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Application of Response Surface Method in Optimization of Impact Toughness of EN24Steel

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Abstract— Impact testing methodology is findings the applications for determining the impact strength of the different materials. Oneof the most important characteristics of structural steels, toughness is assessed by the Charpy V-notch impact test. The objective of the research was to maximize the impact toughness by selecting various combinations of Charpy Impact test parameters. In this paper, experiments were carried out to Study the Effect of Thermal Treatments (annealing, cryogenic treatment and tempering) on Impact Toughness. Cryogenic treatment (CT) is the supplementary process to conventional heat treatment process in steels, by deep–freezing materials at cryogenic temperatures to enhance the mechanical and physical properties of materials being treated. For this purpose, the temperature was used -196^{o}C as deep cryogenic temperature. The effects of cryogenic temperature (deep), cryogenic time (kept at cryogenic temperature for 36 hr) on the wear behavior of EN24 steel were studied. The findings showed that the cryogenic treatment decreases the retained austenite and hence improves the wear resistance and hardness. The process has various advantages like increase in hardness, increase in wear resistance, reduced residual stresses, fatigue resistance, increased dimensional stability, increased thermal conductivity, toughness, by transformation of retained austenite to martensite, the metallurgical aspects of eta-carbide formation, precipitation of ultra- fine carbides, and homogeneous crystal structure. The findings show that the cryogenic treatment improves the wear resistance and hardness of EN24 steel. En24 steel is generally used in the hardened and tempered condition to achieve an optimum combination of hardness and ductility.

In the present study, heat treatment process of En24 steel was done which includes Annealing and Tempering at high temperature. The specimens tempered at different temperatures (in the range 473–823 K) exhibited decreasing hardness with increase in tempering temperature. Response surface methodology was adopted in designing the experiments for three factors with 27 levels.

Keywords—EN24 Steel, Impact Toughness, Thermal Treatment, Cryogenic Treatments, Hardness, Austenite, Martensite, Carbide formation, Tempering, Wear Resistance.

INTRODUCTION

Engineering materials, mostly steel and their alloys are heat treated to alter their mechanical and physical properties so as to meet the engineering applications. Impact testing methodology is finding its applications for determining the impact toughness of any materials. The absorbed impact energy and the transition temperature defined at a given Charpy energy level are regarded as the common criteria for toughness assessment[1]. The Charpy impact testing process consists of hammering the steel specimens with a reasonable height with certain velocity on the reverse side of the notch, so that the amount of energy required for the failure of steel specimen can be determined [2].

Here, EN24 steel specimen is used for the impact testing experiment& the effect of different process parameters on the value of impact toughness of EN24 steel is being determined in this paper [2].

During the World War II, the US Army used many 'Liberty Ships' but a lot of them got damaged due to brittle fracture. The term brittle fracture is used to describe rapid propagation of cracks without any excessive plastic deformation at a stress level below the yield stress of the material. The brittle fracture that occurred in the "Liberty Ships" was caused by low notch toughness at low temperature of steelspecimens [3]. CryogenicSteel experiences ductile fracture at high temperature and brittle fracture at low temperatures; therefore steel shows the characteristic of ductile-to-brittle transition. Brittle fracture usually occurs under the conditions of low temperature, high loading rate. Cryogenic treatments are useful in these types of cases [3].As recent researches were going on, the scientists showed a lot of confidence and interest on the Deep Cryogenic Treatment of steels.According to the experimental results, martensitic transformation occurred after the deep cryogenic treatment[4]. Grain shape and size gets refined and is made uniform. Defect elimination takes placeand inter atomic distance is reduced [5].Cryogenic treatment is an extension of conventional heat treatment process which converts austenite to martensite.The findings showed that the cryogenic treatment decreases the retained austenite and hence improves the wear resistance and hardness [6].A thermal treatment of steel specimens of EN24 grade steel is done. Heat treatment of the steel specimens consists of Austenitizing (Annealing) and Tempering.The mechanical properties such as ductility, toughness, strength, hardness and tensile strength can easily be modified by heat treating the steel specimens to suit a particular design purpose [7]. And secondly the Cryogenic treatment is done at low temperature in a jar known as Cryocan filled with liquified nitrogen. The Cryogenic treatment involves cooling of steel specimens of EN24 at very low temperature (-1960 C) for about 36 hours. Due to more homogenized carbide distribution as well as the elimination of the retained austenite, the deep cryogenic treatment demonstrated more improvement in wear resistance and hardness compared with the conventional heat-treatment [8].Cryogenic treatment improves hardness, microstructure of metal (retained austenite to marten site), dimensional stability and decreases residual stresses [17].A Comparative study on conventionally heat treated and cryogenic treated EN24 steel specimens has been presented in this paper. Specimens initially subjected to conventional heat treatment at austenitizing temperature of 810 ℃ and goes under deep cryogenic treatment at –195 ℃ for 24 hours [10].

