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Analysis of Specimen Dimensions in Torsion Testing of AISI 1020 Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Analysis

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***Abstract* - The current study aims at investigating the influence of solid specimen dimensions such as total length, useful length, outer diameter and fillet radius on torsion test results of mild (AISI 1020) steel.L_9 orthogonal array was selected for design of experiments. Three important output parameters of torsion testing such as modulus of rigidity, yield shear stress and ultimate shear stress were calculated by using Nadai method. Attempt was further made to simultaneously optimize the specimen dimensions using grey relational analysis. The recommended optimized combination based on studied output parameters was found to be total length =162 mm, useful length =50 mm, outer diameter =10 mm and fillet radius =2.5 mm. The confirmation test was also carried out to check the analysis.**
***Keywords* : Grey Relational Analysis; Modulus of rigidity; Torsion; Ultimate shear stress; Yield shear stress.**

I. INTRODUCTION

AISI 1020 is one of the widely used grade of steel in engineering applications. Torsion testing is conducted to determine different mechanical properties in new product design and development. Han Chin-Wu *et al.* [1], addressed problems related to torsion tests as: material homogeneity, specimen geometry, strain measurement and determination of shear stress-strain curve. Zarroug et al. [2], examines the results obtained in combined tension–torsion loading tests for Mild steel (En8) specimen. The specimens were tested in two different ways: (i) maintaining tensile force or axial displacement constant and increasing torque or angle of twist (ii) maintaining torque or angle of twist constant and increasing load or axial displacement. In this study, (i) method was used to conduct torsion experiment. Bressan et al. [3], developed, torsion machine using encoder and load cell for measurement of angle and torque. Graber et al. [4], used new method for calculation of shear stress and shear strain in torsion test results. In this study, torsion tests are performed on solid specimens of AISI 1020 steel using digital torsion testing machine having capacity 200 Nm.

Taguchi method is a powerful tool for design of experiments (DOE) which is used for optimization. It is an important tool to identify critical parameters and also predict optimal settings of each process parameter. Taguchi parameter technique is a single parameter optimization based on signal to noise ratio [12]. This methodology has been widely adopted in the experimental design related to a large variety of machining processes (Patil and Inamdar [5], Kulkarni et al. [6], Refaie et al. [7], Kamaruddin et al. [8], Kacker et al. [9], Una and Dean [10]).

GRA converts multi-objective optimization problem in a single objective optimization problem. Shreemoy Kumar Nayak et al. [11] have used grey relational grade technique to optimize machining parameters during turning. Analysis of variance (ANOVA) is performed to find most significant parameter. Mechanical and physical properties of AISI 1020 steel are shown in table 1.

TABLE 1 PHYSICAL AND MECHANICAL PROPERTIES OF MILD STEEL (AISI 1020)

S.No.	Property	Value	Units
1	Maximum stress	400- 560	N/mm^2
2	Yield Stress	300-440 min.	N/mm^2
3	0.2 % proof stress	280-420 min.	N/mm^2
4	Poisson's ratio	0.29	N/A
5	Shear modulus in XY	77000	N/mm^2
6	Mass density	7900	Kg/m^3

II. DESIGN OF EXPERIMENTS

Taguchi technique is used to plan the experiments. Orthogonal arrays are designed in 1940's and used to in designing experiments. It is used to reduce the number of experiments conducted during full factorial experiments. Based on strength of specimen and ASTM A938-07, the specimen dimensions and their levels are given in table 2.

TABLE 2 SELECTED SPECIMEN DIMENSIONS AND THEIR LEVELS

S. No.	Specimen dimensions	Level I	Level II	Level III
1	Total length	203.0	162.0	130.0
2	Useful length	78.0	62.4	50.0
3	Outer diameter	10.0	8.0	6.0
4	Fillet radius	3.0	2.5	2.0

The control factors are 4 and levels are 3, hence the Degree of freedom are 4(3-1) =8. The no of experiments in the OA should be equal to or greater than DOF, so L_9 OA is selected. The required combination of input paramters using L_9 orthogonal array are listed in table 3.

