

Effect of Post Heat-treatment on Hardness and Case Depth of 17NiCrMo6-4 Gear Steel after Liquid Carburizing

^a*M. Ishtiaq, ^aF. Ahmed, ^aBilal Saleem, ^aL.Ali ^bA. Inam, ^cT.A.Tabish

^a*Metallurgical and Materials Engineering, University of Engineering and Technology, Lahore-Pakistan*

^a*Metallurgy and Materials Engineering, College of Engineering and Emerging Technologies, University of Punjab, Lahore-Pakistan*

^c*Institute of Advanced Materials, Bahauddin Zakariya University, Multan-60800, Pakistan*

*Corresponding Author (M. Ishtiaq, ishtiaq_145@yahoo.com)

Abstract

Materials having high hardness and wear resistance are being increasingly used for gear manufacturing. So it is the need of time either to develop such materials or some treatments to achieve such a combination of said properties. Carburization is a thermo-chemical treatment to attain high surface hardness and wear resistance in steels. A hard case is developed over a soft core in steel by diffusion of carbon from carburizing media (solid, liquid, or gas). The gear steel 17NiCrMo6-4 is difficult to carburize by conventional carburizing techniques because of its high nickel content (~ 1.35 wt. %). Therefore, in this work different carburizing bath compositions have been used to carburize 17NiCrMo6-4 steel. It was found that a liquid salt bath of composition Na₂CO₃ (30%), NaCN (40%) and BaCl₂ (30%) worked well for the carburising of the 17NiCrMo6-4 steel. Furthermore, an additional post heat-treatment process has been adapted, in which steel was heated to 850 °C for a period of 2 hours followed by oil quenching. This additional post heat-treatment process proved beneficial and resulted in case depth >1.5 mm and hardness > 50 HRC.

Keywords: liquid carburizing; gear steel; carburizing media; case depth; carbon diffusion

1. Introduction

Surface hardening is a process used to improve wear resistance of parts by changing surface composition without affecting the core of the part [1]. Carburizing is a thermo-chemical surface hardening process in which some heat is needed to enhance the diffusion of carbon into the surface of the part. The depth of case obtained by diffusion is dependent on time as [2]:

$$\text{Case Depth} \propto K \sqrt{\text{Time}} \quad (1)$$

where

K= Diffusivity Constant; depends upon temperature.

In the case of liquid carburizing, immersion time varies from 30 minutes to 15 hours for the required case depth. [3]

Carburizing can be performed in various atmospheres like solid, liquid, gaseous, vacuum and plasma. Gas carburizing is the most widely used now a days and it uses hydrocarbon gases as carburizing medium. Liquid carburizing uses different molten salts for surface carburization, and it is quick, efficient and economical process. Furthermore, it produces uniform surface. Mainly cyanide is used as a source of carbon in liquid carburizing process [4]. Carburizing using cyanide is also called cyaniding. Parts to be carburized are immersed in a bath of molten salts with varying concentration of sodium cyanide between 25% and 90%. In this process, sodium cyanide is oxidized to produce carbon and nitrogen in atomic form which are diffused in to the surface of the part. A hard case of 0.5- 2.0 mm depth can be achieved depending upon the time and temperature [5,6]. The case depth also depends upon the available carbon potential at the surface [7] and the dimensions of the part or work-piece. Case depth would be equivalent to a depth of carbon penetration down to 0.40% C assuming that only martensite will form in the case on

quenching [8]. The solubility of carbon is maximum in austenitic region and the amount of dissolved or diffused carbon determines the final hardness, but when the carbon concentration at the surface exceeds 0.70%, the Ms-temperature falls steeply resulting in decrease in hardness because of increase in the amount of retained austenite after quenching. By controlling the amount of retained austenite, the final hardness can be controlled [9].

Gears, used for rotation or relative movement of almost all machine parts, are the most important components. They tend to reduce the friction among the machine parts and increase the life length. So the gears are supposed to sustain high wear, have high fatigue life and bear high loads in different environments. It makes necessary for the gears to possess hard and wear resistant surfaces along with tough and shock resistant cores. So these properties are enhanced by surface hardening treatment like carburizing. [10]

In the present research work, the effect of carburizing on the microstructure, hardness and case depth of 17NiCrMo6-4 steel was examined using liquid carburizing media. The aim was to increase the hardness and case depth of the steel grades to make them suitable for gear applications. A local industry had to produce gears from 17NiCrMo6-4 steel and then the surfaces of these gears were required to be hardened using carburizing process. But they were facing the issue that carburizing in gas as well in liquid baths was not giving the required case depth (>1.5 mm) and hardness (>50 HRC). In literature no data/solution is available to this specific problem. In order to resolve this issue, carburizing in two different liquid carburizing media was carried out. Furthermore, an extra step of post carburizing heat treatment followed by oil quenching was also proposed for the deep diffusion of carbon to increase the case depth.

