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INVESTIGATION CORROSION AND MECHANICAL PROPERTIES OF CARBURIZED LOW CARBON STEEL

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Abstract: In this research, Taguchi method is used (S/N) ratio for measuring the variations in experimental design. Taguchi designs used in converting the multi-performance problem into a single-performance problem for experiments which will are in building (Taguchi (L_{27}) orthogonal array) for carburization operation. The main variables that had a great effect on carburizing operation are Carburization temperature (^{o} C), carburization time (hrs.) and tempering temperature (^{o}C). It was focused also on calculating the amount of carbon penetration, the value of hardness, wear rate, corrosion rates and optimal values obtained during the optimization by (Taguchi) approach method for multiple parameters. In this study, the carburization process was done in temperature between (850 to 950 ^{o}C) for (2 to 6 hrs.). Quenching process was done for the specimens after heat treatments in furnace chamber by different quench solution (water, salt and polyvinyl alcohol). Taguchi design used to achieve maximum hardness and depth penetration, Minimum wear and corrosion rates.

Keywords: *Low carbon steel, Carburization process, Corrosion resistance, Taguchi design, Wear rate, Microhardness.*

دراسة التأكل والخواص الميكانيكية للفولاذ المنخض الكاربون المكربن

الخلاصة: في هذا البحث، يستخدم أسلوب تاغوتشي (S / N) نسبة لقياس الاختلافات في التصميم التجريبي. تصميم تاغوتشي يستخدم في تحويل المشكلة متعددة الأداء إلى مشكلة أداء واحد للتجارب التي سوف تكون في بناء (تاجوشي (L27) مجموعة متعامدة) لعملية الكربنة. المتغيرات الرئيسية التي كان لها تأثير كبير على عملية الكربنة هي درجة حرارة الكربنة (°س)، وقت الكربنة (ساعات.) ودرجة حرارة التلدين (°س). وركزت أيضا على حساب كمية اختراق الكربون، وقيمة الصلابة، ومعدل البلى، ومعدلات التآكل والقيم المثلى التي تم الحصول عليها خلال عملية التحسين بواسطة طريقة (تاغوتشي) المتعددة. في هذه الدراسة، تم إجراء عملية الكربنة في درجة حرارة بين (850 إلى 950 درجة مئوية) لمدة (2 إلى 6 ساعات). وقد أجريت عملية التبريد لعينات بعد العلاجات الحرارية في غرفة الفرن بواسطة حل إخماد مختلفة (الماء والملح والبولي فينيل الكحول). تصميم تاغوتشي تستخدم للحصول أقصى قدر من الصلابة وعمق الاختراق، والحد الأدنى من معدلات البلى والتآكل.

1. Introduction

Mild steel is considered the most form of steel that used because its price relatively low. It is widely used for many industrial applications; surface hardness can be increased through carburizing [1, 2]. Carburizing process is heat treatment in which carbon can be dissolve in the surface layers of mild steel part at austenite temperature, carburizing process is followed by quenching and tempering in order to form a

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martensitic microstructure [3, 4]. The mechanical properties of mild steel samples were found to be strongly influenced by the process of carburization treatment [5]. Formation of martensite phase leads to increases the micro hardness with increasing cooling rate and carbon content [6]. Carburized process has been improved properties including surface hardness, wear resistance, and corrosion resistance [7].

Belete Kefarge Azmite et.al [8] studies the mechanical properties of mild steel samples for achieving better performance. The samples subjected to pack carburization process at (850 °C, 900 °C and 950 °C). The observation was showed that the mechanical properties strongly influenced by the carburization process and concludes that the properties like hardness and abrasive wear resistance are improved. Jitendra Prasad et.al [9] the investigation on the mechanical properties of (mild steel) was carburizing at temperature range (890, 920 and 950^0C). It was found that the heat treatment process improved the hardness and wears resistance for hand tool. Paul Aondona Ihom [10] in this study, the experiment was carried out using a muffle furnace at (900 °C) for (8 hrs.). The result showed that (60 wt. % charcoal / 40 wt. % cow bone) had the best result. Fatai Olufemi Aramide et. al. [11] the investagation on studied the effects of carburized temperature and time on the mechanical charcteristic of mild steel. It was carburized at temperature (850, 900 and 950 ºC), for (15 and 30) minutes and quenched in oil. It was found that the optimum conditions of mechanical properties at temperature (900 ºC) followed by quenching in oil and (tempering at 550 ºC). Hesham elzanaty [12] investigation on effect of carburizing process on mild steels, then the samples subjected for kinds of testing such as abrasive wear, hardness, tensile and toughness.

