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Effect of carburizing time and wear properties on carburized heat treated Chromium (Cr) and Nickel-Chromium (Ni-Cr) steel.

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Abstract

The effect of carburizing time and wear behavior of the carburized, hardened Cr and Ni-Cr steel were studied. Due to the complexity of controlling parameters in carburization, there has been relatively little work on process variables during the surface hardening process. This work focuses on effects of the carburizing temperature and time on the mechanical properties of these steels carburized with activated carbon, at 945ºC, soaked at the carburizing temperature for 1,2 and 3 hours respectively, quenched in salt water. Prior carburization process, standard test samples were prepared from the as received specimen. After carburization process, the wear test was carried out by using pin on disc type apparatus under dead loads of 1.5kg, 2kg and 3kg at a linear speed of 2.64 ms^{-1} in ambient air. The sliding distance was 6336m. It has been obtained, Wear rate increases with the increases of the dead load. Wear rate of Ni-Cr steel found higher than that of Cr steel due to the presence of Retain austenite in Ni-Cr steel. The structure of worn surface was observed, by the digital optical microscopy. The surface hardness was measured by Rockwell hardness tester. The case and core hardness of the carburized, hardened samples were measured by shimadzu's microhardness tester. It has been found that, Ni increases the amount of retained austenite content in the case of the carburized low carbon Cr steel. Ni reduces the surface hardness, case hardness and core hardness of the low carbon Cr steel. The presence of retain austenite along with the martensite that the surface hardness found lower than the maximum hardness of the both the steels. It was concluded that, the mechanical properties of these steels were found to be strongly influenced by the process of carburization, carburizing temperature and soaking time at carburizing temperature.

Keywords: Heat treatment, Packed Carburization, Carburizing temperature, Wear rate, Chromium steel, Nickel-Chromium steel, Hardness, Micro study.

1. Introduction

Steel can be made stronger than pure iron by varying the amount of alloying elements either as solute elements, or as precipitated phases, retards the movement of dislocations that make iron so ductile and so weak, and so it controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. It is associated with increasing the strength of materials, improve formability and restore ductility after cold working process and increasing other desirable characteristics. Steels are particularly suitable for heat treatment. Steels are heat treated for one of the following reasons: Softening, Hardening and Material modification. Carburizing is one of the most commonly performed heat treatment in steel. Perhaps three thousand years ago, it was performed by packing the low carbon wrought iron parts in charcoal, then raising the temperature of the pack to red heat for several hours. The entire pack, charcoal and all, was then dumped into water to quench it. The surface became very hard, while the interior or "core" of the part retained the toughness of low carbon steel[1]. The engineering of surfaces of components to improve the life and performance of parts used in automobiles and aerospace engineering is an active area of research. The others more important treatment processes such immersion hardening, induction hardening and case carburizing[1].Automobile components such as rack and pinion, gears, cam shaft valve rocker shafts and axles, which require high fatigue resistance, are normally case hardened by carburizing. The carburizing furnaces are either gas fired or electrically heated. The carburizing temperature varies from 885 to 950ºC the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbons such as propane, butane or methane[4]. The study of process parameters in metals during heat treatment has been of considerable interest for some years[2,3] but there has been relatively little work on process variables during the surface hardening process since controlling parameters in carburization is a complex problem. The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench time in oil[9]. The present work is focused on the effects of carburizing temperature and holding time on the wear properties of carburized Cr and Ni-Cr steel. Wear can also be defined as a process where interaction between two surfaces or bounding faces of solids within the working atmosphere results in dimensional loss of one solid. Aspects of the working atmosphere which affect wear include loads and features such as unidirectional sliding, reciprocating, rolling and impact loads, speed, temperature, but also different types of counter-bodies such as solid, liquid or gas. Wear rate (m^3/Nm) is volume loss per unit distance and load applied. It depends upon the mass loss of the sample; the more is mass loss, wear rate increases. The following equation is used to calculating the wear rate, $k=V/F_n.d=m_{lost} / (p.F_n.d)$

K: wear rate

V: total volume of material removed during sliding (the wear volume),

F_n is the normal load, d the sliding distance.

