

A STUDY OF ESSENTIAL PARAMETERS ON GAS CARBURIZING OF AISI 8620 (Ni-Cr-Mo) ALLOY STEEL

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Abstract

Carburizing of steel components is an essential process in the automotive industry especially for heavy load bearing machine parts such as gear teeth, pinions, crank and camshafts. Carburizing is used to induce carbon in the steel component and the final part has a surface of higher carbon content whereas the core remains soft, thus making it to bear heavy loads. In this paper effect of physical and chemical parameters in gas carburizing atmosphere furnace were observed. Various samples of 8620 steel were carburized in different furnaces for discrete time periods and temperatures followed by water, oil quenched and tempered. The gas carburized samples were characterized performing different tests like impact, hardness and metallographic. Any changes in properties were determined. It was concluded that for optimum carburizing of 8620 alloy steel with a case depth of 1 mm after carburizing the samples, the temperature in the furnace should be lowered to 830°C before quenching in oil medium to avoid distortion.

Keywords: Carburizing; CCF (Continuous Carburizing Furnace); Tempering.

INTRODUCTION

Carbon is dissolved in surface layers of metallic parts at the temperatures required to produce an austenitic microstructure in low carbon steels. Austenite is then subsequently converted into martensite by quenching and tempering [Chandler 2007]. Carburizing is carried out to obtain a surface carbon content of 0.6 to 1.10%, with still higher surface carbon content. The carburizing temperature varies from 870 to 940 °C and the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbons. Such temperature limits are imposed to avoid the wear

and tear of furnace accessories which along with the parts also get carburized [Drotlew 2005, Aramidea 2009].

In gas carburizing, the most important variant of carburizing available commercially as a source of carbon is a carbon-rich furnace atmosphere produced either from gaseous hydrocarbons, for example, methane (CH₄), propane (C₃H₈), and butane (C₄H₁₀), or from vaporized hydrocarbon liquids [ASM Handbook]. More recent approaches include the acetylene pyrolysis under vacuum and electric discharge carburizing conditions [Khan et al. 2007].

GAS CARBURIZING ATMOSPHERE REACTIONS

Gas carburizing utilizes endothermic based gas (carburizing gas) as a carrier gas. Endothermic carburizing atmosphere consists of a mixture of carburizing (CO, CH₄) and decarburizing (CO₂, H₂O) agents; their ratio determines the carburizing potential. The driving force for carburizing is determined by a gradient between carbon potentials in the atmosphere as well as at the steel surface. Endothermic gas is most commonly produced by mixing air and natural gas in a fixed proportion, where the ratio may range from 2.5 to 5. The carrier gas entering the furnace is composed of CO, CO₂, CH₄, H₂, H₂O and N₂. During carburizing some important reactions are as under:



As carburizing proceeds most rapidly by CO molecule decomposition, the by-products of these carburizing reactions (CO₂ and H₂O) act as decarburizing agents. The presence of CO₂ even in small quantities requires a high CO concentration to balance this decarburizing action. Since carburizing with endothermic gas only is practically inefficient and requires large flow rates, the endothermic carrier gas is enriched by blending with an additional hydrocarbon gas.

The purpose of the enrichment of a gas is to react with CO₂ and H₂O, thus reducing their concentration and producing more CO and H₂ gases as reaction products:



Although enrichment reactions (1.4) and (1.5) are slow and do not approach equilibrium, effectiveness of such carburizing process is determined by the atmosphere carbon potential and controlled by the ratio of CO/CO₂ and H₂/H₂O components in the heterogeneous water-gas reaction [Karabelchtchikova 2007]:



It is estimated that 90% of gear carburizing is performed in a carbonaceous gas atmosphere. Varying the ratio of methane to air alters the composition of endothermic gas and corresponding chemical reactions slightly. Free carbon resulting from chemical reactions is then dissolved in the austenite phase which is formed when gears are heated above 720 °C (1330 °F) and is precipitated as iron carbide (Fe_3C) [Rakhit 2010].