2. Experimental Work

The samples of 17NiCrMo6-4 steel were procured from a local industry and the chemical analysis was carried out using Maxwell Spectrometer Germany (Model 2010). The chemical composition (wt. %) of the steel is given in Table 1.

Table 1. Chemical composition (wt. %) of 17NiCrMo6-4 steel.

Material Designation	C	Mn	Cr	Ni	Mo
17 CrNiMo6-4	0.17	0.75	0.95	1.35	0.20

The samples were machined into rod shape having 4 inch diameter and 1.5 inch length in a lath machine. Then, the samples were carburized in two different carburizing salt-baths. The compositions of salt-baths are given in Table 2.

Table 2. Compositions of the salt-baths used for liquid carburizing.

Baths designations	NaCN(%)	BaCl ₂ (%)	Na ₂ CO ₃ (%)
Bath-1	30	70	-----
Bath-2	30	30	40

In the first experiment, the samples were carburized in Bath-1 for a period of 4 hours at 930 °C and then oil quenched.

In order to study the effect of carburizing time, few samples were carburized in the same bath (Bath-1), at same temperature (930 °C) for a period of 6 hours and then oil quenched, in the second experiment.

In the third experiment, the samples were carburized in Bath-2 for a period of 4 hours at 930 °C and then quenched in oil.

An additional heat-treatment process was used to improve the case depth by heating the carburised samples at a temperature of 830 °C for a period of 2 hours in an electric chamber furnace followed by oil quenching.

Then, the carburized samples were tested for hardness and case depth using micro-Vickers hardness tester. The hardness values reported are taken as the mean of three readings. For microscopic examination, the samples were sectioned, mounted, ground and polished by following standard metallographic procedures and methods. The samples were etched by 2% nital. Digital micrographs were taken by using CCD camera attached to the optical microscope.

3. Results and discussion

The samples carburised in the Bath-1 for a period of 4 hours showed hardness of 38-40 HRC and no visible case depth was found. It was assumed that the carburizing time might be less; therefore, the samples were then carburized in the same salt-bath (Bath-1) for an extended period of time of 6 hours and tested for case depth and hardness. Again no hard case was found and the hardness of 40-43 HRC was recorded.

An optical micrograph showing microstructure across the cross section of a sample, given in Fig. 1 does not reveal any carbon diffusion/penetration from the salt-bath after carburisation of 6 hours. The reason might be the absence of inert salts like NaCl or K₂CO₃ from cyanide bath, which are used to provide fluidity and to lower the melting point of the mixture and thereby enhance the carburizing process [2].

