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

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Abstract - *This paper presents the investigations on mechanical properties and wear properties of mild steel, carburized are studied at different ranges of temperature that is 800 ℃, 870 ℃ and 940 ℃. In this paper the main focus was on the effect of carburization temperatures at different- different scales and conditions on mechanical and wear properties of carburized mild steel.*

The mild steel samples are carburized at 500 ℃ temperature and socking time up to 30 min. After tempered process different tests such as hardness, tensile stress, abrasive wear and toughness test were performed at different temperature.

Test data was analyzed and the result is shows that mechanical and wear properties are improved. Results show that as carburization temperatures increases, as improvement in the mechanical and wear properties. After Experimental data investigation it is found that toughness decrease with increase in carburization temperature. So 940 ℃ are best suited for mechanical and wear properties of mild steel because it gives highest tensile strength, hardness and wear resistance. Experimental result shows that a simple heat treatment of solid carburizing process can improve the hardness, tensile strength and wear resistance of the mild steels.

Key Words: Mild Steel, Carburization, Temperature, Tensile, Hardening etc.

1. INTRODUCTION

The carburization provides a gradual change in carbon content and carbide volume from the surface to the bulk, resulting in a gradual alteration of mechanical and wear properties. The heat treatment and carburization increases the mechanical and wear resistance. Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures generally between 860°C and 940°C at which austenite, with its high solubility for carbon, is the stable crystal structure. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core [1]. Carburizing steels for case hardening usually have base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.7 and 1% C. However, surface carbon is often limited to 0.9% because too high a carbon content can result in retained austenite and brittle martensite. Carburizing is one of the most widely used surface hardening processes. The process involves diffusing carbon into a low carbon steel alloy to form a high carbon steel surface. Carburizing steel is widely used as a material of automobiles, form implements, machines, gears, springs and high strength wires etc. which are required to have the excellent strength, toughness, hardness and wear resistance, etc. because these parts are generally subjected to high load and impact. Such mechanical properties and wear resistance can be obtained from the carburization and quenching processes [2]. This manufacturing process can be characterized by the key points such as: it is applied to low carbon workpieces, workpieces are in contact with high carbon gas, liquid or solid, it produces hard workpiece surface, workpiece cores retain soft[3].

2. MATERIAL AND METHODS

Mild steel was selected as work material. It was purchased from local market as per required dimensions. Specimens for different test were prepared as per ASTM standard. Chemical composition and its % (wt) is shown in table-1.

Table -1: Chemical Composition of Mild Steel

Chemical Composition of Mild Steel used for Experimental Work						
Element	C	Si	Mn	S	P	Ni
%(wt)	0.16	0.03	0.32	0.05	0.2	0.01
Element	Cu	Cr	Remaining is **Fe**			
%(wt)	0.s01	0.01				

2.1 Specimen for abrasive wear and hardness test

The abrasive wear and hardness is determined from the same specimen. A standard specimen of dimensions (4cm x 2.5cm x 0.5cm) of mild steel is prepared for the same purpose.

Fig -1(A): Specimen for abrasive wear and hardness test

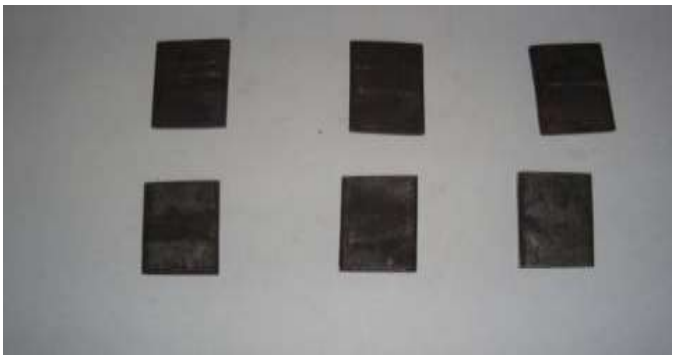

Fig -1(B): Specimen for abrasive wear and hardness test

2.2 Specimen for toughness test

A toughness test specimen as per ASTM standard is prepared for the same purpose having the following dimensions.

