

Application of the Response Surface Methodology to Find Out the Effect of Input Parameters on Fe500D Steel

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ABSTRACT: The effect of major alloying elements, namely carbon, copper and chromium on mechanical properties of Fe500D steel is studied in the present research work. Centre composite design is utilized to develop non-linear input -output relations. Experiments have been conducted as per the central composite design matrix. Non linear regression model developed for the responses namely yield strength, ultimate tensile strength, and percentage elongation has been tested for their statistical adequacy by utilizing ANOVA. The influence of process parameter and their relation with response is studied with the help of surface plots. The performance of the input – output relation is checked with the help of test cases. The alloying elements carbon and chromium are found to have more influence on the response yield strength and Ultimate tensile strength as compare to copper. It is to be noted that all alloying elements have negative contribution on the response yield strength and ultimate tensile strength as compare to copper. It is to be noted that all alloying elements have negative contribution on the response –elongation. The non linear regression model can be used to predict the mechanical properties for different combination of alloying elements without conducting any experiments.

KEYWORDS: Alloying element, Response Surface methodology, Surface plot, Steel

I. INTRODUCTION

The composition of Fe500D comprises of Carbon, Manganese, Phosphorous, Sulphur, Copper and Chromium. The responses to measure strength of the steel are Yield strength, Ultimate tensile strength and elongation percentage. 500 stands for the minimum yield stress in N/mm². The letter D denotes that such bars have higher values of minimum percentage elongation. Along with this the standards have lowered the quantity of S and P values in the bar which are harmful for steels used in construction. Also the Carbon percentage has been lowered and the physical properties have been enhanced. Fe500D is used for different purposes and different field like multi-floor buildings, bridges, housing and different construction purpose. The performance of steel at definite proportion is known, while changing the proportion of alloying elements the properties are changed. Hence experimental study is carried out to investigate the effect of composition on the mechanical property in steel. Response surface methodology uses various graphical, statistical and mathematical techniques to develop, improve or optimize a process, also use for modeling and analysis of problem if our response variables are influenced by several independent variables. RSM is used in different fields of real life. Like Agriculture, Industries, Medical fields and many other like this. It is use where we want to get optimum response. A central composite design is the most typically used response surface designed experiment. Central composite styles are a factorial or incomplete factorial design with center points, augmented with a cluster of axial points (also known as star points) that allows estimating curvature. A study conducted by Laz'ko et al. [1] showed the

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high strength weldable steel 03G4N2MAF increases significantly as its carbon content increases from 0.05 to 0.10-0.12% with retention of plasticity and resilience. Babichev and velikanova [2] found that manganese added to steel containing one percent of carbon affects their weld ability. The wear ability of quenched steel (1%) carbon and the hardness decrease with increasing amount of manganese, while in annealed steel containing 0.90%-1.20% carbon, manganese has no effect either on the hardness or the wear ability. A study by Adnan Calik et al. [3] showed that carbon content ranging from 0.30 to 0.55 weight percent were investigated by tensile and micro hardness test at room temperature it was observed that the higher carbon content results in an increase in yield stress. H.E. Townsend [4] conducted experiment and it was observed that P, Si, Cr, Cu, Ni, Sn and More beneficial to improve corrosion resistance. Sulphur had show very large adverse effect whereas V, Mn, Al, Co, As, and W had a little, if any effect on corrosion. Izelu et al. [5] conducted the study in which the contribution made by the alloying elements on the mechanical properties of weld metal was analyzed using regression analysis. Six alloying elements namely C, P, Ni, Cr, Nb and V have been identified to continue the chemical composition of the weld that is expected to achieve the required impact strength. A study conducted by G.S.Cho et al. [6] showed addition of Cu and Cr elements rapidly changed the ferrite matrix to pearlite matrix so strength and hardness were rapidly increased. Ankit Dua et al. [7] showed that elongation is the only property that decreases with the addition of copper in austempered ductile iron while hardness, yield strength and ultimate tensile strength increases. Yao-nan chang [8] studied low alloy steel and found that both yield strength and tensile strength increases with chromium content while the elongation decreases. Ismar et al. [9] focused their study on the importance of toughness parameter for novel structure true material such as high strength steels. Design of experiment (DOE) is one of the powerful statistical tools that can be used to investigate the effect of parameter and develop accurate input output relationship [10]. Many of the researchers have successfully applied DOE to model and analyze casting processes. It is to be noted that not much of work is carried in analyzing the effect of alloying element and modeling of structural steel production by using statistical regression analysis. Zyska et al. [11] used two level full-factorial design of experiment to study the effect of squeeze pressure, die temperature and percentage of modifier on percentage elongation the tensile strength of squeeze cast component. Further, linear and nonlinear model successfully applied to establish the input output relationship in different casting process, namely component bonding molding [12-13], green sand molding [14-15], resin-bonded molding sand mold [16], sodium bonded molding system [17], die casting [18-20] and evaporative casting process [21]. Design of experiments with Response surface methodology has been successfully used by the researchers to model and analyze manufacturing process such as welding, machining etc. [22-24]. The literature shows that conventional statistical tool such as Design of experiment, taguchi and response surface methodology have been used by many researchers to modify and analyze various manufacturing process. Young-Don Ko et al. [25] has successfully developed non linear model by applied Response surface methodology also mentioned manufacturing process have non-linear properties. It can be controlled through the predicted value which is obtained from modeling using DOE and Response Surface Methodology.