TABLE 3 TAGUCHI L9 STANDARD ORTHOGONAL ARRAY DESIGN MATRIX

Parameters → / Expt. No.↓	Total length mm	Useful length mm	Outer diameter mm	Fillet radius mm
1	203.0	78.0	10.0	3.0
2	203.0	62.4	8.0	2.5
3	203.0	50.0	6.0	2.0
4	162.0	78.0	8.0	2.0
5	162.0	62.4	6.0	3.0
6	162.0	50.0	10.0	2.5
7	130.0	78.0	6.0	2.5
8	130.0	62.4	10.0	2.0
9	130.0	50.0	8.0	3.0

The mild steel solid specimens as per table 4.were prepared. The specimens as per L_9 orthogonal array are shown in fig.1.The torsion test was conducted on digital torsion testing machine of capacity 200 Nm. The specimens were tested till failure as shown in fig.2.and the results for three output parameters are given in table 5.

Fig.1.Mild steel solid specimen

Fig.2.Specimens after Torsion

TABLE 4 EXPERIMENTAL RESULTS

S. No.	Modulus of rigidity (gpa)	Yield shear stress (mpa)	Ultimate shear stress (mpa)
1	77.44	380.00	493.93
2	77.00	379.00	503.27
3	78.55	399.00	511.76
4	78.00	385.00	509.62
5	77.60	387.87	474.71
6	79.27	390.00	537.57
7	78.13	386.00	495.93
8	77.23	390.55	499.34
9	79.37	370.56	499.96

III. TAGUCHI'S OPTIMIZATION METHOD

According to Taguchi method, signal to noise ratio is used to find optimal parameters. The experimental results are converted into S/N ratios for output parameters as Lower the Better characteristic using Eq. (1)

S/N_{LB} = -10 Log_{10} [mean of sum of squares of measured data] (1)

The S/N ratio for experiments conducted is shown in table 5.

TABLE 5. S/N RATIOS FOR EXPERIMENTAL RESULTS

Modulus of rigidity (GPa)	Yield shear stress (MPa)	Ultimate shear stress (MPa)
-37.779	-51.596	-53.873
-37.730	-51.573	-54.036
-37.903	-52.020	-54.181
-37.842	-51.709	-54.145
-37.797	-51.774	-53.529
-37.982	-51.821	-54.609
-37.856	-51.732	-53.908
-37.756	-51.834	-53.968
-37.993	-51.377	-53.979

IV. GREY RELATIONAL ANALYSIS

Grey theory is used for multi objective optimization of specimen dimensions considering output parameters as modulus of rigidity, yield shear stress, ultimate shear stress. Steps to be followed as follows: [10]

1. Normalization of the S/N ratio
2. Determination of deviation sequence
3. Calculation of Grey Relational Coefficient (GRC)

4. Determination of Grey Relational Grade (GRG)

Step 1: Normalize the experimental values of modulus of rigidity, yield shear stress and ultimate shear stress in range of 0-1.This process is known as Grey Relational Normalization. In this study three output parameters are normalized using "Smaller the better" characteristics as per Eq. (2).

$$x_i^*(k) = \frac{max\, x_i^0\,(k) - x_i^0(k)}{max x_i^0(k) - min x_i^0(k)} \quad (2)$$

Normalized S/N ratios are given in table 6.

TABLE 6 NORMALIZED S/N RATIOS

Expt. No.	Modulus of rigidity	Yield shear stress	Ultimate shear stress
Ref.	1.0000	1.0000	1.0000
Comparability sequence			
1	0.188	0.3402	0.3191
2	0.000	0.3045	0.4698
3	0.658	1.0000	0.6043
4	0.426	0.5169	0.5706
5	0.256	0.6173	0.0000
6	0.959	0.6914	1.0000
7	0.481	0.5519	0.3516
8	0.098	0.7104	0.4067
9	1.000	0.0000	0.4167

Step 2: Deviation sequence represents the absolute difference between the reference sequence and comparability sequence after normalization. It is determined by using equation (3).

$$\Delta_{oi}(k) = |x_0^*(k) - x_i^*(k)| \quad (3)$$

The deviation sequences are shown in table 8.