m_{lost}: mass lost

The principal alloying elements added to steel in widely varying amounts either singly or in complex mixtures are nickel, chromium, manganese, molybdenum, vanadium, niobium, silicon and cobalt. The Chromium steels (5xxx series) contain between 0.15 to 0.64 percent carbons and between 0.70 to 1.15 percent chromium. It is called low-Chromium steel (51xx series).The presence of Chromium increases the wear resistance of the case, increases strength and toughness of the ferrite. When chromium is present in amounts in excess of five percent, the temperature properties and corrosion resistance of the steel are greatly improved. The nickel-Chromium steels (3xxx series),the ratio of nickel to chromium is approximately 2.5 parts nickel to 1 part chromium. A combination of alloying elements usually imparts some of the characteristic properties of each one. The effect of nickel in increasing toughness and ductility is combines with the effect of chromium in improving hardenability and wear resistance. The combined effect of two or more alloying elements on hardenability is usually greater than the sum of the effects of the same alloying elements used separately. The micro study which is defined as very small scale studies by using optical microscope. The worn surface morphology and microstructure of the carburized steels were carried out using optical microscope. For micro structural investigation samples were prepared by using standard metallographic technique.

2. Materials and Method

The materials used for this research work are low carbon steel. The composition of Cr steel and Ni-Cr based on low carbon steel is presented in Table 1. Steel-1 is Cr steel and steel-2 is Ni-Cr steel.

Table 1.Chemical Composition of steel 1 and 2

Steel no.	Chemical Composition, Wt%						
	C	Si	Mn	S	P	Ni	Cr
1	0.15	0.10	1.26	0.018	0.027	------	0.91
2	0.15	0.12	1.24	0.026	0.027	1.27	0.72

2.1. Test specimen preparation

About 8mm diameter and 6.5mm thick cylindrical specimens were machined from the bars of each of the steels. The surface of these specimens was polished by emery papers up to grit no.2/0.

2.2. Carburization of these steel samples

These steels were carburized by pack carburization method. The prepared test samples were embedded in the activated carbon inside a steel pot which was then tightly sealed with clay cover to prevent the CO from escaping and prevent unwanted furnace gas from entering the steel pot during heating. The furnace temperature was adjusted to the required temperature at 945ºC and the loaded steel pot was charged into the furnace. When the furnace temperature reaches the required carburizing temperature, it was then held/soaked at the temperature for the required time (1, 2 and 3 hrs respectively). After the material was held at the specified time, the steel pot was removed from the furnace and the material was quenched in salt water.

2.3. Tempering of the carburized samples

The carburized test samples were then tempered at a temperature of 160 ºC, held for one hour, and then cooled in air. After the cycles of heat-treatment, the test samples were subjected to wear test and hardness test.

2.4. Wear test

The dimension of wear test specimens was 8mm in diameter and 6.5 mm in length. The wear tests of the carburized samples were carried out under a dry sliding using a pin on disk type apparatus. The carburized specimens were used as pins. Hardened steels with a hardness value of 48-55 HRC having 48 mm diameter were used as rotating counter body. Before the tests, both the pin and the counter body were degreased, cleaned thoroughly in running water and dried immediately by acetone. During the test some dead load of 1.5kg, 2kg, 3kg were used to press the pin against the counter body while disc was moving in the horizontal plans at a liners speed of $2.64 ms^{-1}$ .The tests were conducted for the sliding distance for each specimen was 6336 m. After the predetermined time (40mins) the specimens were taken and weighed. The wear rate for each specimen was calculated from the weight loss.

2.5. Hardness test

In present experimental work, Rockwell hardness was measured on carburized, tempered steel samples which are carburized under the temperature of 945ºC. For each of the sample, test was conducted for 3 times and the average of all the samples was taken as the observed values in each case. The surface hardness of two different carburized steel specimens was taken by the hardness testing machine like Rockwell hardness machine. The micro hardness from subsurface to the core of the lightly etched specimens was measured by using Shimadzu micro hardness tester.

2.6. Optical microscopy

The worn surface morphology and microstructure of the carburized steels were carried out using optical microscope. Sample of wear test specimens were macro examination. For micro structural investigation samples were prepared standard using standard metallographic technique.