II. METHODOLOGY

The methodology to study the influence of process parameters and to establish non-linear input-output relationships of mechanical properties of structural steel has been explained in the following steps.

1. Identify the important process parameters and their feasible limits. Decide on the number of replicates.
2. Develop the design matrix with the help of Minitab software
3. Conduct the experiments with the input variable combination as per design matrix and record corresponding response values.

There are three input variables (three alloying elements) namely percentage composition of Carbon, Copper and Chromium. The responses (output) measured are Yield strength, Ultimate tensile strength and percentage elongation.

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Table1. Process parameter and their levels

Parameter	Notation	Levels		
		Low	Medium	High
%Carbon	A	0.18	0.22	0.25
%Copper	B	0.19	0.21	0.23
%Chromium	C	0.36	0.41	0.45

The operating range of each parameters (i.e. alloying element) is decided based on the literature and by consulting industry experts. However in the experimental analysis and testing, the alloying elements namely sulphur, phosphorus and aluminum are not considered as these are present in very small amount. Silicon and the amount of manganese are constant. The test specimens were prepared as per the standards and experiments were conducted to measure YS, UTS and % elongation.

2.1 Determining the Adequacy of the Developed Models

The non-linear regression model will be developed using the data collected as per the central composite design. The effect of individual parameters and their interaction terms are examined by conducting a significance test. The adequacies of the models are tested with the help of Analysis of variance (ANOVA) technique. Surface plots are used to understand the relationships of process parameters and their interaction with responses. Further, they are utilized to study the contribution of process parameters by using MINITAB software.

III. RESULT AND DISCUSSION

This section discusses the non-linear regression models developed for effect of alloying elements on mechanical properties of structural steel using MINITAB software.

3.1 Response-Yield Strength

To examine the effect of various input parameters and their interaction terms on Yield strength, a significance test (refer to Table 2) has been conducted. As the 'P' values of the responses A, B,C, A^2 and C^2 are found to be less than 0.05(corresponding to 95% confidence level), these factors are considered to make significant contribution on the response-Yield strength. "Table 3" shows the results of ANOVA performed for testing the significance of the factors on Yield strength. It is important to note that A,B and C are found to be significant on Yield strength as the value of 'P' is found to be less than 0.05.Moreover the coefficient of correlation for this model is seen to be equal to 0.98.

