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Statistical Analysis of the Mechanical Properties of Double Edge Notched Welded Aluminum Plates

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Abstract—*Statistical analyses of the effect of weld-parameters on the mechanical properties of have been focused in many literatures. However, none of them deals with the statistical analysis of the effect of notches and strain rate on the mechanical properties of welded double edge notched plates under tension. This paper focuses on the analysis of variance (ANOVA) performed at 95% confidence level to identify the significance of mechanical testing and notch parameters in effecting the tensile properties. F-test has been utilized in statistics to analyze the measure of the significant effects of the parameters (strain rate and notch root radius). This study indicates that the strain rate is the main parameter which has the highest influence on the tensile properties of the welded components with notch.*

Keywords*: Statistical Analysis, Tensile Properties, Aluminum alloy, Static loading, Double Edge Notched Welded Plate.*

1. INTRODUCTION

The need of lightweight alloys and quality welds with superior mechanical properties is of great interest for increasing the life of the component. Different welding techniques in aluminum and its alloys are used in various manufacturing processes. The strength of welded components is affected due to various welding parameters [1-4]. Many researchers have focused on the various mechanical properties of the Friction stir welds (FSW) [5-7], Resistance spot welded joints (RSW) [8], MIG-welded joints [9] and seam welded components [10]. In this work, the tungsten inert gas (TIG) welding has been used for welding aluminum alloy to form a butt-joint. It is the preferred method when high quality, clean and stronger welds are required. It is highly suited for welding small objects and thin sections of various light weight metals and non-metals [11-13]. The mechanical properties of the welded joints mainly depend on the welding parameters. For a welding joint to be efficient the mechanical properties of welded joints should be maximized and the defects must be minimized. In case of butt-welded joints, misalignment may result in residual bending stresses due to which the strength of weld component is severely affected [13-15]. This may also cause decrement of ultimate strength and fatigue strength. Several studies have been made to investigate the effects of various weld-parameters on fatigue [13-15] and tensile properties [16-18] of welded components. However, little attention has been given to find the effect of notch and test parameters on the mechanical properties of a welded component. A series of experiments have been performed in this work to analyze the effect of these parameters on the tensile properties of welded aluminum alloy. Further, the statistical analysis has been performed using two-way analysis of variance (ANOVA) at 95% confidence level to identify the significance of mechanical testing and notch parameters in effecting the tensile properties.

2. EXPERIMENTAL ANALYSIS

2.1 Material Used

Aluminum alloy employed for the experimental investigation contains 1.12%-Mg, 1.12%-Mn, 0.97%-Fe, 0.96%-Si, 0.31%-Cu, 0.04%-Cr in weight percentage. Table 1 shows the mechanical properties of the used aluminum alloy for different strain rates.

Table 1: Mechanical properties of aluminum alloy.

S. No.	Strain Rate (mm/min)	Yield Strength (σy) (MPa)	Ultimate strength (σult) (MPa)	% Elongation
1.	1	140.578	152.346	15.97
2.	10	147.308	161.907	16.31
3.	100	153.373	158.237	19.74
4.	1000	169.22	171.960	22.42

2.2 Specimen Geometry

TIG-welded butt-joints are made using two 60×30×3.2 mm^3 plates and the corresponding welding parameters are mentioned Table 3. Notches of different dimensions are introduced in the welded specimens on both edges as shown in Figs. 2 and 3. Details of notch parameters such as notch radius (ρ), notch depth (a), notch width (w) and included angle (2α) are listed in Table 2. The gauge length is 100 mm. The welding direction is in the rolling direction of the parent plate. The welds have been obtained at an average speed of 1.57 mm/sec.

