International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 15 No. 2 Jun. 2015, pp. 379-388

http://www.ijisr.issr-journals.org/

Improvement in the Wear Resistance and Mechanical Properties of Carburized Mild Steel by varying Carburization Temperature and constant Tempering Temperature

Manav Verma, K.S. Dhillon, and Mukesh Verma

Department of Mechanical Engineering,
Sri Sukhmani Institute of Engineering and Technology,
Dera Bassi, Punjab, India

ABSTRACT: The various mechanical and wear properties of alloys and metals are investigated by acknowledging the heat treatment and various carburization processes. In this investigation, the mechanical and wear properties of mild steel carburized were studied at different ranges of temperature i.e. 800, 870 and 940 degree Celsius. The aim of the present study was to analyze the effect of carburization temperatures at different scales and conditions on mechanical and wear properties of carburized mild steel. The above different temperatures were tempered at 500 degree Celsius for half an hour and then subjected for different tests such as hardness test, tensile stress test, abrasive wear test and toughness test. The results after experimental work showed that mechanical and wear properties are improved and these properties increase with increase in the carburization temperature. It was analyzed from experimental calculations through proper investigations that the toughness property decreased with the increase in the carburization temperature. So, 940 degree Celsius is best suited for mechanical and wear properties of mild steel because it gives highest tensile strength, hardness and wear resistance. It can be concluded from the experimental results of the present study that hardness, tensile strength and wear resistance of the mild steels can be improved by a simple heat treatment of solid carburizing process.

KEYWORDS: Carburization, tempering temperature, soak time, tensile stress, hardness test.

1 BACKGROUND

Carburization is a case hardening process with a simple heat treatment of simple mild steel in the presence of carbon monoxide or charcoal as a carbon bearing material in an operating temperature of 815 degree Celsius (1500 degree F) to 1090 degree Celsius (2000 degree F). In carburization with process of diffusion, the addition of carbon is coated to the surface of low carbon steel to make the outer surface hard followed by quenching process after cooling the steel. In this way phase transformation takes place from austenite to martensite to form a single phase body-cantered tetragonal iron with carbon dissolved in it. Whereas, the inner core part of steel remains soft and tough with high martensite phase.

Patidar et al [14] studied the carburized mild steel at 950 degree Celsius with soaking time of 2 h and then tempered with different temperature range of 200, 250, and 300 degree Celsius for different soaking time of 1 h, 1.5 h, and 2 h. After this, the carburized and tempered mild steel are subjected for various kind of test such as abrasive wear test at different load like 75 N, 200 N, 375 N, and mechanical properties test like hardness, and tensile. Finally it was analyzed that wear resistance and mechanical properties increased with increase in tempering temperature.

Singh et al. [15] studied three heat treatment processes namely quenching, carburizing, and tempering. The carburized mild steel at 860 degree Celsius and different soaking time 2 h, 2h 30 m, and 3 h and then it is tempered at constant tempering temperature of 200 degree Celsius and constant soaking time of 60 min. After this the carburized and tempered mild steel are subjected for various kind of test such as abrasive wear test at different load like 75 N, 200 N, 375 N, and hardness test, and tensile test, Finally it was concluded that as wear rate increases, hardness increases for different soaking time of 2 h, 3 h, and 2 h 30 m. Also tensile strength increases with increasing the soaking time from 2 h to 3 h.

Corresponding Author: Manav Verma

D.A. Fadare et al. [7] studied the effect of heat treatment (annealing, normalizing, hardening, tempering) on the microstructure and some selected mechanical properties of NST 37-2 steel like tensile yield strength, ultimate tensile strength, young's modulus, percentage reduction, percentage elongation, toughness, and hardness. The sample carburized mild steel are heat treated at 910 degree Celsius for annealing with holding time of 90 min, normalizing with holding time of 90 min, hardening process with holding time of 40 min and then it is tempered at 450 degree Celsius with holding time of 90 min. finally it was concluded that mechanical properties of NST 37-2 can be changed and improved by various heat treatment process.