Length = 5.5 cm, Width = 1 cm, Thickness= 1 cm, Notch depth = 0.5 cm

Fig -2(A): Specimen for toughness test

Fig -2(B): Specimen for toughness test

2.3 Specimen for tensile strength test

A tensile test specimen as per ASTM standard is prepared for this purpose is based on the following equation.
L0 /sqr root A0 = 5.65
Where,
L0 = Gauge length
A0 = Cross sectional area

Fig -3(A): Specimen for tensile test

Fig -3(A): Specimen for tensile test

2.4 Coal selection and preparation

Coal is crushed into -50 mesh size with the help of crusher and test sieve, about 4.5 kg of coal is prepared for this purpose and this coal is used for the pack carburization of mild steel samples.

2.4 Proximate analysis of coal

Analysis for moisture, volatile matter, ash and fixed carbon contents in coal (Table-3) were carried out on Samples ground to pass through -70 mess B.S. test sieve by the method given below.

- Moisture determination
- Volatile matter determination
- Ash determination
- Fixed carbon determination

2.5 Carburization of mild steel specimen

The different test specimen samples made up of mild steel for mechanical and wear properties testing were subjected to pack carburization treatment. In this process the mild steel 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 different required carburization temperatures of 800℃, 870℃ and 940℃ with the soak time of 2 hours by this way the mild steel samples gets carburized and then they were quenched in water i.e. the hardening was effected immediately after carburization. By this carburization process the mechanical and wear properties of mild steel samples increased considerably. The carburized steel samples were then tempered for a particular temperature and time and then it processed for different type of mechanical and wear test.

Fig -4(A): Muffle furnace

Fig -4(B**)**: Muffle furnace for carburization

2.6 Tempering of carburized mild steel

After carburization process, the steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, we should temper the steel after it is hardened. So in this tempering process the carburized steel samples were heated at the temperature of 500℃ for duration of 0.5 hours and then cooling it usually in the still air. The carburized and tempered mild steel specimens are then subjected to various kind of mechanical and wear test.

2.7 Abrasive wear test

The materials considered for this experiment is carburized mild steel samples which is carburized under different temperature range of 800, 870 and 940℃with dimensions 4.0cm x 2.5 cm x 0.5 cm. The test was conducted on a machine called Pin on disc machine (make: SD scientific industries) as shown in fig. (5A & 5B). The sample was mounted perpendicularly on a stationary vice such that its one of the face is forced to press against the abrasive that is fixed on the revolving disc. Hence it is the abrasive paper that tends to wear the surface of the samples. When the disc rotates for a particular period of time, the sample can loaded at the top to press against the disc with the help of a lever mechanism.

In this experiment the test can be conducted with the following parameters

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

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

Table -2: Parameter taken constant in abrasive wear test

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. Once the parameter is set and work piece is mounted, the test is carried on for the desired time. The wear track so formed on the rotating disc is a circle. 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 is determined by weighing the specimen before and after the test using precession electronic follows weighing machine. Since the mass loss is measured it is converted to volume loss using the density of the specimen. Hence wear volume, wear rate and wear resistance can be calculated as:

- **Wear volume**

Wear volume = weight loss / density
Density of specimen = 7.86 g /cm^3

- **Wear rate**

It is defined as wear volume per unit distance travelled
Wear rate =wear volume / sliding distance(s)
Sliding distance (s) can be calculated as
Sliding distance (s) = V x time
= (2 π R N / 60) x time
Where, R = radius of abrasive wheel (6.90 cm)
N = R.P.M (300) Π = 3.14 (constant)
Time = 5 minute = 300 s

- **Wear resistance**

wear resistance is a reciprocal of wear rate wear resistance = 1 / wear rate

Fig -5(A): Pin on disc machine for abrasive wear testing

Fig -5(B): Pin on disc machine for abrasive wear testing

3. VARIOUS TYPE OF MECHANICAL AND WEAR TEST

3.1 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°C, 870°C and 940°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.

3.2 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°C, 870°C and 940°C and performed in Instron 1195 machine.