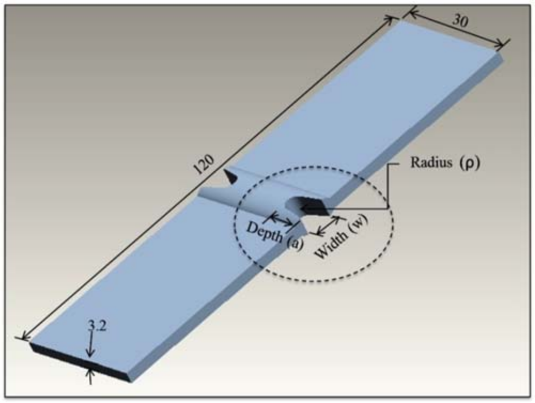
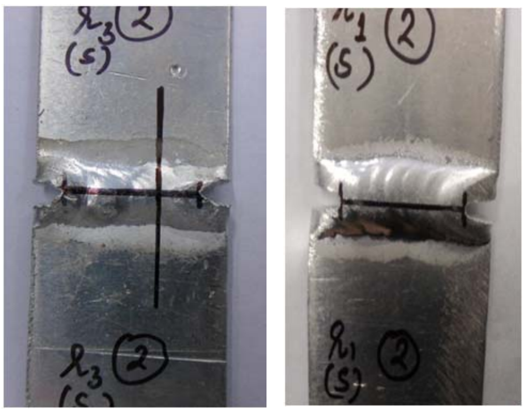
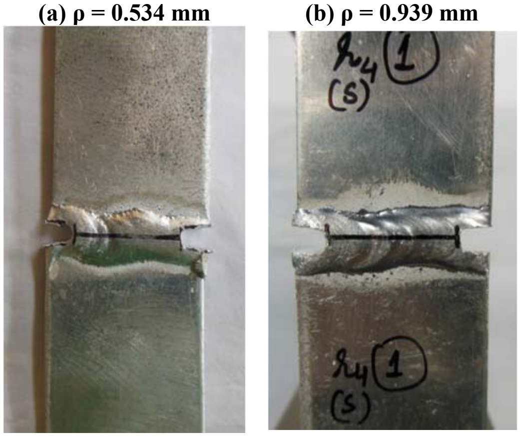


Fig. 2: Geometry of Welded Double Edge Notched Tensile (DENT) specimen (all dimensions are in mm).



(a) ρ = 0.534 mm **(b) ρ = 0.939 mm**



(c) ρ = 1.516 mm **(d) ρ = 1.919 mm**

Fig. 3: Images of Welded Double Edge Notched Tensile (DENT) specimens wit different notch radius.

Table 2: Details of notches in Welded Double Edge Notched Tensile (DENT) specimen.

S. No.	Notch Radius(ρ) (mm)	Notch Width(w) (mm)	Notch Depth(a) (mm)	Included Angle(2α) (deg)
1.	0.534	3.772	5	30o
2.	0.939	2.906	5	16o
3.	1.516	4.005	5	18o
4.	1.919	3.577	5	15o

Table 3: Welding Parameters

<table>
<tr><th>S. No.</th><th colspan="2">Parameters</th><th colspan="2">Details</th></tr>
<tr><td>1.</td><td colspan="2">Current</td><td colspan="2">75-76 A</td></tr>
<tr><td>2.</td><td colspan="2">Voltage</td><td colspan="2">440 V</td></tr>
<tr><td>3.</td><td colspan="2">Pressure</td><td colspan="2">30-33</td></tr>
<tr><td>4.</td><td colspan="2">Gas used</td><td colspan="2">Argon</td></tr>
<tr><td>5.</td><td colspan="2">Welding Time (Average)</td><td colspan="2">19.087 sec</td></tr>
<tr><td rowspan="7">6.</td><td rowspan="7">Filler material used</td><td>Material</td><td colspan="2">Aluminum wire</td></tr>
<tr><td rowspan="4">Name</td><td>AWS510</td><td>ER-4043</td></tr>
<tr><td rowspan="3">IS-5897</td><td>43000</td></tr>
<tr><td>Si 4.5-6.0%</td></tr>
<tr></tr>
<tr><td>Size (Diameter)</td><td colspan="2">3.15 mm</td></tr>
<tr><td>Melting Point</td><td colspan="2">1065o F-1170o F</td></tr>
</table>

3. RESULTS AND DISCUSSION

The uniaxial stress-strain behavior of the welded specimen has been studied on servo-controlled computerized universal testing machine under displacement control loading. The mechanical properties of butt-welded specimens for different strain rates i.e. 1 mm/min, 10 mm/min, 100 mm/min & 1000 mm/min have been determined. For each specimen two set of tests have been performed and the average values of yield strength and ultimate tensile strength have been used for the statistical analysis. At the strain rate of 1 mm/min, the yield strength (σ_{y0}) and ultimate tensile strength (σ_{ult0}) are 47.167 MPa and 106.296 MPa respectively. At 10 mm/min, increase in yield strength by 12.6% and decrease in ultimate strength 1.97% is observed respectively. Increase of the strain rate to 100 mm/min results in an increment of yield strength and ultimate strength by 62.19% and 12.04% respectively as compared to 1 mm/min, and become 76.5 MPa and 119.084 MPa respectively. Finally, for 1000 mm/min, an increment in yield strength (σ_{y0}) and ultimate strength (σ_{ult0}) by 72.8% and 3.29% noticed. All values are compared with respect to the corresponding values at the strain rate of 1 mm/min.