3. Results and Discussions

3.1 Surface Hardness and micro hardness

The surface hardness of the carburized, hardened and tempered Cr steel and Ni-Cr steel (Fig.3a.1).From this figure it is clear that the surface hardness of Cr steel is higher than Ni-Cr steel due to Ni reduces the hardness. This is because of higher retained austenite content in Ni-Cr steel. From this fig.3a.1, it is evident that surface hardness of Cr steel is higher than that of Ni-Cr steel for all the carburizing periods used. As the carburization time increases hardness of both steel increased. The micro hardness profile from subsurface to the core of the carburized, hardened and tempered specimens is not same. Fig.3b.1 to fig.3b.3 shows that the hardness of the surface is lower than the maximum hardness. The lower surface hardness in all the steels is clearly due to the presence of retained austenite along with martensite. With the increase in distance from the surface, the content of retained austenite decreases resulting higher hardness. Cr steel produces higher core hardness than Ni-Cr steel. Both the steels contain some ferrite along with low carbon martensite in the core. The amount of ferrite in the core of Cr steel is found lower than that of Ni-Cr steel. The higher core hardness of Cr steel is due to presence of more low carbon martensite than that in Ni-Cr steel.

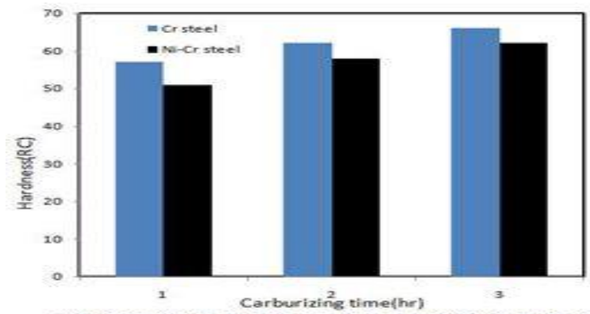

Fig. 3a.1. Surface hardness of Cr and Ni-Cr steel vs. carburizing time

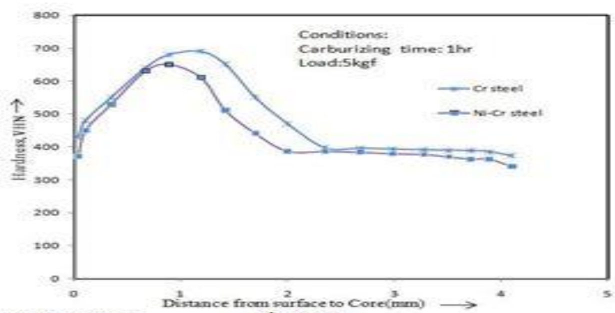

Fig. 3b.1

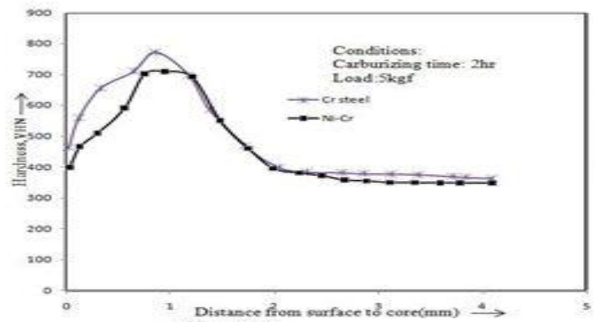

Fig. 3b.2

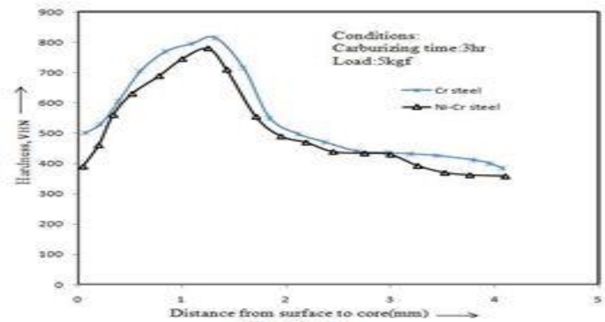

Fig. 3b.3

Fig. 3b.1 to 3b.3. Comparisons of micro hardness profile between Cr and Ni-Cr steel

Table 2. Relationship between surface, maximum and Core hardness of carburized hardened Cr and Ni-Cr Steel.

