Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P) Vol.8 No.1, 2019, pp.52-57

DOI: https://doi.org/10.51983/arme-2019.8.1.2458

Effect of Specimen Dimensions on Yield Shear Stress in Torsion Testing of AISI 1020 Steel by Using GRA

Rajkumar D. Patil[1], P. N. Gore[2] and Vishal R. Balwan[3]
[1&3]Assistant Professor, [2]Associate Professor
[1,2&3]Mechanical Engineering, DKTE's Textile and Engineering Institute, Ichalkaranji, Maharashtra, India
E-Mail: rajsidhant13909@gmail.com

Abstract - **This current research work aims at studying the influence of hollow specimen dimensions such as inner diameter, useful length, outer diameter and fillet radius on yield shear stress of mild steel (AISI 1020) in torsion testing. L_9 orthogonal array was selected for design of experiments. Three output parameters of torsion testing such as modulus of rigidity, yield shear stress and ultimate shear stress were calculated by using Nadai method. Single objective optimization was done by using Taguchi method. Further effort was made to simultaneously optimize the specimen dimensions using grey relational analysis (GRA). The yield shear stress was found maximum for the specimen dimensions with outer diameter of 12 mm, inner diameter 3.8 mm, useful length 16.0 mm, and fillet radius 2.0 mm. The confirmation test was also carried out to check the GRA results.**
Keywords: **Torsion Testing, Grey Relational Analysis, Yield Shear Stress, Taguchi Method, Nadai Method, Smaller-The-Better, ANOVA**

I. INTRODUCTION

Torsion experiment is performed to determine different mechanical properties in new product design and development. The problems listed related to torsion tests as: material homogeneity, specimen geometry, strain measurement and determination of shear stress-strain curve [1].The results were obtained in combined tension–torsion loading tests for Mild steel (En8) specimen. The specimens were tested in two different ways: (i) upholding tensile force or axial displacement constant and increasing torque or angle of twist (ii) keeping torque or angle of twist constant and increasing load or axial displacement. In this study, (i) method was used to conduct torsion experiment [2].

The torsion machine was established using encoder and load cell for measurement of angle and torque [3]. Nadai method was used for calculation of shear stress and shear strain in torsion test results [4]. 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 single objective optimization. It is an important tool to recognize critical parameters and also forecast optimal settings of each process parameter. Taguchi parameter technique is a single parameter optimization based on signal to noise ratio [11]. Taguchi methodology has been widely embraced in the experimental design related to a large variety of machining processes [5-10].

GRA converts multi-objective optimization problem in a single objective optimization problem. Grey relational grade (GRG) technique was used to optimize machining parameters during turning. Analysis of variance (ANOVA) is performed to find most significant parameter [11].

II. DESIGN OF EXPERIMENTS

Taguchi technique has used in designing experiments. It has used to reduce the number of experiments conducted during full factorial experiments. Based on strength of specimens and ASTM A938-07, the specimen dimensions and their levels are given in Table I.

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 Degrees of freedom, so L_9OA has been selected. The required combination of input parameters using L_9 orthogonal array are listed in Table II.

The mild steel hollow specimens as per Table II were prepared. The specimens as per L_9 orthogonal array are shown in Fig. 1.

The torsion test has been performed on digital torsion testing machine of capacity 200 Nm. Each experiment has conducted for three trials. The specimens have been tested till failure as shown in Fig. 2.

TABLE I SELECTED SPECIMEN DIMENSIONS AND THEIR LEVELS FOR HOLLOW MILD STEEL

S. No.	Specimen dimensions	Level I	Level II	Level III
1.	Outer diameter	12.0	10.0	8
2.	Inner diameter	6.0	4.8	3.8
3.	Useful length	25.0	20.0	16.0
4.	Fillet radius	3.0	2.5	2.0

TABLE II TAGUCHI L9 STANDARD ORTHOGONAL ARRAY DESIGN MATRIX FOR HOLLOW MS

Parameters / Expt. No	Outer diameter mm	Inner diameter mm	Useful length mm	Fillet radius mm
1	12.0	6.0	25.0	3.0
2	12.0	4.8	20.0	2.4
3	12.0	3.8	16.0	2.0
4	10.0	6.0	20.0	2.0
5	10.0	4.8	16.0	3.0
6	10.0	3.8	25.0	2.5
7	8.0	6.0	16.0	2.5
8	8.0	4.8	25.0	2.0
9	8.0	3.8	20.0	3.0

Fig. 1 Mild steel hollow specimens

Fig. 2 Specimens after Torsion failure

III. TAGUCHI'S OPTIMIZATION METHOD

The yield shear stress value for each trial and S/N ratio against trial numbers are shown in Table III.

