Application of Grey Based Design of Experiment Technique in Optimization of Charpy Impact Testing

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Abstract— The Mechanical Properties of different materials are determined by conducting various design experimental runs. That should be according to the actual working and operating conditions. In this phenomena the type of applied load(s), its duration and the working conditions play a vital role. Engineering materials are always subjected to external loadings therefore it is of great significance if the effect of these loadings can be quantified. In the current research work an attempt was made to optimize the process parameters with the help of surface treatments in order to maximize the impact toughness and minimize the hardness of EN 31 Steel. For this purpose grey based design of experiment method was used and results works were validated graphically and analytically the obtain result shows the height of the hammer affected the impact toughness significantly on the other hand thermal treatment was the most influenced factor that affected materials hardness significantly.

Keywords— Impact Value, ANOVA, Heat Treatment, Cryogenic Treatment.

INTRODUCTION

As part of the government project during World War II, United States planed continuous block constructions of all- welded cargo vessels (DWT 11000, “Liberty ship”). The construction was started with outbreak of the Pacific war from 1942. 2708 Liberty ships were constructed from 1939 to 1945. 1031 Ships got damaged due to Brittle fracture were reported by April 1, 1946. More than 200 Liberty Ships were sink or damaged beyond all of repair. These mark the Start of the discipline of fracture mechanics [1]. “Schenectady” is one of those, which broken in two with a large sound when it was moored at wharf. AASHTO introduced a fracture control plan [2] in the aftermath of the silver bridge collapse in 1967 due to brittle fracture. The judgment of all these researches concluded that these fractures was due to lack of understanding of the ductile-to-brittle transition [1,3].The accident was caused by incidence and development of brittle crack, which were due to the lack of fracture toughness of welded joint. The accident should be the most exclusive and huge scale experiments of the century. The accident showed importance of fracture toughness, which marked the birth of the fracture mechanics. Recently many industries and researchers have shown their interested in cryogenic treatment (CT). Cryogenic treatment is an extension of conventional heat treatment (CHT) which converts retained austenite to martensite. [4] Lipson (1967) studied the effect of cryogenic treatment on the grain size and suggested that the cryogenic treatment reduces grain size by 1-4%. This refinement of grain structure would increase in toughness of the specimens. Cryogenic treated materials enhance the mechanical properties. CT brings about thermal volatility to martensite by means of supersaturating it with carbon which further leads to migration of carbon atoms and atoms of alloying elements to the nearby lattice defects and separate there [5]. Cryogenic treatment improves not only toughness but also microstructure of intellectual and decrease residual stresses. Use of cryogenic treatment in enhancing properties of tool materials has received broad receiving by researchers and industries, recently. The research publications during the past two decades show an increase in interest, on the use of cryogenic treatment, on various cutting tool materials, die materials and bearing materials to exploit the positive effects of such a simple and cost effective technique. Improvements in hardness, fatigue resistance, toughness, and wear resistance of cryogenically treated materials, have been reported invariably in every scientific publication.

HEAT TREATMENT SEQUENCE FOR MAXIMIZING MARTENSITE TRANSFORMATIONS

The complete treatment process of the steels consists of Austenitizing, Annealing, Cryo-treatment or deep cryogenic treatment (DCT), and Tempering. To achieve better microstructure of the steel to get most preferred properties, it is recommended by the most researchers to execute DCT after completion of Austenitizing and before tempering in conventional heat-treatment cycle as shown in Fig-1. The complete process sequentially consists of the steps Austenitizing, Annealing, Cryogenic treatment and Tempering.

Conventional heat treatment consists of annealing, and tempering, while deep cryogenic treatments involves an more low temperature treatment cycle to conventional heat treatment process. Arockia Jaswin et.al [6] determined that the cooling rate for EN 52 and 21-4N valve are respectively 1^0C /min and 1.5^0C /min. A. Joseph Vimal et.al [7] state Cryogenic treatment refers to sub-zero temperature of EN31 steel to 90K in 3 hours and saturated time at that temperature for 24 hours and allowing it to attain room temperature in another 6 hours.