3.1 Effect of Notch Radius and Strain Rate on the Mechanical Properties

To observe the effect of notches on the mechanical properties, U-type notches with different root radii (0.534, 0.939, 1.516 and 1.919 mm) are introduced in the specimen. Each specimen is tested at different strain rate like the un-notched specimens. The stress-strain diagrams of welded DENT specimens of different notch root radius at different strain rates are shown in Fig. 5. The effect of notch radius and strain rate on the values of yield strength and ultimate tensile strength is explained by comparing them with their respective values obtained for the welded specimens (without notch) at 1 mm/min.

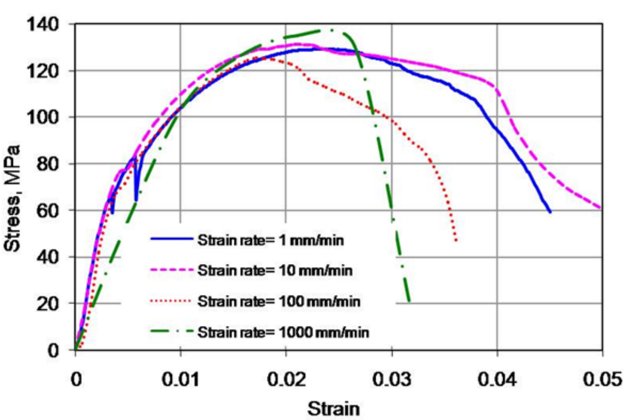
The stress-strain plots for 0.534 mm notch radius are shown in Fig. 4(a). The yield strength at the strain rate of 1 mm/min is 85.166 MPa and ultimate strength is 129.219 MPa. At 10 mm/min and 100 mm/min, yield strength decreases by 8.40%

and 15.97% respectively. The ultimate tensile strength increases by 1.45% and decreases by 2.93% mm/min and 100 mm/min respectively. At 1000 mm/min the yield strength increases by 23.28% and ultimate tensile strength by 4.52% respectively.

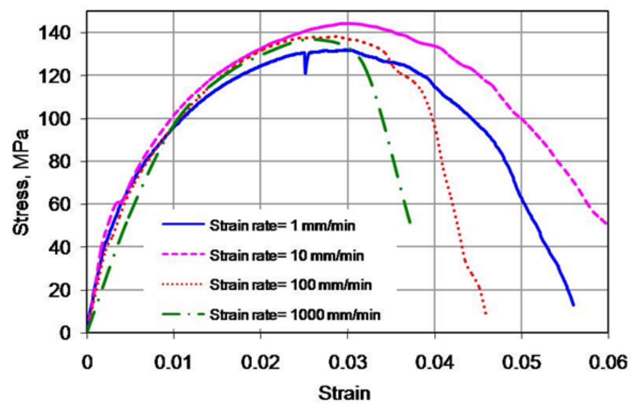
For the notch radius 0.939 mm the stress-strain plot has been shown in Fig. 4(b). The yield strength at 1 mm/min is 72.174 MPa and ultimate tensile strength is 131.915 MPa. At 10 mm/min, yield strength decreases by 3.42% and ultimate tensile strength increases by 9.36%. At 100 mm/min and 1000 mm/min the yield strength (σ_y) increases by 5.26% and 36.35% respectively. The ultimate tensile strength (σ_{ult}) increases by 4.8% (138.235 MPa) and 3.62% (136.679 MPa) at 100 mm/min and 1000 mm/min respectively.

The stress-strain plot for notch radius of 1.516 mm is plotted in Fig. 4(c). The yield strength and ultimate tensile strength is 92.66 MPa and 139.483 MPa at 1 mm/min. At 10 mm/min, the yield strength decreases by 0.56% and becomes 92.149 MPa and the ultimate tensile strength increases by 5.11% and becomes 146.599 MPa. At 100 mm/min and 1000 mm/min the yield strength increases by 1.17% and 47.47% respectively and ultimate tensile strength increases by 6.09% and 9.73% respectively. All comparisons are with respect to the values at 1 mm/ min of the notched geometry.

