Optimization of Friction Stir Welding Parameters for Joining Aluminum Pipes Using Regression Analysis

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Abstract— *Friction stir welding was a promising welding technology from the same moment of its existence because of its easy use, being ecologically friendly processed and with no need for filler metal. The present paper discusses the investigate the mechanical properties in order to demonstrate the feasibility of friction stir welding for joining Al 6061 aluminum alloy welding was performed on pipe. The pipe sections, 30mm, and relatively thin walled 2, 3 and 4 mm. Wire welded as similar alloy joints using (FSW) process In order to investigate the effect of rotation speed 485,710, 910, 1120,1400 and 1800 RPM and travel speeds 4, 8 and 10 mm/min. On mechanical propertie.*

This work also focuses on mathematic models such as regression analysis (RA) to predict the tensile strength, the percentage of elongation and hardness of friction stir welded 6061 aluminum alloy. The Tensile strength, the percentage of elongation and hardness of weld joints were predicted by taking the parameters Tool rotation speed, material thickness and travel speed as a function. The results obtained through regresion analysis The models have been proved to be successful in terms of agreement with experimental results ratio 94.6%.

Keywords— Friction stir welding, Aluminum pipe, Regression analysis.

I. INTRODUCTION

Developed by The Welding Institute (TWI) [1] the Friction Stir Welding (FSW) process was invented and patented in 1991 meaning that in terms of a manufacturing process it is a relatively new one. FSW is a modification on an already known method of joining metal via frictional heating known simply as Friction welding.

Friction welding (FW), , is a joining process which has been in development for more than 100 years. This form of joining is most suited to material which is in rod or pipe form. It involves rotating or oscillating one rod whilst keeping the other stationary. The two are brought together and friction results. This in turn causes heat. Once sufficient heat has been generated the two rods are pushed together with a force which forges the two rod sections together. The excess extruded material from the circumference of the join can then be removed leaving a welded section[2].

In FSW the heat is generated by a non-consumable tool which is rotated at high speed, plunged into and traversed through the material creating a join at the rear of the tool. The forging force in this case is the downwards force exerted by the spindle. The friction stir welding process is a simple one by its nature. It uses simple technology to produce state-of-the-art joins in previously difficult to weld or un-weldable materials [6]. A simple breakdown of the processing steps result in: Material positioning, tool plunge, tooling traverse and pull out/run off, these stages will be described in detail below.

The advantage of hydroforming of FSW tubes is the tailoring of the starting materials that can vary in thickness and/or composition to optimize weight or performance. This tailoring is typically carried out in stamping by welding sheets of different thickness together. The blank is then stretch formed and drawn, resulting in a part with optimized weight [3-6]. Recently, more, attempts have been made to weld dissimilar aluminum alloys, which ultimately could provide flexibility in design as well as optimize strength, weight, and corrosion resistance [7-9]. To date, no work has been reported on the welding of tailor welded tubes for hydroforming

The mechanical properties in order to demonstrate the feasibility of friction stir welding for joining Al 6061 aluminum alloy welding was performed on pipe with different thickness 2 ,3 and 4mm, five rotational speeds (485,710,910,1120,1400 and1800) RPM and a travel speed (4,8 and 10) mm/min was applied. This work focuses on regresion analysis to predict the tensile strength, the percentage of elongation and hardness of friction stir welded 6061 aluminum alloy.

The tensile strength, the percentage of elongation and hardness of weld joints were predicted by taking the parameters tool rotation speed, material thickness and travel speed as a function

II. HEXPERMINTAL WORK

Material: The chemical composition and mechanical properties of Al 6061 aluminum pipe parts used in the present study as delivered by the Miser Aluminum company are given in Tables (1-2).

Table (1) Chemical composition (weight %) of Al 6061 aluminum pipe

Weight %	Al	Si	Fe	Cu	Min	Mg	Cr	Zn	Ti
6061	Ball	0.6	0.70	0.2	0.15	0.80	0.33	0.23	0.12

Table (2) the mechanical properties of Al 6061 aluminum pipe

Alloy	Ultimate Tensile Strength σ_{UTS} M pa	Elongation EL%	Hardness VHD
6061	252.690	8	86

Design and constructed

Setup friction stir welding: constructed apparatus is mounted on the drilling press machine bed to the two work pieces of the studied materials which will be welded by friction stir welding technique, Fig. (1). Showing Illustration, Drawing and Construction Setup friction stir welding for pipe parts

Fig.1: Friction stir welding machine

Tensile Testing:

Tensile testing, also known as tension testing, is a fundamental material science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength (UTS), maximum elongation (EL %).

