Study the effect of case carburizing on the mechanical properties and microstructure of local structural steel by using different time and temperatures

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Abstract

The main purpose of this paper is an experimental study for the effect of pack carburizing of local structural steel on its mechanical properties and microstructure by using two parameters (holding time and carburizing temperature). This study was conducted by using electrical furnace. This process is carried out at temperatures from 950°C at four various duration times which are 1, 2, 3 and 4 hours.
From the experiment, the surface hardness and thickness of carbon layer was different according to the parameters used. The quenching medium that use in this experiment is water. For carburizing temperature at 950°C, the highest value of surface hardness was 286.33HV when carburized for one hour. Metallurgical investigation was conducted and it was observed that quenched sample form a martensite microstructure due to rapid cooling. As for carburizing and tempering process, it formed pearlite and ferrite microstructure due to slow cooling rate. Then, hardness test was carried out and the highest hardness value was achieved by carburizing (water quenched) sample with one-hour time and at 950 ˚C. as given above ,and this because of the, existence of fine grain size and also the effect of carbon diffusion from the process. Meanwhile as-received sample gave a lowest hardness value with 188.54 HV compared to with 286.33HV due to larger grain size.

Keywords: Case carburizing, Local structural steel, Surface hardening, Mechanical properties, Microstructure, Quenching and Tempering, Martensite, pearlite, ferrite.

1. Introduction

Case hardening is a simple method of hardening steel. This technique is used for steels with a low carbon content. Carbon is added to the outer surface of the steel, to a depth of approximately 0.03mm. This hardening process includes a wide variety of techniques is used to improve the mechanical properties and wear resistance of parts without affecting the softer, tough interior of the part. This combination of hard surface and resistance and breakage upon impact is useful in parts such as a cam or ring gear that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation. Further, the surface hardening of steels has an advantage over through hardening because less expensive low-carbon and medium carbon steels can be surface hardened without the problems of distortion and cracking associated with the through hardening of thick sections. One advantage of this method of hardening steel is that the inner core is left untouched and so still processes properties such as flexibility and is still relatively soft.

2. Experimental Method

a, Case hardening

The carburization of local structural steel was carried out in the higher vocational center of casting Sedi Alssaeh. The carburizing was conducted using case hardening temperatures of 950C^{o} with a heating time of 1, 2 3- and 4-hours consequence, followed by water quenching for half an hour. The details of the carburizing process are carried out by using mild steel box with top cover and dimensions of 500 mm length x 200mm thickness. The sample used was a rod of 10 mm diameter and 170 mm length.

b.Tempering

After the case carburizing process, tempering was carried out at temperatures of 550C^{o} for 30 minutes in a tempering oven, followed by air cooling.

c, Characterization of local structural steel

The initial hardness measurement for the raw material was conducted using a Rockwell hardness testing machine with a load of 150 kg. Then micro hardness measurements were made at intervals of 0.50 mm through the surface layer of carburizing local structural steel using a Rockwell hardness testing machine with a load of 5 kg. Cross-section samples of the rod were then mechanically polished and etched in a 2% nital solution to reveal the microstructure by optical microscopy.

3. Results and discussion

a. Chemical Composition

The composition of the local structural steel was determined by spectrometry, Table 1.

Table 1 Chemical compositions (wt%) of the local structural steel

Element	C	Si	Mn	S	P	Ni	Cu	Cr	Fe
wt %	0.114	0.149	0.547	0.0271	0.0113	0.163	0.271	0.157	Bal

3.- Mechanical Testing

a. Impact testing

Impact tests are designed to measure the resistance to failure of a material to a suddenly applied force. The test measures the impact energy, or the energy absorbed prior to fracture. Charpy bar test pieces (10*10*55 mm) as showing in figures 1a and 1b were machined using milling CNC machine. Three specimens of each regime were tested to ensure the repeatability from which the average is calculated.

