IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X
PP. 41-46
www.iosrjournals.org

Optimization of Parameters for Recycling Of Steel Process by Using Response Surface Methodology

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Abstract: *The need for steel recycling from scrap is need of the hour as huge amount of natural resources are saved and also environmental pollution is minimized. In this paper Response Surface Methodology was applied to optimize process parameters for recycling of steel process. Higher strength is demanded in steel as it is used in construction of civil structures, machinery and in other streams of engineering system. The material selected for experimentation was steel rod of 16 mm diameter manufactured by recycled steel scrap. Experiments were conducted in a secondary steel mill. By considering Hardness (Strength) Number as objective function, experimental analysis was carried out. According to Design of Experiments, 46 experiments were conducted. After performing experiments, data is generated, to which Response Surface Methodology is applied and critical analysis is presented for achieving better quality of secondary steel and enhancing the value Hardness Number of steel.*
Key words: *Response Surface Methodology (RSM), Steel Recycling, Process Parameters, DOE. Hardness Number*

I. Introduction

Steel Recycling has gained large scale importance recently because of continuous improvement in its quality. Current research work was focused on enhancing Hardness (strength) Number of steel by the application of Response Surface Methodology (RSM). Response Surface Methodology is a combination of statistical and mathematical techniques that was applied for the formulation and analysis of complex engineering problems. The main goal was to optimize the response surface that is affected by various process parameters. This technique was used to express the output parameters which are decided by the input process parameters. It uses a series of designed experiments to obtain an optimal response and is concerned with multiple response variables. These variables create problems as what was optimal for one response may not be optimal for remaining responses. The five input process parameters considered for analysis were Furnace Temperature (Ft), Sponge Steel (SS), Scrap Steel Composition (SCS), TDS of water used for Quenching (TDS) and Quenching Steel Temperature (Qw).

II. Steps in RSM

For applying RSM to experimental results, the following procedure is followed:

- Designing a series of experiments for precise measurement of required response.
- Obtaining a mathematical model of response surface with best fittings.
- Obtaining the optimal set of experimental parameters that generate a minimum or maximum value of response.
- Two and three dimensional plots are used to indicate the direct and relational effects of process parameters.

To solve real life industrial problems, two important methods are used for response surface methodology. They are

i) Central Composite Design (CCD) method
ii) Box - Behnken method

From the above mentioned methods, Box-Behnken method gives a confined way for optimization. Hence it was used in this experiment for analysis.
Box-Behnken design gives maximum efficiency for a process consisting of multiple factors and three levels. The other advantage is number of experiments conducted are much lesser as compared to a central composite method. The proposed Box-Behnken model requires 46 runs for modeling a response surface.

III. Experimental Details

Based on Box-Behnken method the level of process parameters are selected for the experimentation as indicated in table1. The three process parameters are Furnace Temperature (Ft), Sponge Steel (SS) and Scrap Steel Composition (SCS).

Sr. No	Level 1	Level 2	Level 3
Ft	1650	1675	1700
SS	10	12.5	15
SCS	75	80	85
TDS	30	35	40
Qw	500	525	550

Table 1. Process parameters with their values at 3 levels

Experiments are conducted in a secondary steel manufacturing industry. The steel bar considered for experimentation is of 16 mm diameter. From every set of experimental values considered for manufacturing, a sample of 2cm length is cut, polished by using polish paper of higher grade and the same was tested on Brinell Hardness Testing Machine for getting Hardness values. The results obtained for each parameter level setting are shown in table.2.