RAW MATERIAL

CRYOGENIC TREATMENT ← **TEMPERING / N** ← **ANNEALING** → **CRYOGENIC TREATMENT** → **TEMPERING**

TEMPERING

MATERIAL AND METHODS

Design of Experiment is a methodology based on statistics and other discipline which is used for analyzing the experimental data for obtaining the valid conclusion with an efficient and effective planning of experiments. Design of experiments is a series of tests in which purposeful changes are made to the input variables of a system or process and the effects on response variables are measured. Design of experiments is applicable to both physical processes and computer simulation models. The Experimental analysis Experimental design is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected. An exact optimization can be determined by the Response Surface Method. The Response Surface methodology is based on experimental design with the final goal of evaluating optimal functioning of industrial facilities, using minimum experimental effort. Here, the inputs are called factors or variables and the outputs represent the response that generates the system under the causal action of the factors.

Orthogonal Array is a statistical method of defining parameters that converts test areas into factors and levels. Test design using orthogonal array creates an efficient and concise test suite with fewer test cases without compromising test coverage. The experiment carried out is based on the principle of L27 Orthogonal Arrays (OAs).

The control parameters were considered for the proposed research work for multiple performance characteristics at three different levels and three different factors and are shown in Table 1 below:

Table no. 1: Different Factors and their Levels:

Factors	Level 1	Level 2	Level 3
Notch Angle(A)	30^0	45^0	60^0
Thermal Treatment(B)	Cooling followed by Tempering(CT)	Cooling followed by Cryogenic Treatment & Tempering(CCTT)	Cooling followed by Tempering & Cryogenic Treatment(CTCT)
Height of the Hammer(C)	1370	1570	1755

In this paper the effect of thermal treatments is studied along with three impact test parameters to maximize the impact toughness of EN24 steel. The experiment is to find the optimum impact value by combining all three parameters like notch angle, thermal treatment and height of hammer. The Chemical composition test of EN 24 steel was performed in the Metal Testing Laboratory, Indian Railways in Bareilly (U.P), India. The details of composition are shown below:

Table no. 2: Chemical Composition of EN24 Steel:

MATERIAL	CARBON %	SILICON %	NICKEL %	CHROMIUM %	MOLYBDENUM%
EN24	0.40	0.30	1.50	1.20	0.25

ExperimentalDetails

Experiments were carried out by using 27 specimens of EN24 steel which are thermally treated in 3stages, each stage containing 9 specimens. Specimens are heat treated in an Electric furnace whose size is 150mm X 150mm X 300mm and resolution is 1^0C. The Thermal treatment process of first 9 specimens follows the sequence as follows:Annealing followed by Tempering. After this other 9 specimens are taken for their thermal treatmentwhich follows the pattern i.e. Annealing followed by Cryogenic treatment followed Tempering (LTT, MTT,and HTT). L.T.T stands for Lower Temperature Tempering, M.T.T stands for Medium Temperature Tempering and H.T.T stands for High Temperature Tempering. Cryogenic treatment is a process in which steel specimens of EN24 are kept at very low temperature(-196^0C) in a bottle known as Cryocan which is filled with liquefied nitrogen. At last the remaining 9 specimens are thermally treated in an order which follows: Annealing followed by Tempering followed by Cryogenic treatment.Heat treatment can alter the mechanical properties of steel by changing the size and shape of the grains of which it is composed, or by changing its micro-constituents. It is applied to improve machinability, refine grain size, increases resistance to wear and corrosion.