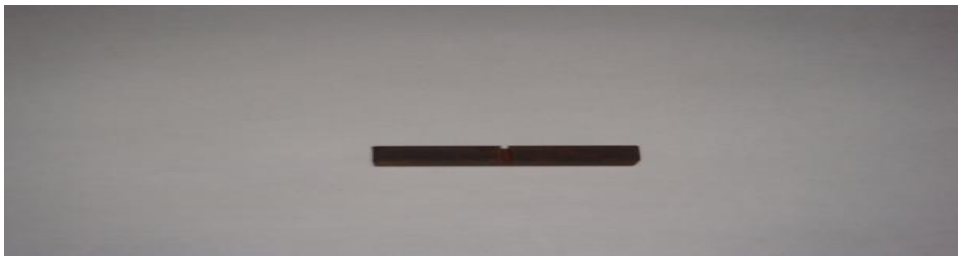

Fig. 1a: specimen for impact test

b. Tensile testing

The tensile test is commonly done to provide basic design information, to identify the strength of materials and as a means for specification of materials. The tensile test was carried out by using BESMAK BMT-1000S testing machine. The rod type specimen was used for tensile test. Two specimens of each regime were tested as showing in figure 2 to ensure the repeatability from which the average is calculated.

Fig. 1b : Tensile test specimen

c. Carburization of local structural steel samples: -

The different test specimen samples made up of local structural steel for mechanical and were subjected to pack carburization treatment are shown in table 1. In this process the samples were placed on the thick bed of carburizer kept in a stainless-steel container and fully covered from all sides, the top of the container was covered with a steel plate. The container was then introduced into the muffle furnace and then maintained at the required carburization temperature of 950^{o}C with different times of 1hr,2hr,3hr,4hr by this way the mild steel samples gets carburized. The hardening was affected immediately after carburization. By this carburization process the mechanical properties of mild steel samples increased considerably.

Table 1: Case carburizing conditions

Condition	carburizing	carburizing	carburizing	carburizing	Tempering
Temperature, °C	950	950	950	950	550

Holding time, hour	**1**	**2**	**3**	**4**	
Cooling medium	**Water**	**Water**	**Water**	**Water**	**Air**

4. Mechanical properties result of hardness test.

In general, as the surface hardening of carburized local structural steel increase in hardness the tensile strength and the impact is decreases
The result of different hardness tests is shown in tables (2,3,4,and 5),

Table 2. Illustrate the hardness test values

temperature	time	Specimen No	hardness
950^{o}C	1hr	A	286.33
950^{o}C	1hr	B	283.33
950^{o}C	1hr	C	274.33

Table 3. Illustrate the hardness test values

temperature	time	Specimen No	hardness
950^{o}C	2hr	A	278.67
950^{o}C	2hr	B	259.33
950^{o}C	2hr	C	262

Table 4. Illustrate the hardness test values

temperature	time	Specimen No	hardness
950^{o}C	3hr	A	196
950^{o}C	3hr	B	259
950^{o}C	3hr	C	268.67

Table 5. Illustrate the hardness test values

temperature	time	Specimen No	hardness
950^{o}C	4hr	A	236
950^{o}C	4hr	B	238.33
950^{o}C	4hr	C	245.67

The hardness values varied between range of 196 HV – 286.33 HV, it is highest for the soaking time of one hour of mild steels and lowest for the soaking time of four hour of mild steels at carburized temperature of 950^{0}C, so at the soaking time of one hour the hardness values increases. This is also shown graphically in the figure 2.

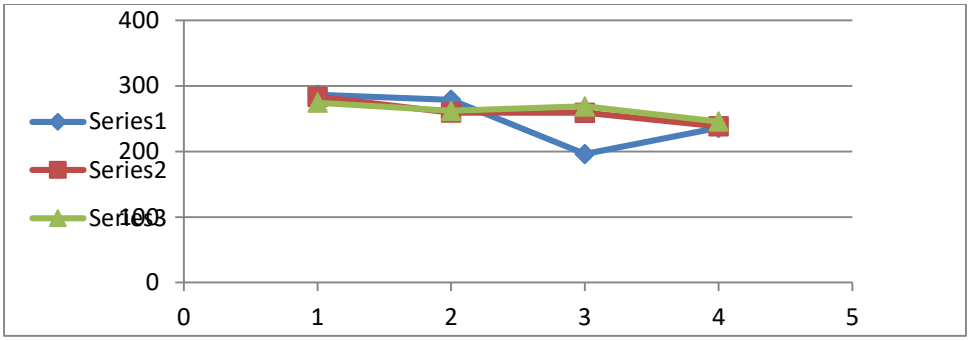

Fig. 2. (a, b, c) the effect of case hardness vs time.

a. Impact test.