CARBON POTENTIAL

Considering the reaction (1.1) where C (Fe) is carbon dissolved at the surface of steel. The equilibrium condition for the reaction can be written as:

$$K_1 = P_{\text{CO}}^2 / a_c \cdot P_{\text{CO}_2} \quad (1.7)$$

where P_{CO} and P_{CO_2} are partial pressures of CO and CO_2 in the gas atmosphere. From a thermodynamic data K_1 comes out to be a function of temperature only,

$$\log K_1 = - 8918/T + 9.1148 \quad (1.8)$$

The activity of carbon, a_c can be obtained from equation (1.7):

$$a_c = P_{\text{CO}}^2 / K_1 \cdot P_{\text{CO}_2} \quad (1.9)$$

The carburizing atmosphere normally contains H_2 and H_2O also. By considering equation (1.6) and generating the equilibrium constant from the thermodynamic data:

$$\log K_2 = 1764/T - 1.627 \quad (2.0)$$

and

$$K_2 = P_{\text{CO}} \cdot P_{\text{H}_2} / P_{\text{CO}_2} \cdot P_{\text{H}_2\text{O}} \quad (2.1)$$

$P_{\text{CO}}/P_{\text{CO}_2}$ and $P_{\text{H}_2}/P_{\text{H}_2\text{O}}$ are related. The carbon potential of the atmosphere can be estimated from either $P_{\text{CO}}/P_{\text{CO}_2}$ and $P_{\text{H}_2}/P_{\text{H}_2\text{O}}$ [Singh 2004].

MATERIALS AND METHODS

MATERIALS AND INSTRUMENTATION

Furnace types and Variables in the Carburizing Process

The carburizing process was done in two furnaces i.e. continuous carburizing furnace and batch furnaces, also there is specifications of the Endothermic gas generators. Operating conditions and different parameters of the furnaces and endo gas generator are given below:

Endogas Generator for Continuous Carburizing Furnace

Air flow rate	:	380 cubic ft hr ⁻¹	
Air pressure	:	760 mmHg at 20 °C	
CH ₄ flow rate	:	200 cubic ft hr ⁻¹	
CH ₄ pressure	:	760 mmHg at 20 °C	
Maximum temperature of endo gas generator	:		1005 °C

Continuous Carburizing Furnace Zones

Zone 1	920 °C	pre-heating
Zone 2	925 °C	carburizing
Zone 3	890 °C	carburizing+Diffusion
Zone 4	840 °C	carburizing+Diffusion
Zone 5	790 °C	hardening

Carbon potential : 0.9-1

Dew point : -4 to +4

Endo gas enters in continuous carburizing furnace at 25 bars and the overall time for process is 8 hours.

Quenching medium is oil.

Endo gas Generator for SQF (Batch Type Furnace)

Air Flow rate	:	100 cubic ft hr ⁻¹
Air Pressure	:	760 mmHg at 20 °C
CH ₄ flow rate	:	90-100 cubic ft hr ⁻¹
CH ₄ pressure	:	760 mmHg at 20 °C

The flow rate at which endo gas enters SQF is about 110-120 cubic ft hr⁻¹.

SQF (Batch Type Furnace)

Single zone furnace	:	920
Hardening temperature	:	820 °C for 1 hr.
Total time of process	:	5-6 hrs.
Carbon potential	:	CP>1
Dew Point	:	-4 to +4
Quenching medium	:	Oil

RESULTS AND DISCUSSION

Table 1 shows the composition of 8620 Alloy steel prior to Carburizing, whereas Fig. 1 represents micrograph of normalized specimen of 8620 Ni-Cr alloy steel before carburizing, the observed microstructure is homogenous with a grain size of about 7 mm while the suitable range of grain size for carburizing is about 5 to 8 mm. Thus it is within the required range, so this material can undergo carburizing effectively. Table 2 shows case depth, case and core hardness determined for different carburizing times. Case

depth is a strong function of carburizing time as time period is increased the case depth is also increased. Increasing or decreasing the case depth will also have an influence on hardness. Fig. 2 (a, b) shows the effect of time on case depth as well as the carburizing time on hardness of the part. Table 3 shows case depth, case and core hardness for different carburizing times after tempering at different temperatures; it shows that there is a decrease in case hardness but this job is done to decrease the amount of retained austenite which causes brittleness. Case depth also depends on the carbon concentration of the processing furnace and core hardness and case hardness are the functions of carburizing time as well as tempering. All of these samples were tempered at 200 °C.