3.3 Toughness Test

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

4. RESULTS AND DISCUSSION

The different kind of mild steel samples were carburized and tempered under the different condition and temperature and then tested for various kinds of test like abrasive wear test, tensile strength test, toughness test and hardness test. The results of abrasive wear test as received for different load (i.e.14.7 N, 29.4 N and 49 N) is recorded in Table 4 – 9, the result of Rockwell hardness test at 150 kg load is recorded in Table 10 - 11. Similarly the result of toughness test and tensile strength test is recorded in Table – 12, 13 and 14, 15 respectively.

The proximate analysis of coal is also done which is used as a carburized and its value is shown in Table – 3.

Table -3: Proximate analysis of coal

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

Table -4: Calculation of average weight loss of abrasive wear test for carburized mild steel, at load 14.7 N

Carburizing Temp.	Weight loss samples			Average weight loss
	1	2	3	
800	0.1289	0.129	0.133	0.13
870	0.118	0.1179	0.119	0.118
940	0.106	0.1086	0.1076	0.107

Table -5: Result of abrasive wear test for carburized mild steel, at load 14.7 N

Carburization Condition	Tempering Condition	Weight	Wear Volu	Sliding	Wear Rate	Wear

				loss (g)	me $cm^3 \times 10^{-2}$	Dist ance	$cm^2 x\ 10^{-7}$	Resi stan ce $cm^2 x\ 10^{-7}$
Temp (°C)	Soak Time (hrs)	Temp (°C)	So ak Ti me (hr s)					
Mild Steel	-	-		0.2	2.54	680. 657	3.73	0.26 7
800°C	2	500°C	0.5	0.13	1.65	680. 657	2.42	0.41 1
870°C	2	500°C	0.5	0.11 8	1.50	680. 657	2.20	0.45 3
940°C	2	500°C	0.5	0.10 7	1.36	680. 657	2.00	0.49 9

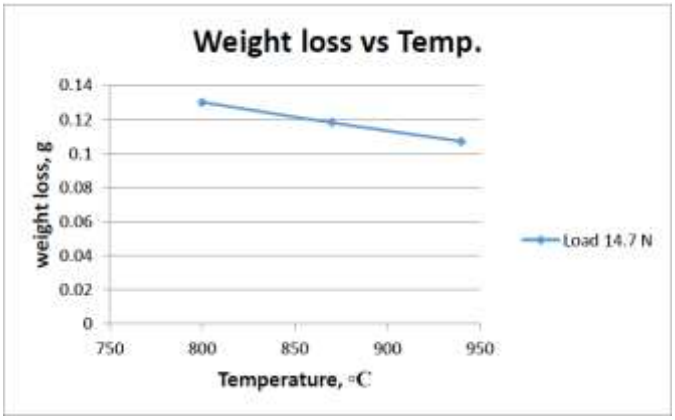

Chart -1: Weight loss due to abrasion VS carburization temperature, at load 14.7 N

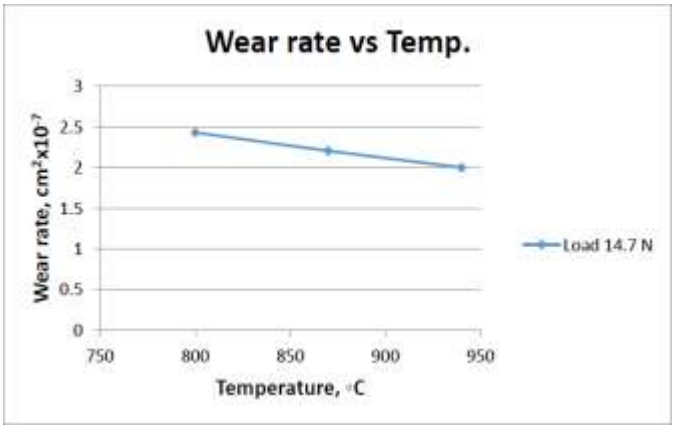

Chart -2: Wear rate VS carburization temperature, at load 14.7 N

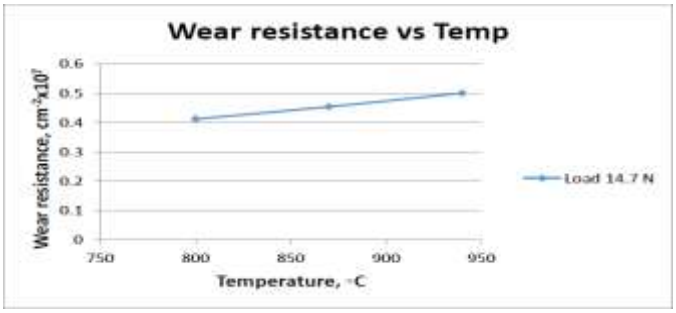

Chart -3: Wear resistance VS carburization temperature, at load 14.7 N

Table -6: Calculation of average weight loss of abrasive wear test for carburized mild steel, at load 29.4 N