Ft	SS	SCS	TDS	Qw	HS
1675	12.5	75	35	550	104.7
1675	12.5	80	40	550	104.4
1675	12.5	80	35	525	105.3
1700	12.5	75	35	525	106.8
1675	15.0	80	35	500	105.1
1675	12.5	75	35	500	104.2
1675	12.5	85	35	550	105.7
1675	12.5	80	30	550	104.6
1650	10.0	80	35	525	101.1
1700	12.5	85	35	525	107.2
1700	12.5	80	35	500	106.9
1700	15.0	80	35	525	107.2
1650	12.5	80	35	500	102.0
1675	12.5	80	30	500	104.6
1675	12.5	80	35	525	105.3
1675	12.5	75	40	525	105.2
1675	10.0	80	40	525	103.7
1675	15.0	85	35	525	105.2
1675	12.5	80	35	525	104.8
1675	15.0	75	35	525	105.2
1700	12.5	80	30	525	106.9
1675	15.0	80	30	525	105.3
1675	12.5	85	30	525	105.2
1675	10.0	80	30	525	103.8
1650	12.5	75	35	525	102.0
1675	10.0	80	35	500	104.5
1700	10.0	80	35	525	106.4
675	12.5	80	35	525	104.5
1700	12.5	80	40	525	106.9
1650	12.5	80	35	550	102.3
1675	10.0	85	35	525	104.2
1675	15.0	80	35	550	105.1
1650	12.5	80	40	525	101.9
1650	12.5	80	30	525	102.3
1675	12.5	80	35	525	104.6

1675	10.0	80	35	550	103.8
1675	15.0	80	40	525	105.1
1675	12.5	80	35	525	104.8
1650	12.5	85	35	525	102.4
1675	12.5	75	30	525	103.8
1700	12.5	80	35	550	106.8
1675	12.5	80	40	500	104.3
1675	10.0	75	35	525	103.6
1675	12.5	85	40	525	104.6
1675	12.5	85	35	500	103.9
1650	15.0	80	35	525	102.6

Table2. Box-Behnken design for the experiment with Hardness (Strength) Number values

Response Surface Regression: HS Vs. Ft, SS, SCS, TDS, Qw
Analysis of Variance

Source	**DF**	**Adj. SS**	**Adj. MS**	**F-Value**	**P-Value**	
Model	5	99.2	19.8	154.42	0.000	
Linear	5	99.2	19.8	154.42	0.000	
Ft	1	92.6	92.6	720.44	0.000	Significant
SS	1	5.8	5.8	45.73	0.000	Significant
SCS	1	0.5	0.5	4.09	0.050	Not Significant
TDS	1	0.01	0.01	0.08	0.782	Not Significant
Qw	1	0.2	0.2	1.75	0.193	Not Significant
Error	40	5.1	0.1			
Lack-of-fit	35	4.5	0.1	1.11	0.511	Not Significant
Pure error	5	0.5	0.1			
Total	45	104.4				

Table3. F-test values of Analysis of variance

By the analysis of variance from table 3, it is clearly observed that the most influencing parameter on Hardness (Strength) Number is Furnace Temperature, followed by Sponge Steel, Scrap Steel Composition, Quenching of steel and the least influencing parameter is TDS of water used.

IV. Results And Discussion

Model Summary

S	R-sq	R-sq(adj)	R-sq.(pred.)
0.3585	**95.07%**	94.46%	93.59%

As per observations and literature review, it is clearly mentioned that the R Square value should be between 90% to 100%, where as the R square value obtained by using Box-Behnken method is 95.07%.

Based on this the regression equation has been generated for un coded units. The fits and diagnostics for unusual observations are also indicated with ‘R’ large residual.

Regression Equation in Un-coded Units obtained is

HS = -1364 + 1.516 Ft + 5.42 SS - 0.07 SCS + 0.66 TDS
+ 0.271 Qw - 0.000397 Ft*Ft - 0.0370 SS*SS -
0.00258 SCS*SCS-0.00692 TDS*TDS -
0.000237 Qw*Qw – 0.00280 Ft*SS + 0.00000 Ft*SCS
+ 0.00080 Ft*TDS - 0.000160 Ft*Qw - 0.0120 SS*SCS –
0.0020 SS*TDS+ 0.00280 SS*Qw-0.02000 SCS*TDS
+ 0.00260 SCS*Qw + 0.00020 TDS*Qw.