From the results of the impact test (table 6) it is analyses that the impact is varied between the range of 60J – 30J and it is highest for the soaking time of one hour and lowest for the soaking time of four at carburized temperature of 950^0C. Figure 3 shows graphically the impact results,

Table 6. Illustrate the result of impact test

time	Impact J	Impact angle
1hr	60	120º
1hr	60	120º
2hr	44	126º
2hr	42	127º
3hr	40	128º
3hr	38	129º
4hr	30	133º
4hr	30	133º

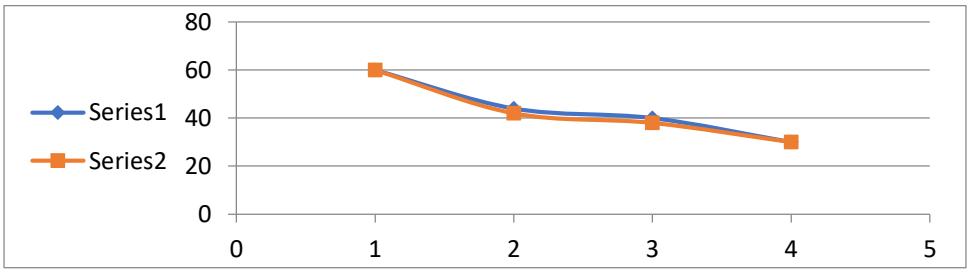

Fig. 3. Illustrate the impact values of J and angle for the time of 1,2,3,4 hours' vs temperature of 950ºC

b. **Effect of carburization temperature of 950^0C and time of one hour on tensile strength of local structural steel.**

Table 7 shows the tensile strength test values of carburized local structural steel for various soaking time of 1,2,3 and 4 hours at temperature of 950^0C.
These results are shown graphically in the figures 4,5,6 and 7.

Table 8. Illustrate the tensile strength test values for various time of 1,2,3,4 hours and temperature of 950°C

temperature	time	Specimen No	Rpy(Nmm^2	Rm(Nmm^2	Fm(kN)	Fb(kN)	Elongation
950°C	1hr	A	158	223	25.20	19.81	21%
950°C	2hr	B	164	233	25.52	23.48	22.5%
950°C	3hr	C	164	243	26.82	23.64	11%
950°C	4hr	D	173	246	27.63	24.86	14%

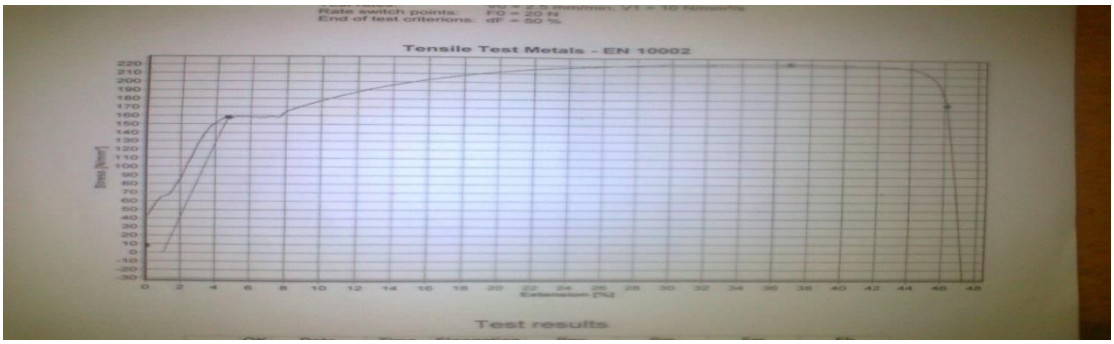

Fig.4. Illustrate the stress-strain diagram for one-hour time and temperature of 950°C