Carburizing Temp.	Weight loss samples			Average weight loss
	1	2	3	
800	0.1492	0.1498	0.151	0.15
870	0.1349	0.1352	0.1351	0.135
940	0.1189	0.1199	0.1212	0.12

Table -7: Result of abrasive wear test for carburized mild steel, at load 29.4 N

Carburizati on Condition		Tempering Condition		Weig ht loss (g)	Wear Volu me $cm^3 \times 10^{-2}$	Slid ing Dist anc e	We ar Rat e $cm^2 x10^{-7}$	Wea r Resi stan ce $cm^2 x10^{-7}$
Tem p (°C)	So ak Ti m e (h rs)	Temp (°C)	So ak Ti m e (h rs)					
Mild Steel	-	-		0.25	3.18	680 .65 7	4.6 7	0.21 3
800 °C	2	500°C	0. 5	0.15	1.90	680 .65 7	2.8 0	0.35 6
870 °C	2	500°C	0. 5	0.13 5	1.71	680 .65 7	2.5 2	0.39 6
940 °C	2	500°C	0. 5	0.12	1.52	680 .65 7	2.2 4	0.45 5

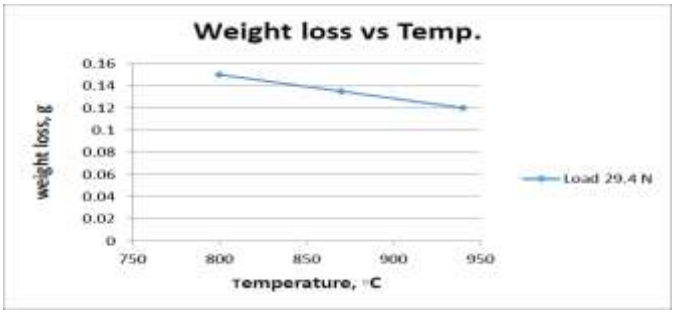

Chart -4: Weight loss due to abrasion VS carburization temperature, at load 29.4 N

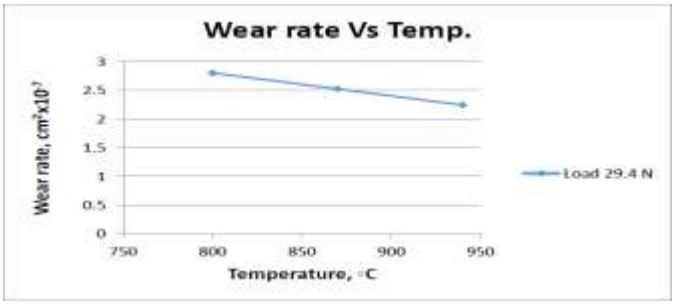

Chart -5: Wear rate VS carburization temperature, at load 29.4 N

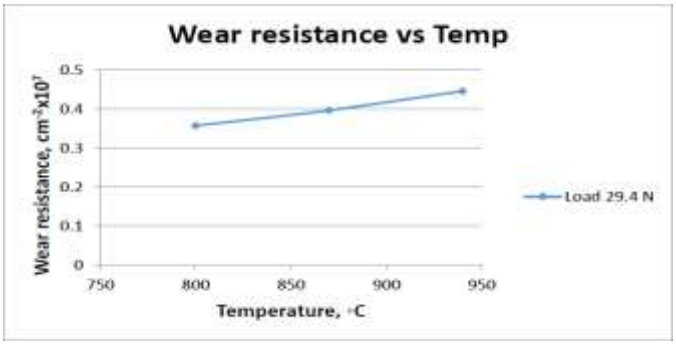

Chart -6: Wear resistance VS carburization temperature, at load 29.4 N

Table -8: Calculation of average weight loss of abrasive wear test for carburized mild steel, at load 49 N