Annealing was carried out on the specimen by heating the metal slowly at 810^oC. It is held at this temperature for sufficient time (about 1 hour) for all the material to transform into austenite. It is then cooled slowly inside the furnace to room temperature. The grain structure has coarse pearlite with ferrite or cementite. Special Electric furnaces are used in the annealing process.Tempering is the process of reheating the steel at predetermined temperatures which is lower than the transformational temperature to obtain different combinations of mechanical properties in steel. Tempering can also be defined as steady heating of martensite steel at a temperature below the recrystallization phase, followed by a gradual cooling process. Tempering reduces residual stresses, increases ductility, toughness and ensures dimensional stability. During tempering, martensite rejects carbon in the form of finely divided carbide phases. The end result of tempering is a fine dispersion of carbides in the α-iron matrix, which bears little structural stability to the original as-quenched martensite. Hence, the micro stresses and hardness of all the samples are reduced after tempering.

Fig.1 Specimen filled in Cryocan for cryogenic treatmentFig.2 Cryogenically treated specimens of EN24 Steel


Fig.3 Heat treatment of EN24 Steel in Electric furnace Fig.4 Specimen after Cryogenic Treatment


Fig.5 EN24 Steel Specimens after Tempering **Fig.6EN24 specimen taken out after Cryo-process**

Charpy Impact Testing

The Charpy impact test continues to be used as an economical quality control method to determine the notch sensitivity and impact toughness ofengineering materials. The Charpy test is done to measure the ability of a material to resist brittle fracture. The principle of the test differs from that of the Izod test in that the test piece is tested as a beam supported at each end; a notch is cut across the middle of one face, and the striker hits the opposite face directly behind the notch. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. The Charpy test sample has a sizes (10 X 10 X 55) mm^3 with three V- Notch 30°, 45° and 60° of 2 mm depth.