Emamian [4] studied the effect of solid carburization on mechanical and tribological properties of powder metallurgy parts. The test specimens made from industry were carburized in a powder pack for about 2 to 5 h at a temperature of about 850 to 950 degree Celsius. The effects of austenitization and quenching are investigated on some specimens and concluded that wear resistance can be increased with moderate toughness.

O.I. Sekunowo et al. [13] studied the wear characteristics of carburized mild steel at different carburization temperature of 750, 800, 850, 900, and 950 degree Celsius and then it is tempered at temperature of 500 degree Celsius with soaking time of 30 min. After this the carburized and tempered mild steel are subjected for various kind of test such as hardness, wear, and flexural properties. Finally it was analyzed that carburization can be used to enhance the wear resistance of mild steel comparable to that achievable through conventional hardening process.

Amit Vishal et al. [2] studied the effect of thermal treatments on the performance of H13 tool steel. In this Cryogenic treatment process was used to improve the mechanical properties and wear resistance of tool steel. At quenching temperature of 1050 degree Celsius the specimens are subjected to heat treatment process and then it is quenched in cold water where again it is subjected to deep cryogenic treatment at 196 degree Celsius for 24 hrs followed by double tempering at 550 degree Celsius. Finally it was concluded that the value of hardness increases after quenching and tempering process via heat treated as compared to simple heat treated process. But toughness and wear resistance have higher value in heat treated and cryogenically treated specimen as compare to the specimen which was only heat treated.

Solid carburizing process is suited for slow cooling from the carburization temperature. It is provided for a wide variety of furnaces because the process produces its own contained environment. The operating temperature range of pack carburizing process is from 815 to 955 degree Celsius (1500 to 1750 degree F). Moreover, in this research case depth for the surface of low carbon steel have not been used. Improvement in the wear resistance and mechanical properties of carburized mild steel by varying carburization temperature and constant tempering temperature was investigated. Finally the optimized condition was introduced.

2 MATERIAL AND METHODS

Mild steels of the required dimensions were purchased from the local market and the test specimens were prepared from it. The mild steel composition by (wt %) is given as follows C-0.16, Si-0.03, Mn-0.32, S-0.05, P-0.2, Ni- 0.01, Cu-0.01, Cr-0.01 and Fe. The air dried coal powdered sample was collected from Agarwal coal limited, Chennai which was ground to pass through 70 mess British standard test sieve by the following methods of moisture, volatile, ash, and fixed carbon determination. After the selection and preparation of coal, the different test specimen samples made up of mild steel for mechanical and wear properties testing were subjected to solid carburization treatment. The temperature range for carburization of mild steel samples was 800, 870, and 940 degree Celsius with a constant soak time of 2 hours. After soaking period of time, it was quenched in water and then mild steel gets carburized which gives hardening effect. The carburized mild steel samples are kept in the muffle furnace as shown in Figure (1).

After carburization process, the phase stage of steel is often harder than needed and too brittle for most practical uses. Severe internal stresses are also set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, we tempered the steel after it was hardened. So in this tempering process the carburized steel samples were heated at the temperature of 500^0C for duration of 0.5 hours and then cooling was done in the still air. The carburized and tempered mild steel specimens were then subjected to various kind of mechanical and wear tests such as abrasive wear test, hardness test, tensile test and toughness test.

Fig. 1 Muffle furnace for carburization of mild steel samples

2.1 ABRASIVE WEAR TEST

The material considered for this experiment was carburized mild steel samples which were carburized under different temperature range of 800, 870 and 940^{0}C with dimensions 4.0 cm x 2.5 cm x 1 cm. The test was conducted on a machine called Pin on disc machine as shown in Figure (2).

Fig. 2 Pin on disc machine for abrasive wear testing

In this experiment, the test was conducted with the following parameters:

(1) Load (2) Speed (3) Time

In the present experimental work, speed and time were kept constant while the load was varied from 14.7N to 49N. Parameters that remained constant throughout all the experiments are given below in Table 1.