Carburizing Temp.	Weight loss samples			Average weight loss
	1	2	3	
800	0.1849	0.1851	0.185	0.185
870	0.1649	0.165	0.1651	0.165
940	0.1451	0.145	0.1449	0.145

Table -9: Result of abrasive wear test for carburized mild steel, at load 49 N

Carburization Condition		Tempering Condition		Weight loss (g)	Wear Volume $cm^3 \times 10^{-2}$	Sliding Distance	Wear Rate $cm^2 x10^{-7}$	Wear Resistance $cm^2 x10^{-7}$
Temp (°C)	Soak Time (hrs)	Temp (°C)	Soak Time (hrs)					
Mild Steel	-	-		0.3	3.18	680.657	5.60	0.178
800 °C	2	500 °C	0.5	0.185	2.353	680.657	3.45	0.289
870 °C	2	500 °C	0.5	0.165	2.09	680.657	3.08	0.324
940 °C	2	500 °C	0.5	0.145	1.84	680.657	2.71	0.368

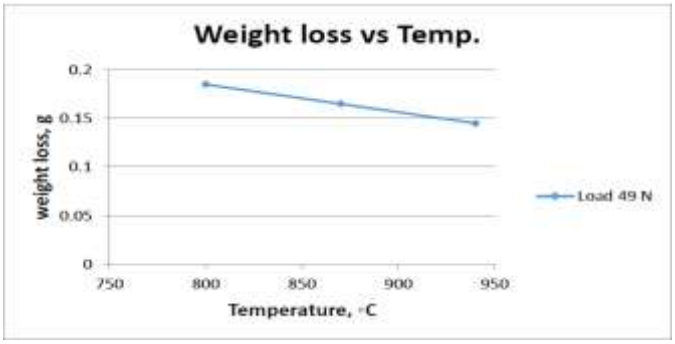

Chart -7: weight loss due to abrasion VS carburization temperature, at load 49 N

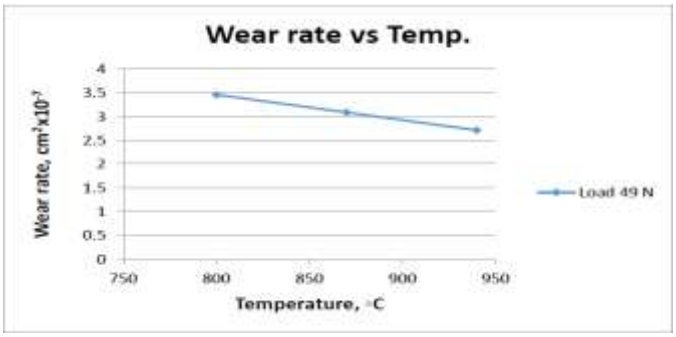

Chart -8: Wear rate VS carburization temperature, at load 49N

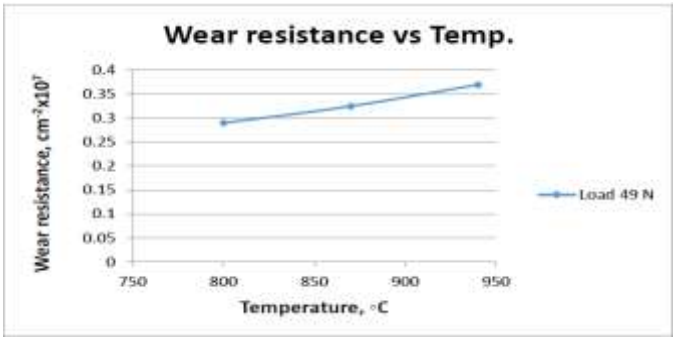

Chart -9: Wear resistance VS carburization temperature, at load 49 N