Table2. Results of the significance test for the non-linear model of Yield strength

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		606.633	0.074	8144.29	0.000	
A	34.8056	17.4028	0.0539	323.09	0.000	1.01
B	19.7981	9.8990	0.0539	183.69	0.000	1.00
C	32.2071	16.1036	0.0539	298.91	0.000	1.01
A^2	4.153	2.077	0.106	19.50	0.000	1.55
B^2	0.100	0.050	0.104	0.48	0.645	1.54
C^2	3.721	1.860	0.106	17.63	0.000	1.54
A*B	0.2569	0.1284	0.0601	2.14	0.070	1.00
A*C	-0.2498	-0.1249	0.0600	-2.08	0.076	1.00
B*C	-0.2447	-0.1223	0.0601	2.03	0.081	1.00

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Table3. Results of ANOVA for the response- Yield Strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	6600.86	733.43	25294.69	0.000
Linear	3	6591.24	2197.08	75773.56	0.000
A	1	3026.71	3026.71	104386.01	0.000
B	1	978.32	978.32	33740.57	0.000
C	1	2590.62	2590.62	89346.13	0.000
Square	3	47.12	15.71	541.64	0.000
A ²	1	11.03	11.03	380.28	0.000
B ²	1	0.01	0.01	0.23	0.645
C ²	1	9.02	9.02	310.92	0.000
2-Way Interaction	3	0.38	0.13	4.34	0.050
A*B	1	0.13	0.13	4.57	0.070
A*C	1	0.13	0.13	4.33	0.076
B*C	1	0.12	0.12	4.14	0.081
Error	7	0.20	0.03		
Lack-of-Fit	5	0.20	0.04		
Pure Error	2	0.00	0.00		
Total	16	6601.06			

Surface plot for the response-Yield strength obtained by varying Chromium and Copper is presented in “Figure 1”. It has been observed that increase in Copper and Chromium has resulted in the rapid increase in response value. Moreover, maximum yield strength value is reached with both alloying elements set at their maximum value. It is to be noted that the response yield strength changes linearly with both Copper and Chromium.

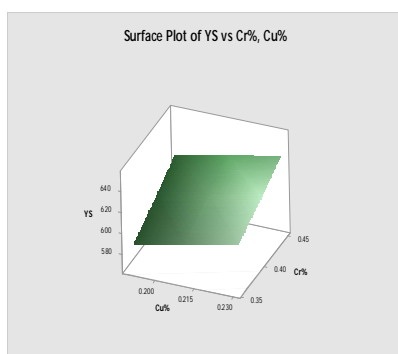


Fig.1 with Cu and Cr

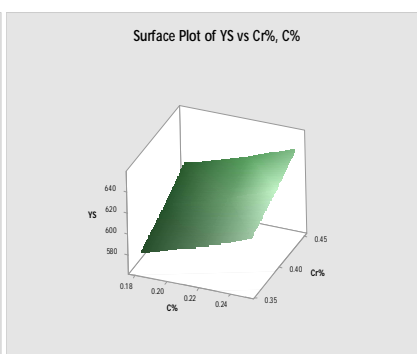


Fig.2 with C and Cr

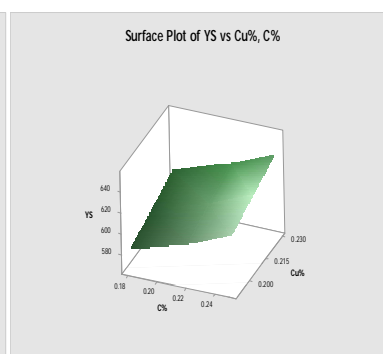


Fig.3 with C and Cu

Surface plot of Yield strength

Surface plot for the response-Yield strength obtained by varying carbon and silicon is shown in “Figure2”. It has been observed that increase in carbon and Chromium has resulted in the rapid increase in the response value. The maximum yield strength value is attained when both carbon and silicon are set at their maximum value. The surface plot of Yield strength changes linearly with both carbon and silicon. Surface plot for the response-Yield strength obtained by varying carbon and manganese is shown in “Figure 3”. It has been observed that increase in

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carbon and copper has resulted in rapid increase in response value. The maximum value of Yield strength is reached when both alloying elements are set at their maximum value. The response yield strength changes linearly with both carbon and manganese.