TABLE 7. THE DEVIATION SEQUENCES

Deviation sequence	$\Delta_{01}(01)$	$\Delta_{01}(02)$	$\Delta_{01}(03)$
No.1, *i=1*	0.812	0.6598	0.6809
No.2, *i=2*	1.000	0.6955	0.5302
No.3, *i=3*	0.342	0.0000	0.3957
No.4, *i=4*	0.574	0.4831	0.4294
No.5, *i=5*	0.744	0.3827	1.0000
No.6, *i=6*	0.041	0.3086	0.0000
No.7, *i=7*	0.519	0.4481	0.6484
No.8, *i=8*	0.902	0.2896	0.5933
No.9, *i=9*	0.000	1.0000	0.5833

Step 3: Grey relational coefficients (GRC) represents relationship between ideal and actual normalized S/N ratios. The GRC are calculated by using Eq. (4).

$$\gamma\big(x_0(k), x_i(k)\big) = \frac{\Delta_{min} + \zeta.\Delta_{max}}{\Delta_{0i}\ (k) + \zeta.\Delta_{max}} \quad (4)$$

$\zeta =$ distinguishing coefficient, $\zeta \in (0,1)$And for present study,ζ is set as 0.5.

Step 4: Grey relational grade (GRG) is the average sum of Grey relational coefficients, which can be calculated by using Eq. (5).

$$\gamma(x_0, x_i) = \frac{1}{m}\sum_{i=1}^{m} \gamma(x_0(k), x_i(k)) \quad (5)$$

The GRC and grade values are represented in the table 8.

TABLE 8 GREY RELATIONAL COEFFICIENTS AND GRADE VALUES

S.No.	Modulus of rigidity	Yield shear stress	Ultimate shear stress	Grade Value	Rank
1	0.3811	0.4311	0.4234	0.4119	9
2	0.3333	0.4182	0.4853	0.4123	8
3	0.5935	1.0000	0.5582	0.7172	2
4	0.4654	0.5086	0.5380	0.5040	4
5	0.4020	0.5665	0.3333	0.4339	7
6	0.9234	0.6184	1.0000	0.8473	1
7	0.4905	0.5274	0.4354	0.4844	6
8	0.3567	0.6332	0.4573	0.4824	5
9	1.0002	0.3333	0.4616	0.5984	3

V. ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) of Grade values has been performed using statistical software, MINITAB on Grey relational grade values to evaluate the influence of specimen dimensions on output parameters. ANOVA for grade values are given in table 9.

Using Taguchi method, response table has been generated to separate out the effect of each level of specimen dimensions on Grey relational grade as shown in Table 9.

TABLE 9 ANOVA FOR GREY RELATIONAL GRADE

Parameter	DOF	Seq.SS	Adj. SS	Adj.MS	% Cont.
Total length	2	0.0120	0.0120	0.0060	6.66
Useful length	2	0.1424	0.1424	0.0712	78.80
Outer diameter	2	0.0085	0.0085	0.0042	4.75
Fillet radius	2	0.0176	0.0176	0.0088	9.76
Total	8	0.1807	-	-	100

TABLE 10 RESPONSE TABLE FOR GREY RELATIONAL GRADE (GRG)

Levels	LT	LU	OD	R
1	0.5138	0.4668	0.5805	0.4814
2	0.5951	0.4429	0.5049	0.5813
3	0.5217	0.7210	0.5452	0.5679
Max-Min	0.0813	0.2781	0.0756	0.0999
Ranking	3	1	4	2
Total mean value of GRG is 0.5435				

VI. RESULTS AND DISCUSSIONS

The results obtained from Taguchi optimization for modulus of rigidity, yield shear stress and ultimate shear stress are shown in table 11.

