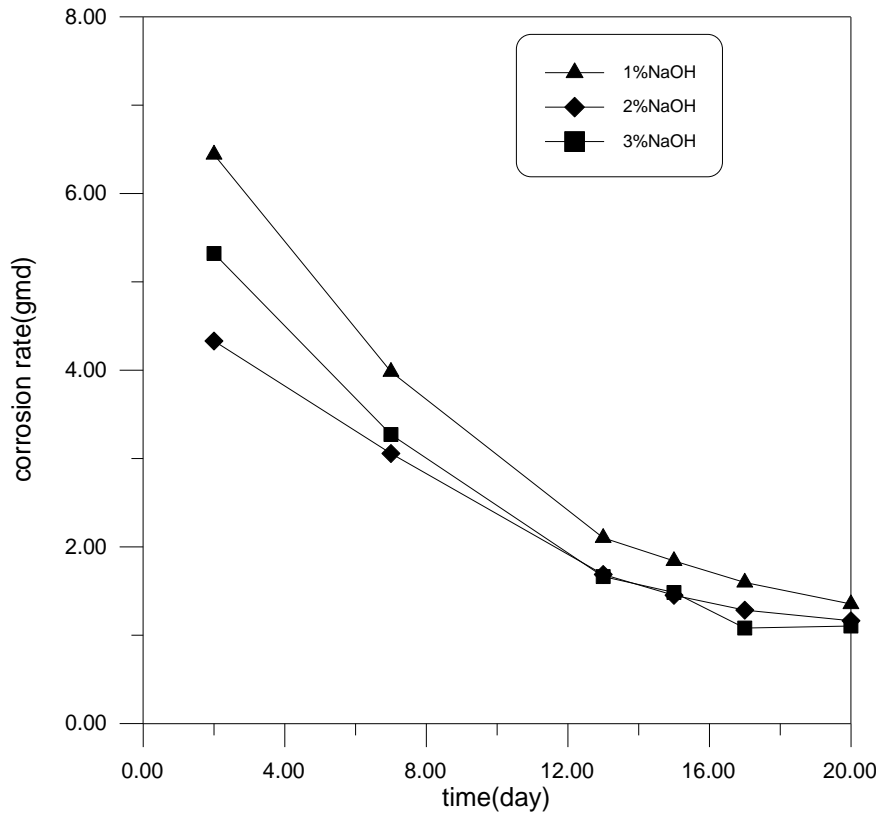


Fig. 1. Corrosion rate of G.C.I in NaOH solutions.

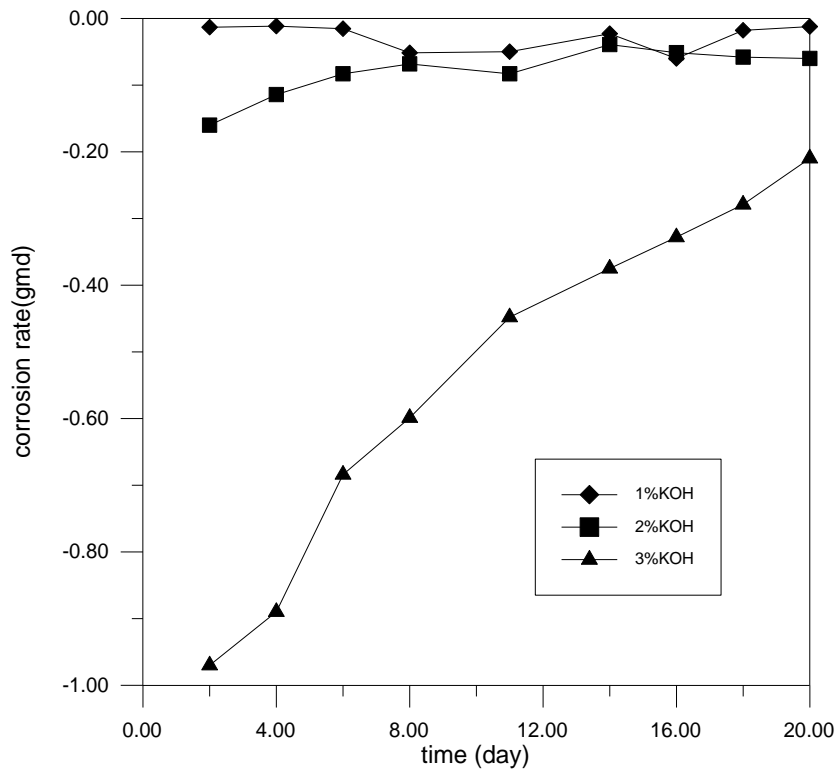


Fig. 2. corrosion rate of G.C.I in KOH solutions.