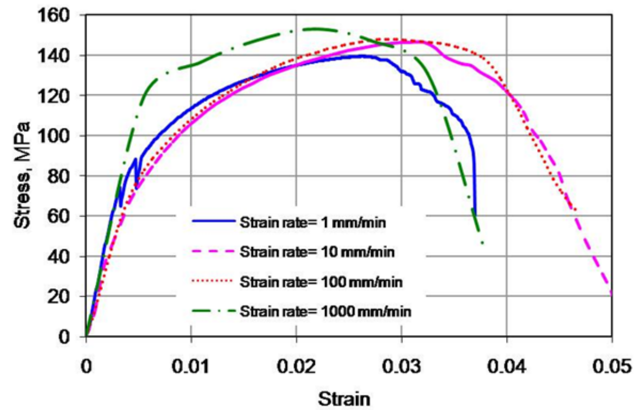
For 1.919 mm notch radius, at 1mm/min the yield strength is 77.755 MPa and ultimate tensile strength is 141.699 MPa. At 10 mm/min, 100 mm/min and 1000 mm/min, the value of yield strength increases by 10.86% (86.196 MPa), 2.41% (79.625 MPa) and 40.83% (109.5 MPa) respectively. The ultimate tensile strength increases by 7.94% (152.941 MPa) at 10 mm/min and decreases by 4.24% (135.693 MPa) and 11.38% (125.588 MPa) at 100 mm/min and 1000 mm/min.



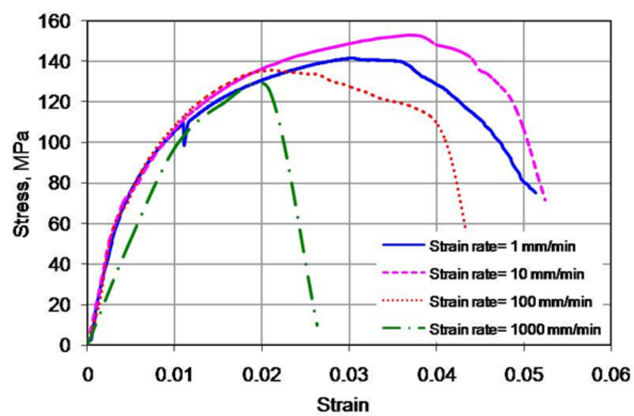
(a) ρ = 0.534



(b) ρ = 0.939 mm



(c) ρ = 1.516 mm



(d) ρ = 1.919 mm

Fig. 4: Stress-Strain behavior for TIG-welded aluminum alloy specimens with different notches.

4. STATISTICAL ANALYSIS

The results obtained in the current work show that the yield strength and ultimate tensile strength of welded DENT plate of aluminum alloy is significantly affected by the notch radius and strain rate. To validate, a statistical analysis based on two way analysis of variance (ANOVA) has been carried out. Analysis of Variance (ANOVA) has been performed at 95% confidence level to identify the significance of each variable in effecting the tensile properties.

4.1 Two way Analysis of Variance (ANOVA) for Yield Strength

F-test is performed to analyze the significant effects of the parameters (strain rate and notch radius) on the yield strength. Table 4 shows the results of two-way ANOVA for yield strength. Only two replications from minimum and maximum values of yield strength out of five test results have been used. The analysis is carried out for a level of significance of 5% i.e. 95% level of confidence. It can be observed that the critical F-value for yield strength is less than the calculated F-value ($F_{0.05,3,16} < F_{calculated}$) and hence there is a significant influence of strain rates and notch radii on the value of yield strength. This is also confirmed from the value of Prob>F, as the Prob>F value is near zero, this casts doubt on the null hypothesis. Smaller value indicates that the sample mean are significantly different and hence there is a noteworthy effect of the concerned factor. In general, if Prob>F value is less than 0.05 it is statistically significant. The value of 'P' shows the percentage contribution of the influence of each factor on the yield strength. Table 4 indicates that contribution of strain rate is 61.78% followed by 28.21% contribution of the notch radius. Though the effect of the interaction of strain rate and notch root radius is significant, but the percentage contribution is only 7.5%. Hence strain rate is the main parameter which has the maximum influence on the value of yield strength followed by the notch radius. However, they both together have the least influence on the yield strength.