Vickers Hardness Testing:

The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure. The HV number is then determined by the ratio *F/A* where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimeters.

III. RESULT AND DISCUSSION

Visual inspection of the upper (external surface of welded specimens) showed uniform semicircular surface ripples, caused by the final sweep of the trailing edge of rotating tool shoulder over weld nugget, under the effect of probe overhead pressure. The presence of such surface ripples, known as onion rings. Fig. (2-3) shows the surface appearances of the weld the interface between the crystallized nugget zone and the parent metal is relatively diffuse on the retreating side of the tool, but quite sharp on the advancing side of the tool.

Fig. 2: Exit Pin

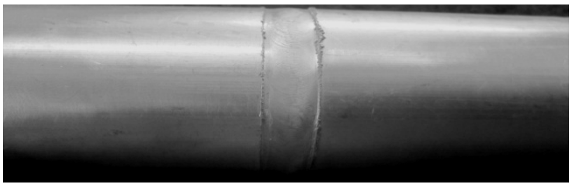

Fig. 3: Finished pipe

Tensile Test Results

The quality of the welds was assessed based on tensile tests, Tensile tests were performed on the base metal and welded specimens, Transverse tensile properties such as tensile strength, percentage of elongation and joint efficiency of the FSW joints have been evaluated. At each condition three specimens are tested and average of the results of three specimens was measured, it can be Inferred that the rotational speed and thickness are having an influence on tensile properties of the FSW joints show in Fig. (4-6).

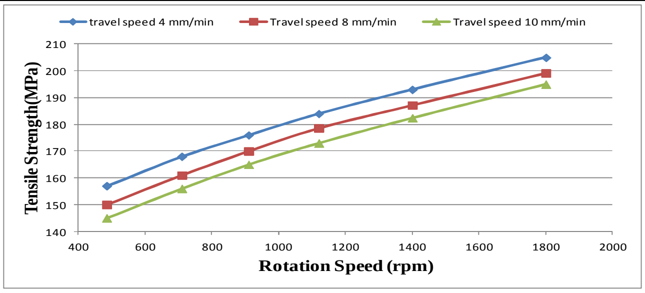

Fig.4: Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 2mm)

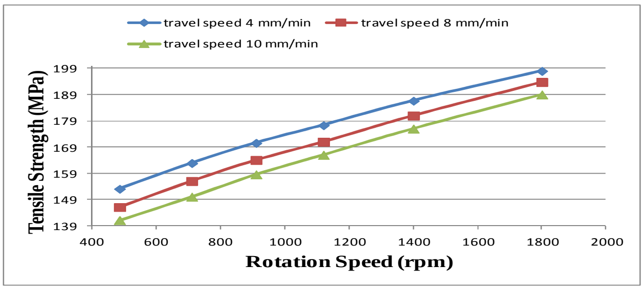

Fig.5: Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 3mm)

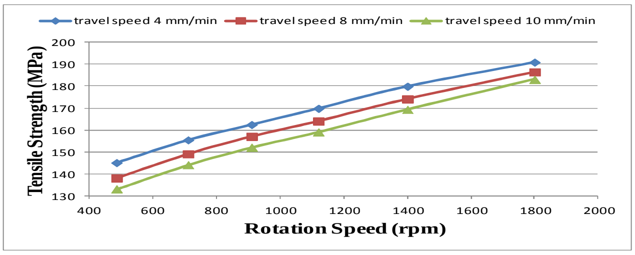

Fig.6: Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 4mm)

Elongation Results

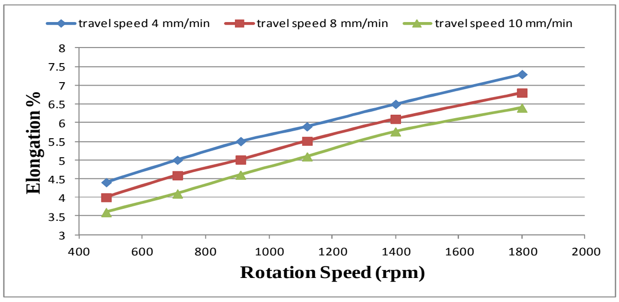

Fig. 7: Relation between elongation and speed of Al 6061 (at thickness 2mm)