Steel no.	Carburizing time (hr)	Surface hardness		Maximum hardness		Core hardness	
		Rc	VHN	Rc	VHN	Rc	VHN
01 (Cr steel)	1	44	430	57	680	38	370
	2	46	463	62	770	37	364
	3	50	500	64	815	39	383
02 (Ni-Cr steel)	1	39	370	56	650	36	340
	2	40	400	58	708	37	350
	3	39	390	62	780	38	358

3.2 Wear Behavior

The wear rate which has been measured using weight loss due to wear for steels 1 and 2 for the sliding distance 6336m is plotted. It is evident from this (fig. 3.2) that the wear rate increases with the increase of dead load for both Cr steel and Ni-Cr steel. Wear rate of Ni-Cr steel increases linearly with increasing load. But wear rate of Cr steel does not increase linearly with increasing load. The wear rate of Ni-Cr steel is higher than of Cr steel at the same load. It is found in the micro structure that retained austenite content of Ni-Cr steel is higher than that of Cr steel. Lower retained austenite content in Cr steel increases the wear resistance of case. The addition of Cr in steel shifts the IT curve to the right also changes its shape. When the specimens were cooled in brine solution it did not cut the nose of the IT diagram. So there was not ferrite in the Case. After reaching M_s Temperature, martensite started to form and it was finished when it reached at M_f temperature. The addition of Ni in Cr lowers the M_f temperature. So more austenite became stable and there was more retained austenite in the case of Ni-Cr steel than that of Cr steel. This retained austenite the lower the hardness of the steel. For this the hardness of the Cr steel is higher than that of the Ni-Cr steel. The hardness controls the wear behavior. For this the wear resistance of Cr steel is higher than that of Ni-Cr steel. From this it is clear that wear loss of Ni-Cr steel is much than Cr steel.

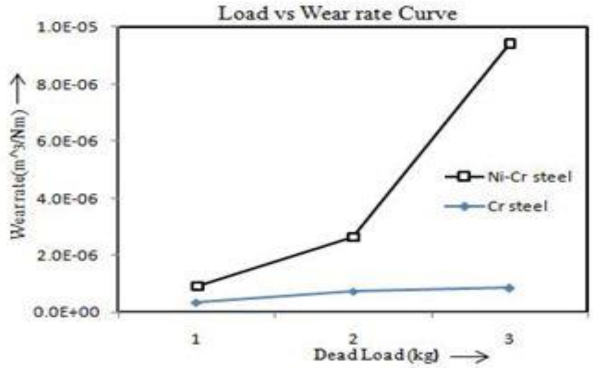

Fig. 3.2. Comparison of wear rate between Cr and Ni-Cr steel

3.3 Wear Mechanism

Wear surface of both steels for different loads are shown figure 3.3. For both the steels, Abrasive groves are observed. The more of the carburization of the steel increases the hardness on the surface by case hardening. Another parameter is dead load. The more of load applied during the wear test that more of mass loss happens. The abrasive grooves on the worn surface increases with increasing load from 1.5kg to 3kg.Steel-1 (Cr steel), at dead load increases more the abrasive grooves formed. Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles. From fig.3.3, first two are Cr steel worn surfaces evident that less plowing is occurred at the 1.5kg load than 3 kg load. From the last two figures are for Steel-2(Ni-Cr steel) evident that more load applied increases the abrasive grooves. Again at the same load, Ni-Cr steels has more abrasive grooves than that of Cr steels because of Ni-Cr steels has lower the hardness.