The results appear that the process of carburization improves the mechanical properties .Amarishkumar J. Patel and Sunilkumar N. Chaudhari [13] investigation focus on carburized mild steel samples at (900 ºC) temperature and socking time up to (120 min). Then quenching in oil bath and tempered at different temperature like (200 ºC, 250 ºC and 300 ºC) for ninety minutes. The results appear improve the wear, hardness, tensile strength value and compromise in toughness at higher tempering process in mild steel material.

Mohammed abdulraoof [14] in this study, the surface for mild steel was carburized then quenched in oil solution. The microstructure, hardness and wear resistance properties have been studied at different carburized temperatures; (850, 900, and 950 ˚C) with constant time (2 hr). The result showed that at carburizing temperature (900 ˚C and 950 ºC) is higher than at (850 ºC). K. palaniredja et.al [15] Optimize the surface hardness and case depth of steel materials. Which is consist of gas carburizing process at temperature range between (870 to 930 º C) .The Taguchi method is design for the optimization process for nine number of experiment, the results appears optimal parameter of carburized part to improve properties. R. Singh [16] studies the optimization process for parameters in order to produce best characteristic in carburized low carbon steel. Taguchi method was used for optimization parameters. The results showed that the low carbon steel was carburized under the different temperature range and investigates suitable temperature at which the mild steel can gave the best results for the mechanical properties. Sorin and

Adriana [17] focused on determine hardness of steels in different moments of deep carburizing and demonstrate an improvement in outcomes deep carburizing. From this study observed that the decrease in residual austenite content that located on the surface of the piece after annealing process, which is leading to increase hardness in the area.

2. Experimental Work

2.1. *Preparation of Sample*

The chemical composition for the mild steel sample is explain in Table 1 (According to ASTM/E/415-14) and also the mild steel sample with diameter and length is(10 mm 30 mm respectively). Carburizing sample can be used in several applications such as gears, ball bearings, railway wheels.so that to successful carburization treatment, at first the sample is cleaned with alcohols solution (CH_3COCH_3) then it will be ready to start carburization steps.

Table1. The chemical compositions of mild steel sample.

Elements	% C	% Si	% Mn	% P	% S	% Ni	% Al	% Co
Aver. Cont.	0.122	0.0005	0.442	0.0005	0.0269	0.0119	0.0052	0.001
Elements	% Cu	% Nb	% W	% Ta	% Sn	% Zr	% Zn	% Cr
Aver. Cont.	0.0135	0.001	0.0056	0.0082	0.001	0.0064	0.0036	0.0097
Elements	% Mo	% Ti	% V	% Fe				
Aver. Cont.	0.001	0.0005	0.0009	Rem				

2.2. *Carburization Process*

Which is consisting that the sample embedded in carburization box that contain graphite within activator ($BaCO_3$). The conditions under which pack carburizing experiments have conducted are given in Table 2. Then the box sealed with clay to prevent reaction of air with this mixture, generally the sample quench with different solution (water solution, salt solution and polymer solution) and the specification of these solutions is generally shown in Table 3.

Table 2. Factors and their levels of carburization.

Factor	Factor code	Levels		
		1	2	3
Carburization Temp. (^oC)	A	850	900	950
Carburization time (hrs.)	B	2	4	6
Tempering Temp (^{o} C)	C	200	250	300
Tempering time	D	1	1.5	2
Activator wt.%	E	10	20	30
Quench Media	F	Water	Brine	Polyvinyl alcohol

Table 3. Characteristics of the used quenching mediums.

Salt specification		Polymer specification
Material	Percentage	Poly vinyl alcohol (PVA): 99% hydrolyzed.
Cl	(99.5%) Min	
Sulphate (SO_4)	0.002%	Concentration = 1.5 gm. /liter in distilled water (amount of salt that distilled in water)
And Max limits of impurities loss on drying at (1050 °C).	1.0%	
Lead (Pb)	0.0005%	
Potassium (K)	0.02%	
Iron (Fe)	0.002%	

2.3. *Test of Samples*

2.3.1. *Microstructure examination*

Sample surface needed to prepare for microstructure examination this can be done by grinding and polishing using (silicon carbides (SiC) paper) (320, 400, 600, 800, 1000 and 1200) followed by etching process by using Nital (2% nitric acid & 98% alcohol), then the specimen examined with microscope and calculate amount of depth penetration that shown in Figure 6. By calculating average amount of carbon penetration in different area from outer surface was done by the same device also.