TABLE 11 OPTIMUM CONDITIONS USING TAGUCHI METHOD

S.No.	Specimen Dimensions (mm)	Modulus of rigidity	Yield shear stress	Ultimate shear stress
1	Total length	203	130	162
2	Useful length	62.4	50	62.4
3	Outer diameter	8	8	6
4	Fillet radius	2.5	3	3

ANOVA for grade values in table 10, shows that useful length is most significant specimen dimension in torsion test. It is clearly observed from Table 9, the specimen dimension “setting of experiment no.6” has the highest Grey relational grade (0.8473) thus the 6th number experiment gives the optimal specimen dimensions. From the response table 11 for Grey relational grade, the best combination of the specimen dimensions is set with A2B3C1D2.Optimal values are total length =162 mm, useful length =78 mm, outer diameter =10, fillet radius = 2.5 mm.

VII. CONCLUSIONS

Torsion testing has been done on Mild steel (AISI 1020) solid specimens using digital torsion testing machine. The following conclusions are made.

Based on Taguchi’s optimization method, optimized input parameter combinations to get minimum modulus of rigidity are total length =203 mm, useful length =62.4 mm, outer diameter =8 mm, fillet radius = 2.5 mm. Similarly to get minimum yield shear stress, total length =130 mm, useful length =50 mm, outer diameter =8 mm, fillet radius = 3 mm. and for minimum ultimate shear stress, total length =162 mm, useful length =62.4 mm, outer diameter = 6 mm, fillet radius = 3 mm.

Based on Grey Relational Analysis, the optimized input parameter combination to get three output parameters minimum, total length =162 mm, useful length =78 mm, outer diameter =10 mm, fillet radius = 2.5 mm.

Analysis of variance resulted that useful length has significant effect on torsion test results.

Grey relational analysis results has been validated with experimental results.

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REFERENCES

[1] Han-Chin Wu, Zhiyou Xu, Paul T Wang, (1997), “Torsion test of aluminum in the large strain range”, International Journal of Plasticity, vol.13,873-892.

[2] N.M Zarroug, R Padmanabhan, B.J MacDonald, P Young, M.S.J Hashmi, (2003),“Mild steel (En8) rod tests under combined tension–torsion loading”, Journal of Materials Processing Technology, vol. 143–144,807-813.

[3] Jose Divo Bressan, Ricardo Kirchhof Unfer, (2006), “Construction and validation tests of a torsion test machine”, Journal of Materials Processing Technology, vol.179, 23-29.

[4] A. Graber, K. Pohlandt, K. Lange, (1989),“A New Approach to the Torsion Test for Determining Flow Curves”, CIRP Annals - Manufacturing Technology, vol. 38, 223-226.

[5] Patil G., Inamdar K. (2014) “Optimization of Casting Process Parameters using Taguchi Method” International Journal of Engineering Development and Research 2, 2, 2506-2511.

[6] Kulkarni A., Malagi R., Pol A. and Kittur J. (2014) “Parameter Optimization of No Bake Core Making Process by Using Taguchi Method” International Journal of Engineering Research 3, 7, 426-429.

[7] Refaie and Li M. (2008) “Alpha Risk of Taguchi Method with L18 Array for NTB Type QCH by Simulation” Proceedings of the World Congress on Engineering 2, 3-7.

[8] Kamaruddin S., Khan Z. and Wan K. (2004) “The use of the Taguchi method in determining the optimum plastic injection moulding parameters for the production of a consumer product” Journal Mekanikal 18, 98-110.

[9] Kacker R., Lagergren E. and Filliben J. (1991) “Taguchi Vs Orthogonal Arrays Are Classical Designs of Experiments” Journal of Research of the National Institute of Standards and Technology 96, 5, 577-591.

[10] Unal R. and Dean E. (1991) “Taguchi approach to design optimization for quality and cost: an overview” Annual Conference of the International Society of Parametric Analysts 1, 1-10.

[11] Shreemoy Kumar Nayak, Jatin Kumar Patro, Shailesh Dewangan, Soumya Gangopadhyay, (2014) “Multi-Objective Optimization of Machining Parameters During Dry Turning of AISI 304 Austenitic Stainless Steel Using Grey Relational Analysis” Procedia Materials Science, 6, 701 – 708.

[12] M. Durairaj, D. Sudharsun, N. Swamynathan, (2013), “Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade”,*Procedia Engineering*,64, 868 – 877.

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