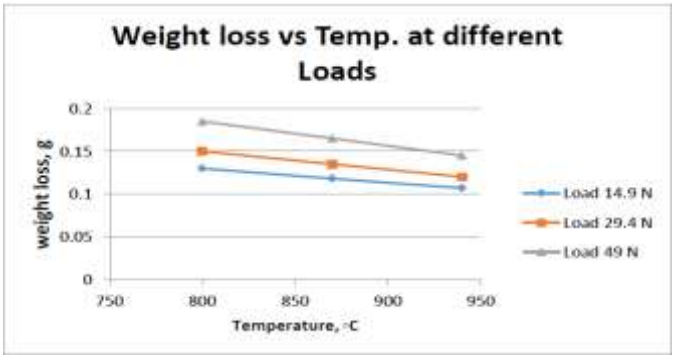

Chart -10: Comparison of weight loss due to abrasion VS carburization temperature for three different loads of 14.7 N, 29.4 N and 49 N

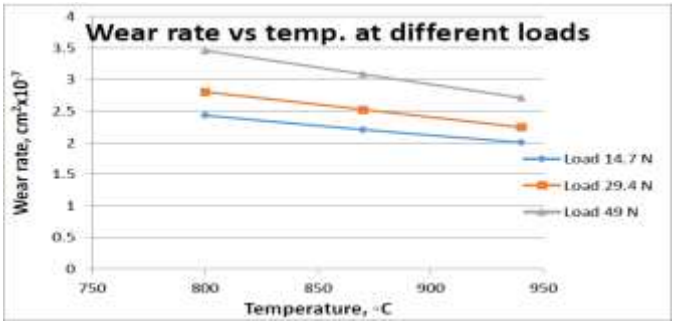

Chart -11: comparison of wear rate VS carburization temperature for three loads of 14.7 N, 29.4 N and 49 N

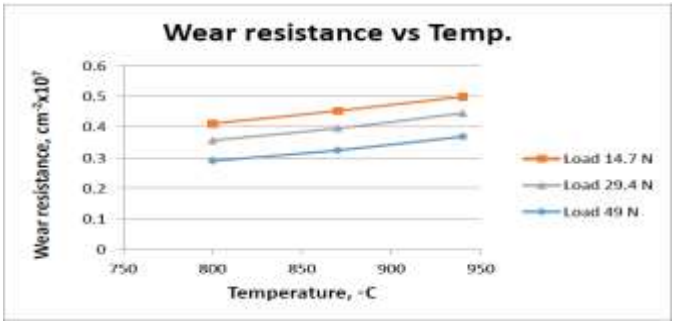

Chart -12: comparison of wear resistance VS carburization temperature for three loads of 14.7 N, 29.4 N and 49 N

Table -10: Calculation of average Rockwell hardness of carburized mild steel, at load 150 kg

Carburizing Temp.	Hardness no. samples			Average Hardness no.
	1	2	3	
800	51	52	53	52
870	53	54	55	54
940	54	55	56	55

Table -11: Result of Rockwell hardness of carburized mild steel, at load 150 kg

Carburization condition		Tempering condition		Hardness (Rc)
Temp (0C)	Soak Time (Hrs)	Temp (0C)	Soak Time (Hrs)	
Mild Steel	-	-	-	50
800°C	2	500°C	0.5	52
870 °C	2	500°C	0.5	54
940 °C	2	500°C	0.5	55