Fig. 3 shows the rate of corrosion against immersion time for concentrations (1%, 2%, 3%) of $\text{Ca}(\text{OH})_2$. At all concentrations, there are an increase in weight (corrosion rate values are negative) coincides with the increasing in concentration. This behavior reflects the formation of passive layer by chemical adsorption on gray cast iron specimens. Unalloyed cast irons exhibit generally good resistance to alkalis approximately equivalent to that of steel. The unalloyed cast irons are not attacked by dilute alkalis at any temperature (Decker, 2005).

Fig. 4 represents the corrosion behavior of gray cast iron in (1%, 2%, 3%) of (LiOH) solutions. At (1%, 2%) solutions, the corrosion rate is very little nearly zero. In 3% solution, the rate of corrosion is approximately zero while at very long time there is a large increasing in weight. This reflects the composing of protective and passive white visible oxide layer according to chemical adsorption that cannot be removed by hand.

Fig. 5 shows Vickers hardness values for gray cast iron specimens at three concentrations (1%, 2%, 3%) in four alkaline solutions (NaOH, KOH, $\text{Ca}(\text{OH})_2$, LiOH). Vickers hardness of gray cast iron in NaOH has decreased with increasing concentration according to the selective leaching corrosion of gray cast iron. Vickers hardness of gray cast iron in KOH solution has decreased at (1% & 2%) because of the formation of oxide film while at 3% the hardness has increased due to the increasing of passive film thickness. Vickers hardness of gray cast iron in $\text{Ca}(\text{OH})_2$ solution has increased continuously at all concentrations according to the formation of protective

solid layer. Vickers hardness of gray cast iron in (LiOH) solution has decreased continuously due to the properties of oxide film (Roberge, 2008).

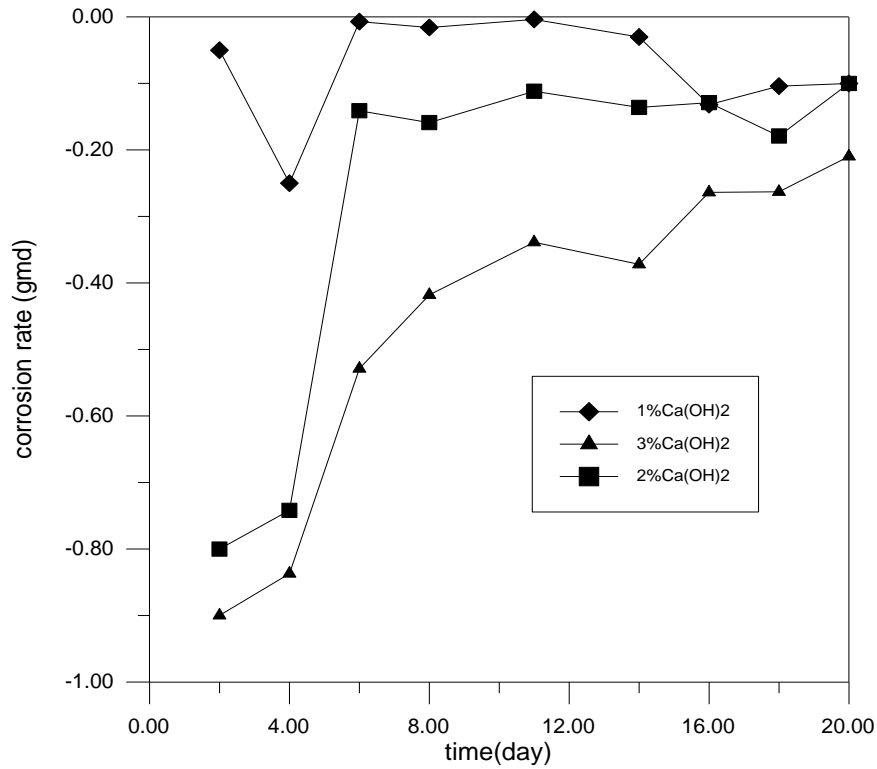


Fig. 3. Corrosion rate of G.C.I in Ca(OH)₂ solutions.