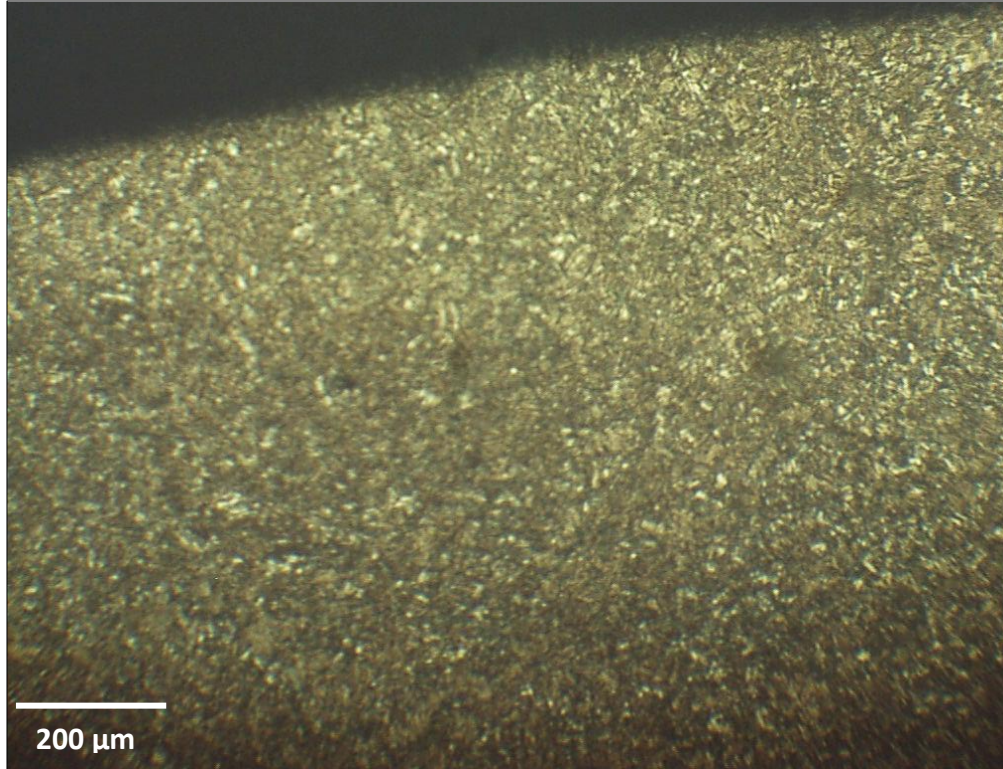


Fig.1 Micrograph showing microstructure across the cross sections of the sample, carburized in Bath-1 for a period of 6 hours at temperature of 930 °C.

In order to check carburizing potential of the salt-bath, few mild steel samples were carburized in the Bath-1 under same conditions, and a reasonable case depth and hardness were achieved. It appears that the specific composition of this steel may also be resisting the diffusion of carbon.

In order to study the effect of bath composition, the samples were carburized in Bath-2 (containing additional Na_2CO_3) for a period of 4 hours at temperature of 930 °C followed by oil quenching at about 80 °C, then, water quenching at room temperature.

The samples were then visually examined for case depth after face turning on a lathe machine, and a case depth of ~0.75 mm was appeared as a shiny periphery. The hardness value

recorded was 60 HRC. These results revealed that the composition of salt-bath Bath-2 suited well to 17NiCrMo6-4 steel for liquid carburizing as the hardness value was found >50 HRC.

As far as the case depth was concerned it was still less than required as revealed in Fig. 2.

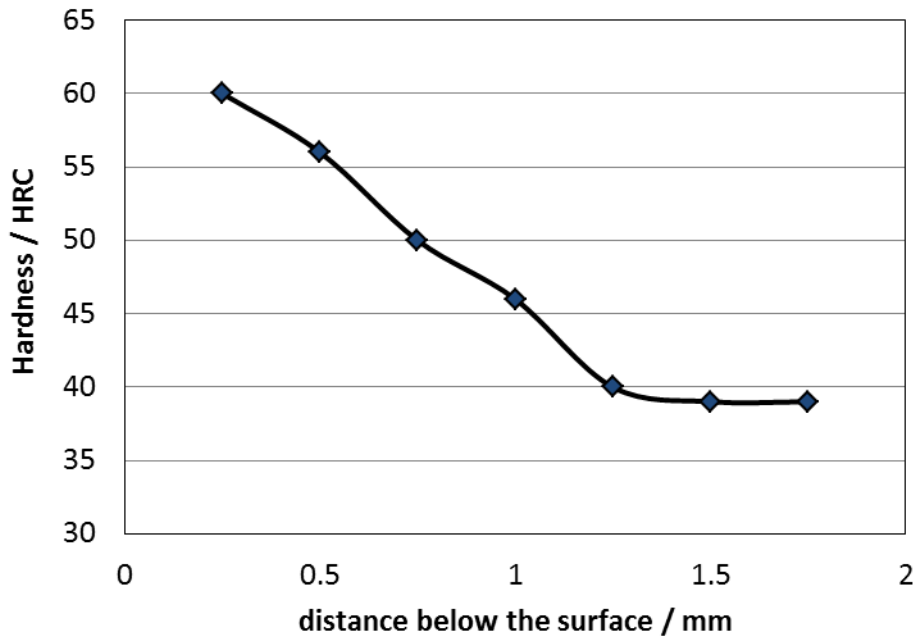


Fig. 2. Hardness profile taken along the cross-section (below the surface) of carburized 17NiCrMo6-4 steel in Bath-2 at 930 °C for 4 hours.

