Vol. XI & Issue No. 6 June - 2018
INDUSTRIAL ENGINEERING JOURNAL

OPTIMIZATION OF GAS CARBURIZATION PROCESS PARAMETERS FOR WEAR RESISTANCE OF AISI 1020 LOW CARBON STEEL

Ramandeep Singh Sidhu
Balwinder Singh Sidhu

Abstract

Gas carburization has been used in order to improve mechanical properties of steel surface hardening in engineering industries. In this investigation optimization of gas carburization process parameters for wear resistance on AISI 1020 low carbon steel has been done by using Taguchi approach. Design of experiments is done on the basis of an orthogonal array L9 (3^4). Nine experiments are performed on the basis of L9 Taguchi approach by using various process parameters like carburizing temperature, soaking time, tempering temperature and temperature time. Signal to noise (S/N) ratios, MEAN ratio Taguchi analysis is performed in order to obtain response variable like wear rate. It is observed during investigation that heat treatment is followed by quenching and tempering tremendously improves wear resistance of AISI 1020. In order to predict optimal parameter, confirmation test is conducted for implementation of L9 Taguchi approach. This study concludes that wear resistance has been improved after the gas carburization process.

I. INTRODUCTION

There are many practical application of steel in various aspects of life. Low carbon steel is used to manufacture mechanical components which are used in daily life. Low carbon steel contain 0.05–0.3% of carbon. Mild steel with favorable properties such as tough, soft, flexibility and ductility are the best among to produce goods. Sometimes chance of wear and battering on the surface of steel exists due to its properties. Surface treatment processes are done in order to improve its properties that is ductile as well as hard component is required[1].

Case hardening is very important process in order to improve wear resistance and increase toughness to withstand tremendous load. Many machines parts are used for heavy duty applications, such as drive gear, drive shaft, cam shaft, bus and truck gear, crank shaftnut, bolts, screws, automobile body panels, tin plate, wire product, tubes, girders, axles general engineering parts and components, machinery parts, shafts, camshafts, gudgon pins, ratchets, light duty gears, worm gears and spindles etc. Demand increase in hardness and it can fulfill by case hardening process. Low carbon steel properties can be improved with best suitable case hardening method known as carburization process[2].

Carburization is one of the case hardening process. In this process of heat treatment carbon is introduced into the surface of steel when it is heated with carbon containing material (gas, liquid, and solid) in order to increase hardness and wear resistance of metal [3]. There are many type of carburization process such as gas carburizing, vacuum carburizing, plasma carburizing and salt bath carburizing.

The work piece to be carburized is placed in furnace contain carburization atmosphere. The carburizing process does not harden the steel it only increases the carbon content to some pre-determined depth below the surface to a sufficient level to allow subsequent heat treatment processes[1].

In gas carburization process of heat treatment carbon is introduced into the surface of steel when it is heated with carbon bearing material (gas, liquid , and solid) in order to increase hardness and wear resistance of metal [3][4]. When steel is transformed from austenite to martensite hardness of steel take place on outer surface [3]. The process can only applied to low carbon steel carbon content (.2 to .3 %) [4,5]. Diffusion of carbon atoms mainly depends upon amount of temperature and duration of time. With increase in temperature and duration of time increases depth of diffusion. Diffusion of carburization is greatest among all the surface hardness processes. Gaseous carburization is most successful and most popular carburization process in present days in the field of automotive and aerospace component. Well defined carbon profiles can easily formed with controlled gas carburization. The gas atmosphere used in gas carburization consist of Endothermic gas, (H2 + N2 + CO), Methanol (CH_3OH) and vaporized hydro-carbon liquids [4][6].Sushil Kumar et. al. investigated the most effective controlling parameters for heat treatment of needle bearing steel, the effect of controlling parameters such as Holding Time, Carburizing temperature. Carbon Potential and Quenching temperature on hardness value of bearing steel. In their case, 9 combinations of the above mentioned 4 parameters were set and Taguchi's method was followed accordingly. Signal to noise ratio (S/N) analysis showed that effective hardness value was obtained when the parameters were chosen on the basis of "Smaller the better" category which were Holding Time: 40 min., Carbon Potential: 1.2 m3/hr., Carburizing Temperature: 890^{0}C and Quenching Time:4 min[7].

Olawale Samuel Fatoba1 et. al. examine that utilization of carburizing materials in surface engineering has undergone many tremendous changes. Effective quality control was possible through carburizing the steel components under optimal conditions. In their research work, process parameters like furnace temperature, soaking time and particle size of energizer were taken for optimization of carburized UNS-G10170 steel to yield maximum hardness using Taguchi's design of experiment concepts and Response Surface Model. Nine experimental runs based on Taguchi's L9 orthogonal array were performed; signal to noise (S/N) ratios, analysis of variance (ANOVA) and regression analysis were used with hardness as response variable. From the optimization and experimental analyses conducted, it was observed that furnace temperature, soaking time and particle size had significant influence in obtaining a better surface integrity. The optimal values obtained during the study optimization by Taguchi approach and Response Surface Model (RSM) were validated by confirmation experiments[8].