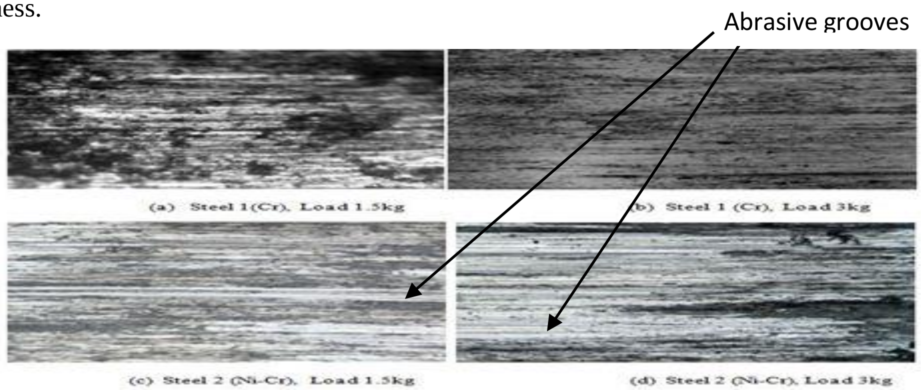

Fig. 3.3. Wear surface of two steels at magnification 20x

3.4 Micro structural study

3.4.1 Case

Optical microscopy revealed that the structures in the case of steels (Cr and Ni-Cr steel) are carburized (both steels are 1, 2, 3h respectively), hardened and tempered consist of high carbon martensite and retained austenite for all the carburizing periods shown in Fig. 3.4 illustrate above features. For all the steels percentage of retained austenite decreases towards the center in the case and at some depth martensite becomes about cent percent. The presence of retained austenite indicates that the carbon content in the surface of all the steels was greater than 0.65%, since it has been reported [2]that the *M*f for carbon content greater than this value is below room temperature. It was also found in Ni-Cr steel (4-6) produced higher percentage of retained austenite than Cr steel (1-3) due to the presence of alloying element like Ni which lower the martensitic transformation temperature that M_f temperature below the temperature of the quenching medium. The retained austenite content also increase with the increase in carburizing time in all the steels. The concentration of carbon in the cases of all these steels increases with the increase of carburizing time. This higher concentration of carbon depresses the *M*f temperature drastically resulting in an increased amount of retained austenite.

3.4.2 Core

Low carbon martensite and few ferrite grains were found in the core of both steels of the carburized, hardened and tempered condition shown in Fig. 3.4 illustrate above features. Carbon cannot be diffused at the core the result of low carbon martensite and few ferrite grains. Cr steel (1-3) produced the coarsest, coarser and coarse low carbon martensite but Ni-Cr steel (4-6) produced fine, finer and finest low carbon martensite. These variations of fineness of low carbon martensite of these steels are clearly due to the difference in their prior austenite grain size [3]. Some ferrite grain was observed along with low carbon martensite in the core of these steels. A few ferrite grains were observed in the core of Cr steel (1-3) contains lesser amount of ferrite grains than Ni-Cr steel (4-6) contains lowest amount of ferrite grains. The presence of ferrite grain indicates that the critical cooling rate in these steels were faster than the actual cooling rated.

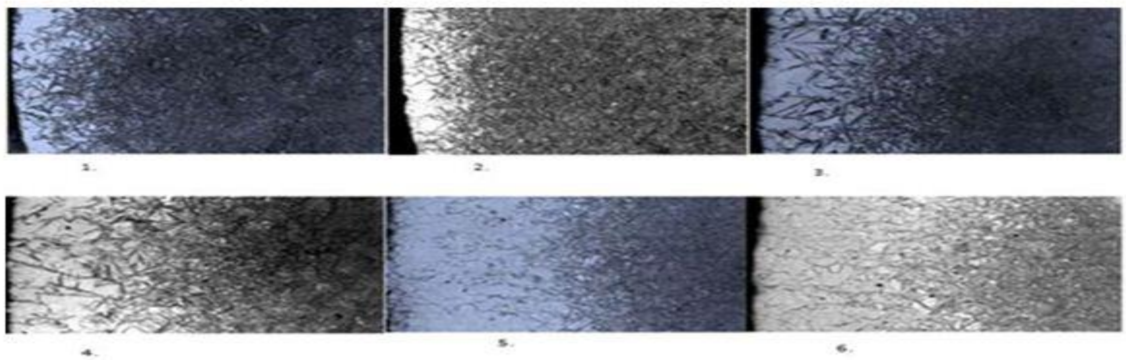

Fig. 3.4. Optical micrographs showing the microstructure in the case and core of carburized (1 to 3 h), quenched (Salt water) and tempered Cr steel (1 to 3) and Ni-Cr steel (4-6).
Etching reagent: 2%Nital, Magnification: 10x

4. Conclusions

From the discussions so far it is concluded that:

- The mechanical properties of mild steels were found to be strongly influenced by the process of carburization, carburizing temperature soaking time at carburizing temperature;
- The carburization process decreases the impact energy (toughness) of the mild steels. And the toughness is decreases with increase in the carburization temperature;
- The carburizing technique is a reasonably satisfactory method for revealing the prior retained austenite in low carbon Chromium and Nickel-Chromium steel. Nickel increases the amount of retained austenite content in the case of the carburized and hardened low carbon Chromium steel. Nickel reduces surface hardness, case hardness and core hardness of the carburized and hardened low carbon chromium steel. The hardness of the surface is found lower than the maximum hardness in both the steels.
- Wear rate of Chromium steel and Nickel-Chromium Steel increases with increasing dead load. Nickel reduces the wear resistance if the case of the carburized and hardened low carbon chromium steel. Predominant wear mechanism for both Chromium and Nickel-Chromium steels is abrasive wear.

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