Table 1. Parameters of experimental work

RPM	300
Time	5 minute
Type of abrasive paper	Emery, 80 grade size

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. After each test only the mass loss of the specimen was considered as the wear. The wear rate of each sample was calculated from the weight loss, the amount of wear was determined by weighing the specimen before and after

the test using precision electronic weighing machine. Since the mass loss was measured so it was converted to volume loss using the density of the specimen. Hence wear volume, wear rate and wear resistance were calculated as:

2.1.1 WEAR VOLUME

Wear volume = weight loss / density

Density of specimen = 7.86 g /cm^3

2.1.2 WEAR RATE

Wear rate = wear volume / sliding distance(s)

Sliding distance (s) can be calculated as,

Sliding distance (s) = V x time

= ($2\pi RN/ 60$) x time

where, R = radius of abrasive wheel(6.90cm)

N = R.P.M (300)

π = 3.14 (constant)

Time = 5 minute (300sec)

2.1.3 WEAR RESISTANCE

Wear resistance = 1 / wear rate

2.2 HARDNESS TEST

This method consisted of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter was forced into the test material under a preliminary minor load *F0* usually 150 kg. In present experimental work, Rockwell hardness was measured on carburized and tempered mild steel samples which were carburized under different temperature range of 800, 870 and 940^{0}C. 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.

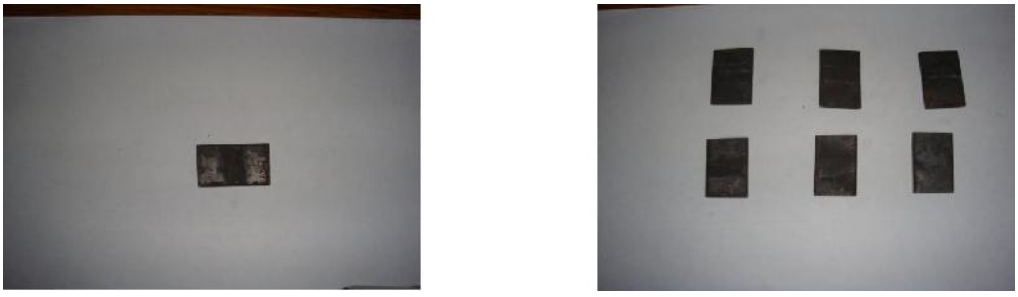

Fig. 3 Specimen for abrasive wear and hardness test

2.3 TENSILE TEST

In the present experiment, the tensile test was carried out on carburized and tempered mild steel samples which were treated under different temperature range of 800, 870 and 940^{0}C and performed in Instron 1195 machine.

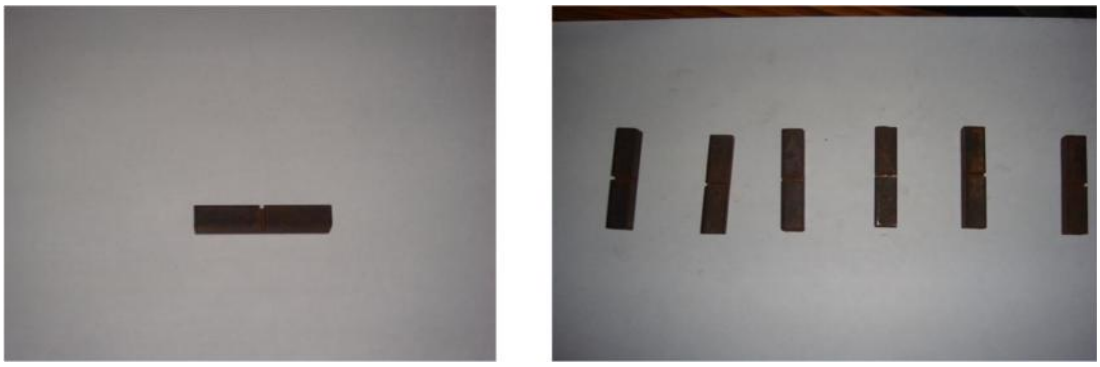

Fig. 4 Specimen for tensile strength test

2.4 TOUGHNESS TEST

This test was also conducted for three different samples carburized under the three different temperatures of 800, 870 and 940^0C.