V.K. Murugan and Dr.P. KoshyMathews observed that carburizing materials in engineering fields has undergone so many tremendous changes in engineering fields. Gas carburizing was one of the surface engineering techniques widely used in the process of heat treatment in all the engineering industries. Carburizing was a complex process; it involves a number of variables for the success of the carburizing process. Effective quality control was possible through carburizing the components under optimal conditions .The objective of there paper was to obtain an optimal setting of carburizing process parameters (carburizing temperature, soaking time, gas diffusion effect ,furnace air circulation) resulting in optimal values of the correct depth of the case in the surface of the components. Taguchi method was a powerful design of the experiment (DOE) tool for engineering optimization of a process. Analysis of variance (ANOVA) was used to study the effect of process parameters and establish correlation among the carburizing temperature, soaking time, gas diffusion effect, furnace air circulation[9].

II. EXPERIMENTATION

Selection of material

In this current work, commercial low grade carbon steel specimens equivalent to AISI 1020 specification having composition (weight%): Carbon .214%, Silicon .222%, Manganese .536%, Phosphorous .017%, Sulphur .005%, Chromium .052%, Nickel.041%, Aluminium 0.11%, Copper .015%, Vanadium .003%, Iron 98.78%. AISI 1020 steel is one of largest used steel grade available. AISI 1020 are hot rolled carbon steel uses for axles general engineering parts and components, machinery parts, shafts, camshafts, gudgon pins, ratchets, light duty gears, worm gears and spindles. After studying the various literature on carburization process four important parameters is selected in this study. Carburizing temperature, soaking time, tempering temperature and tempering time are four important parameters are selected in order to investigate various properties of AISI 1020 steel after carburization. The output process parameters chosen are hardness, impact strength and wear strength.

Table 1: Levels for Various Factors.

S no.	Carburizing temperature (°C)	Soaking time (hr.)	Tempering temperature (°C)	Tempering time (hr.)
1	870	4	200	0.5
2	900	5	240	1
3	930	6	260	1.5

III. DESIGN OF EXPERIMENT

A Taguchi technique is one of easy and efficient technique among available Design of Experiment techniques for analysis of experiment. Taguchi technique is famous for its development of new product in the field of quality control. L9 orthogonal array product of Minitab software is used for this experiment as shown in Table 2. All these experiments were performed by performing input parameters like carburizing time or soaking time, carburizing temperature, tempering temperature and tempering time. The experiment was performed on the basis of furnace capacity and experiment limitation. Above factors were selected for output parameters like impact strength, wear resistance and hardness as provided in the literature. In this study three different soaking time were taken these are (4, 5 and 6 hr.) and three different carburization temperature (870, 900, 930 °C) respectively. After preparation of sample it were embedded in the activated carbon inside furnace which was tightly sealed with aluminium cover prevent to escape gas outside and unwanted gas to enter inside the furnace. Furnace temperature was adjusted to the required temperature (870, 900, 930 °C for each stage respectively) after desired temperature was attained then soaked at the temperature at desired time (4,5 and 6 hr). After the material was held at desired time,then after lowering carbon monoxide concentration, the atmosphere is further used for tempering.

IV. WEAR RESISTANCE TEST

The wear tests were performed on various samples using Multiple Tribo Tester TR-201 which is helpful in order to study friction and wear characteristics in rolling sliding contacts under desired conditions. Tangential force and wear are measured with electronic sensors and recorded in PC.Various types of parameters used in order to find desired output are, given in table 3.

Table 2.Design of Experimentation.

S No.	Carburization Temp. (C°)	Soaking Time (hr.)	Tempering Temp. (C°)	Tempering time (hr.)
1	870	4	200	0.5
2	870	5	240	1.0
3	870	6	260	1.5
4	900	4	240	1.5
5	900	5	260	0.5
6	900	6	200	1.0
7	930	4	260	1.0
8	930	5	200	1.5
9	930	6	240	0.5

Table 3.Specification of TR 25.

Parameter	Unit	Min	Max
Load	N	0	1000
Speed	Rpm	0	2000
Temperature	°C	Ambient	120
Wear	Micron	0	2000

Wear rate was calculated on the basis of following steps:-

1 Wear volume:-

Wear volume = weight loss / density

Density of specimen= 7.87 g /cm^3

2 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 (60 mm)

N = R.P.M (150)

Π = 3.14 (constant)

Time = 10 minute = 600 S. All of 9 specimens were assigned at constant load of 2.00 kgf and constantsample time of 10 min at constant speed of 150 r.p.min with track radius of 60 mm. The wear with respect to time is recorded for each of specimen.

