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INTERACTION EFFECT OF CARBURIZATION PROCESS ON HARDNESS PROPERTY OF AN A36 GRADE STEEL

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ABSTRACT
In engineering industries, pack carburization has been utilized to enhance the mechanical qualities of steel surface hardening. In this study, the response surface method was used to study the interaction effect on the pack carburization process parameters for surface hardness property on ASTM A36 low-carbon steel gear for drilling machine application. A total of 17 gears were machined from a long circular bar of A36 steel. Charcoal was used as a carburizer with sugar cane thrash as an energizer. The Box Behnken design was used to output the design of the experiment on a three factors and three-level setting. Pack carburization variables of carburization temperature, soaking time, and tempering temperature were varied on a constant tempering time of 2 hours and found to have the most interaction effect of soaking time and tempering temperature as output from the predicted mathematical model for hardness.

INTRODUCTION

Steel has many real-world applications in many facets of life. Manufacturing mechanical parts that are used in daily life use low-carbon steel 0.05-0.3% of the carbon in low-carbon steel is carbon. Mild steel is the greatest material to create things since it has beneficial features including toughness, ductility, softness, and flexibility. Due to its characteristics, steel occasionally has the potential of wearing and bruising on its surface. Its ductile and hard component qualities need to be improved; hence surface treatment methods are used.[1] Because they are readily available, workable, and weldable, steels are currently one of the materials used most frequently in a variety of industrial activities designed for the production of piston pins, camshafts, levers, pump shafts,... [2]. Low carbon content mild steels, however, have less significant chemical, physical, and mechanical characteristics. Due to their low carbon content, middle steels have been utilized for springs, washers, automobile seat belt components, and clutch and chain parts in industrial applications. When compared to other carbon steels, however, the mechanical properties—such as hardness, toughness, and stress resistance—are relatively subpar [3]. The technique of case hardening is crucial for enhancing wear resistance and toughness to sustain heavy loads. Numerous machine parts, such as shafts, camshafts, gudgeon pins, ratchets, light-duty gears, worm gears, spindles, bus and truck gear, crankshaft nuts, bolts, screws, automobile body panels, tin plates, wire products, tubes, girders, axles, general engineering parts, and components, are used in heavy-duty applications. Hardness demands rise, and the case hardening procedure can meet them. With the most appropriate case hardening technique, known as the carburization process, low-carbon steel characteristics can be improved [4]. One of the most used steel heat treatments is carburizing. The low-carbon wrought iron components were packed in charcoal for a lengthy period, and the temperature was raised for hours. The entire bag, including the charcoal, was then thrown into some water to put out the fire. As a result, the part's interior or core preserved its low-carbon steel's toughness while the surface of the part became extremely hard [5]. When low carbon steels are subjected to the carburizing process, carbon is added to the surface of the steel at temperatures that fall within the austenitic range, which for mild steels is typically between 850°C and 950°C. The most stable crystal structure in this temperature range is austenite, which has a high solubility for carbon. When the following high-carbon surface layer is quenched to create martensite, hardening is achieved, resulting in the superimposition of a high-carbon martensitic case with good wear and fatigue resistance on a hard, low-carbon steel core (Krauss, 1980). Due to the low strength of the carbon concentration, low-carbon steel cannot be directly heated to harden it [7]. Low-carbon steel has a carbon percentage of 0.1% to 0.3%. Since low-carbon steels are easily machinable and can have their surface layers carburized and then hardened, the effort is intended to improve the hardness and wear resistance of the mild steel through carburization.

Experimentation

Commercial low-grade carbon steel locally machined spur gear meeting A36 grade steel specifications was used in this study, and their weight percentages were as follows: Carbon 0.25%, Silicon 0.28%, Manganese 1.02%, Phosphorous 0.04%, Sulphur 0.05%, Copper 0.2%, One of the most widely used steel grades is A36 low carbon steel.

Design of Experimentation

A three-factor three-level design was output using the box Behnken design on response surface methodology.

Table 1 below indicates the dependent factors, response, and levels.

	Variable	Units	Type	Levels	L[1]	L[2]	L[3]
A[Numeric]	Carburization Temperature	oC	Discrete	3	850	900	950
B[Numeric]	Soaking Time	Hours	Discrete	3	3	4	5
C[Numeric]	Tempering temperature	oC	Discrete	3	210	230	250

Table 2. Design of Experiment

The design of experiment was output in the Box behnken design (BBD) environment on response surface methodology. A total of 17 runs were contained in the design corresponding to factors mixtures. When compared to a standard factorial method, Box-Behnken designs require fewer runs to produce higher-order response surfaces [10]. To preserve the higher-order surface definition, this technique and the central composite technique essentially suppress chosen runs. Twelve middle edge nodes and three center nodes are used in the Box-Behnken design to fit a second-order equation.