The various heat treatment cycles is indicated in fig.1 below:

Raw material (EN 31)

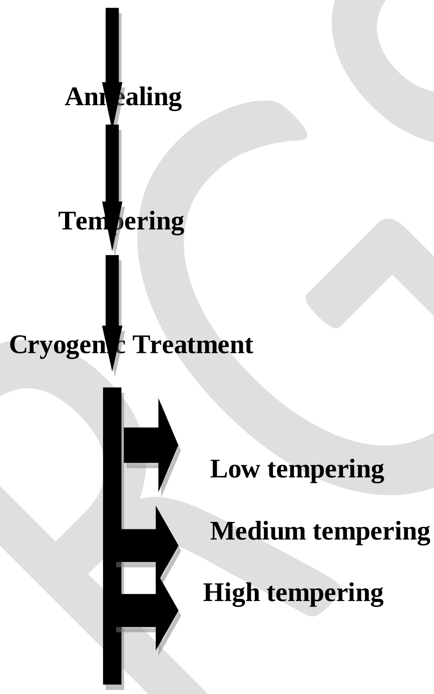

Fig: 1: Thermal Treatments

GREY RELATIONAL ANALYSIS

Grey relational analysis was proposed by Deng in 1989 as cited in is widely used for measuring the degree of relationship between sequences by Gray relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through Grey relational grade. The use of grey relational analysis to optimize the face milling operations with multiple performance characteristics includes the following steps:

Identify the performance characteristics and impact parameters to be evaluated.

Determine the number of levels for the process parameters.

Select the appropriate orthogonal array and assign the parameters to the orthogonal array

Perform the grey relational generating and calculate the grey relational coefficient

Analyses the experimental results using the grey relational grade.

A. Data Pre-Processing:

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. As the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger-the-best':

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \qquad (1)$$

Where $x_i^{(*)}(k)$ is comparable sequence, $\min x_i^{(0)}(k)$ and $\max x_i^{(0)}(k)$ are minimum and maximum values respectively of the original sequence $x_i^{(0)}(k)$

B.Grey Relation Grade

Next step is the calculation of deviation sequence, $\Delta oi(k)$ from the reference sequence of pre-processes data $x_i^*(k)$ and the comparability sequence. The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$\gamma(x_o^*(k), (x_i^*(k)) = \frac{\Delta\min - \xi\Delta\min}{\Delta oi(k) + \xi\Delta\max} \quad 0 < x_o^*(k), (x_i^*(k)) \leq 1 \qquad (2)$$

Where $\Delta oi(k)$ is the deviation sequence of the reference sequence $x_o^*(k)$ and comparability sequence $x_i^*(k)$.

$$\Delta oi(k) = |x_o^*(k) - x_i^*(k)|$$

$$\Delta\max = \underset{\forall j \in i \forall (k)}{\max\ \max} |x_o^*(k) - x_i^*(k)| \qquad (3)$$

$$\Delta\min = \underset{\forall j \in i \forall (k)}{\min\ \min} |x_o^*(k) - x_i^*(k)| \qquad (4)$$

ξ is the distinguishing coefficient $\xi \varepsilon [o, 1]$. the distinguished coefficient (ξ) value is chosen to be 0.5.

The Grey relational grade implies that the degree of influence related between the comparability sequence and the reference sequence. In case, if a particular comparability and reference sequence has more influence on the reference sequence then the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other gray relational grades. Hence, grey relational grade is an accurate measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

EXPERIMENTAL DETAILS AND RESULTS

Design of Experiment (DOE)

Its method based on statistics [8] and other discipline for incoming at an well-organized and efficient planning of experiments with a view to obtain valid conclusion from the analysis of experimental data [9]. The design of experiment (DOE) is done in such a way to find a parameter that will improve the performance characteristics to an acceptable or optimum value. It is also kept in mind that the design will enable us to find a less expensive, alternative design, material, or methods which will provide equal performance. Depending on situations experiment were carried out and dissimilar strategies are creature implemented.