3.2 Response-Ultimate tensile strength

The significance test shows that the linear term C%, Cu%, Cr% and interaction terms Cu*Cr% is found to make significant contributions on ultimate tensile strength as

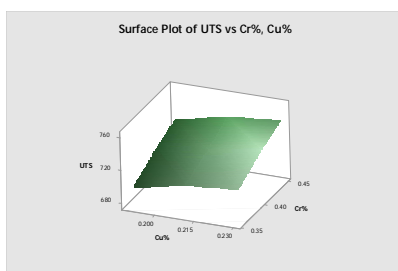


Fig.4 with Cu and Cr

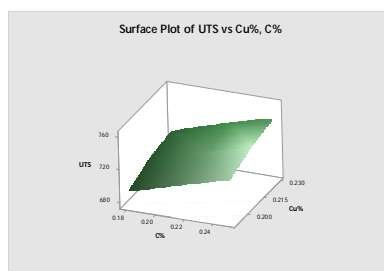


Fig.5 with C and Cu

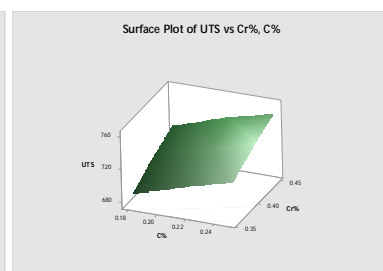


Fig.6 with C and Cr

Surface plot of Ultimate tensile strength

Surface plot for the response-Ultimate tensile strength obtained by varying Cu and Cr is presented in “Figure 4”. It has been observed that increase in copper and chromium has resulted in the rapid increase in response value. Moreover, maximum ultimate tensile strength value is reached with both alloying elements set at their maximum value. It is to be noted that the response ultimate tensile strength changes linearly with both copper and chromium. Surface plot for the response-Ultimate tensile strength obtained by varying carbon and copper is presented in “Figure 5”. It has been observed that increase in carbon and copper have resulted in the rapid increase in response value. Moreover, maximum ultimate tensile strength value is reached with both alloying elements set at their maximum value. It is to be noted that the response ultimate tensile strength changes linearly with both carbon and copper. Surface plot for the response-Ultimate tensile strength obtained by varying chromium and carbon is presented in “Figure 6”. It has been observed that increase in chromium and carbon has resulted in the rapid increase in response value. Moreover, maximum ultimate tensile strength value is reached with both alloying elements set at their maximum value. It is to be noted that the response ultimate tensile strength changes linearly with both chromium and carbon.

3.3 Response-Percentage elongation

The significance test shows that only the terms C%, Cu%, Cr% and interaction term Cr%*Cr% are found to make significant contribution to the response percentage elongation as their values are less than 0.05. The surface plots are also drawn for the response-percentage elongation. The coefficient of correlation for this model is seen to be equal to 0.927.

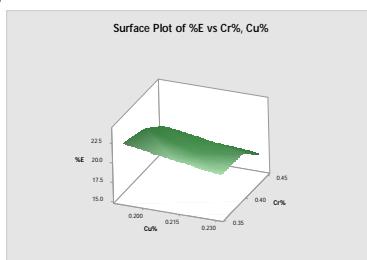


Fig.7 with Cu and Cr

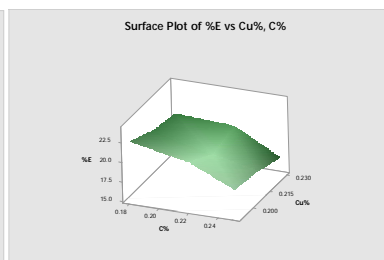


Fig.8 with C and Cu

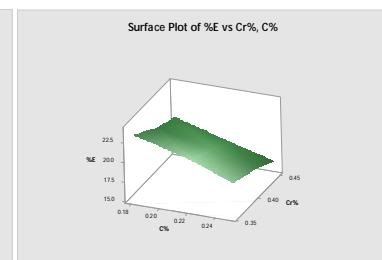


Fig.9 with C and Cr

Surface plot of Percentage elongation

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Surface plot for the response-percentage elongation obtained by varying copper and chromium is shown in “Figure7”. It has been observed that increase in copper and chromium have resulted in gradually decrease in the value of percentage elongation. Moreover, maximum percentage elongation is reached with both alloying elements set at their minimum value. It is to be noted that the response-percentage elongation changes non-linearly with both silicon and manganese. Surface plot for the response-percentage elongation obtained by varying carbon and copper is shown in “Figure 8”. It has been observed that increase in carbon and chromium percent have resulted in the gradually decrease in the value of percentage elongation. Surface plot for the response-percentage elongation obtained by varying carbon and chromium is presented in “Figure9”. It has been observed that increase in carbon has resulted in gradual decrease in percentage elongation. But increase in chromium has resulted in very small decrease in the value of the response-percentage elongation. It is to be noted that the response-percentage elongation changes non-linearly with both chromium and carbon.