2.3.2. *Wear rate test*

The wear rate can be defined as follow equation

$$\text{Wear rate} = \text{weight loss } (\Delta W) \,/\, (s) \qquad (1)$$

Wear rate = (W1 – W2) / (s)
Sliding distance (s) can be measured from:-

$$\text{Sliding distance } (s) = V \times t \qquad (2)$$

$$\text{Sliding distance } = (2\,\pi\, R\, N) \times t \qquad (3)$$

Where, R = abrasive wheel radius (6 cm), t = time
N =950 R.P.M (constant), Time = 10 minute and the amount of load applied is (30 N).

2.3.3. *Microhardness test*

Micro-hardness instrument was used of a diamond Vickers pyramid. Which it can be produce a square impress and also the micro-hardness determine by the size of the impress diagonal by the used of optical microscopy so that the hardness (H) has defined as the ratio of the indentation force to the area of the impress after unloading. And also is the angle of the pyramid sides For a Vickers pyramid ∂ equal 136^o
So that (Hv) will be

$$VHN = \frac{1.845\, p}{d^2} \qquad (4)$$

Where p = amount of Applied load (kg)

D = represent the length of the diagonals impression

2.3.4. *Corrosion rate test*

The majority of metallographic specimen mounting is done by mixing the resin with hander in order to form mounting compound. Then the specimen is place in compound (which is considered self-curing compound) and let it to dry. This specimen is place in container full with solution (Nacl+Water), the salt (Nacl) concentration in water is about (0.6M).

The corrosion rate (C.R.) was convenient and customary to express corrosion rate as (mille inches per year- mpy). This unit gives an indication of penetration. Dividing the above equation by the electrode area and the density gives:

$$C.R.\ (mm/y) = 87.6 \times (W / DAT) \qquad (5)$$

$$1\ mpy = 0.0254\ mm/y \qquad (6)$$

Where:
W = weight loss in milligrams
D = metal density in (g /cm^3).
A = area of sample in (cm^2).
T = times in hours,

3. Results and Discussion

The result of tests for all samples is shown in Table 4. The S/N ratios for case depth, micro hardness, wear rate, corrosion rate have been calculated from experimental values in Table 4. The S/N ratio corresponding to each experimental run was given in Table 5.

Table 4. Result of the testing specimens

Exp of No.	Case depth (mm)	Micro hardness(HV)	Wear Rate (cm² x 10^{-7})	corrosion rate (mpy)
1	0.23	660	5.74	0.064
2	0.417	725	3.35	0.063
3	0.621	840	1.22	0.068
4	0.233	944	1.01	0.062
5	0.441	881	1.54	0.05
6	0.432	837	1.12	0.047
7	0.345	855	1.11	0.058
8	0.661	663	4.33	0.078
9	0.618	709	3.11	0.061
10	0.114	934	1.02	0.077
11	0.712	966	1.01	0.046
12	0.332	899	1.12	0.069
13	0.643	1050	0.992	0.003
14	0.764	776	3.22	0.054
15	0.443	993	1.01	0.006
16	0.713	775	3.06	0.033
17	0.334	883	1.449	0.005
18	0.789	881	1.33	0.079

19	0.662	1088	0.882	0.002
20	0.331	889	1.22	0.069
21	0.778	776	3.13	0.076
22	0.662	669	5.66	0.065
23	1.77	799	1.55	0.059
24	0.777	889	1.22	0.084
25	0.467	994	1.02	0.077
26	0.772	1010	0.773	0.005
27	1.75	833	1.11	0.048

Table 5. The (S/N) ratio for case depth, microhardness, wear rate, corrosion rates values.