The experiment accepted out is based on the principle of Orthogonal Arrays (OAs). This principle [10] state that factors can be evaluated separately of one another; the effect of one factor does not trouble the opinion of the effect of another factor. DOE is a balanced experiment: an equal numbers of samples under the various treatment circumstances.

The control parameters were measured for the planned research work for multiple performance characteristics at three different levels and three different factors and are shown in table 1 below:

Table 1: Different Factors and their Levels for Annealing EN 31

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 was studied along with three impact test parameters to maximize the impact toughness of EN31 steel. The experiment is to find the optimum impact value by combining all parameters like notch angle, thermal treatment, and height of the hammer at different point.

The material chosen in this work was given various thermal treatments. Specimens were subjected to conventional heat treatment and deep cryogenic treatment separately.

Table 2.Different Heat Treatments Employed to EN 31 steel

Sr. No.	Nomenclature	Thermal Treatment
1	ACTLTT	Annealing(810^0c for 1 hr) followed by Cryogenic treatment & Low Temperature Tempering (250^0c for 1 hr)
2	ACTMTT	Annealing(810^0C for 1 hr) followed by Cryogenic Treatment & Medium Temperature Tempering (400^0C for 1 hr)
3	ACTHTT	Annealing(810^0C for 1hr) followed by Cryogenic Treatment & high Temperature Tempering (550^0C for 1 hr)

Chemical compositions of EN31 steel

The chemical composition test of EN 31 steel was performed in the Metal Testing Laboratory, Indian Railways, Bareilly, India. The details of composition are shown below.

Table 3: Chemical Composition of EN 31 Steel

Sl. No	*Composition*	*Percentage*
1	*C%*	*1.10*

2	*Mn%*	*0.46*
3	*Si%*	*0.22*
4	*Cr%*	*1.08*
5	*S%*	*0.023*
6	*P%*	*0.026*

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. 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. In this paper, L27 Standard Orthogonal Array design matrix was used to set the control parameters to evaluate the process performance. Table 4 shows the design matrix used in this work.

Charpy Impact Test

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition.

Charpy impact test is practical for the assessment of brittle fracture of metals and is also used as an indicator to determine suitable service temperatures. The charpy test sample has a size (10×10×55) mm^3 with three V- Notch 30^0, 45^0, 60^0 of 2mm depth will be hit by a pendulum at the opposite end of the notch.

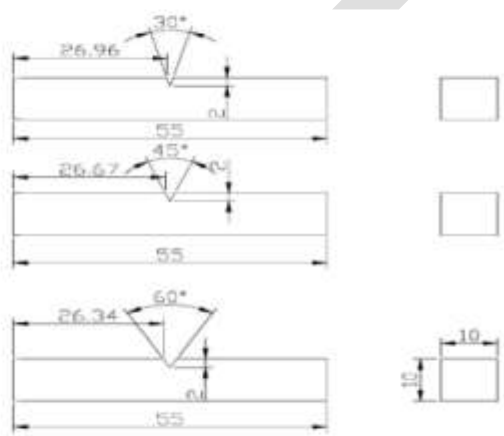

Fig: 2 Dimension of the Specimen

Fig: 3 Charpy Impact Test machine

ANALYSIS OF RESULTS

Experiments are carried out using L27 Standard Orthogonal Array design matrix with three levels of the procedure parameters. All together 27 specimens be taken to be tested with different thermal treatments. All specimens follow the following pattern as “Annealing followed by Cryogenic Treatment & Tempering”.

It was also assumed that to test sub-zero temperature of -196^0C a deep cryogenic treatment was to be employed. The impact values were the combined effect of test parameters according to Orthogonal Array.