TABLE III YIELD SHEAR STRESS FOR EACH TRIAL AND S/N RATIO AGAINST TRIAL NUMBERS

Exp. No.	Yield shear stress(Mpa)				S/N ratio (LB)	Mean
	1	2	3	Avg.		
1	349.38	348.68	350.58	349.28	50.863	349.28
2	354.35	353.31	355.25	353.31	50.963	353.31
3	355.24	356.24	357.24	357.24	51.059	357.24
4	346.64	346.64	346.64	346.64	50.797	346.64
5	345.44	346.54	347.64	346.64	50.797	346.64
6	356.67	357.75	356.97	356.84	51.049	356.84
7	331.82	329.62	328.90	330.92	50.394	330.92
8	350.10	348.06	355.16	352.01	50.931	352.01
9	350.84	353.93	354.80	352.87	50.9523	352.87

The yield shear stress is found maximum for the specimen dimensions with outer diameter of 12 mm, inner diameter 3.8 mm, useful length 16.0 mm, and fillet radius 2.0 mm.

The graph showing the effects of specimen dimension on yield shear stress are shown in Fig. 3.

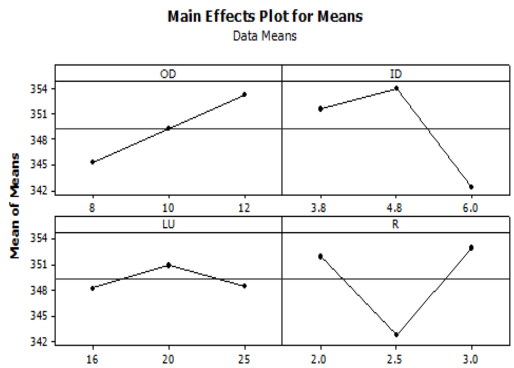

Fig. 3 Effects of specimen dimensions on yield shear stress

After analyzing the graphs in Fig. 3, it is observed that the yield shear stress increases with increase in inner diameter and further decreases.

TABLE IV RESPONSE TABLE FOR MEANS

Level	Outer diameter	Inner diameter	Useful length (LU)	Fillet radius
1	345.3	351.5	348.3	352.0
2	349.3	354.1	350.9	342.9
3	353.3	342.3	348.6	353.0
Delta	8.0	11.8	2.6	10.1
Rank	3	1	4	2

The ranks and the delta values are shown in Table IV, indicates that inner diameter has the greatest effect on yield shear stress value compared to other dimensions. The ANOVA for yield shear stress is shown in Table V.

TABLE V ANOVA FOR YIELD SHEAR STRESS

Source	DF	Seq. SS	Adj. SS	Adj. MS	% Contribution
Outer Diameter	2	96.242	96.242	48.121	18.34
Inner Diameter	2	230.317	230.317	115.159	43.89
Useful Length	2	12.453	12.453	6.227	2.37
Fillet Radius	2	185.666	185.666	92.833	35.38
Total	8	524.679	-	-	100

It is observed from Table V, that inner diameter affect the yield shear stress value significantly.

IV. GREY ANALYSIS FOR MS HOLLOW SPECIMEN

The S/N ratios for each trial numbers and for three output measures are shown in Table VI.

TABLE VI SEQUENCE OF S/N RATIO

Expt. No.	Modulus of rigidity	Yield shear stress	Ultimate shear stress
1	-37.8863	50.8635	-52.7424
2	-37.795	50.9631	-52.7544
3	-37.8017	51.0592	-52.7792
4	-37.9712	50.7976	-53.2429
5	-38.1729	51.0495	-52.9713
6	-37.8174	50.742	-52.7135
7	-37.9877	50.3945	-50.7918
8	-37.786	50.9311	-52.3249
9	-37.8174	50.9523	-52.4154

A. Normalization of S/N ratio

The “Larger-the-better” is a characteristics used normalized yield shear stress. Original sequence should be normalized using Equation, which is reproduced below (11),

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

For experiment No. 1 yield shear stress value can be normalized as:

$$x_i^*(k) = \frac{(50.8635) – (50.3945)}{(51.0592) - (50.3945)} = 0.7056$$

In this GRA analysis, response such as modulus of rigidity, ultimate shear stress is normalized using “Smaller the better” characteristics. As already noted, for these quality characteristics, original sequence should be normalized using Equation, which is reproduced below,

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

For Experiment No.1, modulus of rigidity value can be normalized as:

$$x_i^*(k) = \frac{(-37.7860) – (-37.8863)}{(-37.7860) - (-38.1729)} = 0.2592$$

Similar procedure is followed for all performance characteristics and original sequences was normalized which are displayed in Table VII.