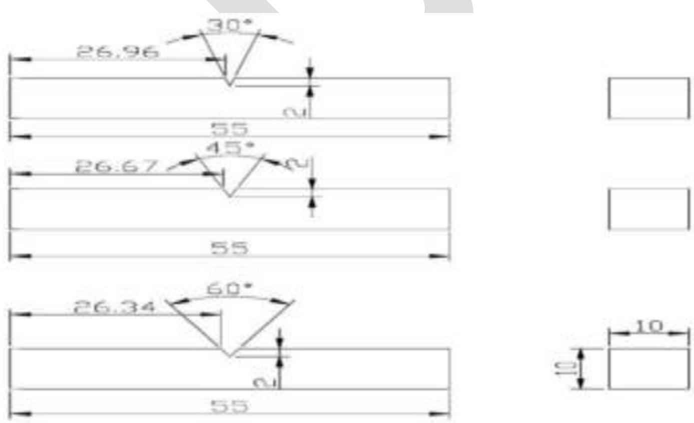

Fig.7 Specimen for Charpy test

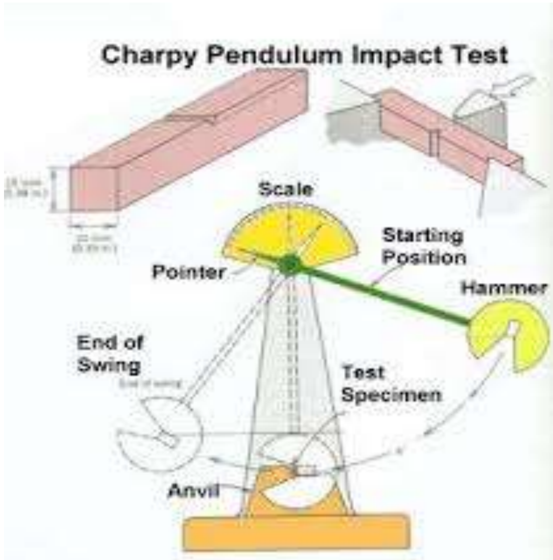

Fig.8 Charpy Impact Testing

Table no. 3: L27 Orthogonal Array for conducting Chapy Impact Testing

Sr. No.	Notch Angle (degree)	Thermal Treatment	Height of the Hammer(mm)	Impact Value(J)	SNRA1
1	30	Tempering	1370	183	45.2490
2	30	Tempering	1570	110	40.8279
3	30	Tempering	1755	71	37.0252
4	30	Cryogenic Treatment followed by Tempering	1370	178	45.0084
5	30	Cryogenic Treatment followed by Tempering	1570	125	41.9382
6	30	Cryogenic Treatment followed by Tempering	1755	69	36.7770
7	30	Tempering followed by Cryogenic Treatment	1370	156	43.8625
8	30	Tempering followed by CryogenicTreatment	1570	100	40.0000
9	30	Tempering followed by Cryogenic Treatment	1755	64	36.1236
10	45	Tempering	1370	95	39.5545
11	45	Tempering	1570	114	41.1381
12	45	Tempering	1755	75	37.5012
13	45	Cryogenic Treatment followed byTempering	1370	154	43.7504
14	45	Cryogenic Treatment followed by Tempering	1570	108	40.6685
15	45	Cryogenic Treatment followed by Tempering	1755	79	37.9525
16	45	Tempering followed by Cryogenic	1370	186	45.3903

		Treatment			
17	45	Tempering followed by Cryogenic Treatment	1570	106	40.5061
18	45	Tempering followed by Cryogenic Treatment	1755	75	37.5012
19	60	Tempering	1370	142	43.0458
20	60	Tempering	1570	103	40.2567
21	60	Tempering	1755	73	37.2665
22	60	Cryogenic Treatment followed by Tempering	1370	162	44.1903
23	60	Cryogenic Treatment followed by Tempering	1570	116	41.2892
24	60	Cryogenic Treatment followed by Tempering	1755	76	37.6163
25	60	Tempering followed by Cryogenic Treatment	1370	151	43.5795
26	60	Tempering followed by Cryogenic Treatment	1570	55	34.8073
27	60	Tempering followed by Cryogenic Treatment	1755	67	36.5215

Experimental Results

Table no. 4: Response Table for Signal to Noise Ratios

Level 1	Notch Angle (degree)	Thermal Treatment	Height of the Hammer(mm)
1	40.76	41.02	43.74
2	40.44	40.21	40.16
3	39.84	39.81	37.14
Delta	0.92	1.21	6.59
Rank	3	2	1

Table no. 5: Response Table for Means

Level 1	Notch Angle (degree)	Thermal Treatment	Height of the Hammer(mm)
1	117.33	118.56	156.33
2	110.22	107.33	104.11
3	105.00	106.67	72.11
Delta	12.33	11.89	84.22
Rank	2	3	1

Table no. 6: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Notch Angle (degree)	2	689.9	344.9	0.87	0.435
Thermal Treatment	2	803.2	401.6	1.01	0.382
Height of the Hammer(mm)	2	32533.6	16266.8	40.96	0.000

Error	20	7942.7	397.1		
Total	26	41969.4			

Table no. 7: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	p-Value
Notch Angle (degree)	2	3.890	1.945	0.75	0.484
Thermal Treatment	2	6.860	3.430	1.33	0.288
Height of the Hammer(mm)	2	196.134	98.067	37.91	0.000
Error	20	51.733	2.587		
Total	26	258.617			

According to Table no.1: This table is called the Response table which shows that the Height of hammer has the highest response grade of 1. So, 'Height of the hammer' is the main effective factor which mostly affects the Impact values.

According to Table no.2: This table is called the Anova table which shows that the 'p-value' is below 0.05 only for the Height of hammer. So it is clear from the table that 'Height of hammer' is the most significant and influential factor amongst the three factors.

Results and Discussions

Graphs Plotted on the basis of Experiments Performed:

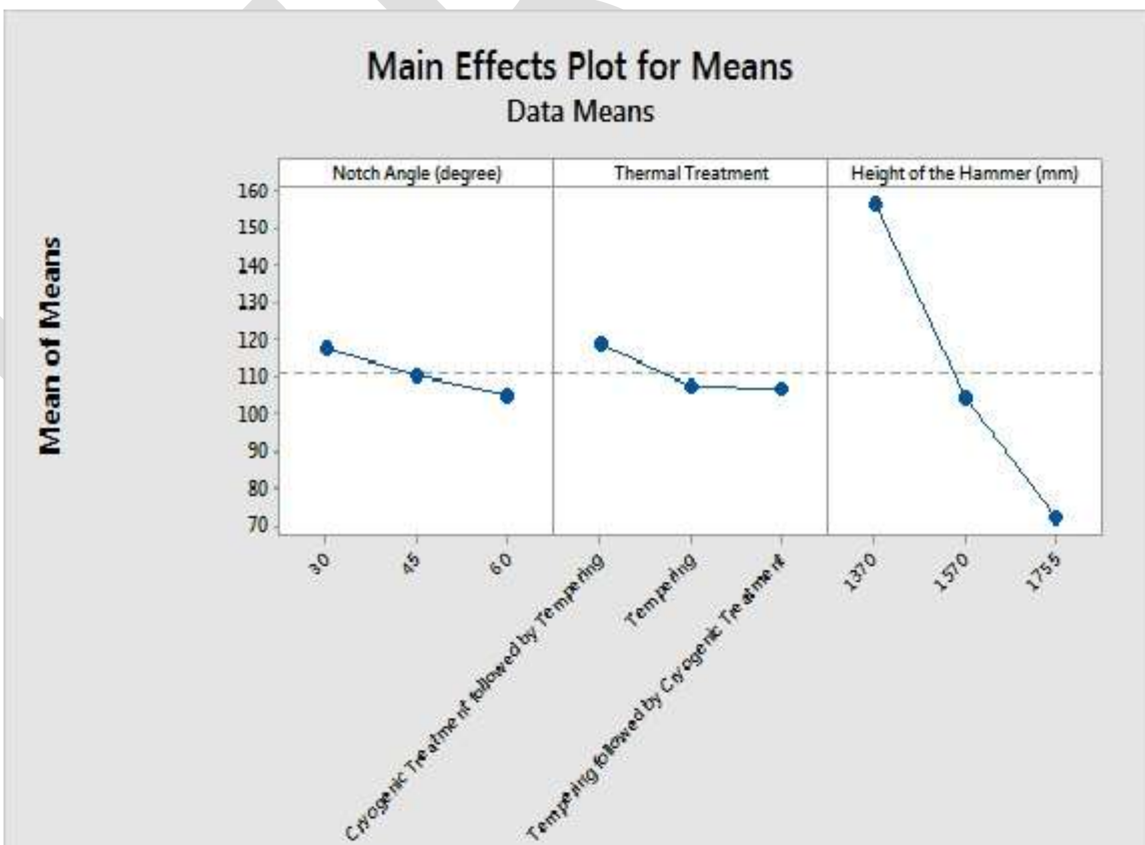

Fig.9: Main effect plot for Means (Data Means)

According to Fig.9: At the first level of Notch angle (30^0), first level of Thermal treatment (Cryogenic treatment followed by Tempering) and first level of Height of hammer (1370) respectively. The Impact value was found to be maximum at Main effects plot for Means(Data Means).