A total of 17 gears were machined from an ASTM A36 steel rod and subjected to a carburization process based on the design of the experiment sheet

Run	Factor 1 (Carburization Temp.)	Factor 2 (Soaking Time)	Factor 3 (Tempering Temp.)	Response 1 Hardness
1	900	4	230	87
2	900	3	250	88
3	850	3	230	78
4	900	4	230	87
5	850	4	250	81
6	950	5	230	86
7	900	4	230	87
8	900	4	230	87
9	900	4	230	93
10	950	4	210	87
11	900	5	210	98
12	950	4	250	79
13	950	3	230	76
14	900	5	250	90
15	850	4	210	89

16	900	3	210	88
17	850	5	230	88

Hardness Test
The Dynamic hardness testing method was employed for this project. The fundamental rule for determining hardness is to look at a sample's capacity to resist plastic deformation from a reliable source. All metals can be tested for hardness dynamically. Brinnel Hardness number is the name of the hardness measurement used in the test.

RESULT AND DISCUSSION
ANOVA for Quadratic model
Table1. ANOVA for Hardness Model

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	**425.32**	**9**	**47.26**	**7.38**	**0.0076**	significant
A-Carbur.Temp	8.00	1	8.00	1.25	0.3004	
B-Soaking Time	128.00	1	128.00	20.00	0.0029	
C-Tempering Temp.	72.00	1	72.00	11.25	0.0122	
AC	0.0000	1	0.0000	0.0000	1.0000	
BC	16.00	1	16.00	2.50	0.1579	
A^2	183.41	1	183.41	28.66	0.0011	
B^2	0.6737	1	0.6737	0.1053	0.7551	
C^2	24.25	1	24.25	3.79	0.0926	
Residual	44.80	7	6.40			
Lack of Fit	16.00	3	5.33	0.7407	0.5808	not significant
Pure Error	28.80	4	7.20			
Cor Total	470.12	16				
R-squared = 0.9047			Adj- R- Squared = 0.7822			
` Predicted R – Squared = 0.3579			Adequate Precision = 11.8539			

The hardness response ANOVA is displayed in Table 1. The R^2, modified R^2, and anticipated R2 adequacy measures are also displayed in the same table. All of the adequacy measures are consistent and show meaningful correlations. The tables also display the statistics overview for each model that Design Expert 13 produced. Despite having lower R^2 and adjusted-R^2 (Adj- R^2) values than the cubic model, a quadratic model was proposed. This is due to the cubic model being aliased, which implies that various signals produced by the effects of each variable are no longer distinguishable. [7] The model is suggested to be significant by the model's F-value of 7.38. The likelihood of noise producing an F-value this large is merely 0.76%. Model terms are considered significant when the P-value is less than 0.0500. B, C, and A2 are important model terms in this instance. Model terms are not significant if the value is higher than 0.1000. Model reduction may enhance your model if it has a lot of unnecessary terms (except those needed to maintain hierarchy). The F-value for the lack of fit, 0.74, indicates that the lack of fit is not significant in comparison to the pure error. A significant Lack of Fit F-value has a 58.08% likelihood of being caused by noise. Since we want the model to fit, a non-significant lack of fit is desirable.

Interaction effects between factors from Predicted Mathematical Equation.

Equation 1 below is the mathematical predicted equation for hardness as output from the analysis. The notable H represents hardness in Brinnel hardness number.

$$H = +88.20 - 1.0000A + 4.00B - 3.00C - 2.00BC - 6.60A^2 + 0.4000B^2 + 2.40C^2 \text{.....}equa1$$

It is possible to anticipate the reaction for specific levels of each element using the equation expressed in terms of coded factors. By default, the factors' high levels are coded as +1 and their low levels as -1. By contrasting the factor coefficients, the coded equation can be used to determine the relative importance of the elements. Amongst the varied factors of carburization temperature, soaking time and tempering temperature, the soaking time with a notable B having a coefficient of 4 indicates the greatest effect on the hardness property and carburization having the least effect on the hardness property with a coefficient of -1.

The most interaction effect between factors was found between the soaking time (B) and the tempering temperature (C) with a coefficient of -2.