3.4 Testing of the non-linear model

The non-linear model is tested by developing regression equations for the responses obtained from 10 test cases. The regression equation obtained for Yield strength (YS), Ultimate tensile strength (UTS) and percentage elongation (E %) is represented by equation (1), (2) and (3) respectively.

$$YS = 475.2 - 238.1 A + 458 B - 340.7 C + 1695.2 A^2 + 125 B^2 + 918.7 C^2 + 183.5 A*B - 79.3 A*C - 135.9 B*C \quad (1)$$

$$UTS = 350.3 + 417 A + 1462 B - 8 C + 673 A^2 - 3075 B^2 + 233 C^2 - 502 A*B - 227 A*C + 993 B*C \quad (2)$$

$$\%E = 112.6 + 53 A - 939 B + 80 C - 413 A^2 + 1899 B^2 - 197 C^2 + 192 A*B + 81 A*C + 147 B*C \quad (3)$$

Table4. Percentage deviation of the responses-Yield strength, Ultimate tensile strength and percentage elongation

Test Case	C%	Cr %	C%	Yield strength			Ultimate tensile strength			Percentage Elongation		
				Exp val.(a)	Equ. Val.(b)	%Deviation (a-b)/a*100	Exp. val.(a)	Equ. Val.(b)	%Deviation		Equ. Val.(b)	%Deviation
1	0.19	0.22	0.37	592	588.63	0.56	705	699.46	0.78	21	21.40	-1.90
2	0.21	0.20	0.39	603	593.94	1.50	712	707.04	0.69	21	21.07	-0.33
3	0.22	0.21	0.38	612	600.67	1.85	716	713.70	0.32	20	20.15	-0.74
4	0.23	0.22	0.42	635	624.86	1.59	745	736.78	1.10	18	18.24	-1.33
5	0.24	0.19	0.37	612	598.64	2.18	722	711.60	1.44	20	20.58	-2.9
6	0.21	0.22	0.41	618	610.81	1.16	728	723.06	0.67	19	19.63	-3.31
7	0.23	0.21	0.40	624	612.58	1.83	734	725.58	1.14	19	19.05	-0.26
8	0.19	0.20	0.41	594	592.06	0.32	704	703.77	0.03	21	21.26	-1.23
9	0.20	0.19	0.42	599	595.25	0.62	709	706.22	0.39	21	21.50	-2.38
10	0.19	0.22	0.43	600	609.56	-1.59	713	720.67	-1.07	20	19.61	1.95

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IV. CONCLUSION

In the present work, the effect of alloying element namely carbon, copper and chromium on the mechanical properties on Fe500D steel is studied. Response surface methodology, Central composite design is used to analyze the process. It is interesting to note that alloying elements Carbon, Copper and Chromium have positive influence on mechanical properties like Yield strength and Ultimate tensile Strength. All alloying elements have negative contribution on the response like Percentage elongation. The influence of alloying elements Carbon and chromium is more compared to Copper on all the responses. The experimental data collected as per central composite design has been utilized to develop the non-linear regression (input-output and relations) models for the responses Yield strength, Ultimate tensile strength and percentage elongation. These models have been tested for their statistical adequacy with the help of ANOVA test. Further, the performance of the models has been tested by considering ten test cases. The test results showed absolute average deviation values equal to 1.32%, 0.763%, 1.229% for the responses Yield strength, Ultimate tensile strength and percentage elongation. The requirement of mechanical properties i.e. strength and ductility (% elongation) varies depending on applications. It is to be noted that the increase in alloying elements namely carbon, chromium and copper will increase Yield strength and Ultimate tensile strength whereas reduce percentage elongation (ductility). From the present work it can be concluded that the statistical tool Design of experiments and Response surface methodology can be used to effectively model and analyze the mechanical properties of structural steel. Moreover, the results are found to be useful for the foundry men to select the quantity of alloying element in order to develop the required mechanical properties.

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