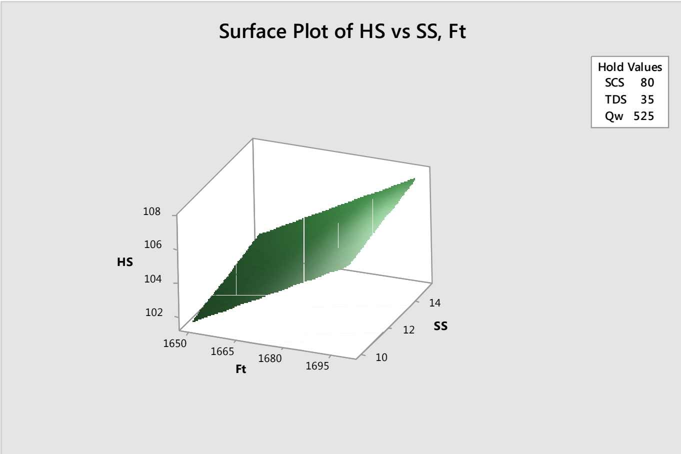

Fig.1 Surface plot of HS Vs Ft & SS

From the Fig.1, it can be stated that Hardness (strength) number varies linearly with Furnace temperature and Sponge Steel addition .The hold values obtained are Scrap steel composition as 80%, TDS of water to be maintained at 35 grade and quenching steel temperature at 525°C.

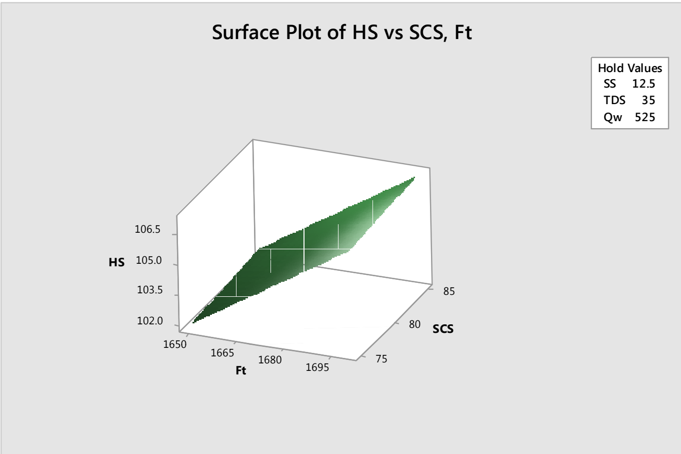

Fig.2 Surface plot of HS Vs Ft & SCS

From the above fig. 2, it can be stated that with increase in SCS Hardness strength increases and also with increase in Furnace Temperature there is gradual increase in Hardness strength. The hold values for Sponge steel as 12.5%, TDS level of water as 35 grade and Quenching steel temperature at 525°C.

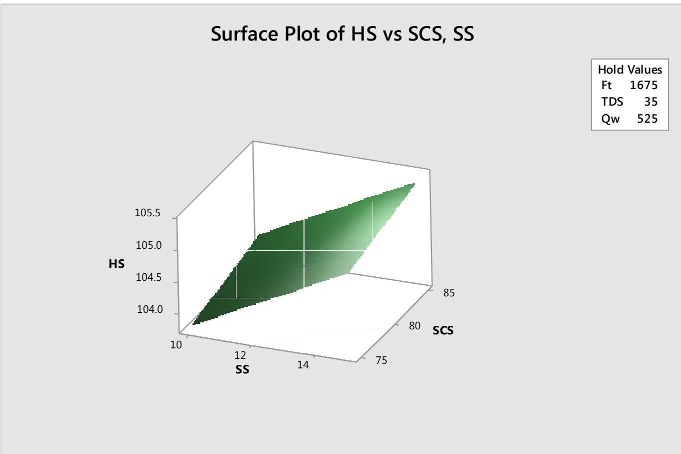

Fig.3 Surface plot of HS Vs SS & SCS

From the above fig.3, it is observed that, with increase in Scrap steel composition marginally Hardness strength decreases and Sponge steel addition with linearly enhance Hardness strength. The hold values obtained are Furnace temperature at 1675°C, TDS of water 35 grade and Quenching steel temperature at 525°C.