No. of Exp	S/N Ratio of case depth	S/N Ratio of microhardness (F)	S/N Ratio for Wear Rate ($cm^2 \times 10^{-7}$)	S/N Ratio for corrosion rate(mpy)
1	-12.765	56.3909	-15.178	23.885
2	-7.597	57.2068	-10.955	23.986
3	-4.138	58.4856	-1.727	23.387
4	-12.653	59.4994	-0.086	24.161
5	-7.111	58.8995	-3.75	25.944
6	-7.29	58.4545	-0.984	26.541
7	-9.244	58.6393	-0.906	24.706
8	-3.596	56.4303	-12.703	22.112
9	-4.18	57.129	-9.855	24.226
10	-18.862	59.4069	-0.172	22.295
11	-2.95	59.6995	-0.086	26.697
12	-9.577	59.0752	-0.984	23.227
13	-3.836	60.4238	-0.07	50.458
14	-2.338	57.7972	-10.157	25.348
15	-7.072	59.939	-0.086	44.846
16	-2.938	57.786	-9.714	29.73
17	-9.525	58.9192	-3.221	45.355
18	-2.058	58.8995	-2.477	22.071
19	-3.544	60.7326	1.091	53.979
20	-9.603	58.978	-1.727	23.163
21	-2.18	57.7972	-9.883	22.422
22	-3.583	56.5085	-15.056	23.772
23	-5.13	58.0509	-3.807	24.651
24	-2.192	58.978	-1.727	21.505
25	-6.614	59.9477	-0.172	22.253
26	-2.248	60.0864	2.238	46.021
27	-16.027	58.4129	-0.906	26.464

The main effects plot for S/N ratios is shown in Figure 1. The optimal conditions of these control factors was easily determining from graphs. The response graph was showed the change of the S/N ratio for various control factor levels. The best case depth value was at the higher S/N values in the response graphs. It will be seen that the initial optimumal condition for the tested specimens becomes (A2B2C2D1E1F1) for main control factors.

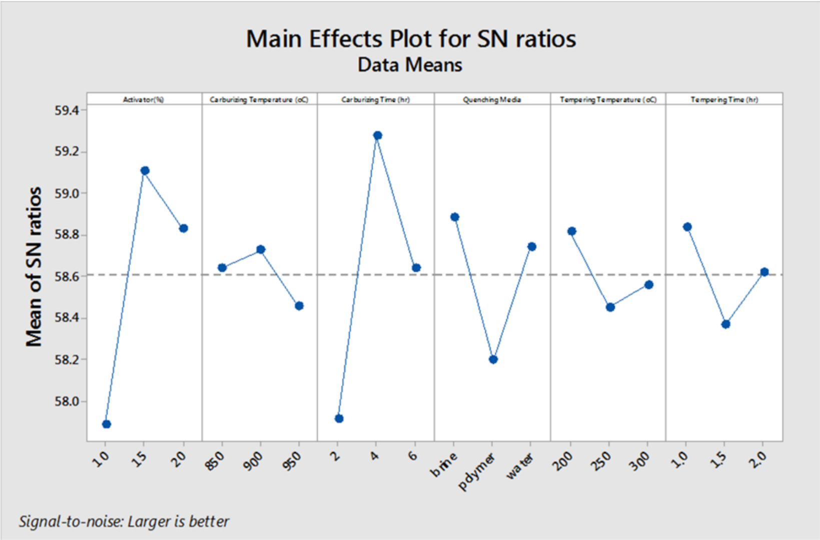

Figure 1. (S/N) values of case depth for carburized steel at optimum condition

The carburizing time is the important factor that affecting on the wear rate i.e. the minimum value of wear rate. Activator (%) has a lower effect. While the carburizing temperature shows the lowest effect among those factors.

For (S/N) ratios suggested that those levels of variables would minimized the wear rate, also were robust against variability due to noises as shown in Figure 2. The optimum conditions for wear rate at (A1B1C1D2E2F2).

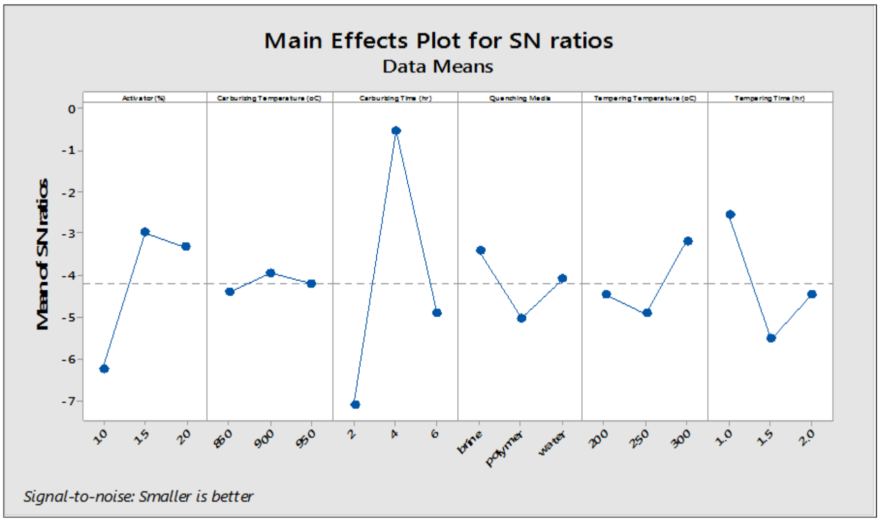

Figure 2. (S/N) values of wear rate for carburized steel at optimum condition.