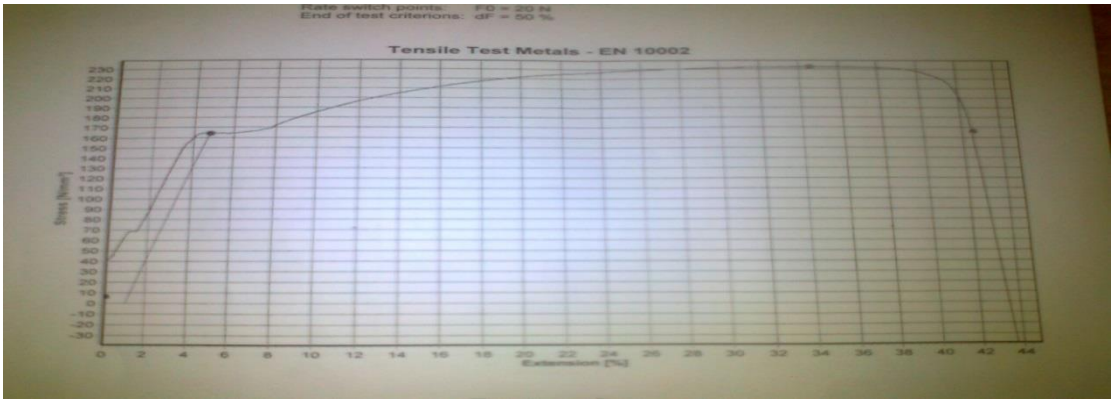

Fig.5. Illustrate the stress-strain diagram for two-hour time and temperature of 950°C

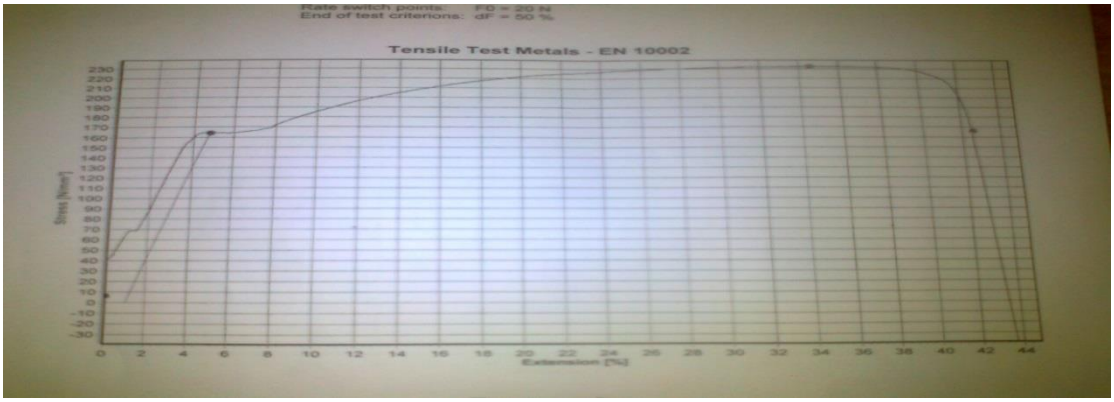

Fig.6 Illustrate the stress-strain diagram for three-hour time and temperature of 950^{o}C

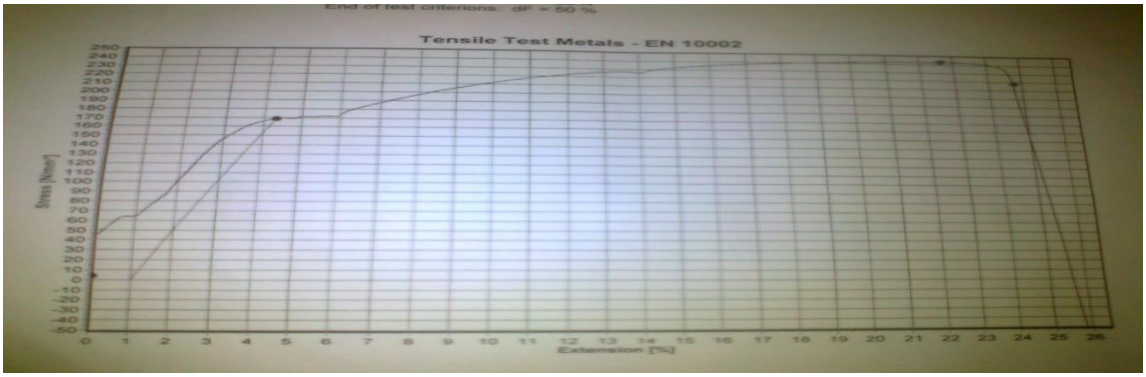

Fig.7 Illustrate the stress-strain diagram for four-hour time and temperature of 950^{o}C

The results of tensile strength test shows that the carburization process greatly improve the tensile strength. The results explain that the tensile strength varied directly with the carburization temperature. This concluded that with the increase in the carburization time, the tensile strength increases linearly and comparing the carburization time of 1, 2, 3, and 4 hours, the highest value of tensile strength for the carburized local structural steels was obtained at 4 hours and lowest value was at 1hour.