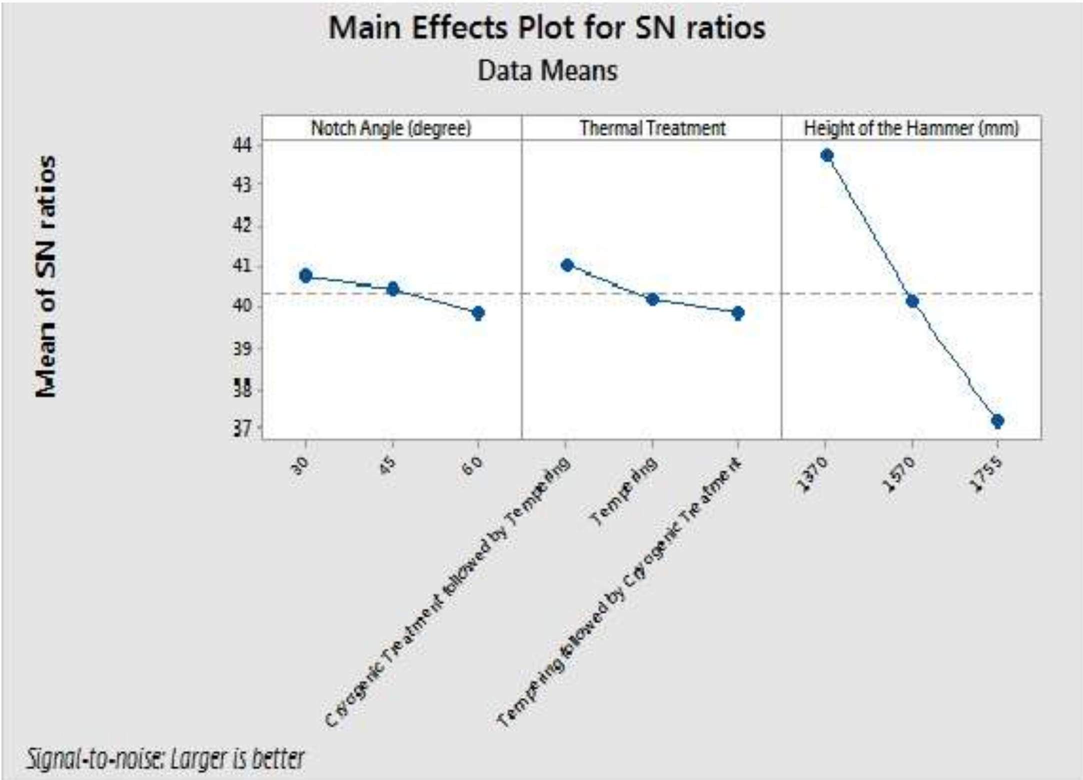

Fig.10: Main effect plot for SN ratios (Data Means)

According toFig.10: At the first level of Notch angle (30^0), first level of Thermal treatment(Cryogenic treatment followed by Tempering) and first level of Height of hammer (1370) respectively. The Impact value was found to be maximum at Main effect plot for SN ratio (Data Means).

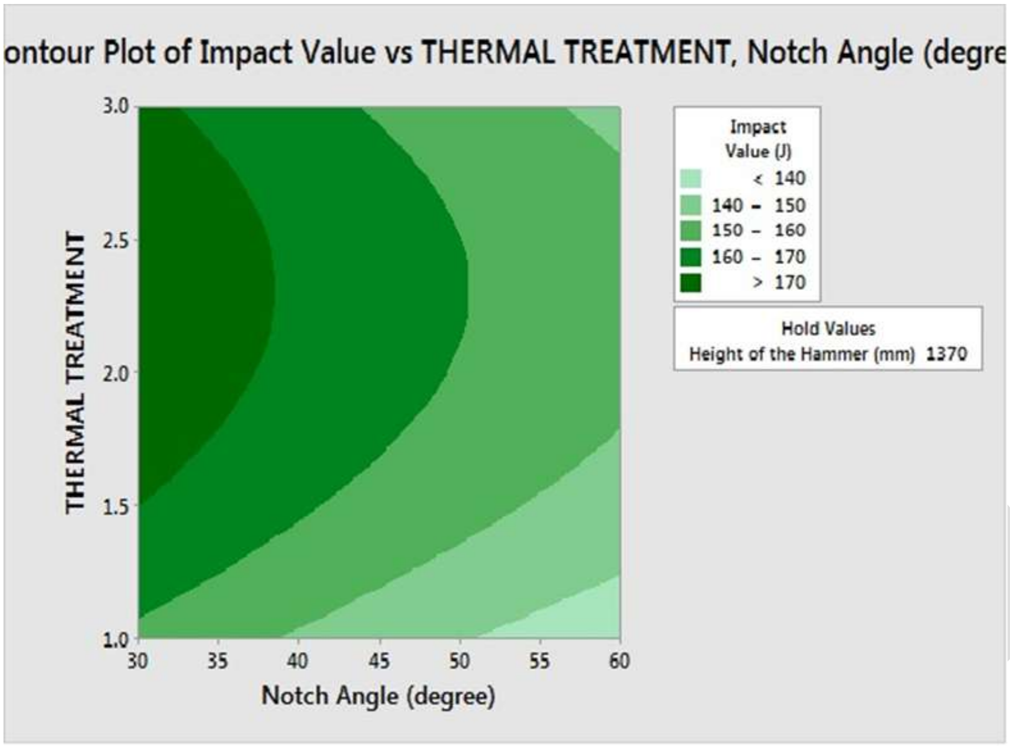

Fig.11: Contour plot of Impact value vs. Thermal treatment, Notch angle(degree)

