INVESTIGATION OF OPTIMAL PROCESS PARAMETERS FOR MECHANICAL AND WEAR PROPERTIES OF CARBURIZED MILD STEEL USING TAGUCHI APPROACH

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ABSTRACT

The properties of metals and alloys can be changed by heating followed by cooling under definite conditions to make them suitable for specific applications. Carburization is a method of producing mild steel having tough inner core and hard outer surface. In this paper, carburized mild steel developed by applying carburization process. After this we carried out different tests for mechanical and wear properties at different parameters. The parameters are considers as carburization temperature, carburization sock time, tempering temperature and tempering sock time. In present paper we optimize the process parameter by which we can produce best properties in carburized mild steel. For optimizing parameters we use Taguchi method. In Taguchi method L_9 (3^4) *orthogonal array is using for experiment purpose. The mathematical values for heating and socking parameters are obtained by different experiments. We also apply ANOVA analysis for further Mathematical calculations, which gives significant parameters influencing mechanical and wear properties.*

Keywords: *Carburization process, Taguchi method, Process parameters, ANOVA analysis, Mechanical and wear properties.*

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INTRODUCTION

Changing demands of dynamic market place have improved and increased the commitment to quality conscious- ness. All over the world, companies are developing quality management systems like ISO 9001-2000 and investing in total quality [1]. One of the critical requirements for the ISO 9001-2000 is adequate control over process parameters. An auditing report of the ISO indicates that the majority of the heat treatment processes in Indus-tries present improper application of process variables and inadequate control over the process parameters [2]. Adequate control of process variables is possible if the level at which each of the parameters has to be maintained. Optimization is one of the approaches that help in finding out the right level or value of the parameters that have to be maintained for obtaining quality output. Determination of optimum parameters lies in the proper selection and introduction of suitable design of experiment at the earliest stage of the process and product development cycles so as to result in the quality and productivity improvement with cost effectiveness [3].

Machine components are subjected to surface damages like wear and corrosion in addition to static and dynamic loads. Therefore, apart from material strength, surface hardness is also an equally important property for the reliability of components against failures [15-17].

Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures within the austenitic region of the steel concern, which generally is between 850°C and 950°C for mild steels. Within this temperature range austenite, which has high solubility for carbon, is the stable crystal structure. Hardening is accomplished when the subsequent 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 [4]. Carbon diffusivity in austenite varies both with carbon concentration and carburizing temperature [5-8]. The study of process parameters in metals during heat treatment has been of considerable interest for some years [9-12] but there has been relatively little work on process variables during the surface hardening process [13] since controlling parameters in carburization is a complex problem. The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench time in oil [14].

In this study, Taguchi's Design of Experiment concept has been used for the optimization of the process variables of pack carburizing process. Taguchi's L_9 orthogonal array and 3^4 Factorial arrays have been adopted to conduct experiments in pack carburizing [18].

DESIGN OF EXPERIMENT USING TAGUCHI METHOD

The experimental procedure included experimental design by Taguchi method, carburized materials, experimental equipments and carburization procedure. Taguchi method can study data with minimum experimental runs. In this paper, the design of experiment work was decided by this method [19]. According to the experiment conditions in carburizing process for mild steel, the number of level and process parameters are given in Table 1. Based on Taguchi method, (L_9) orthogonal array with four columns and nine rows was employed in Table 2.

Table 1. Number of level and process parameters

Control Variable	Level			Observed Values
	1	2	3	
	Low	Middle	High	
Carburization Temperature (oC)	820	890	960	1. Hardness (Rc) 2. Toughness (J) 3. Tensile Strength (MPa) 4. Wear Rate ($cm^2 x10^{-7}$)
Carburization Sock Time (hr)	2	3	4	
Tempering Temperature (oC)	210	260	320	
Tempering Sock Time (hr)	0.6	1.1	1.5	

Table 2. Layout of experiments using Orthogonal Array

Control Variable Exp. No.	Carburization Temperature (oC)	Sock Time (hr)	Tempering Temperature (oC)	Sock Time (hr)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

ANOVA (Analysis of variance)

For the analysis of experimental data, Analysis of variance (ANOVA) and F-test (standard analysis) method are used, which are based on the Taguchi method given below:

$C.F. = \{T^2 / N\}$,

C.F. = Correction factor,
T = Total of all result,
N = Total no. of experiments

$S_T = \{\sum_{I=1 \text{ to } 18} Z_I^2 - C.F\}$,

S_T = Total sum of squares to total variation.
Z_I = Value of results of each experiments (I=1to18),