5. Microstructure of carburized local structural steels: -

The microstructure examination for the sample of local structural steel at carburized temperature of 950°C and time of 1 hour was carried out. Typical optical micrographs are illustrated that the microstructure comprises of ferrite (light areas) and pearlite (dark areas) and a typical SEM micrograph which is taken in magnifications of 200 x. Figures (8,9,10,11) Ullistrait Optical micrographs showing prior austenite grain size in the case of local structural steel after carburized at 950°C for 1 hour.

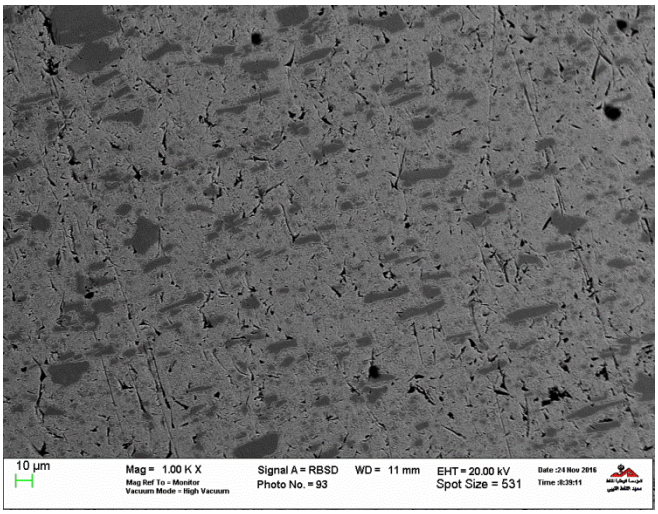

Fig. 8: Optical micrographs showing prior austenite grain size in the case of local structural steel after carburized at 950°C for 1 hour.

The microstructure of carburized sample at temperature of 950°C for 1 hour is shown in figure 8, as it can be seen that the ferrite grains had undergone complete recrystallization and these constituted the major portion of the microstructure the carburized local structural steel with stress free matrix. At 950^{o}C the deformed structure was fully homogenized and during the slow cooling from austenizing range to room temperature the final microstructure consisted of fine ferrite grains in which the pearlite was more uniformly distributed.

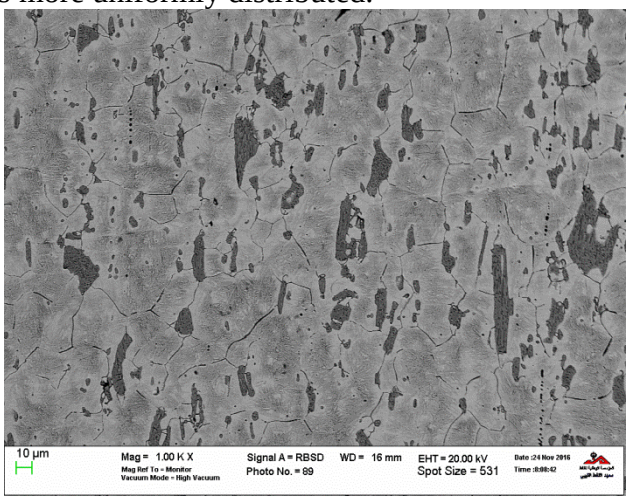

Fig. 9: Optical micrographs showing prior austenite grain size in the case of local structural steel after carburized at 950°C for 2 hours.

Figure 9 shows the massive martensite structure of carburized sample at temperature of 950°C for 2 hours, when the carburized local structural steel is rapidly quenched from its austenite temperature to room temperature, the austenite will decompose into a mixture of some local structural steel martensite and fewer pearlite as a result of this microstructure which is hard, hence, there was increase.