Table 1: Composition of 8620 Alloy steel prior to Carburizing.

Elements	C	Mn	P	S	Si	Cr	Ni
Weight %	0.20	0.817	0.040	0.053	0.098	0.560	0.455

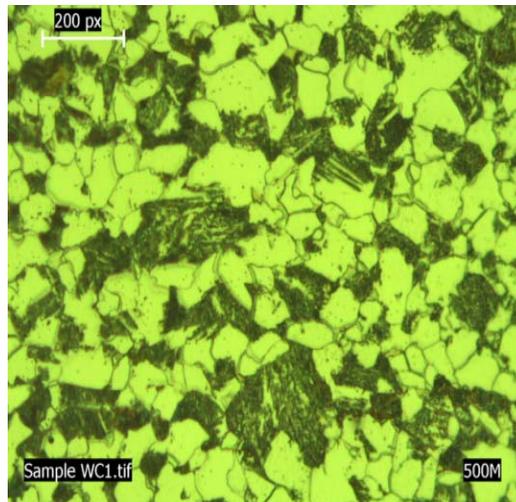


Fig. 1: Normalizing of 8620 Ni-Cr alloy steel before carburizing.

Table 2: Case depth and hardness of oil quenched parts (without tempering).

Sample	Furnace Type	Carburizing Time (hrs)	Case depth (mm)	Core hardness (HRC)	Surface hardness (HRC)
2 WT	CCC	8.0	0.8	32	61
3 WT	SQF5/BT	5.5	0.7	30	64
5 WT	SQF1/BT	5.0	0.8	32	63

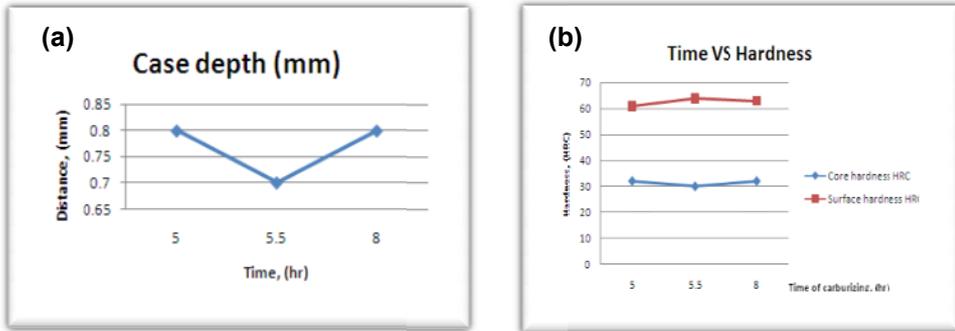


Fig. 2: Effect of carburizing time (hr) on case depth (a) and hardness (b) of 8620 alloy steel before tempering.

Table 3: Case depth and hardness of oil quenched parts (after tempering).