The effect of carburizing temperature soaking time, tempering temperature, tempering time on wear rate of carburized AISI 1020 structural steel is shown in Table 4.Main effects plot for Mean ratios of wear rate represented graphically in the Fig 1. Fig 2.shows Main effects plot for S/N ratios of wear rate Wear results were concluded on the basis of option of smaller is better. It is observed from the results that wear rate varies directly with that of carburization temperature. It is concluded that with increase in carburization temperature wear rate decreases. Wear rate is minimum at carburization temperature 930°C. So it is preferred that carburization temperature must be at 930°C to obtain minimum wear.

Table 4.Wear Results of Experimentation.

S No ..	Carburi zation Temp. (°C)	Soaki ng Time (hr.)	Temp ering Temp. (°C)	Temp ering time (hr.)	Wear rate (cm^2 Micron)
1	870	4	200	0.5	46.8
2	870	5	240	1.0	47.1
3	870	6	260	1.5	43.6
4	900	4	240	1.5	32.3
5	900	5	260	0.5	34.3
6	900	6	200	1.0	31.5
7	930	4	260	1.0	22.2
8	930	5	200	1.5	23.6
9	930	6	240	0.5	22.0

From the main effect plot minimum S/N ratio is obtained at level-3 for carburizing temperature, level-3 for soaking time, level-3 for tempering temperature and level-2 for tempering time. Therefore the optimal combination for process parameter is found to by carburizing temperature C-3, Soaking time S-3, Tempering temperature TT-3 and tempering time Tt-2. The graph reveals that wear rate is minimum at level 3 for carburization temperature i.e. 930°C, at maximum soaking time i.e. 6 hr. and tempering temperature 240°C and tempering time 0.5 hr. The influence of carburizing temperature is maximum then soaking time but on the other hand effect of tempering temperature and tempering time is minimum..Table 5 shows response for means of wear strength.

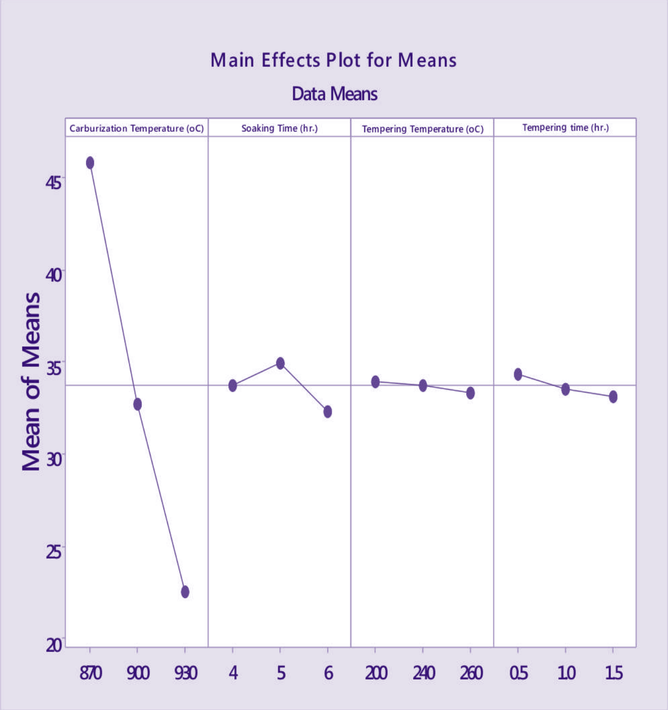

Fig. 1 Main effects plot for Mean ratios of wear

Table 5. Response for Means of wear strength

Level	Carburizing temp. (°C)	Soaking time(hr.)	Tempering temp. (°C)	Tempering time (hr.)
1	45.83	33.77	33.97	34.37
2	32.70	35.00	33.80	33.60
3	22.60	32.37	33.37	33.17
Delta	23.23	2.63	0.60	1.20
Rank	1	2	4	3