Table 4: Results of ANOVA for Yield Strength.

	SS	DF	MS	F	Fcritical	Prob>F	P(%)	Remarks
Strain rate (mm/min)	5620.75	3	1873.58	131.46	3.24	0	61.78	S
Notch radius (mm)	2566.99	3	855.66	11.29	3.24	0.00032	28.21	S
Interaction	682.10	9	75.79	5.32	2.54	0.0019	7.50	S
Error	228.04	16	14.25				2.51	
Total	9097.87	31					100	

4.2 Two way Analysis of Variance (ANOVA) for Ultimate Tensile Strength

From the results of two-way ANOVA for ultimate strength shown in Table 5, it is observed that all critical F-values at 95% level of confidence are less than the calculated F-value ($F_{0.05,3,16} < F_{calculated}$). There is a significant effect of strain rate and notch radius on the ultimate tensile strength. This also confirms from the Prob>F values shown in Table 5. The percentage contribution of each factor on the ultimate tensile strength is given as 'P'. The contribution of strain rate, notch radius and interaction of both is 12.41%, 43.49% and 36.09%.

Table 5: Results of ANOVA for Ultimate Tensile Strength.

	SS	DF	MS	F	Fcritical	Prob>F	P(%)	Remarks
Strain rate (mm/min)	315.14	3	105.05	8.26	3.24	0.0015	12.41	S
Notch radius (mm)	1104.67	3	368.22	3.62	3.24	0.0363	43.49	S
Interaction	916.48	9	101.83	8.01	2.54	0.00019	36.09	S
Error	203.38	16	12.71				8.01	
Total	2539.67	31					100	

5. CONCLUSION

The effect of notches and strain rate on the yield strength and ultimate tensile strength of TIG welded components has been investigated in this work. It was seen that the yield strength and ultimate strength decreases on increasing the strain rate up to 100 mm/min. The analysis of variance (ANOVA) has been performed at 95% confidence level to identify the significance of strain rate and notch radius in effecting the tensile properties. F-test has been utilized in statistics to analyze the measure of the significant effects of the parameters (strain rate and notch root radius). This study indicates that the strain rate is the main parameter which has the highest influence on the tensile properties of the welded components with notch.

REFERENCES

[1] Canyurt O E, *Int J Mech Sci* 47 (2005) 1249.

[2] Xiao Z G, Chen T, and Zhao X L, *Int J Fatigue* 38 (2012) 57.

[3] Bruder T, Störzel K, Baumgartner J, and Hanselka H, *Int J Fatigue* 34 (2012) 86.

[4] Selvamani S T, and Palanikumar K, *Measurement* 53 (2014) 10.

[5] Imam M, Biswas K, and Racherla V, *Mater Des* 44 (2013) 23.

[6] Threadgill P L, Leonard A J, Shercliff H R, and Withers P J, *Int Mater Rev* 54 (2009) 49.

[7] Topic I, Höppel H W, and Göken M, *Mater Sci Eng A* 503 (2009) 163.

[8] Florea R S, Bammann D J, Yeldell A, Solanki K N, and Hammi Y, *Mater Des* 45 (2013) 456.

[9] Morgenstern C, Sonsino C M, Hobbacher A, and Sorbo F, *Int J Fatigue* 28 (2006) 881.

[10] Kumar A, and Sundarrajan S, *Mater Des* 30 (2009) 1288.

[11] Borrisutth R, Mitsomwang P, Rattanacha S, and Mutoh Y, *Energy Res J* 1 (2010) 82.

[12] Branco C M, Maddox S J, Infante V, and Gomes E C, *Int J Fatigue* 21 (1999) 587.

[13] Lillemäe I, Lammi H, Molter L, and Remes H, *Int J Fatigue* 44 (2012) 98.

[14] Nguyen N T, and Wahab M A, *Eng Fract Mech* 55 (1996) 453.

[15] Cui W, Wan Z, and Mansour A E, *J Constr Steel Res* 52 (1999) 159.

[16] Rajakumar S, Muralidharan C, and Balasubramanian V, *Mater Des* 32 (2011) 2878.

[17] Lakshminarayanan A K, Balasubramanian V, and Elangovan K, *Int J Adv Manuf Technol* 40 (2009) 286.

[18] Rajakumar S, Muralidharan C, and Balasubramanian V, *Trans Nonferrous Met Soc China* 20 (2010) 1863.