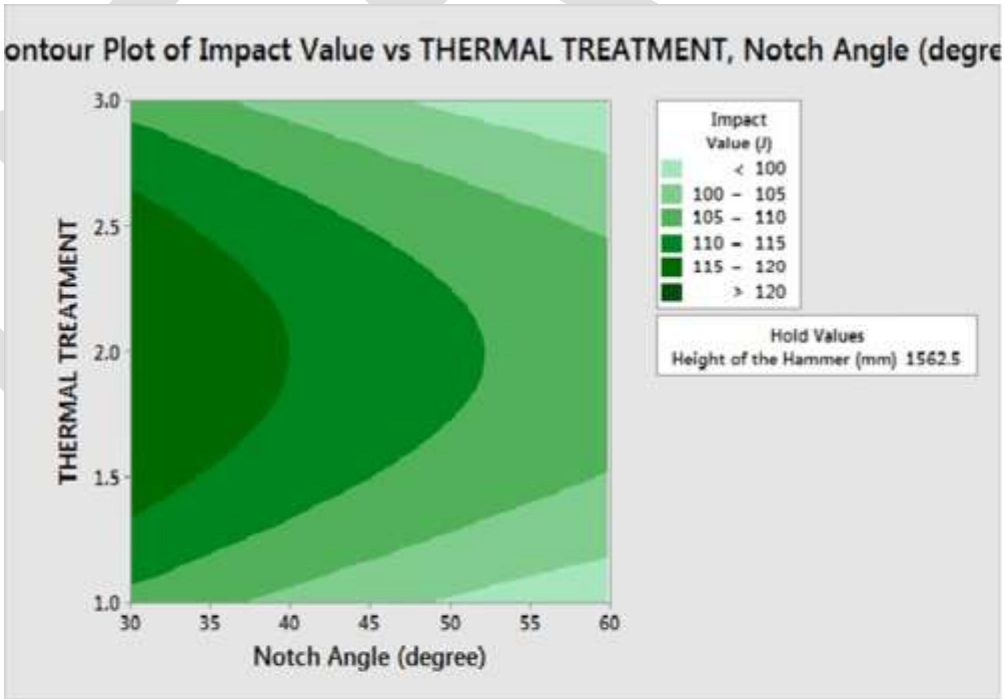

Fig.12: Contour plot of Impact value vs Thermal treatment, Notch angle(degree)

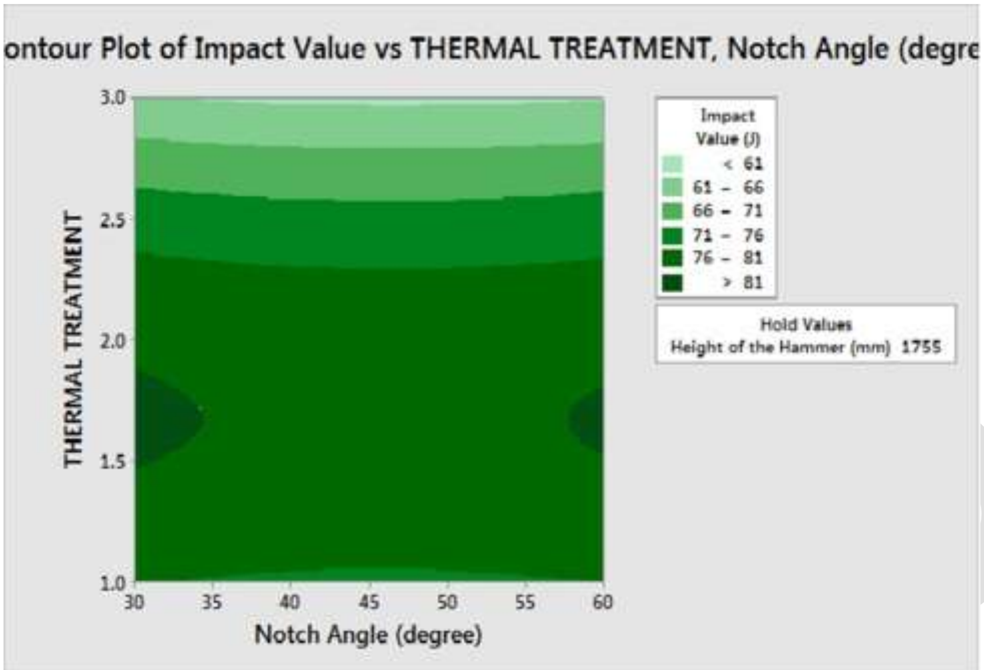

Fig.13Contour plot of Impact Value vs. Thermal treatment, Notch angle (degree)

According to Fig.11: The Contour plot is among Thermal treatment and Notch angle, the maximum region covered by the colour depicts that the maximum number of Impact value were found in the range of 150 to 160(J) while the Height of hammer is hold at 1370mm..