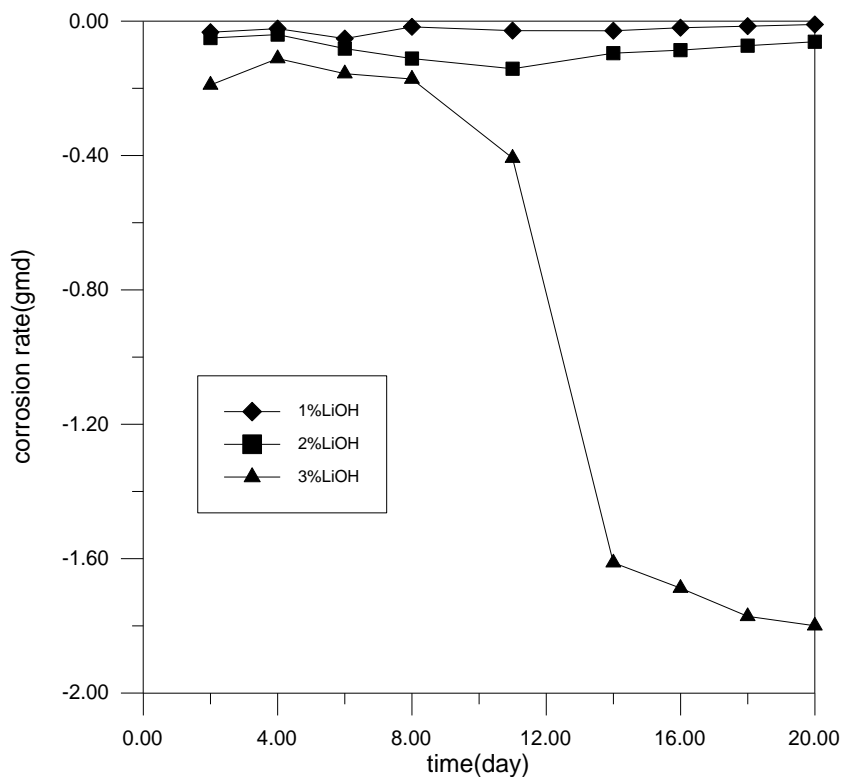


Fig. 4. Corrosion rate of G.C.I in LiOH solutions.

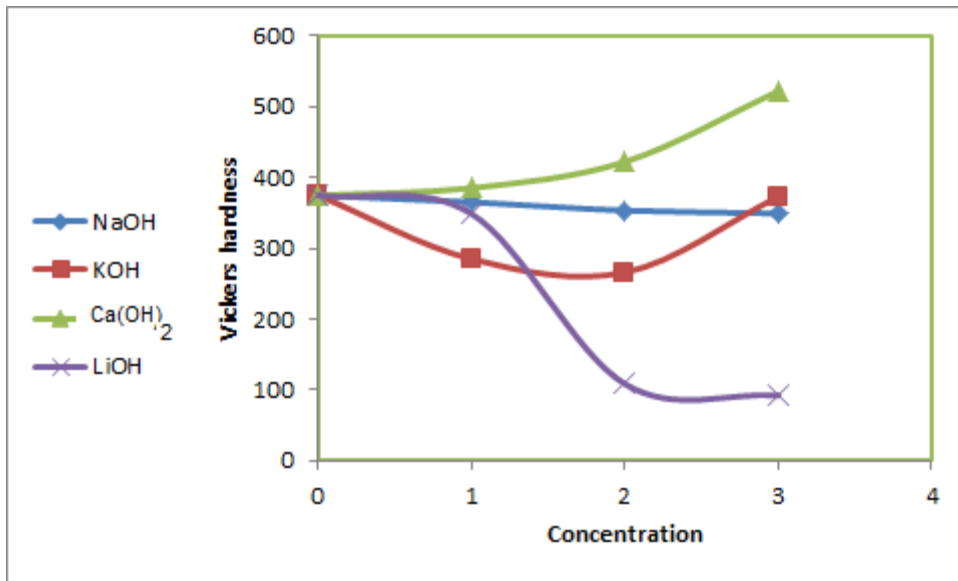


Fig. 5. Vickers hardness of G.C.I in different solutions.