4.1 Response Optimization: HS

The Response Optimization of Hardness Strength Number is obtained by using the Response Optimizer of Response Surface Methodology and found the fitted variable for obtaining optimal Hardness values are Furnace temperature (Ft) as1700°C, Sponge Steel (SS) mixed with charge as 15% of weight, Scrap Steel Composition (SCS) as 85%, TDS of water as 30 and Quenching temperature of steel as 550°C.

Parameters

Response	Goal	Lower	Target	Upper	Weight Importance
HS	Maximum	101.1	107.2	1	1

Solution

						HS	Composite
Solution	Ft	SS	SCS	TDS	Qw	Fit	Desirability
1	1700	15	85	30	550	107.9	1

Response	Fit	SE Fit	95% CI	95% PI
HS	107.9	0.207	(107.5, 108.3)	(107.08, 108.7)

Optimization Plot

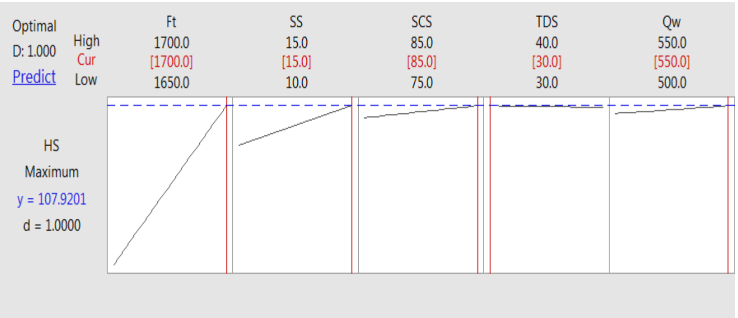

Fig.4 Optimization plot of Hardness Number Vs. Ft, SS, SCS, TDS and Qw

From the above optimization plot, it is observed that with increase in furnace temperature there is drastic increase in hardness strength and with sponge steel addition it is slow where as the effect of Scrap steel composition on Hardness strength is negligible, effect of TDS of water and Quenching steel temperature is normal and does not affect significantly

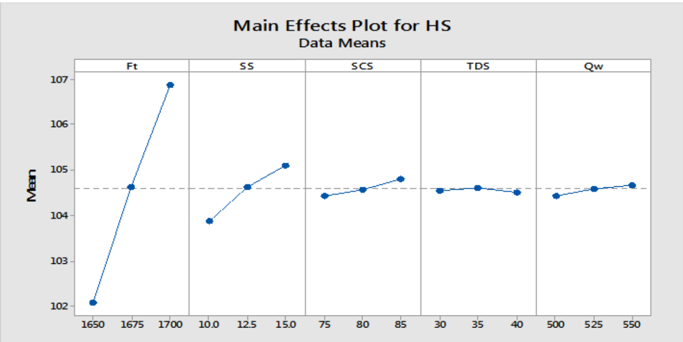

Fig.5 Main effect plot of Hardness Number Vs. Ft, SS, SCS, TDS and Qw

From the above main effect plot in fig.4.8, it is found that the values of Furnace Temperature and Sponge steel has highest influence on Hardness strength of strength where are the values of Scrap steel composition, TDS levels of water and Quenching steel temperature coincide each other and have less influence.

V. Conclusion

Experiments were conducted based on DOE 46 combinations and observed that the influence of process parameter on Hardness (strength) Number is maximum. According to F-test, Furnace temperature (Ft) is the most influential parameter on Hardness (strength) Number, followed by Sponge steel, Quenching steel temperature, TDS of water and scraps steel composition. The R-square value obtained is 95.07% and for validation of this result, regression ANOVA has been carried out and found that the impact of process parameters on Hardness Number is same as that of Response Surface Methodology (RSM) results. Regression equation have been generated for uncoded units by RSM and the standard regression equation is generated by ANOVA and found that the final regression is satisfactory.

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