Sample	Furnace Type	Carburizing time (hrs)	Case depth (mm)	Core hardness (HRC)	Surface hardness (HRC)	Tempering time (hrs)	Tempering temperature (°C)
2 T	CCC	8.0	0.6	30	58	2	200
3 T	SQF5/BT	5.5	0.8	32	59	2	200
5 T	SQF1/BT	5.0	0.8	31	60	2	200

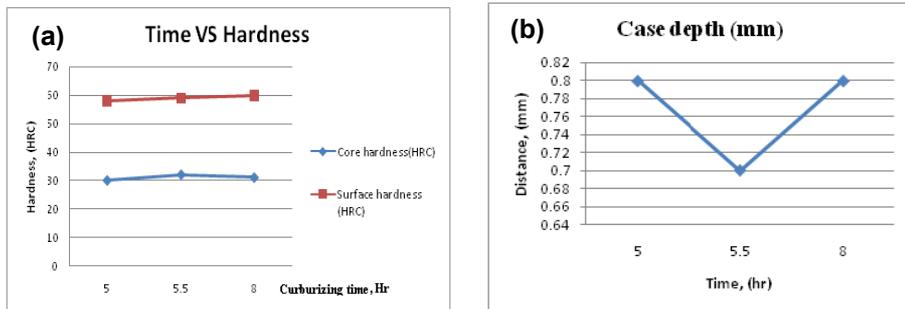


Fig. 3: Effect of carburizing time (hrs) on hardness (a) and case depth (b) of 8620 alloy steel after Tempering.

Fig. 3 (a, b) and Tables (4-6) are continuation of different samples that were carburized in the batch and continuous carburizing furnaces. Fig. 4 (a, b) represents tempering carried out at different temperatures and times for different samples to achieve standard hardness of 60 HRC. The tempering temperatures were 120 °C, 150 °C, 180 °C, and 200 °C. Time duration for tempering was one hour for each sample at each temperature. Hardness before tempering was 64 HRC after carburizing in SQF (Batch type furnace) for 5.5 hours. Fig. 5 shows the results of impact test on carburized and uncarburized 8620 samples.

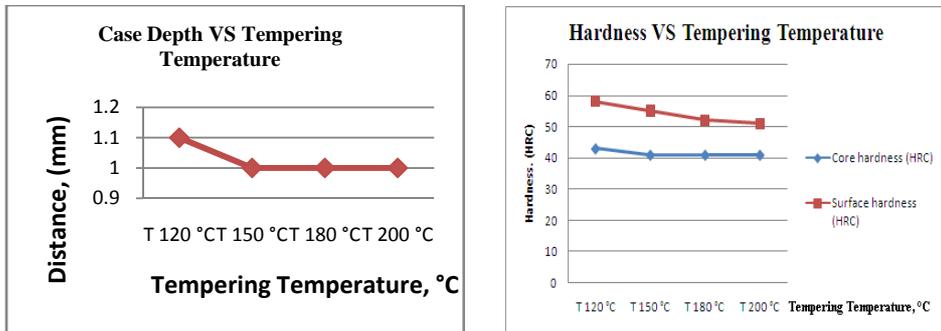


Fig. 4: Relationship between case depth (a) as well as hardness (b) with tempering temperature.

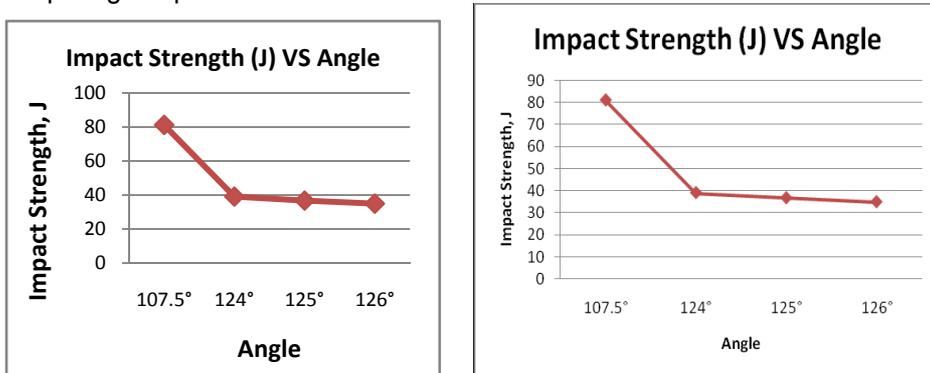


Fig. 5: Relation between impact strength and angle of impact in carburized (a) and uncarburized (b) 8620 alloy steel.