TABLE VII SEQUENCE AFTER DATA PRE-PROCESSING

Expt. No.	Modulus of rigidity	Yield shear stress	Ultimate shear stress
Ref. sequence	1.0000	1.0000	1.0000
Comparability sequence			
1	0.2592	0.7056	0.7958
2	0.0233	0.8554	0.8007
3	0.0406	1.0000	0.8108
4	0.4787	0.6064	1.0000
5	1.0000	0.9854	0.8892
6	0.0812	0.5228	0.7840
7	0.5213	0.0000	0.0000
8	0.0000	0.8073	0.6255
9	0.0812	0.8392	0.6624

B. Determination of Deviation Sequence

It is determined using Eq. as follows,

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

For experiment no.1, for modulus of rigidity, deviation sequence Δ_{o1} can be calculated as follows

$$\Delta_{oi}(1) = |1.0000 - 0.2592| = 0.7408$$

Similar procedure is followed for all 9 experiments and Deviation sequence were calculated and displayed in Table VIII.

TABLE VIII THE DEVIATION SEQUENCES

Deviation sequence	$\boldsymbol{\Delta_{01}(01)}$	$\boldsymbol{\Delta_{01}(02)}$	$\boldsymbol{\Delta_{01}(03)}$
No.1, *i=1*	0.7408	0.2944	0.2042
No.2, *i=2*	0.9767	0.1446	0.1993
No.3, *i=3*	0.9594	0.0000	0.1892
No.4, *i=4*	0.5213	0.3936	0.0000
No.5, *i=5*	0.0000	0.0146	0.1108
No.6, *i=6*	0.9188	0.4772	0.2160
No.7, *i=7*	0.4787	1.0000	1.0000
No.8, *i=8*	1.0000	0.1927	0.3745
No.9, *i=9*	0.9188	0.1608	0.3376

C. Calculation of Grey Relational Coefficient (GRC)

The Grey relational coefficient can be calculated by Equation. Investigating the data presented in Table XIII of deviation sequence**,** we can observe Min. and Max. Values ($\Delta_{\max}$ (k) and Δ (k)) as follows:

$$\Delta_{max} = \Delta o_8\,(1) = \Delta o_7\,(2) = \Delta o_7\,(3) = 1.0000,$$
$$\Delta_{min} = \Delta o_5\,(1) = \Delta o_3\,(2) = \Delta o_4\,(3) = 0.0000$$

Using Table VIII and Eq. the Grey relational coefficient$\gamma(x_0^*(1).\,x_0^1(1))$ can be calculated as follows and subsequent values for all experiments are displayed in Table IX.

$$\gamma\big(x_0^*(1).\,x_0^1(1)\big) = \frac{0.0000 + 0.5 \times 1.0000}{0.7408 + 0.5 \times 1.0000} = 0.4030$$

D. Determination of Grey Relational Grade (GRG)

The Grey relational grade is an average sum of the Grey relational coefficients, which can be calculated using Equation. It is represented in Table IX.

TABLE IX GREY RELATIONAL COEFFICIENTS AND GRADE VALUES

No. (Comparability sequence)	Modulus of rigidity	Yield shear stress	Ultimate shear stress	Grade Value	Rank
1	0.4030	0.6294	0.7100	0.5808	5
2	0.3386	0.7757	0.7150	0.6098	4
3	0.3426	1.0000	0.7255	0.6894	2
4	0.4896	0.5596	1.0000	0.6830	3
5	1.0000	0.9716	0.8186	0.9301	1
6	0.3524	0.5117	0.6983	0.5208	8
7	0.5109	0.3333	0.3333	0.3925	9
8	0.3333	0.7218	0.5717	0.5423	7
9	0.3524	0.7566	0.5969	0.5687	6

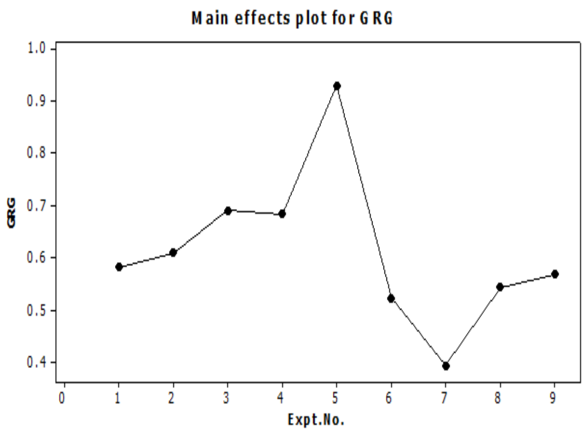

Fig. 4 Graph showing experiment no. versus respective grade

E. Analysis of Grey Relational Grade and Selection of Optimal Level of Parameters

It is clearly observed from Table IX and Figure 4, the specimen dimension "setting of experiment no.5" has the highest Grey relational grade (0.9301) thus the 5^{th} number experiment gives the best multiple performance characteristics among the 9 experiments. 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 X. Basically, larger the Grey relational grade, better the corresponding output measures. From the response table for Grey relational grade, the best combination of the process parameters is set with A2B2C3D1.