Fig. 5 Specimen for toughness test

3 RESULTS AND DISCUSSION

The different kind of mild steel samples were carburized under different condition and temperature and tempered under the different condition and constant temperature and then tested for various kinds of test like abrasive wear test, tensile strength test, toughness test and hardness test. The abrasive wear test results for different load (i.e.14.7 N, 29.4 N and 49 N) are recorded in Table 3-5, the Rockwell hardness test result at 150 kg load is recorded in Table 6. Similarly the toughness test and tensile strength test results are recorded in Table 7 and 8, respectively.

3.1 RESULTS OF PROXIMATE ANALYSIS OF COAL FROM AGARWAL COAL LIMITED, CHENNAI

The results of proximate analysis of coal are shown in Table 2. This analysis was performed to find out the moisture percentage (wt %), volatile matter, ash and carbon content in the given coal sample. From the analysis, we found limited content 29% of carbon, 3% of moisture, 32% of volatile matter and 36% of ash.

3.2 RESULTS OF ABRASIVE WEAR TEST: ABRASION CHARACTERISTICS OF CARBURIZED MILD STEELS

From the experimental results of abrasive wear test (Table 3-5), the following regularities were found:

1. The weight loss during abrasion was highest for uncarburized simple mild steel and was lowest for the mild steel carburized at temperature of 940^0C.
2. As comparing the case of carburized mild steel only, the weight loss during abrasion was highest for the mild steel carburized at temperature of 800^0C and lowest at temperature of 940^0C, that may be because of comparatively low carbon content at lower carburization temperature. So it was concluded that as the carburization temperature increases, the weight loss during abrasion decreases. This conclusion is also shown graphically in the Fig.6.

3. The three different loads of 14.7 N, 29.4 N and 49 N was conducted on abrasion test and obtained from the test that the weight loss during the abrasion was highest for the load of 49 N and lowest for 14.7 N. Hence it was concluded from the test that as the load increases, the weight loss during abrasion also increases as shown graphically in Fig.6.

4 The wear resistance was highest for the mild steel carburized at the temperature of 940^0C and it is lowest for the uncarburized mild steel. Also when considering only carburized mild steels, the wear resistance was highest for the mild steel carburized at the temperature of 940^0C and lowest at 800^0C. Hence the abrasion results explained that the wear resistance is directly proportional to the carburization temperature i.e. as the carburization temperature increases the wear resistance increases as shown graphically in Fig.7.

5 The net result is that the mild steel carburized at temperature of 940^0C gives the best results, as it has the highest wear resistance, lowest weight loss due to abrasion and lowest wear rate.

3.3 EFFECT OF CARBURIZATION TEMPERATURE ON HARDNESS OF CARBURIZED MILD STEELS

From the results, we found that as temperature increases hardness also increases. The hardness was found to be highest for the mild steel carburized at temperature of 940^0C and was lowest for the mild steel carburized at temperature of 800^0C (Table 6 and Fig. 8).

3.4 EFFECT OF CARBURIZATION TEMPERATURE ON TOUGHNESS OF CARBURIZED MILD STEELS

The toughness properties of mild steels are highly influenced by the carburization process. Table 7 shows the toughness results of carburized and uncarburized mild steels where it was observed that the toughness values of uncarburized mild steels were higher than that of carburized mild steels and toughness values decrease with the increase in carburization temperature.

3.5 EFFECT OF CARBURIZATION TEMPERATURE ON TENSILE STRENGTH OF CARBURIZED MILD STEELS

The effect of carburization temperature on tensile strength of carburized mild steels is shown in Table 8 and it is also represented graphically in Fig.10. The results showed that the carburization process greatly improve the tensile strength of mild steels. This concluded that with the increase in the carburization temperature, the tensile strength increases linearly. When the carburization temperature of 800, 870 and 940^0C were compared, the tensile strength was found to be highest for the mild steel carburized at 940^0C, and lowest for 800^0C. So it was concluded that mild steel carburized at 940^0C give the best results and it can be preferred.