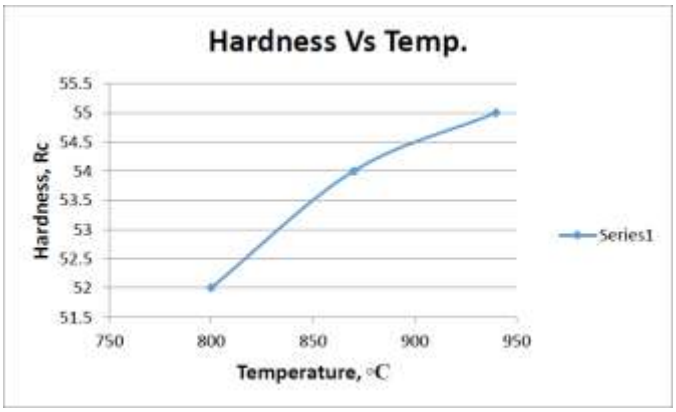

Chart -13: Variation of hardness with the carburization temperature

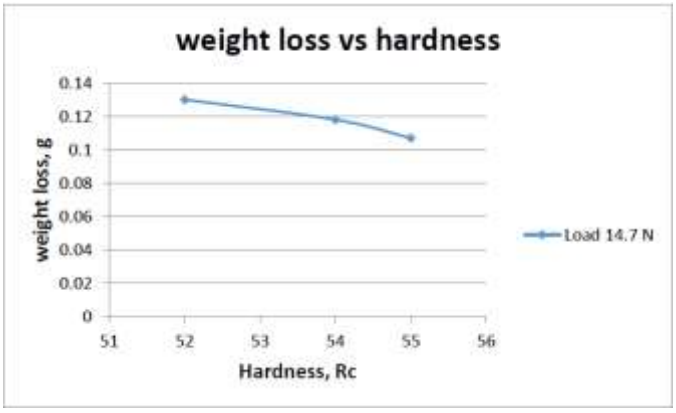

Chart -14: Weight loss due to abrasion VS hardness, at load 14.7 N

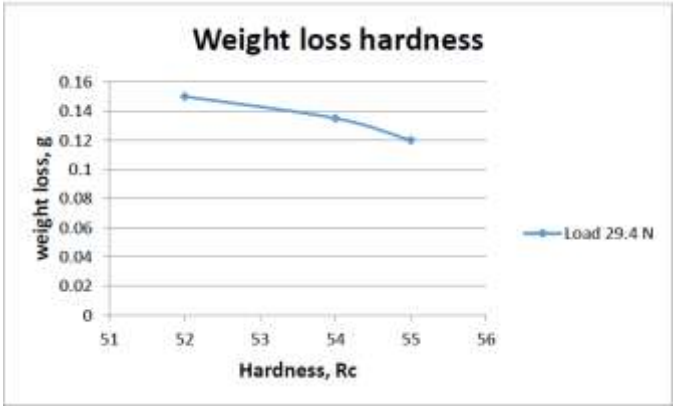

Chart -15: Weight loss due to abrasion VS hardness, at load 29.4 N

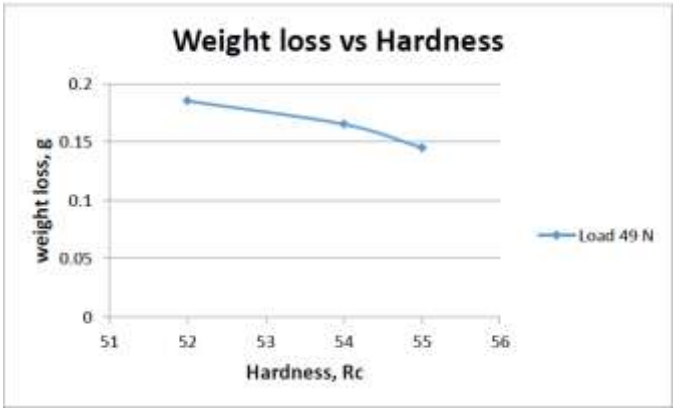

Chart -16: Weight loss due to abrasion VS hardness, at load 49 N

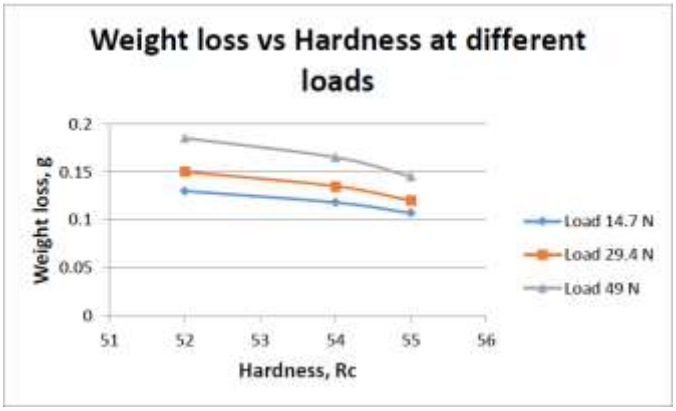

Chart -17: Comparison of weight loss due to abrasion VS hardness for the three Different loads of 14.7 N, 29.4 N and 49 N