Table 4: Results before tempering.

Sample	Carburizing time (hrs)	Case depth (mm)	Core hardness (HRC)	Surface hardness (HRC)
3 WT	5.5	0.7	30	64

Table 5: Results after tempering.

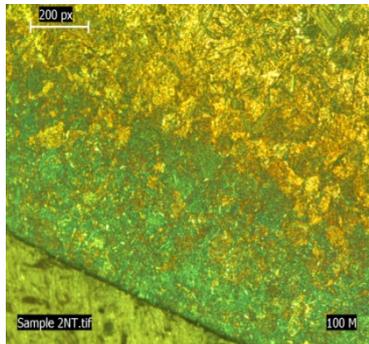
Sample	Tempering Temperature (°C)	Case depth (mm)	Core hardness (HRC)	Surface hardness (HRC)
1	120	1.1	43	58
2	150	1.0	41	55
3	180	1.0	41	52
4	200	1.0	41	51

Table 6: Effect of Impact strength of 8620 alloy steel after Carburizing.

Sample	Carburizing time (hrs)	Angle (Θ)	Impact Strength (J)
1	Not carburized	107.5°	81.24
2	8.0	124.0°	39.10
3	5.5	125.0°	36.75
4	5.0	126.0°	34.95

Results for sample 02 are represented in Figs. 6-8. The microstructures of carburized and uncarburized 8620 samples are presented in Figs. 9-18. Microstructures are without any tempering therefore, there is an excess amount of coarse bainite and less percentage of coarse martensite but after tempering the excess bainite becomes finer and the martensite is more uniformly and evenly distributed. The white region in the micrograph is retained austenite which is about 25% (Figs. 9-18). From these results it can be concluded that the amount of tempered martensite increases on tempering and bainite becomes finer so that the surface hardness decreases with corresponding tempering. Sample 03 and 04 also show the same results but in batch carburizing furnaces. Impact test results show that toughness of a material is inversely proportional to the impact strength as toughness increases impact strength decreases and as toughness decreases impact strength increases. This result is due to the increasing hardness of the case.

Before Tempering



After Tempering

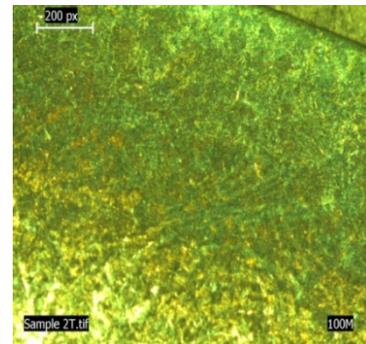


Fig. 6: Martensite (Greenish) and Bainite (golden) structures of oil quenched Sample 02 (8 hrs carburizing in Gibbons (Continuous Carburizing Furnace)).

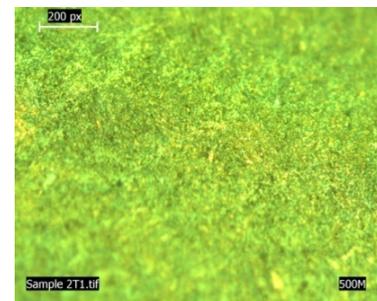
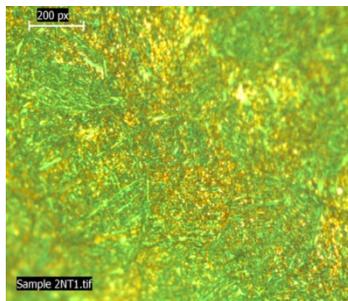


Fig. 7: Martensite structure in both micrographs.