$S_X = \{(Z_{X1}^2 / M_{X1} + Z_{X2}^2 / M_{X2} + Z_{X3}^2 / M_{X3}) - C.F\}$,

S_X = Sum of the squares of due to parameter X (X=A, B, C, D),
M_{X1}, M_{X2}, M_{X3} = Repeating number of each level (1, 2, 3) of parameter X,
Z_{X1}, Z_{X2}, Z_{X3} = Values of result of each level (1, 2, 3) of parameter X,

$F_E = \{F_T - \sum F_X\}$,

F_E = Degree of freedom (D.O.F.) of error terms,
F_X = Degree of freedom (D.O.F.) of parameter of X,
F_X = (Number of levels of parameter X) – 1,
F_T = Total degree of freedom (D.O.F.),
F_T = (Total number of results)-1,

$V_X = \{S_X / F_X\}$, V_X = Variance of parameter X,
$S_E = \{S_T - \sum S_X\}$, S_E = Sum of square of error terms,
$V_E = \{S_E / F_E\}$, V_E = Variance of error terms,
$D_X = \{V_X / V_E\}$, D_X = F-ratio of parameter of X,
$S_X' = \{S_X - (V_E * F_X)\}$, S_X' = Pure sum of square,
$C_X = \{(S_X' / S_T) * 100\%\}$, C_X= Percentage of contribution of parameter X,

Experimental Procedure

The experiment was performed on mild steel work piece. The four process variables namely, carburizing temperature, socking time, tempering temperature and socking time, which affect the hardness, toughness, tensile strength and wear rate were selected for the Taguchi design. A L_9 (3^4) orthogonal array design was adopted for experimentation for mild steel. The 9 experiments for mild steel were conducted by varying all the parameters and study the influence of these parameters (between low, medium and high) on surface hardness, toughness, Tensile strength and wear rate. Every carburized mild steel work-piece was taken to measure the surface hardness, toughness, tensile strength and wear rate and listed in Table 4. The surface hardness (Rc) was measured using a Rockwell hardness tester at a scale with a load of 170 Kg, and wear rate (cm^2x10^{-7}) was measured using a Pin on disc wear testing machine with a load 55 N. The ranges of parameters were given in Table 3.

Table 3. Operating range of parameters

Serial no	Control Variable	Notations	Value with range
1	Carburization Temperature (oC)	A	820 – 960
2	Carburization Sock Time (hr)	B	2 – 4
3	Tempering Temperature (oC)	C	210 – 320
4	Tempering Sock Time (hr)	D	0.6 - 1.5

Testing of specimens: Tensile strength at break is determined according to ISO R527:1966. Shows the shape of the test specimens. . The tensile testing was performed using an Instron 1195 series IX automated material testing system with crosshead speeds of 1mm/s and 2mm/s respectively. Charpy impact test performed in Instron Wolpert pendulum impact test machine is used to determine the impact strength of specimen as per ISO/179:1982. During impact testing specimen is subjected to quick and intense blow by hammer pendulum striking the specimen with a speed of 3.8 m/s. The impact energy absorbed is measure of the toughness of material and it is calculated by taking the difference in potential energies of initial and final position of hammer.

following condition were taken during the different test:

Hardness test:-

In present experimental work Rockwell hardness was measured on carburized and tempered mild steel samples which are carburized under different temperature range of 820, 890 and

960 ^{0}C. For each of the sample, test was conducted for 2 times and the average of all the samples was taken as the observed values in each case.

Toughness (Charpy impact) test:-

The test is conducted for the three different samples carburized under the three different temperatures of 820, 890 and 960 ^{0}C. In present work for each of the sample, test was conducted for 2 times and the average of all the samples was taken as the observed values in each case.

Machine parameter Instron - Wolpert Pendulum Impact Testing Machine: -

Sample type	:	ASTM (D256)
Weight of hammer	:	18.75 kg
Striking of hammer	:	5 cm / s to 5.5 cm / s
Angle of hammer striking edge	:	30^{0}
Radius of curvature of striking edge	:	2 mm
Swing of hammer both ways	:	0 - 160^{0}

Tensile test:-

The tensile strength is measured by tensile test which is carried out on an Instron 1195 machine. In present experiment the tensile test was carried out on carburized and tempered mild steel samples which are treated under different temperature range of 820, 890 and 960 ^{0}C and the following condition were taken during tensile test in Instron 1195 machine.