Table 2. Proximate analysis of coal from Agarwal coal limited

Coal	Proximate analysis (Wt %)			
	Moisture	Volatile matter	Ash	Fixed carbon
Agarwal coal limited	3	32	36	29

Table 3. Abrasive wear test for carburized mild steel, at load 14.7 N

Carburization Condition		Tempering condition		Weight loss, g	Wear volume, cm^3x10^{-2}	Sliding distance (s)	Wear rate, cm^2x10^{-7}	Wear resistance, $cm^{-2}x10^7$
Temp (^{0}C)	Soak Time (hrs)	Temp (^{0}C)	Soak time (hrs)					
Sample Mild Steel		_	_	0.2	2.54	680.657	3.73	0.267
800^0C	2	500^0C	0.5	0.13	1.65	680.657	2.42	0.411
870^0C	2	500^0C	0.5	0.118	1.50	680.657	2.20	0.453
940^0C	2	500^0C	0.5	0.107	1.36	680.657	2.00	0.499

Table 4. Abrasive wear test for carburized mild steel, at load 29.4 N

Carburization Condition		Tempering Condition		Weight loss, g	Wear volume, cm^3x10^{-2}	Sliding distance (s)	Wear rate, cm^2x10^{-7}	Wear resistance, $cm^{-2}x10^7$
Temp (^{0}C)	Soak Time (hrs)	Temp (^{0}C)	Soak time (hrs)					
Sample Mild Steel	-	-	-	0.25	3.18	680.657	4.67	0.213
800^{0}C	2	500^{0}C	0.5	0.15	1.90	680.657	2.80	0.356
870^{0}C	2	500^{0}C	0.5	0.135	1.71	680.657	2.52	0.396
940^{0}C	2	500^{0}C	0.5	0.12	1.52	680.657	2.24	0.445

Table 5. Abrasive wear test for carburized mild steel, at load 49 N

Carburization Condition		Tempering Condition		Weight loss, g	Wear volume, cm^3x10^{-2}	Sliding distance (s)	Wear rate, cm^2x10^{-7}	Wear resistance, $cm^{-2}x10^7$
Temp (^{0}C)	Soak Time (hrs)	Temp (^{0}C)	Soak time (hrs)					
Sample Mild Steel	_	_	_	0.3	3.81	680.657	5.60	0.178
800^{0}C	2	500^{0}C	0.5	0.185	2.353	680.657	3.45	0.289
870^{0}C	2	500^{0}C	0.5	0.165	2.09	680.657	3.08	0.324
940^{0}C	2	500^{0}C	0.5	0.145	1.84	680.657	2.71	0.368

Table 6. Rockwell hardness of carburized mild steel at load 150 kg

Carburization condition		Tempering condition		Hardness (R_c)
Temp (^{0}C)	Soak time(Hrs)	Temp(^{0}C)	Soak time (Hrs)	
Simple mild Steel	-	-	-	50
800^{0}C	2	500^{0}C	0.5	52
870^{0}C	2	500^{0}C	0.5	54
940^{0}C	2	500^{0}C	0.5	55

Table 7. Toughness test of carburized mild steel

Carburization Condition		Tempering Condition		Toughness, Joule(Nm)
Temp (^{0}C)	Soak Time (hrs)	Temp (^{0}C)	Soak time (hrs)	
Simple mild Steel	_	_	_	54
800^{0}C	2	500^{0}C	0.5	36
870^{0}C	2	500^{0}C	0.5	34
940^{0}C	2	500^{0}C	0.5	31

Table 8. Tensile strength of carburized mild steel

Carburization condition		Tempering condition		Tensile Strength (MPa)
Temp (^{0}C)	Soak Time (hrs)	Temp(^{0}C)	Soak time (hrs)	
Simple mild Steel	_	_	_	441
800^{0}C	2	500^{0}C	0.5	1870
870^{0}C	2	500^{0}C	0.5	1920
940^{0}C	2	500^{0}C	0.5	1950