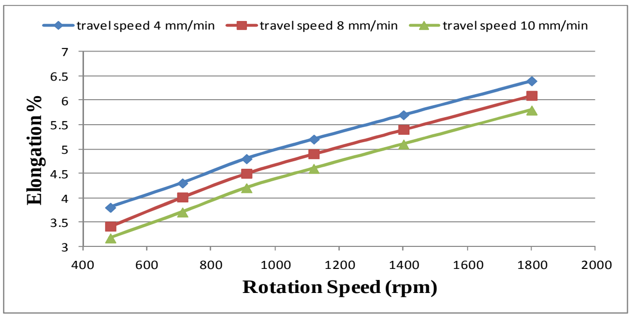

Fig. 8: Relation between elongation and speed of Al 6061 (at thickness 3mm)

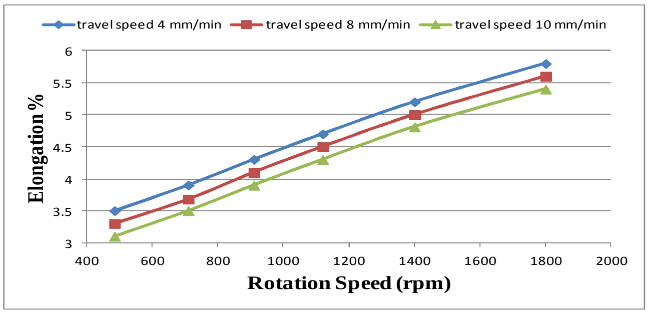

Fig.7: Relation between elongation and speed of Al 6061 (at thickness 4mm)

Hardness Results

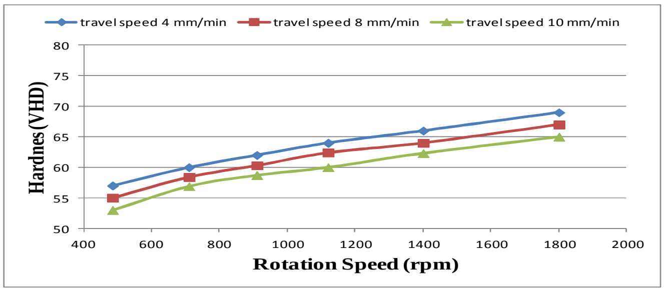

Fig. 10: Relation between hardness and speed of Al 6061 (at thickness 2mm)

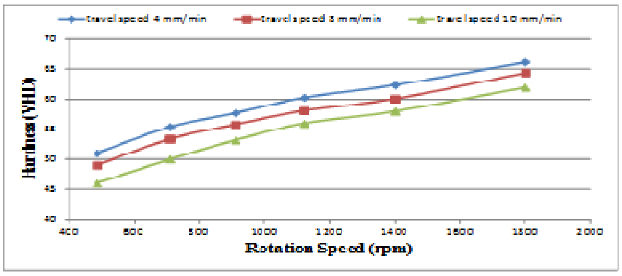

Fig. 11: Relation between hardness and speed of Al 6061 (at thickness 2mm)

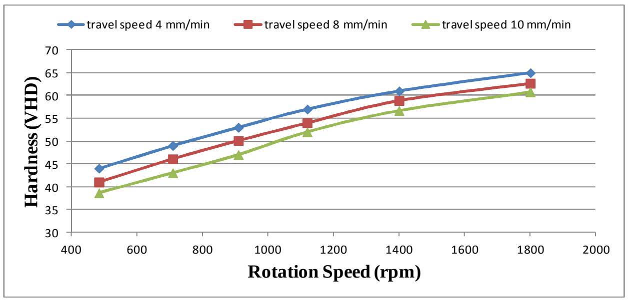

Fig. 12: Relation between hardness and speed of Al 6061 (at thickness 2mm)

The joints fabricated at high rotational speed (1800rpm) exhibited superior tensile properties compared to other joints. Similarly, the joints fabricated with high material thickness are showing a good tensile properties comparable to that of a less material thickness see fig. See fig. (7-9)

Hardness measurement of the joints

Hardness measurement was taken across the BM, HAZ and NZ, For FSW specimens it can be Inferred that the decrease in hardness at weld centerline increases by increasing the rotational speed. Such observation could be understood in the light of relative increase in the degree of plastic deformation an frictional heat generate at higher rotational speeds, which effect the dynamic crystallization as well as the dynamic recovery at the TMAZ . In general, the Hardness decreases from the base metal towards the weld centerline show in fig (10-12).