Table 4: Results of Experimental Trials

Notch Angle (degree)	Thermal Treatment	Height of the Hammer (mm)	Impact Value (J)	SNRA1
30	Tempering	1370	95	39.5545
30	Tempering	1570	59	35.4170
30	Tempering	1755	13	22.2789
30	Cryogenic Treatment followed by Tempering	1370	92	39.2758
30	Cryogenic Treatment followed by Tempering	1570	56	34.9638
30	Cryogenic Treatment followed by Tempering	1755	14	22.9226
30	Tempering followed by Cryogenic Treatment	1370	94	39.4626
30	Tempering followed by Cryogenic Treatment	1570	59	35.4170
30	Tempering followed by Cryogenic Treatment	1755	14	22.9226
45	Tempering	1370	95	39.5545
45	Tempering	1570	52	34.3201
45	Tempering	1755	12	21.5836
45	Cryogenic Treatment followed by Tempering	1370	94	39.4626
45	Cryogenic Treatment followed by Tempering	1570	55	34.8073
45	Cryogenic Treatment followed by Tempering	1755	15	23.5218
45	Tempering followed by Cryogenic Treatment	1370	85	38.5884
45	Tempering followed by Cryogenic Treatment	1570	58	35.2686
45	Tempering followed by Cryogenic Treatment	1755	12	21.5836
60	Tempering	1370	88	38.8897
60	Tempering	1570	52	34.3201
60	Tempering	1755	15	23.5218
60	Cryogenic Treatment followed by Tempering	1370	85	38.5884
60	Cryogenic Treatment followed by Tempering	1570	60	35.5630
60	Cryogenic Treatment followed by Tempering	1755	12	21.5836
60	Tempering followed by Cryogenic Treatment	1370	80	38.0618

60	Tempering followed by Cryogenic Treatment	1570	61	35.7066
60	Tempering followed by Cryogenic Treatment	1755	8	18.0618

All experiments have been performed on Impact testing Machine of energy range 0-300J manufactured by Fuel instruments and Engineer Private Ltd. The respond changeable measured was Impact value in Joules. Typically superior impact values are attractive. Thus the data sequences have the "larger-the-better" individuality, the larger – the –better methodology.

Using Grey Relational Analysis the data pre-processing was obtained to normalize the random grey data with different measurement to change them to dimensionless parameters. Therefore it converts the original sequences to a position of similar sequences.

Table 5: Data Pre-Processing Result

Sr. No.	Impact Value (J)
1	0.0000
2	0.4137
3	0.9425
4	0.0344
5	0.4482
6	0.9310
7	0.0114
8	0.4137
9	0.9310
10	0.0000
11	0.4942
12	0.9540
13	0.0114
14	0.4597
15	0.9195
16	0.1149
17	0.4252
18	0.9540
19	0.0804

20	0.4942
21	0.9195
22	0.1149
23	0.4022
24	0.9540
25	0.1724
26	0.3908
27	1.0000

Table 6: Deviation sequences

Sr. No.	Impact value (J)
1	1.0000
2	0.5863
3	0.0575
4	0.9656
5	0.5518
6	0.0690
7	0.9886
8	0.5863
9	0.0690
10	1.0000
11	0.5058
12	0.0460
13	0.9886
14	0.5403
15	0.0805
16	0.8851
17	0.5748
18	0.0460

19	0.9196
20	0.5058
21	0.0805
22	0.8851
23	0.5978
24	0.0460
25	0.8276
26	0.6092
27	0.0000

Table 7: Calculation of Grey Relational Grade

Sr. No.	**A**	**B**	**C**	**Grade**
1	1	1	1	0.3333
2	1	1	1	0.4602
3	1	1	3	0.8968
4	1	2	1	0.3411
5	1	2	2	0.4753
6	1	2	3	0.8787
7	1	3	1	0.3358
8	1	3	2	0.4602
9	1	3	3	0.8787
10	2	1	1	0.3333
11	2	1	2	0.4971
12	2	1	3	0.9157
13	2	2	1	0.3358
14	2	2	2	0.4806
15	2	2	3	0.8613
16	2	3	1	0.3609
17	2	3	2	0.4652

18	2	3	3	0.9157
19	3	1	1	0.3522
20	3	1	2	0.4971
21	3	1	3	0.8613
22	3	2	1	0.3609
23	3	2	2	0.4554
24	3	2	3	0.9157
25	3	3	1	0.3766
26	3	3	2	0.4507
27	3	3	3	1.0000