Machine parameter of Instron 1195 tensile test:

Sample type	:	ASTM
Sample rate (pts/sec)	:	9.103
Cross head speed (mm/min)	:	2.000
Full scale loading range (KN)	:	50.00
Humidity (%)	:	50
Temperature (0F)	:	73

Wear test:-

The materials considered for this experiment is carburized mild steel samples which is carburized under different temperature range of 820, 890 and 960 ^{0}C 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).

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

Load	:	55N
RPM (N)	:	300
Time	:	5 minute
Type of abrasive paper	:	Emery, 80 Grade Size

1. Wear volume:-

Wear volume = weight loss / density

Density of specimen = 7.86 g /cm3

2. Wear rate: - Wear rate =wear volume / sliding distance(s)

Sliding distance (s) = V x time = (2 π R N / 60) x time

Where, R = radius of abrasive wheel (7.25cm)

Π = 3.14 (constant)

3. Wear resistance: - Wear resistance = 1 / wear rate

Table 4. L9 table and Observed value

Exp. No.	**Control Variable**				**Hardness (Rc)**		**Toughness (J)**		**Tensile Strength (MPa)**		**Wear Rate (cm^2x10^{-7})**	
	A	**B**	**C**	**D**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
1	820	2	210	0.6	50	51	37	37	447	460	4.87	4.96
2	820	3	260	1.1	51	52	37	36	590	615	4.41	4.60
3	820	4	320	1.5	52	53	36	35	760	810	4.20	4.12
4	890	2	260	1.5	55	54	33	33	938	985	3.73	3.70
5	890	3	320	0.6	54	55	32	31	1290	1301	3.50	3.35
6	890	4	210	1.1	57	56	32	32	1445	1530	3.04	3.05
7	960	2	320	1.1	59	60	30	30	1650	1715	2.52	2.42
8	960	3	210	1.5	58	57	29	28	1830	1910	2.30	2.23
9	960	4	260	0.6	60	59	27	27	1970	2005	2.11	2.05
					496	497	293	289	10920	11331	30.68	30.48

Experimental data analysis

Table 5. Analysis of variance and F test for Hardness

Variable (X)	D.O.F (F_X)	Sum of square (S_X)	Variance (V_X)	F-ratio (D_X)	Pure sum (S_X')	C_X (%)
A	2	161.33	80.67	161.33**	160.33	88.83
B	2	9.33	4.67	9.33*	8.33	4.62
C	2	1.33	0.67	1.33*	0.33	0.18
D	2	4.00	2.00	4.00*	3.00	1.66
Error	9	4.50	0.50			

** Significant Parameter, * Sub-significant parameter

Table 6. Analysis of variance and F test for Toughness

Variable (X)	D.O.F (F_X)	Sum of square (S_X)	Variance (V_X)	F-ratio (D_X)	Pure sum (S_X')	C_X (%)
A	2	184.33	92.17	414.75**	183.89	91.94
B	2	10.33	5.17	23.25*	9.89	4.94
C	2	0.33	0.17	0.75*	0.11	0.06
D	2	3.00	1.50	6.75*	2.56	1.28
Error	9	2.00	0.22			

** Significant Parameter, * Sub-significant parameter

Table 7. Analysis of variance and F test for Tensile Strength

Variable (X)	D.O.F (F_X)	Sum of square(S_X)	Variance (V_X)	F-ratio (D_X)	Pure sum (S_X')	C_X (%)
A	2	4,562,163.00	2,281,081.50	1,662.39**	4,559,418.67	90.057
B	2	454,009.00	227,004.50	165.44*	451,264.67	8.9133
C	2	25,417.00	12,708.50	9.26*	22,672.67	0.4478
D	2	8,896.00	4,448.00	3.24*	6,151.67	0.1215
Error	9	12,349.50	1,372.17			

** Significant Parameter, * Sub-significant parameter

Table 8. Analysis of variance and F test for Wear Rate

Variable (X)	D.O.F (F_X)	Sum of square(S_X)	Variance (V_X)	F-ratio (D_X)	Pure sum (S_X')	C_X (%)
A	2	15.26	7.63	1,482.68**	15.24	92.51
B	2	1.10	0.55	106.72*	1.09	6.60
C	2	0.02	0.01	2.04*	0.01	0.07
D	2	0.06	0.03	5.46*	0.05	0.28
Error	9	0.05	0.01			