TABLE X ANOVA FOR GREY RELATIONAL GRADE

Parameter	DOF	Seq.SS	Adj.SS	Adj.MS	% Contri. (P)
Outer diameter	2	0.067	0.067	0.033	38.01
Inner diameter	2	0.032	0.032	0.016	18.16
Useful length	2	0.022	0.022	0.011	12.94
Fillet radius	2	0.054	0.054	0.027	30.87
Total	8	0.176	-	-	100

TABLE XI RESPONSE TABLE FOR GREY RELATIONAL GRADE (GRG)

Levels	OD	ID	LU	R
1	0.626	0.552	0.548	0.693
2	0.711	0.694	0.620	0.507
3	0.501	0.592	0.670	0.638
Max-Min	0.210	0.141	0.122	0.185
Ranking	1	3	4	2
Total mean value of GRG is 0.6130				

F. Prediction of Grey Relational Grade under Optimum Parameters

The optimal Grey relational grade η_{opt} is predicted using Equation as below

$$\eta_{opt} = 0.9301$$

V. CONCLUSION

Three confirmation experiments were conducted using the optimal process parameters (A3, B2, C3 and D1). The measured mean value at optimal parameters for outer diameter, inner diameter, useful length and fillet radius is 10 mm, 4.8 mm, 16 mm and 3 mm respectively. The grey relational grade computed is 0.9301. Table XII summarizes the predicted and experimental results.

TABLE XII PREDICTED AND EXPERIMENTAL VALUES

S. No.	Process Parameters	Initial setting	Predicted Value	Experimental value
1	Optimal parameter	A2B2C3D1	A2B2C3D1	A2B2C3D1
2	Modulus of rigidity	81.03		81.03
3	Yield shear stress	356.84		356.84
4	Ultimate shear stress	445.21		445.21
6	Grey Relational Grade	0.9301	0.9301	0.9301

The yield shear stress is found maximum for the specimen dimensions with outer diameter of 12 mm, inner diameter 3.8 mm, useful length 16.0 mm, and fillet radius 2.0 mm. It is observed that the yield shear stress increases with increase in inner diameter and further decreases. It is observed from main effects plot for means that yield shear stress increases with increase in outer diameter.

REFERENCES

[1] S. P. Timonshenko, and D.H.Young, "Elements of strength of materials", Fifth Edition, *citton educational publishing, INC.*, pp 70 - 94, 1988.

[2] G.E. Dieter, "The Torsion Test in Mechanical Metallurgy", Chapter 10, Third Edition, *Mc Graw-Hill, Inc., New York*, 1986.

[3] N.M. Zarroug, R. Padmanabhan, B. J. MacDonald, P. Young, and M.S.J. Hashmi, "Mild steel (En8) rod tests under combined tension–

torsion loading", *Journal of Materials Processing Technology*., Vol. 143–144, pp.807-813, 2013.

[4] A. Graber, K. Pohlandt, and K. Lange, "A New Approach to the Torsion Test for Determining Flow Curves", *CIRP Annals – Manufacturing Technology*, Vol. 38, pp. 223-226, 1989.

[5] A. Pavel Mossakovsky, K. F edor Antonov, and A .Lilia, Kostyreva, "Investigation of Failure Criterion in Dynamic Torsion Tests with Solid Cylindrical Specimens", *8th European LS-DYNA Users Conference*, pp.1423-1430, 2011.

[6] F. Berto, M. Elices, P. Lazzarin, and M. Zappalorto, "Fracture behaviour of notched round bars made of PMMA subjected to torsion at room temperature", *Engineering Fracture Mechanics*., Vol. 90, pp.143-160, 2012.

[7] Han-Chin Wu, Zhiyou Xu, and Paul T. Wang, "Torsion test of aluminium in the large strain range", *International Journal of Plasticity*, Vol.13, pp.873-892, 1997.

[8] Jose Divo Bressan, and Ricardo Kirchhof Unfer, "Construction and validation tests of a torsion test machine", *Journal of Materials Processing Technology*, Vol.179, pp.23-29, 2006.

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

[10] Milan Kumar Das, koushik kumar,Tapan Kr Barman,Prasanta Sahoo, "Optimization of process paramaters in plasma arc cutting of EN 31 steel based on MRR and multiple roughness characteristics using Grey Relational Analysis", *Procedia material science*, 5, pp.1550-1559, 2014.

[11] PSG College of Technology, *Design data book, Kalaikathir Achchagam*, 2010.