IV. MATHEMTICAL MODLING

Regression analysis

The tensile strength of the joints is the function of rotational speed, welding speed, and axial force and it can be expressed as

$$Y = f(N, T, F)$$

Where

Y-The response.

N- Rotational speed (RPM).

T- material thickness,.

F – travel speed (mm/min).

For the three factors, the selected polynomial (regression) could be expressed as

$$Y = k + aN + bT + cF$$

Where k is the free term of the regression equation, the coefficients a, b, and c are linear terms [12-18]

Table (3): Estimated regression coefficients of mathematical models (Al 6061)

Regression Coefficients	Tensile Strength	Elongation%	Hardness
k	160	5	62
A	0.036	0.001	0.009
B	7.05	0.542	3.67
C	-1.44	-0.067	0.604

MINITAB 15 Software Packages are used to calculate the values of these coefficients for different responses. After determining the coefficients, the mathematical models are developed. The developed final mathematical model equations in the coded form are given below:

Tensile strength = 160 + 0.0364 (N) -7.05 (T) - 1.44 (F)

Elongation % = 5 - 0.001 (N) + 0.542 (T) + 0.067 (F)

Hardness(VH) = 62 + 0.0099 (N) - 3. 67 (T) - 0.604 (F)

The validity of regression models developed is tested by drawing scatter diagrams. Typical scatter diagrams for all the models are presented in Fig. (13-15). The observed values and predicted values of the responses are scattered close to the 45° line, indicating an almost perfect fit of the developed empirical models.

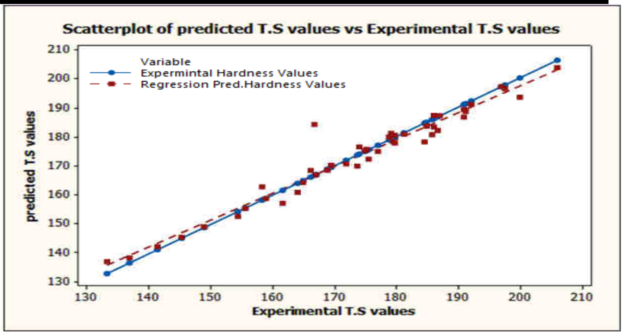

Fig. 13: Relation between experimental tensile strength and predicted tensile strength

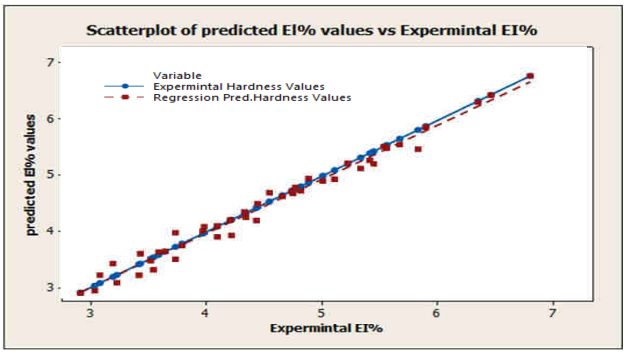

Fig. 14: Relation between experimental elongation% and predicted elongation%

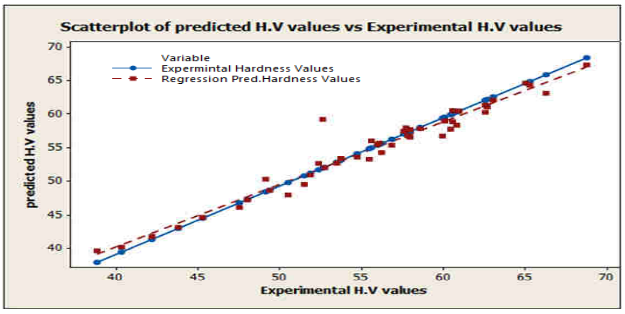

Fig.15: Relation between experimental hardness and predicted hardness

V. CONCLUSION

1. The FSW weld efficiency increase with increase rotation speed and decrease travel speed.
2. The FSW efficiency increases with decrease the material thickness.
3. The joint efficiency of FS welded(ratio of ultimate tensile strength of welded joint to that of the base material was found 80 , 78% and 76% for 6061 at thickness 2,3and 4mm.
4. The hardness values decrease gradually across the weld, with the minimum hardness value in the weld center or weld nugget.
5. A regression analysis model has been developed for the prediction of tensile strength and hardness as a function of rotation speed, material thickness and travel speed. The models have been proved to be

successful in terms of agreement with experimental results ratio 94.6% .

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