Fig. 6 represents the loss in weight against time from the wear test. The wear test was applied on four gray cast iron specimens. Maximum loss in weight (minimum wear resistance) can be obtained from stress relief heat treatment, followed by the specimen without heat treatment, Then the normalizing sample while minimum loss in weight (maximum wear resistance) can be obtained by hardening and tempering sample. The increasing of hardness is very useful in the modification of brake rotor wear resistance since the rotor subjected to almost continuous contacting by the brake pads (Ateia, 2010). Now the improvement in hardness that accompanied with a noticeable improvement in ductility can gives a supporting for the using of this type of heat treatments in the manufacturing of an automotive brake rotor where an impact resistance is high due to a modified ductility that accompanied with a high hardness and ultimate tensile strength (Ateia, 2010).

Fig. 7 represents the optical microstructure of gray cast iron. The structure of the sample before heat treatment consists of matrix of perlite, graphite flakes, and ferrite. A large portion of the graphite flakes giving the material a characteristic brittle nature as in (a) (Black and Kohser, 2008). The stress relief heat treatment stills the same structure of the sample but without stresses as in (b). The stress relief heat treatment has relieved the residual stresses, improved ductility, and consequently decreasing the wear resistance.

Fig. 7-c represents the microstructure after normalizing when the cooling rate is fast enough to prevent the diffusion of carbon atoms. This results in more amount pearlite on the account of ferrite. However the area adjacent to the graphite flakes experiences carbon decomposition and

ferrite presence around the flakes. It is clear from the microstructure that the normalizing process has given harder behavior and more improvement in wear resistance according to the pearlite structure that consists of brittle and hard cementite layers (Ateia, 2010; Copley, 2005).

After hardening and tempering treatment. The quenching process results martensite which is a supersaturated solid solution of carbon but because of the drastic cooling and carbon entrapment in iron crystal lattice, the martensite is very hard, very brittle and of little use in industry. Therefore, another heating cycle is needed to precipitate carbon out of martensite as $(Fe_3 C)$ by a process of tempering. The resulted microstructure is graphite flakes in a tempered martensitic matrix as in Fig. 7-d. Gray irons are hardened and tempered to improve their mechanical properties, particularly strength and wear resistance (Ateia, 2010; Copley, 2005).

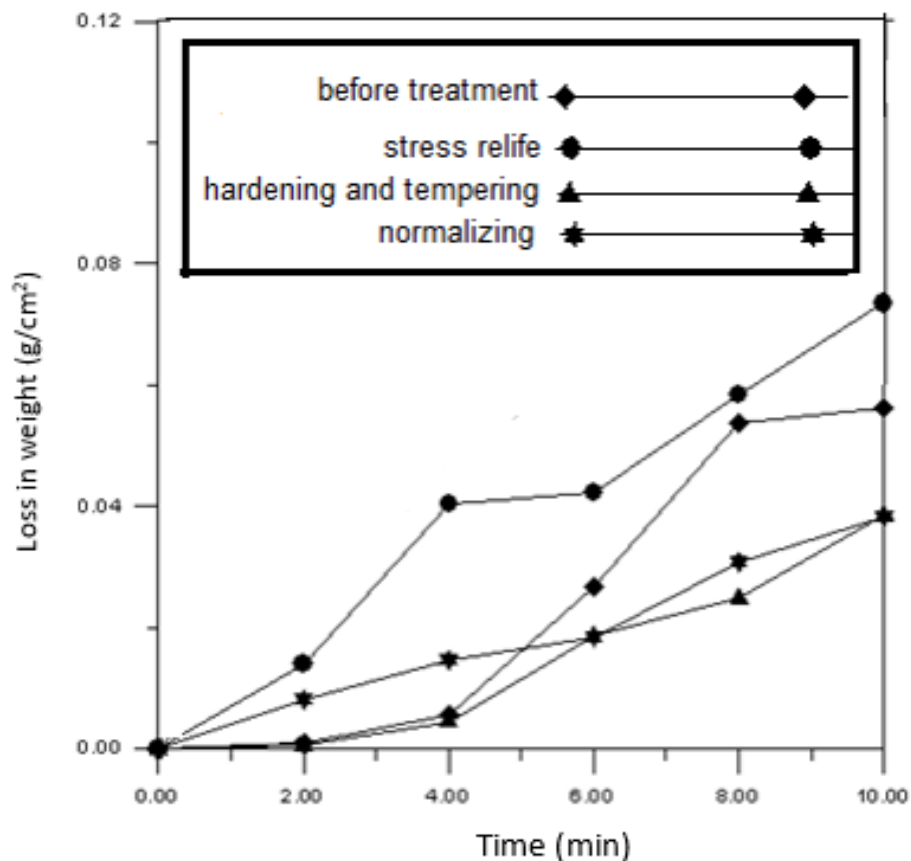


Fig. 6. Loss in weight of G.C.I with time after heat treatments.