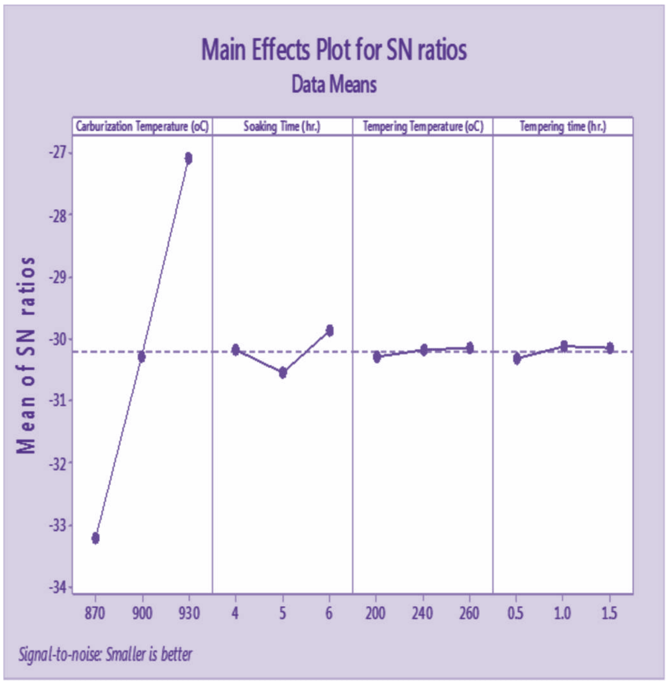

Fig 2.Main effects plot for S/N ratios of wear rate.

Table 6 Response Table for Signal to Noise Ratios of wear test

Level	Carburizing temperature(°C)	Soaking time (hr.)	Tempering temperature (°C)	Tempering time (hr.)
1	-33.22	-30.17	-30.28	-30.32
2	-30.29	-30.54	-30.16	-30.12
3	-27.08	-29.87	-30.14	-30.14
Delta	6.14	0.67	0.14	.020
Rank	1	2	4	3

Wear results were concluded on the basis of option of smaller is better. It is observed from the results that wear rate varies directly with that of carburization temperature. It is concluded that with increase in carburization temperature wear rate decreases. Wear rate is minimum at carburization temperature 930°C. So it is preferred that carburization temperature must be at 930°C to obtain minimum wear.

Table 22 represents S/N ratio of, wear rate for different parameters levels. From the main effect plot Figure 21 minimum S/N ratio is obtained at level-3 for carburizing temperature, level-3 for soaking time, level-3 for tempering temperature and level-2 for tempering time. Therefore the optimal combination for process parameter is found to by carburizing temperature C-3, Soaking time S-3, Tempering temperature TT-3 and tempering time Tt-2. The graph ravels that wear rate is minimum at level 3 for carburization temperature i.e. 930°C, at maximum soaking time i.e. 6 hr. and tempering temperature 240°C and tempering time 0.5 hr. The influence of carburizing temperature is maximum then soaking time but on the other hand effect of tempering temperature and tempering time is minimum.

V. CONCLUSIONS

Following conclusions can be made on the basis of experimentation.

1 Wear rate goes on decreasing with increase in carburizing temperature and minimum at carburization temperature at 930 °C.

2 Wear rate get minimum at soaking time at 6 hr, tempering temperature 260 °C and tempering time 1.5 hr.

3 It is observed that wear resistance improves with increase in most influence factor that is carburizing temperature. After carburizing temperature most influence factor is carburizing soaking time. Maximum hardness and minimum wear obtained with increase in carburizing soaking time

REFERENCES

1. *H. Azri and A. Sabri, "Experimental study of pack carburizing of carbon steel" Universiti Malaysia Pahang 2011.*
2. *J. Dossett and G. Totten, "Introduction to Surface Hardening of Steels" 2013.*
3. *E. Oberg et al., "Machinery's handbook: Industrial Press New York" Vol. 200, 2004.*
4. *A.S.M., "Handbook: Heat treating" 1991, Volume 4.*
5. *R.H.Todd , D.K. Allen, and L. Alting, "Manufacturing processes reference guide: Industrial Press Inc" 1994.*
6. *S. Natarajan, "Thermochemical Surface Engineering of Steels. Surface Engineering" 2015, 31(11), p. 875-878.*
7. *S. Kumar, and A. kumar Singh, "Optimization of heat treatment processes of steel used in automotive bearings".*
8. *O.S.Fatoba, O.L. Akanji, and A.S. Aasa, "Optimization of Carburized UNS G10170 Steel Process Parameters Using Taguchi Approach and Response Surface Model (RSM)" Journal of Minerals and Materials Characterization and Engineering, 2014. 2(06): p. 566.*
9. *V. Murugan, and P.K. Mathews, "Effect of Tempering Behavior on Heat Treated Medium Carbon (C35 Mn75) Steel" International Journal of Innovative Research in Science, Engineering and Technology, 2013. Vol 2.*

AUTHORS

Ramandeep Singh Sidhu, Department of Mechanical Engineering, Guru Nanak DevEngg College Ludhiana.

E-mail ramandeepsidhu92@gmail.com

Balwinder Singh Sidhu, Department of Mechanical Engineering, GZS Campus CET Bathinda;

E-mail:drbwssidhu07@ gmail.com