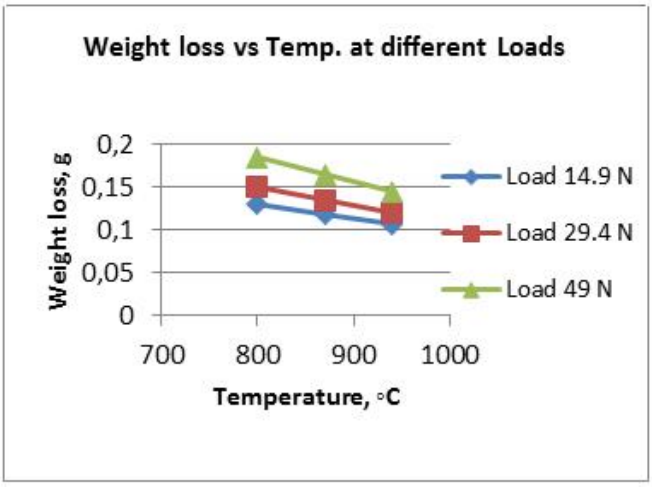

Fig. 6. Comparison of weight loss due to abrasion vs carburization temperature for three different loads of 14.7 N, 29.4 N and 49 N

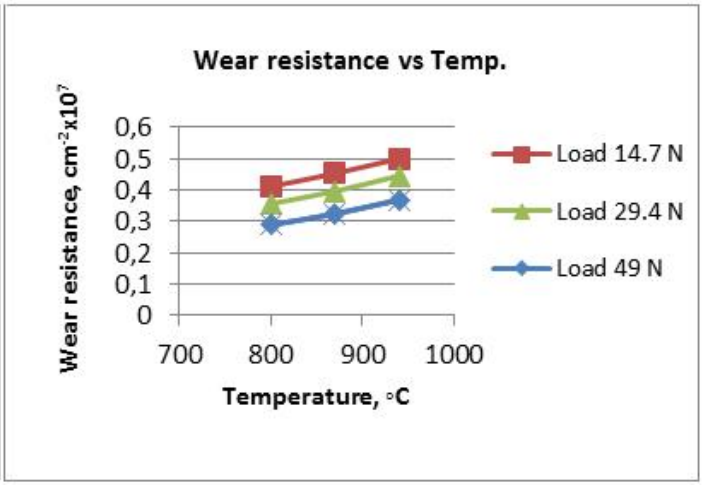

Fig. 7. Comparison of wear resistance vs carburization Temperature for three loads of 14.7 N, 29.4 N and 49 N