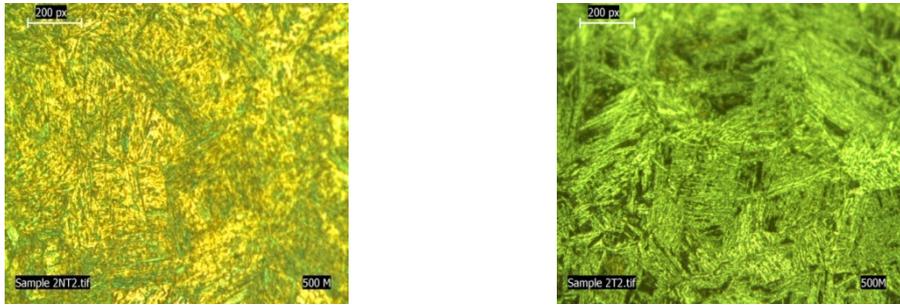


Fig. 8: Bainite structure in both micrographs.

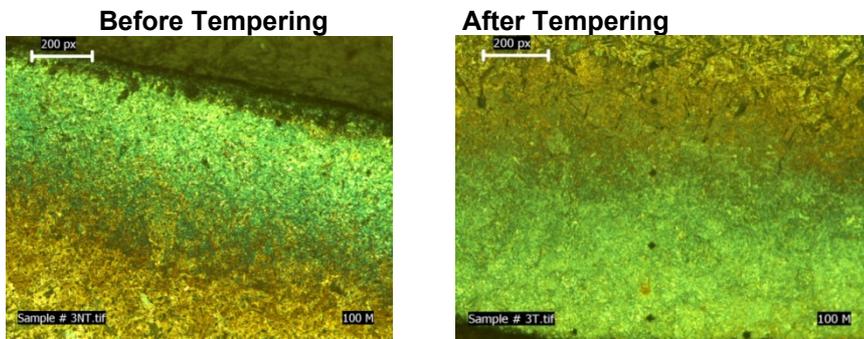


Fig. 9: Martensite (Greenish) and Bainite (golden) structures of oil quenched sample 03 after 5.5 hrs carburizing in SQF 5.5 (Batch type carburizing furnace).

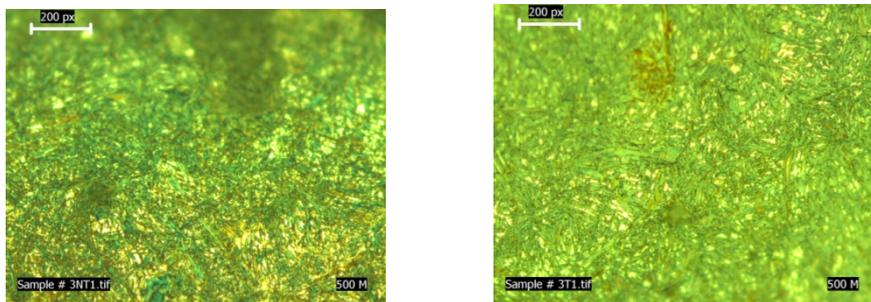


Fig. 10: Martensite Structure in both micrographs.

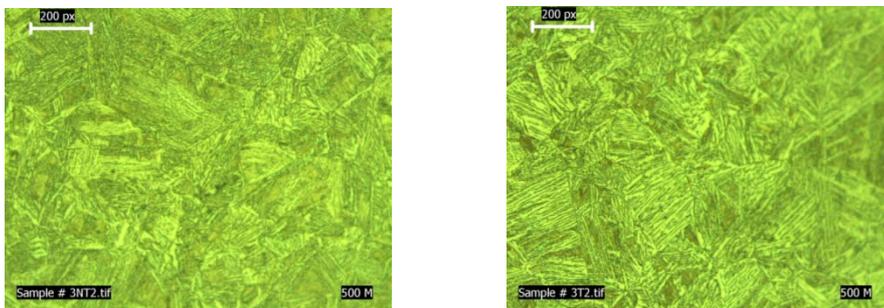


Fig. 11: Bainite structure in both micrographs.