The graph shows that the surface hardness of the steel is 60 HRC and at 0.75 mm distance below the surface the hardness is 50 HRC but below 0.75 mm steel does not have sufficient hardness to comply with the application requirements. The microstructure of the carburized sample as shown in Fig. 3 reveals martensitic microstructure and indicating increased carbon content at the surface by presence of dark area due to high attack of nital.

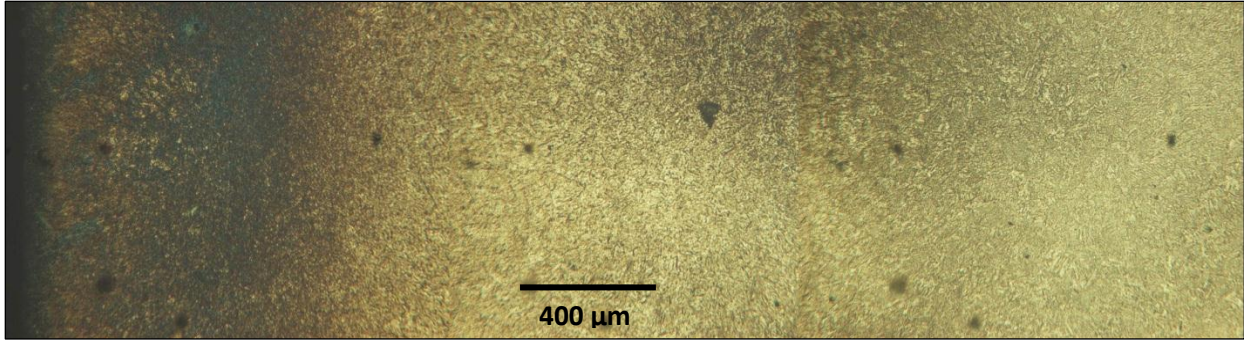


Fig. 3. The panoramic micrograph taken along the cross section of the steel sample carburized in Bath-2 at 930 °C for a period of 4 hours. (2% nital)

Since the case depth was less than the required value i.e. 1.5 mm, therefore, an additional step of post carburizing heat-treatment was adopted by heating the samples to a temperature of 830 °C for a period of 2 hours in an electric chamber furnace followed by oil quenching.

The objective of this post heat-treatment process was to further diffuse carbon from surface to core of the samples. This post heat-treatment step was proved beneficial as the depth of case was increased from 0.75 to 1.50 mm.

The hardness values across the case depth are plotted as a graph as shown in Fig. 4. It can be seen in Fig. 4 that at the surface maximum hardness is ~66 HRC and at a distance of 1.5 mm, it reduces to 50 HRC, which shows sufficient case hardness till 1.5 mm distance from the surface i.e. case depth is ~1.5 mm.

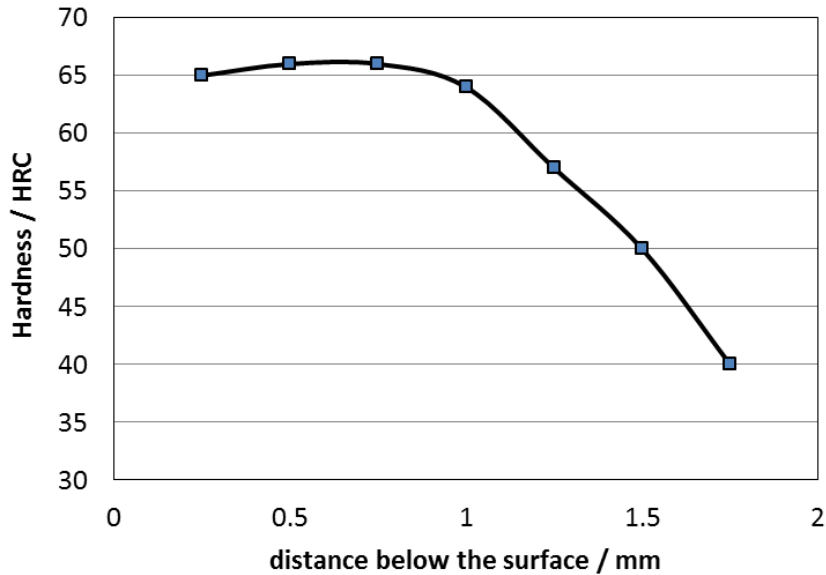


Fig. 4. Hardness profile taken along the cross-section (below the surface) of carburized 17NiCrMo6-4 steel in Bath-2 and diffused at 830 °C for 2 hours.