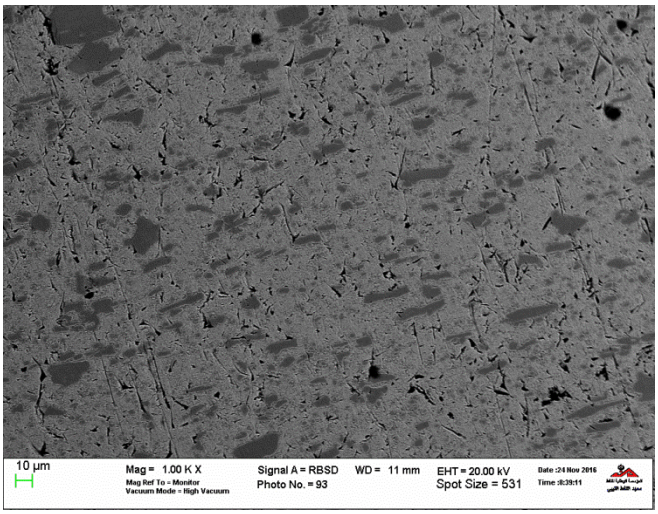

Fig.10: Optical micrographs showing prior austenite grain size in the case of local structural steel after carburized at 950°C for 3 hours

The microstructure of carburized sample at temperature of 950°C for 3 hours illustrate in figure 10, shows that the structure of local structural steel sample consists of dispersion of massive carbides particles and small spheroidal carbide particles in matrix of pearlite and ferrite.

The figure shows that the microstructure of local structural steel when quenched in water composed of small carbide (white region), and martensite (black region). Sample reveal non-uniform delivery of big, extended, white regions of small carbon carbides.

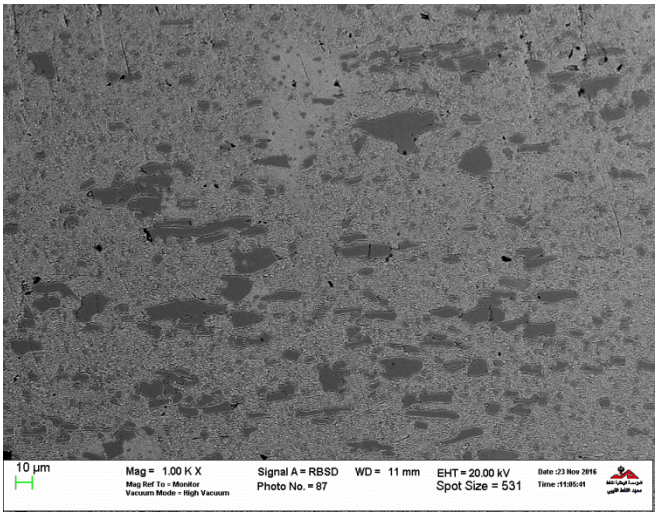

Fig.11: Optical micrographs showing prior austenite grain size in the case of local structural steel after carburized at 950°C for 4 hours.

The microstructure of carburized sample at temperature of 950°C for 4 hours and tempered at 550^{o}C is shown in figure 11. A highly recrystallized ferrite grains (white dotted areas) with some secondary graphite site was observed.

This micrograph revealed that the microstructure of tempered specimen consisted of a number of appreciable carbide particles precipitated out from the matrix, which indicated that the precipitate carbide particles decomposed by a process of solution in ferrite matrix.

6.0 Conclusions:-

It concluded from this study that the effect of case carburizing on the mechanical properties and microstructure of local structural steel by using different time and temperatures, the following conclusions have been drawn.

1. The mechanical properties of local structural steel were found to be strongly influenced by the process of carburization at the temperature of 950^{o}C with different times of 1hr, 2hr, 3hr, and 4hr.

2. The carburization process decreases the toughness of the local structural steel and the toughness is decreases with increase in the times of carburization from 60J for 1hr to 30J for 4hr at the temperature of 950^{o}C.

3. The Hardness decreases with increase in the times of carburization from 286.33 HV for 1hr to236 HV for 4hr at the temperature of 950^{o}C and tensile strength increases with increase in the times of carburization.

4. The comprising of different times of carburization. The local structural steel carburized at the temperature of 950^{o}C with different times of 1hr, 2hr, 3hr, 4hr shows the best combination of higher hardness of 286.33 HV and higher tensile strength of 246 N/mm^2.

5. The tempered samples gave an increase in tensile strength and hardness than untreated sample as a result of formation of tempered martensite and resultant ferrite structure that were obtained. Case carburizing sample at temperature of 950°C for 4 hours had the highest tensile strength and hardness with lowest ductility and impact strength when compared to other case carburizing samples. Hardening is strongly recommended when the strength and hardness are the prime desired properties in design.

5. Finally the net conclusion is that the local structural steel carburized under the different times range at the temperature of 950^{o}C is giving the best results for the mechanical properties like tensile strength, hardness.

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