** Significant Parameter, * Sub-significant parameter

Table 9. Summarization of significant parameters on the machinability of Carburized Mild Steel

Control Variable	Hardness	Toughness	Tensile strength	Wear rate
A	**	**	**	**
B	*	*	*	*
C	*	*	*	*
D	*	*	*	*

** Significant Parameter, * Sub-significant parameter

RESULTS AND DISCUSSION

HARDNESS

The hardness values varied between range of 50 Rc – 60 Rc and it is highest for the mild steel carburized at temperature of 960 ^oC and is lowest for the mild steels carburized at 820 ^oC, so with increase of carburization temperature the hardness values increases as shown in figure 1. From the hardness test experiment it is also noted that the hardness values of uncarburized simple mild steel is unable to calculate in Rc scale because of its very less hardness values. We have done the confirmation test according to optimal setting (A_3, B_3, C_3, and D_2) from Table 10 and found hardness 59.88 Rc, which shows the successful implementation of the method.

Figure 1. Effect of each factor on Hardness:

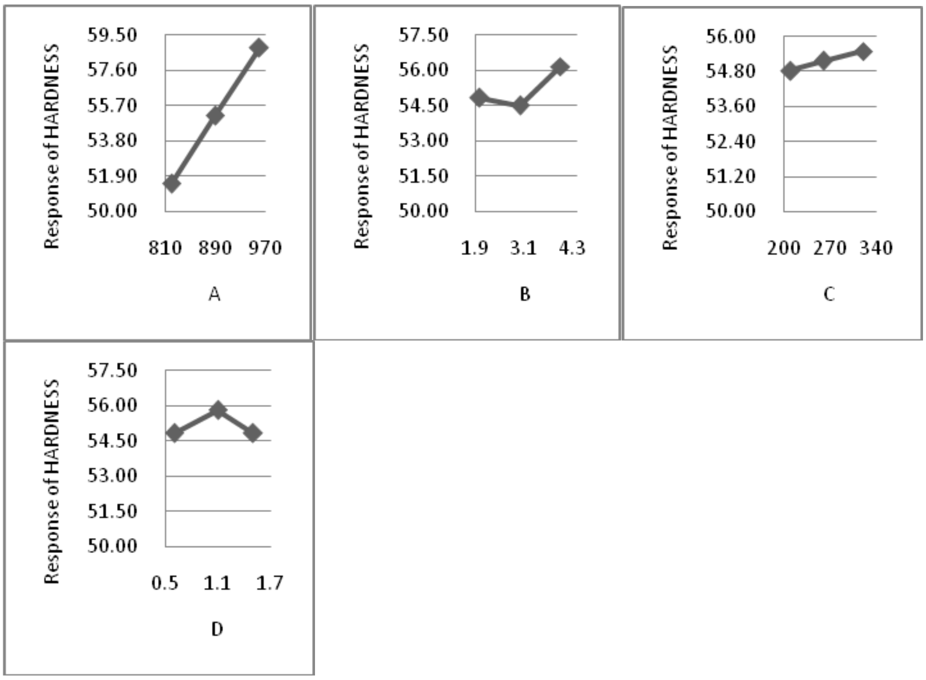

Table 10. Optimum condition based on results of Hardness

Variable	Level Description	Level
A	960	3
B	4	3
C	320	3
D	1.1	2

TOUGHNESS

From the results of the toughness test it is analyses that the toughness is varied between the range of 37J – 27J and it is highest for the uncarburized mild steels and lowest for the mild steels carburized at temperature of 960 ^{o}C. So it is concluded that the carburization process decreases the toughness of the mild steels. It is also obtained from the toughness test results that. As the carburization temperature increases from value of 820 – 960 ^{o}C, there is a decrease in the toughness values from 37J – 27 J as shown in figure 2, so it is concluded from the results that with increase of carburization temperature, the toughness values decreases. We have done the confirmation test according to optimal setting (A_1, B_1, C_1, and D_2) from Table 11and found toughness 36.33J, which shows the successful implementation of the method.