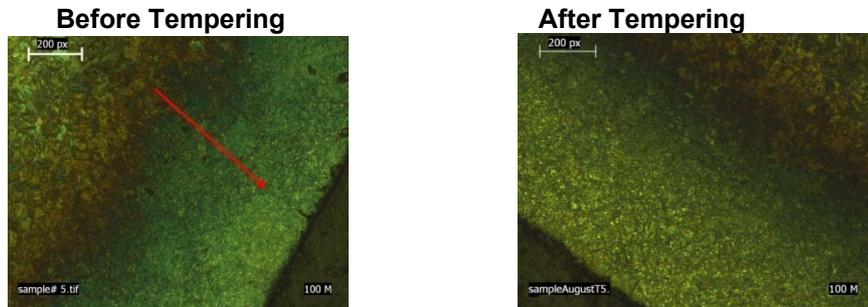


Fig. 12: Martensite (greenish) and Bainite (golden) structures of oil quenched sample 04 after 5 hrs. carburizing in SQF 5 furnace.

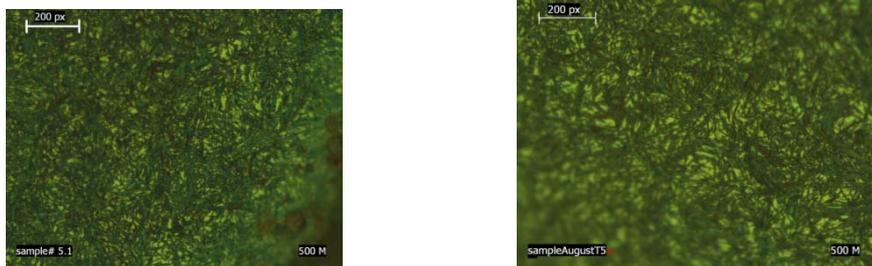


Fig. 13: Martensite structure in both micrographs.

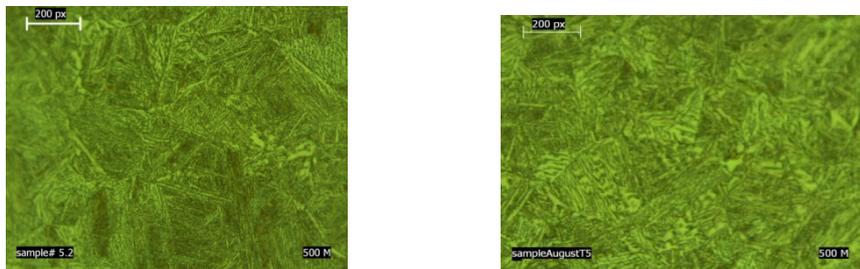


Fig. 14: Bainite structure in both micrographs.

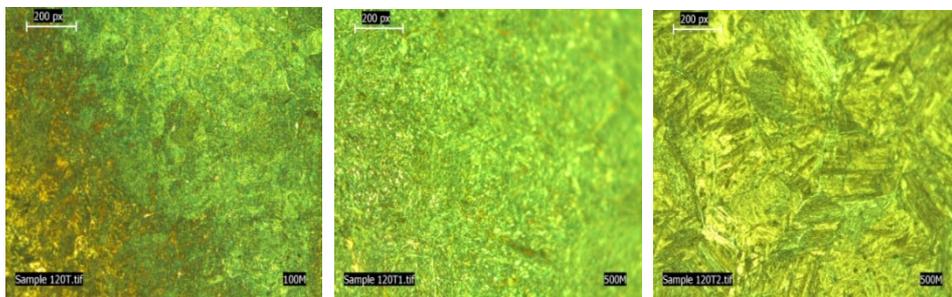


Fig. 15: (a) Martensite and bainite, (b) martensite, (c) bainite structures of samples tempered at 120 °C.