Table No.-8 Response table for Grey Relational Grade for Factors

Levels	**A**	B	**C**
1	0.5622	0.5718	0.3477
2	0.5739	0.5672	0.4713
3	0.5855	0.5826	0.9026

Table no.-9 Response table for Signal to Noise Ratios of Impact Values at different Levels of the Parameters

Level	Notch Angle (degree)	Thermal Treatment	Height of the Hammer(mm)
1	32.47	32.30	39.05
2	32.08	32.16	35.09
3	31.59	31.67	22.00
Delta	0.88	0.62	17.05
Rank	2	3	1

Table no.-10 ANOVA Table for main effect for Signal to Noise ratio

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Notch Angle (degree)	2	3.50	1.748	1.63	0.221
Thermal Treatment	2	1.93	0.966	0.90	0.422
Height of the Hammer (mm)	2	1433.26	716.631	667.50	0.000
Error	20	21.47	1.074		
Total	26	1460.16			

In Table no.10 In P-value, factor minimum than 0.05 will be considered as the significant factor. So, Height of hammer with the value of 0.000 is the significant factor.

Table no.-11 Response table for Means for Impact Values at different Levels of the Parameters

Level	Notch Angle (Degree)	Thermal Treatment	Height of the Hammer(mm)
1	55.11	53.67	89.78
2	53.11	53.44	56.89
3	51.22	52.33	12.78
Delta	3.89	1.33	77.00
Rank	2	3	1

Table no.-12 ANOVA Table for main effect for Means

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Notch Angle(mm)	2	68.1	34.0	2.36	0.120
Thermal Treatment	2	98.2	4.6	0.32	0.731
Height of the Hammer (mm)	2	26869.4	13434.7	930.57	0.000
Error	20	288.7	14.4		
Total	26	27235.4			

In Table no.12 In P-value, factor minimum than 0.05 will be considered as the significant factor. So, Height of hammer with the value of 0.000 is the significant factor

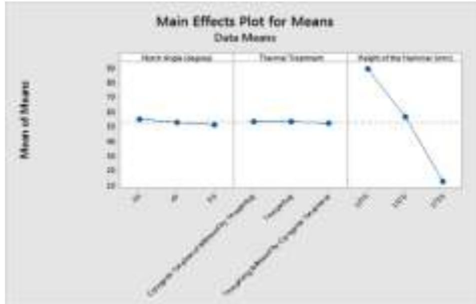

Figure no.-4 Main Effects plot for means

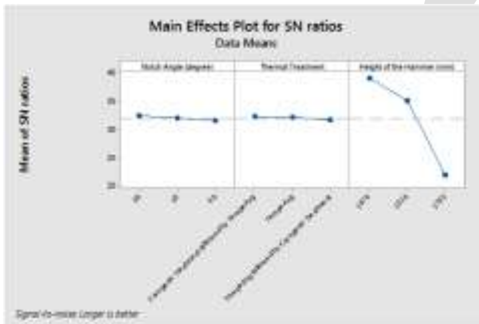

Figure no.-5 Main Effects plot for SN ratios

According to Fig.4

As per the observations of the above experimental trial runs, the following results can be drawn out and discussed as follows in terms of graphical analysis

Indicates that at 1st level of notch-Angle (30^0) the impact value obtained is maximum. Similarly at 1st level of Thermal Treatment (Cryogenic Treatment followed by Tempering) and at 1st level of Height of Hammer (1370mm) respectively, the impact value obtained is highest.

According to Fig.5

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CONCLUSION

The present research work has successfully verified the application of Grey relational analysis for multi objective optimization of process parameters in impact testing of EN 31 Steel. The termination can be drawn from this research paper are as follows:

1.The highest Grey relational grade of 1.0000 was observed for the experimental run 27, shown in table no. 7 of the average Grey relational grade, which indicates that the optimal combination of control factors and their levels was 60^0 notch angle, height of the hammer of 1755 mm and thermal treatment of Tempering followed by Cryogenic treatment.

2. This research work can also be utilized for further studies in future.

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