According to Fig.12: The Contour plot is among Thermal treatment and Notch angle, the maximum region covered by the colour depicts that the maximum number of Impact value were found in the range of 105 to 110(J) while the Height of hammer is hold at 1562.5mm.

According to Fig.13: The Contour plot is plotted among Thermal treatment and Notch angle, the maximum region covered by the colour depicts that the maximum number of Impact value were found in the range of 71 to 76(J) while the Height of hammer is hold at 1755mm.

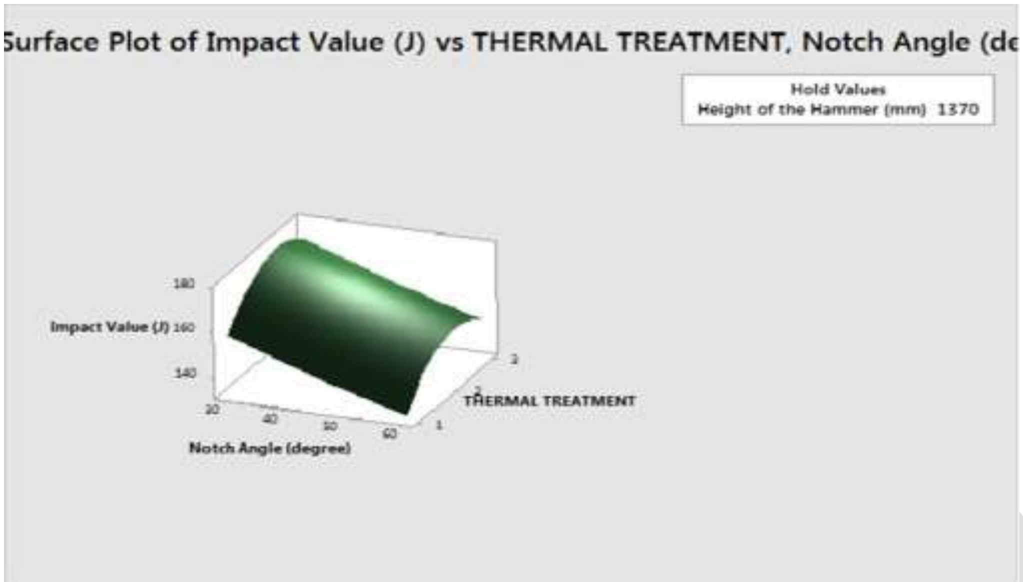

Fig.14: Surface plot of Impact value (J) vs. Thermal treatment, Notch angle (degree)

According to Fig.14: Surface plot of Impact value (J) vs. Thermal treatment; Notch angle (degree) shows the 3D figure of parameter. Using the general steps involved in the Design of Experiments and the L27 Orthogonal Array (Reference: Table 3). The obtained results for Impact values have been analyzed analytically and graphically using RESPONSE SURFACE METHOD with the application of MINITAB 17 software.

The combination of the optimum levels of the factors has been determined with the application of S/N RATIO for Impact values. The Parameter Design has been obtained i.e. the combination of optimum levels of the factors. In the obtained Parametric Design, each optimum combination has the greatest influence on the Impact Toughness and the least variation from the target of the design.

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CONCLUSION

The present research work has successfully demonstrated the application of Response Surface Method for the optimization of process parameters in Impact testing of EN24 steel. The conclusions can be drawn from the present work are as follows:

1. The highest Response surface grade of 1.0000 was observed for the experimental process, as shown in Response table no. 4 and 5.
2. It is also observed through ANOVA that the Height of hammer is the most influential factor among the three process parameters investigated in the present work.
3. The order of importance for the controllable factors was Height of hammer, followed by Notch angle and Thermal treatment.

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