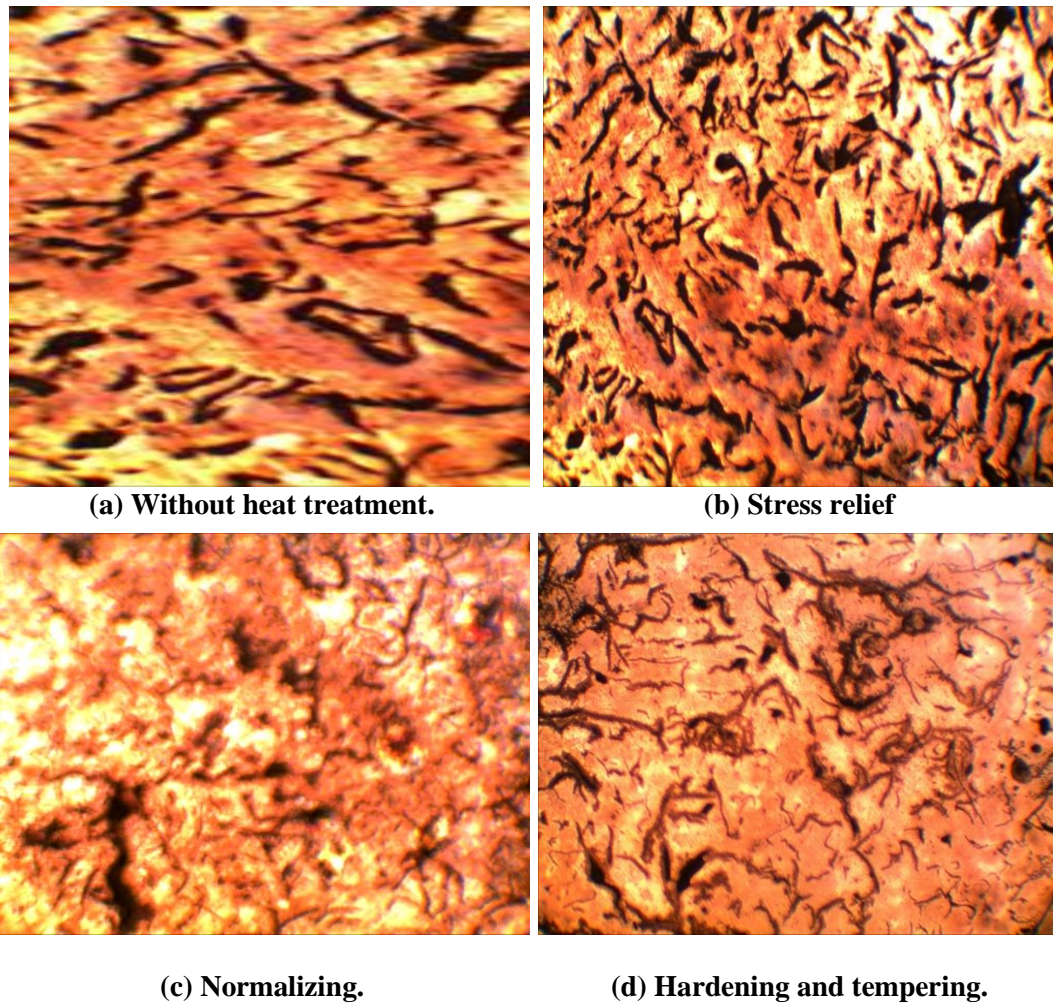


Fig. 7. Optical microstructure of G.C.I samples (100X).

6. CONCLUSIONS

According to the previous results and discussions, the following can be concluded:

1. Maximum wear strength has been obtained at tempered gray cast iron.
2. Maximum vickers hardness has been obtained for gray cast iron specimens that immersed in $\text{Ca}(\text{OH})_2$ solution.
3. Gray cast iron has been corroded at minimum rate in LiOH solution by forming a protective and passive oxide layer
4. Gray cast iron has been corroded at maximum rate of in NaOH solution.

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