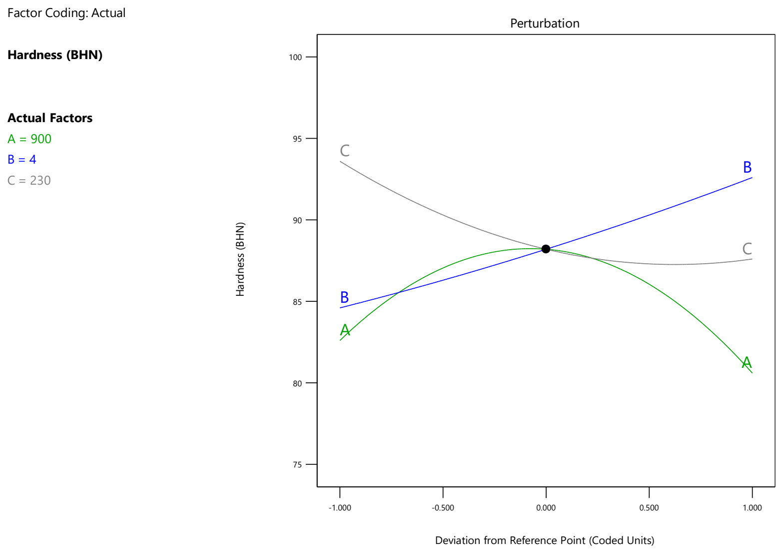

Fig.1 Perturbation Plot of carburization parameters on Hardness

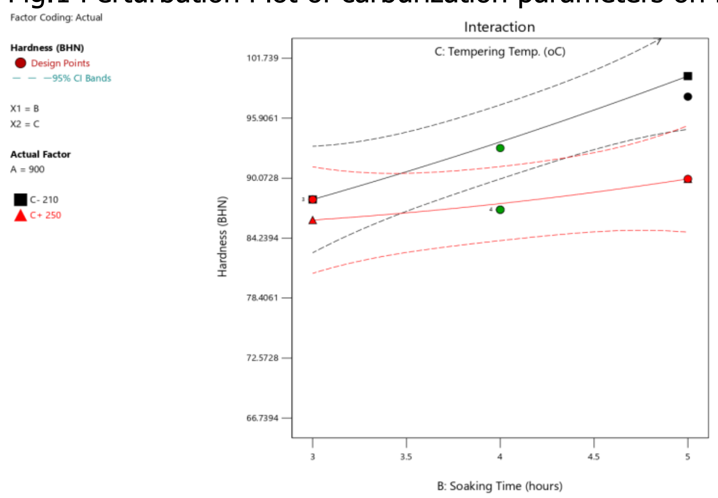

Fig.2. Parameter interaction plot on Hardness Response

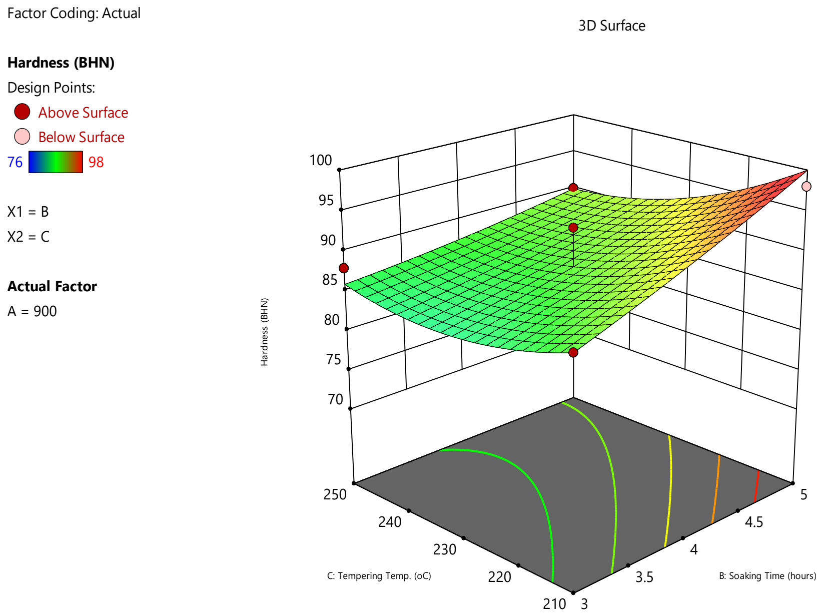

Fig.3. Three Dimension contour plot of interacting parametric effect on hardness Response

Figures 1-3 are representations of interacting factors using three plots. Fig 1 is the perturbation plot, the perturbation plot makes it easier to compare each factor's impact at a specific location in the design space. Plotting the response involves adjusting just one element along its range while maintaining the constant values of all the other factors. The soaking time factor has a steadily increasing effect on the hardness response within the design space. Fig.2 is the interaction effect plot showing the overlapping lines representing notable B and C. The overlapping or interacting lines further validate the interaction effect of soaking time and tempering temperature on the hardness response. Fig.3. is the three-dimensional contour plot. The response surface more clearly illustrates how each component tends to affect hardness. A substantial interaction is shown by an elliptical contour plot, whereas a minimal effect is shown by a circular contour map.

CONCLUSION

The following conclusions can be made based on the study

1. The Most interactive effect of the studied parametric effect on the hardness of A36 steel after carburization using charcoal and sugar gane thrash as energizer is the tempering temperature and soaking time.
2. A predicted mathematical model connecting the influence of interaction effect and single factor effects on the hardness property of carburized A36 grade steel was output.
3. Charcoal as carburizer with sugar gane thrash was successfully used to increase the hardness of A36 grade steel
4. Response surface methodology is an accurate tool for studying the interaction effects of parametric factors on response

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