Since "smaller is the better" was selected for corrosion rate, the smallest values were depended to calculate the optimal combination of carburization temperature, carburization time, activator (%), tempering temperature, tempering time and quenching media. Therefore, the optimum combinations of corrosion resistance were determined as A1B1C1D2E3F2. The calculated optimal values were proposed for (27) trials is shown in Figure 3.

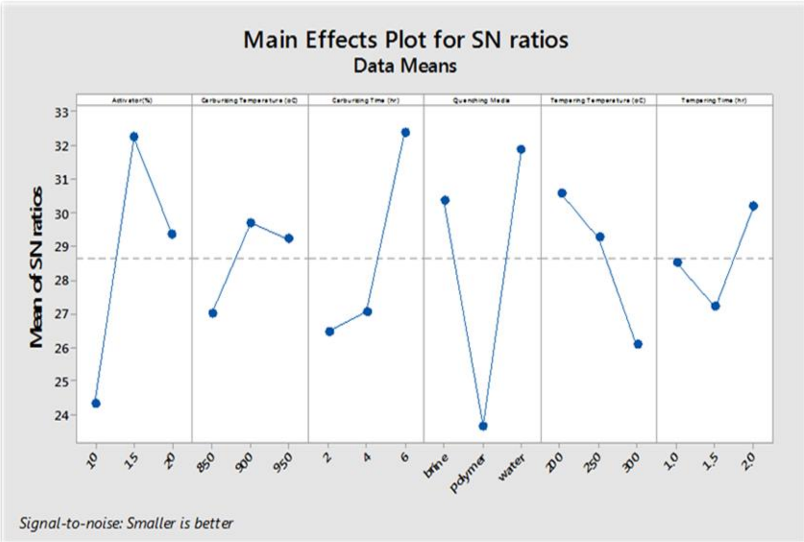

Figure 3. (S/N) values of corrosion rate for carburized steel at optimum conditions.

The graphical representations of factors effect at different levels are shown in Figure 4. The optimum parameter level is the level corresponding to maximum average S/N ratio for a control factor. The predicted value for microhardness at the optimum condition is (A2B2C2D1E1F1).

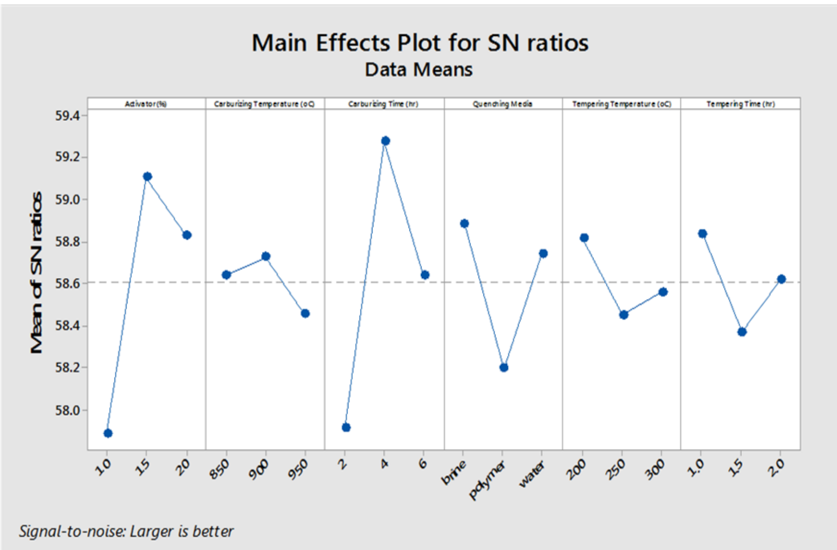

Figure 4. (S/N) values of microhardness for carburized steel at optimum condition.

4. Conclusions

- The optimum parameters level predicted in (S/N) optimization for maximum values of microhardness and case depth and for minimum value of wear rate and corrosion rate are A1B1C1D2E3F2, A1B1C1D2E2F2, A2B2C2D1E3F1 and A1B1C1D2E3F2 respectively.

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