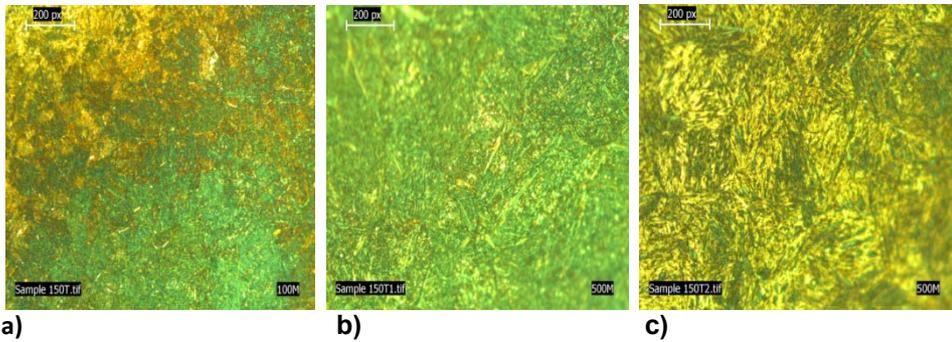


Fig. 16: (a) Martensite and bainite, (b) martensite, (c) bainite structures of samples tempered at 150 °C.

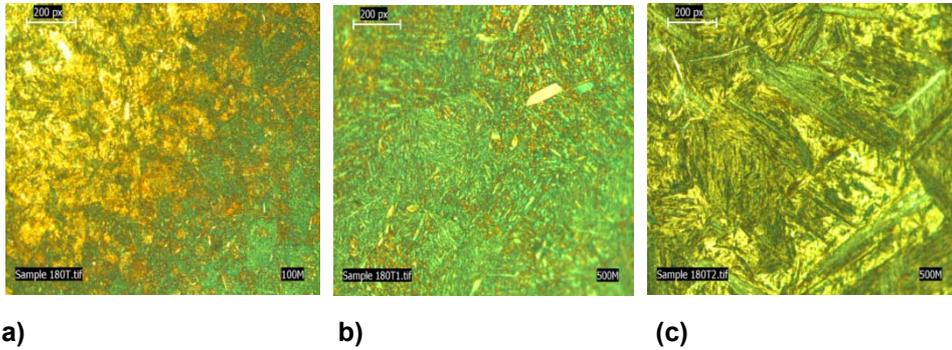


Fig. 17: (a) Martensite and bainite, (b) martensite, (c) bainite structures of samples tempered at 180 °C.

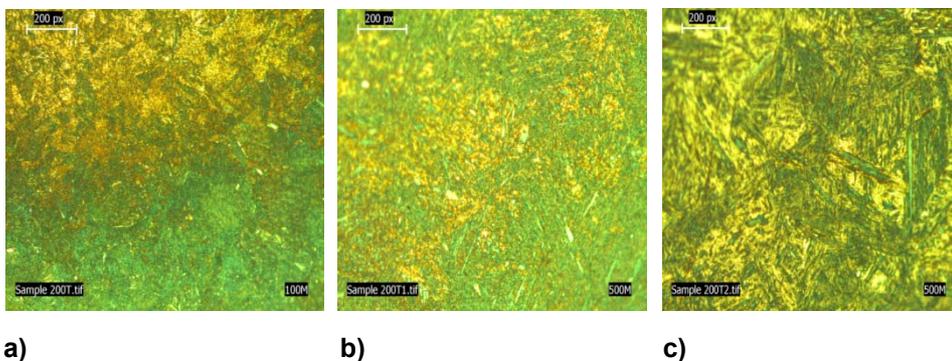


Fig. 18: (a) Martensite and bainite, (b) martensite, (c) bainite structures of samples tempered at 200 °C.

CONCLUSIONS

Following conclusions have been drawn from the current research:

- Case depth depends upon the carbon concentration of the processing furnace.
- Case and core hardness are functions of carburizing time and temperature.
- The amount of tempered martensite increases after tempering and bainite becomes finer so that the surface hardness decreases with corresponding tempering.
- Surface hardness is a function of tempering temperature as tempering temperature increases the surface hardness decreases.
- The toughness of a material is inversely proportional to the impact strength as toughness increases impact strength decreases and as toughness decreases impact strength increases.

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