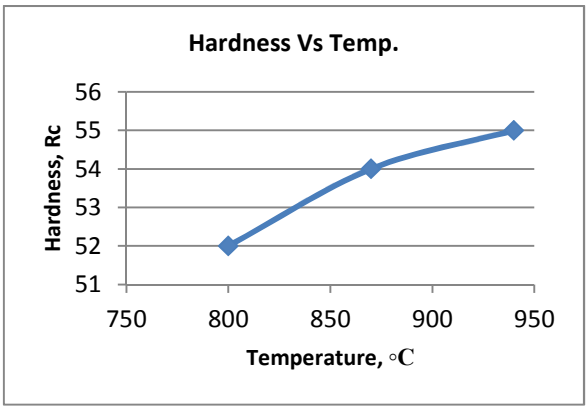

Fig. 1. Fig. 8. Variation of hardness with the carburization temperature

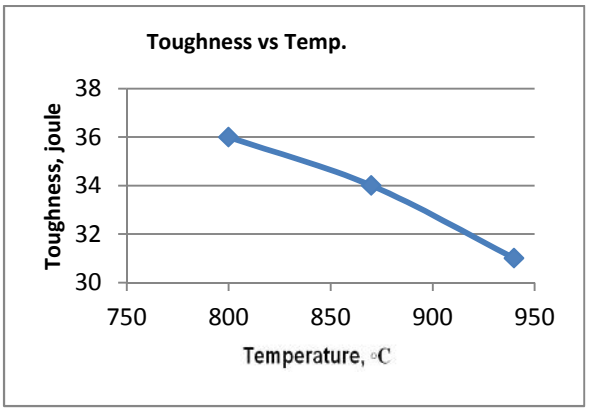

Fig. 2. Fig. 9. Variation of toughness with carburization temperature

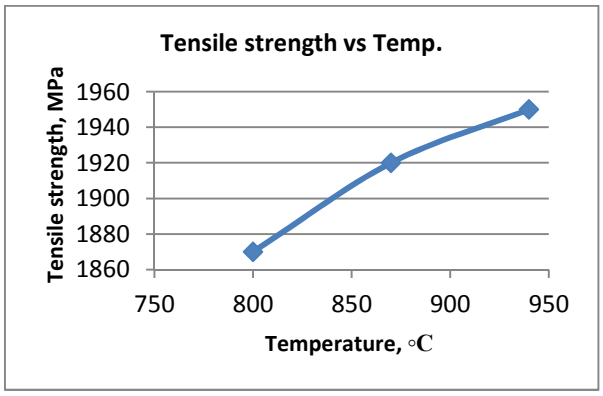

Fig. 10. Variation of tensile strength with carburization temperature

4 CONCLUSIONS

1. The mechanical and wear resistance properties of sample carburized mild steel sare increased by varying carburizing temperature from 800 to 940 degree Celsius.
2. The mechanical property of toughness decrease by increasing the carburizing temperature.
3. Hardness, wear resistance and tensile strength increases with increase in the carburization temperature.
4. Weight loss due to abrasion, wear volume, wear rate and toughness decrease with increase in the carburization temperature.
5. The wear resistance is increased due to small amount of increase in the hardness and at the same time there is loss in weight of the sample steel due to abrasion and wear rate.
6. From the range of carburizing temperatures, 940 degree Celsius gave the best result for higher hardness, higher tensile strength and higher wear resistance with low weight loss and less wear rate for carburized mild steel.

REFERENCES

[1] A. Clark, “Comparison of Austempering and Quench and Tempering Processes for carburized automotive steels”, SAE international journals, pp. 109 – 115, 2013.
[2] A. Vishal, R. Davis, “Effect of thermal treatments on the performance of H13 tool steel”, volume 3, pp. 170 – 173, 2014.
[3] A. Akdemir, R. Kus and M. Simsir “Impact toughness and microstructure of continuous steel wire – reinforced cast iron composite”, Material science and Engineering, pp. 119-125, 2009.
[4] A. Emamian, “Study on wear resistance, Hardness, and impact behaviour of Carburized Fe-Based Powder Metallurgy parts for automotive applications”, Materials Sciences and Applications, pp. 519 – 522, 2012.
[5] P. Baldissera and C. Delprete, “Effect of deep cryogenic treatment on static mechanical properties of 18NiCrMo5 carburized steel”, Material and design, 30, pp. 1435 – 1440, 2009.

[6] O. Celik , "High temperature abrasive wear behavior of an as-cast ductile iron, wear", 258; Second International Conference on Erosive and Abrasive Wear, pp. 189 – 193, 2005.
[7] D. A. Fadare, T. G. Fadara and O. Y. Akanbi, "Effect of heat treatment on mechanical properties and microstructure of NST 37-2 Steel", Journal of Minerals & Materials Characterization & Engineering, pp. 299 – 308, 2011.
[8] F. O. Aramide, S. A. Ibitoye, I. O. Oladele and J. O. Borode, "Effects of carburization time and temperature on the mechanical properties of carburized mild steel, using activated carbon as carburizer", material research journals, pp. 290 – 305, 2009.
[9] A. Gulyaev , Physical Metallurgy, 5th Edn. , Mir publishers, Moscow, pp – 173, 1980.
[10] H. Elizanty, "Effect of carburization on hardness and wear properties of the mild steel samples", International Journal of Innovation and Applied Studie, pp. 120 – 127, 2014.
[11] M. Izciler and M. Tabur "Abrasive wear behavior of different case depth gas carburized AISI gear steel", Wear, 220, pp. 90 – 98, 2006.
[12] O.I. Sekunowo, O.I. Nwagu, "Wear Characteristics of carburized mild steel", International journal of scientific & Technology research volume 3, pp. 87 – 93, 2014.
[13] S. Patidar, A. Jain, and D. Singh, "Effect of tempering temperature and applied load on various wear environment of carburized mild steel", IOSR Journal of Mechanical and Civil Engineering, pp. 62 – 69, 2012.
[14] S. Singh, D. Singh, K. Sachan and A. Arya, "Effects of soaking time and applied load on Wear Behaviour of Carburized mild steel", IOSR Journal of Engineering (IOSRJEN), pp. 10 – 19, 2013.