Figure 2. Effect of each factor on Toughness:

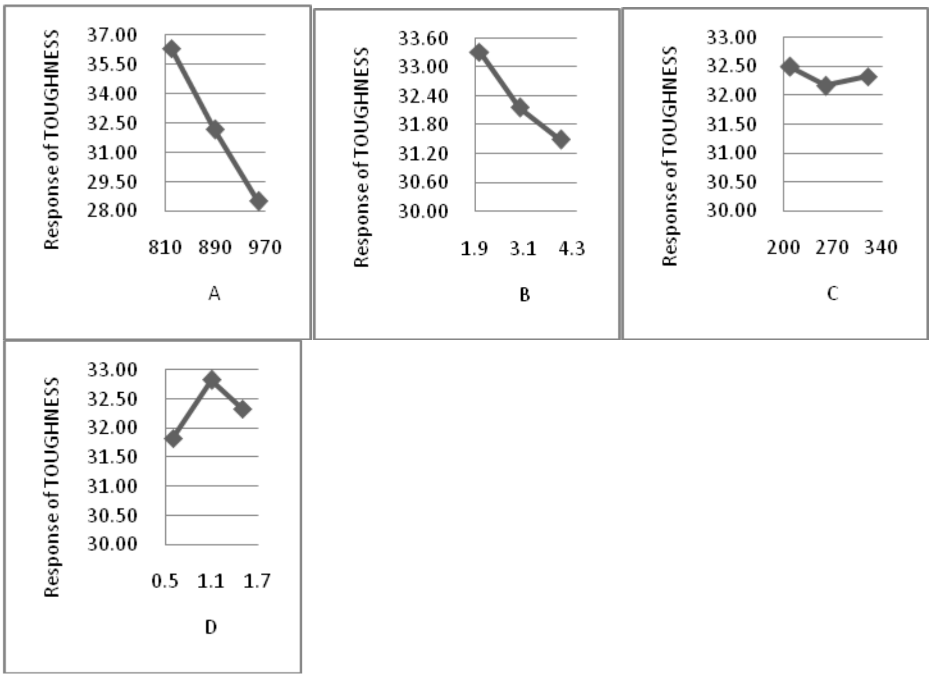

Table 11. Optimum condition based on results of Toughness:

Variable	Level Description	Level
A	820	1
B	2	1
C	210	1
D	1.1	2

TENSILE STRENGTH

The tensile strength is varied between the ranges of 447MPa – 2005 MPa and is highest for the mild steel carburized at temperature of 960 ^{o}C and lowest for the uncarburized simple mild steel. This results shows that the carburization greatly improved the tensile strength of mild steels. For taking the case of carburized mild steels only, the tensile strength is highest for the mild steels carburized at the temperature of 960 ^{o}C and is lowest for the mild steels carburized at temperature of 820 ^{o}C as shown in figure 3, that's leads to the conclusion that with the increase in the carburization temperature, the tensile strength of carburized mild steels increases. We have done the confirmation test according to optimal setting (A_3, B_3, C_1, and D_2) from Table 12 and found tensile strength 1846.50MPa, which shows the successful implementation of the method.

Figure 3. Effect of each factor on Tensile Strength:

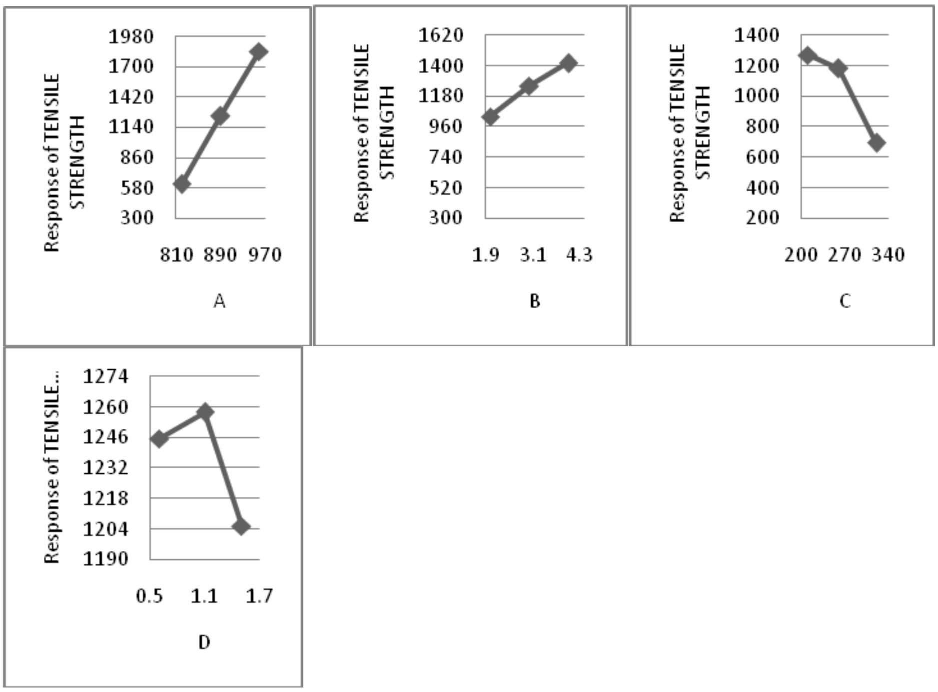

Table 12. Optimum condition based on results of Tensile Strength:

Variable	Level Description	Level
A	960	3
B	4	3
C	210	1
D	1.1	2

WEAR RATE

The wear resistance is higher for the carburized mild steel and it is lowest for the uncarburized mild steel. For taking only the case of carburized mild steels the wear resistance is highest for the mild steel carburized at the temperature of 960 ^{O}C and is lowest for mild steels carburized at temperature of 820 ^{O}C as shown in figure 4. Hence the abrasion results explain that the wear resistance is directly proportional to the carburization temperature, as the carburization temperature increases the wear resistance increases. The net results is that the mild steel carburized at temperature of 960 ^{o}C giving the best results, as it has having the highest wear resistance, lowest weight loss due to abrasion and lowest wear rate. We have done the confirmation test according to optimal setting (A_3, B_3, C_3, and D_2) from Table 13 and found wear rate 2.33 cm^2 $x10^{-7}$,which shows the successful implementation of the method.

Figure 4. Effect of each factor on Wear Rate:

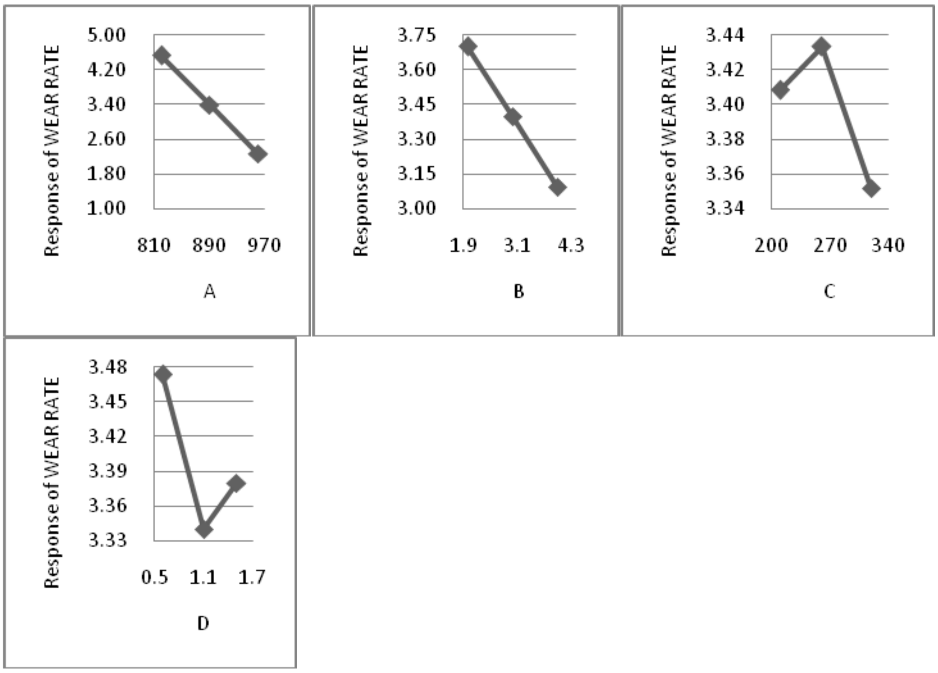

Table 13. Optimum condition based on results of Wear Rate:

Variable	Level Description	Level
A	820	3
B	2	3
C	260	3
D	0.6	2

CONCLUSIONS

From the above studies on carburized mild steels samples the following conclusions have been drawn.

1. The mechanical and wear properties of mild steels were found to be strongly influenced by the process parameters.

2. Hardness and tensile strength increases with increase in the carburization temperature.

3. Wear rate and toughness decreases with increase in the carburization temperature.

4. As comparing for different carburization temperature. The mild steels carburized at the temperature of 960 ^{o}C shows the best combination of higher hardness, higher tensile strength and less wear rate.

5. Finally the net conclusion is that the mild steel carburized under the different temperature range of 820, 890, and 960 ^{o}C in which the mild steel carburized at the temperature of 960 ^{o}C is giving the best results for the mechanical and wear properties like tensile strength, hardness and wear rate.

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