The microstructure taken along the polished and etched cross section of the sample carburized in Bath-2 and diffused at 830 °C for 2 hours is given in Fig. 5.

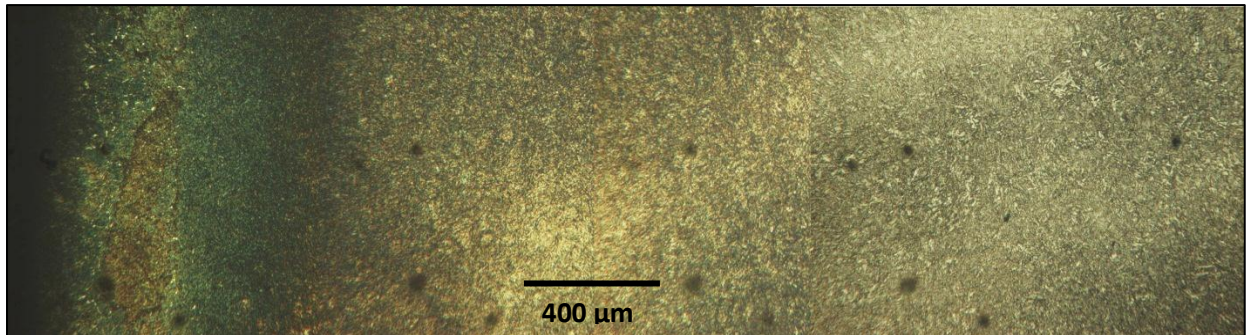


Fig.5 The panoramic micrograph taken along the cross section of the sample carburized in Bath-2 and then diffused at 830 °C for 2 hours.

It shows martensite along with varying degree of carbides, comparatively larger grain size at the surface than the core indicating increased carbon content at and below the surface. Now the carbon at the surface has diffused deeper than earlier (just carburized in Bath-2) which has also

been reflected by the presence of larger dark area due to higher attack of nital and increase in hardness values. This additional step of post heat treatment has added to the cost of the component but there is no other solution available to resolve this problem.

4. Conclusions:

The objective of the research was to enhance the hardness and case depth of the steel grade to make this appropriate for gear applications. The gear steel 17NiCrMo6-4 is difficult to carburize by using salt-bath containing NaCN and BaCl₂. Salt-bath containing Na₂CO₃ along with NaCN and BaCl₂ worked well for the carburizing of 17NiCrMo6-4 steel. Case depth can also be improved by post carburizing heat-treatment process as it diffuses the surface carbon deeper into the sample. In the current work, the effect of carburizing on the microstructure, hardness and case depth of 17NiCrMo6-4 steel was evaluated using liquid carburizing media.

References:

- [1] S. Lampman, Introduction to Surface Hardening of Steels, Heat Treating, Vol. 4, ASM Handbook, ASM International, (1991) 607.
- [2] J. R. Davis, Surface hardening of Steels, ASM International,(2002) 01.
- [3] B. K. Agarwal, Introduction to Engineering Materials, Tata McGraw-Hill edition, (2007) 162.
- [4] K. H. Prabhudev, Hand Book of Heat Treatment of Steels, Tata McGraw-Hill edition, (2008) 302.

- [5] F. D. Waterfall, Case- Hardening Steels in Cyanide-containing Salt Baths, *Mettallurgica*, (1949) 29-33.
- [6] M. A. Grossman and E. C. Bain, *Principles of Heat Treatment.*, (Edited by M. Hetenyi), ASM, Cleveland, OH. (1964)
- [7] “Case Hardening of Steel”, ASM International, Vol. 1 (1987) 4
- [8] Beumelburg, The Behaviour of Case-hardened Specimens of Various Surface Finish and Surface Carbon Content when subjected to Rotating Bend Test, Static Bend Test and Impact Bend Test, Thesis, University of Karlsruhe, Germany. (1964)
- [9] G. H. Robinson, The Effect of Surface Condition on the Fatigue Resistance of Hardened Steel, *Fatigue Durability of Carburized Steel*, American Society for Metals, Cleveland, Ohio, (1957) 11-46.
- [10] A.K. Rakhit, “Heat Treatment of Gears” “A Practical Guide for Engineers”, ASM Internationals (2000) 1-4.