Table -12: Calculation of average of toughness test of carburized mild steel

Carburizing Temp.	Toughness no. samples			Average Toughness no
	1	2	3	
800	35	36	37	36
870	33	34	35	34
940	30	31	32	31

Table -13: Result of toughness test of carburized mild steel

Carburization condition		Tempering condition		Toughness Joule(Nm)
Temp (0C)	Soak Time (Hrs)	Temp (0C)	Soak Time (Hrs)	
Mild Steel	-	-	-	54
800	2	500	0.5	36
870	2	500	0.5	34
900	2	500	0.5	31

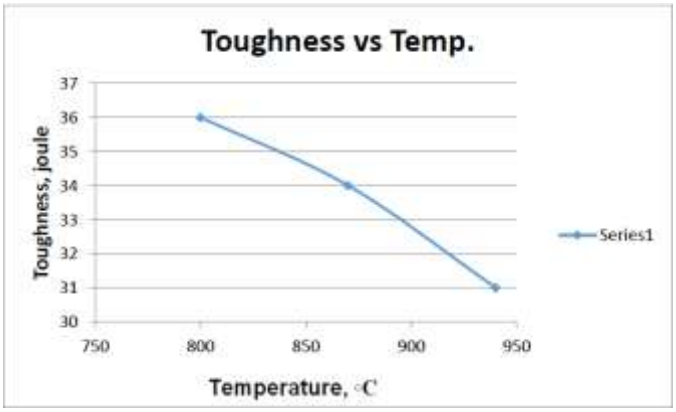

Chart -18: Variation of toughness with carburization temperature

Table -14: Calculation of average Tensile strength of carburized mild steel

Carburizing Temp.	Tensile strength samples			Average Tensile strength
	1	2	3	
800	1871	1870	1869	1870
870	1921	1919	1920	1920
940	1949	1950	1951	1950

Table -15: Tensile strength of carburized mild steel

Carburization condition		Tempering condition		Tensile Strength (MPa)
Temp (0C)	Soak Time (Hrs)	Temp (0C)	Soak Time (Hrs)	
Mild Steel	-	-	-	441
800	2	500	0.5	1870
870	2	500	0.5	1920
900	2	500	0.5	1950

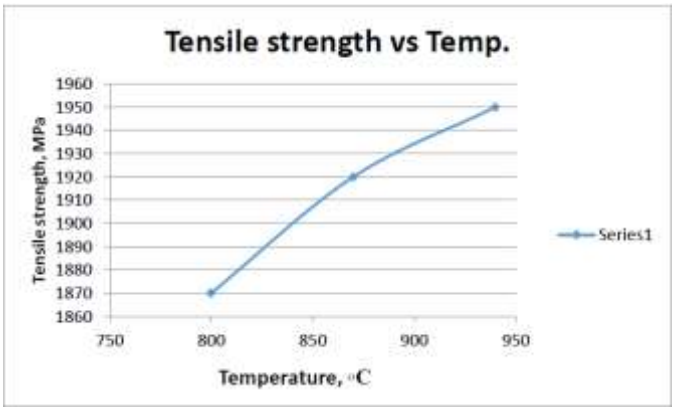

Chart -19: Variation of tensile strength with carburization temperature

5. CONCLUSIONS

1. The mechanical and wear resistance properties of sample carburized mild steel are increased by varying carburizing temperature from 800 to 940 degree Celsius.
2. After carburizing, water quenching process improves the mechanical properties of sample carburized mild steel.
3. The mechanical property of toughness decreases by increasing the carburizing temperature.
4. Hardness, wear resistance and tensile strength increases with increase in the carburization temperature.
5. The weight loss due abrasion, wear volume and wear rate increases with the increase in the applied load
6. Weight loss due to abrasion, wear volume, wear rate and toughness decreases with increase in the carburization temperature.
7. With increase in the hardness the wear resistance increases, but there is decrease in weight loss due to abrasion and wear rate.
8. From the range of carburizing temperature, 940°C is the best result of higher hardness, higher tensile strength and higher wear resistance with low weight loss and less wear rate for carburized mild steel.

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