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MECHANICAL PROPERTIES OF FRICTION STIR WELDED ALUMINIUM ALLOY PIPES

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ABSTRACT: *Friction stir welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follows: joining of conventionally non-fusion weldable alloys, reduced distortion and improved mechanical properties of weldable alloys joints due to the pure solid-state joining of metals. This work presents a systematic approach to develop the mathematical model by three methods such as artificial neural networks using software, Response surface methodology (RSM) and regression Analysis for predicting the ultimate tensile strength, percentage of elongation and hardness of 6061 aluminum alloy which is widely used in automotive, aircraft and defense Industries by incorporating (FSW) friction stir welding process parameter such as tool rotational speed, welding speed and material thickness. The results obtained through regression analysis and response surface methodology were compared with those through artificial neural networks.*

KEYWORDS: Friction stir welding, Aluminum pipe, Regression analysis, Response surface methodology, artificial neural network

INTRODUCTION

The Aluminum and its alloys are increasingly used in many important manufacturing areas, such as the automobile industry, aeronautic and military, because of their low-density and good mechanical properties, however, the welding of aluminum and its alloys has always represented a great challenge for designers and technologists [1].Many difficulties are associated with this kind of joint process. It is obvious that serious problems, such as tenacious oxide layer cavities, hot cracking sensitivity, and porosity, may occur when fusion welding is applied to aluminum and its alloys. Moreover, the conventional techniques, such as fusion welding, often lead to significant strength deterioration in the joint because of a dendritic structure formed in the fusion zone [2].

The joining of aluminum alloys, especially those which are difficult to weld, has been the initial target for developing and judging the performance of (FSW). Friction stir welding, a process invented at TWI, Cambridge, involves the joining of metal without fusion or filler materials. It is used already in routine, as critical applications, for the joining of structural components made of aluminum and its alloys. Indeed, it has been convincingly demonstrated that the process results in strong and ductile joints, sometimes which in systems have proved difficult using conventional welding techniques [3-5]. The process most suitable for components which are flat and long (plates and sheets) but can be adapted for pipes, hollow sections and positional welding. The welds are created by the combined action of frictional heating and

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mechanical deformation due to a rotating tool. The maximum temperature reached is of the order of 0.8 of the melting temperature [6].

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 two methods such as artificial neural networks (ANN) using software (Pythia) and response surface methodology (RSM) to predict the tensile strength, the percentage of elongation and hardness of friction stir welded 6061 aluminum alloy. An artificial neural network (ANN) model was developed for the analysis of the friction stir welding parameters of Al 6061aluminum pipe.

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. A comparison was made between measured and predicted data. Response surface methodology (RSM) also developed and the values obtained for the response Tensile strengths, the percentage of elongation and hardness are compared with measured values. The effect of FSW process parameter on mechanical properties of 6061 aluminum alloy has been analyzed in detail [7].

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

Allo y	Ultimate Tensile Strength σ_{UTS} M pa	Elonga tion EL%	Hardness VHD
6061	252.690	8	86

Tool design

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is desirable that the tool material is high carbon steel, sufficiently strong, tough and hardwearing, at the welding temperature. [8]. The tool pin penetration depth was suggested to be at least about 90% of the work piece thickness. We used two tools with flat shoulder, Tools was fixed on the spindle of the drilling. In present study the tool length (L) (2,3and4mm), were50mm, and two different pin length pin diameter (d) 1mmandshoulder Diameter (D) (10mm) .

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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.

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.

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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).

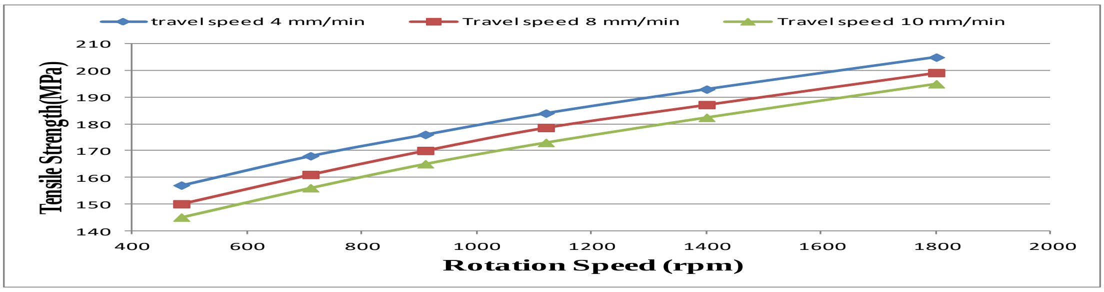

Fig. (4) Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 2mm)

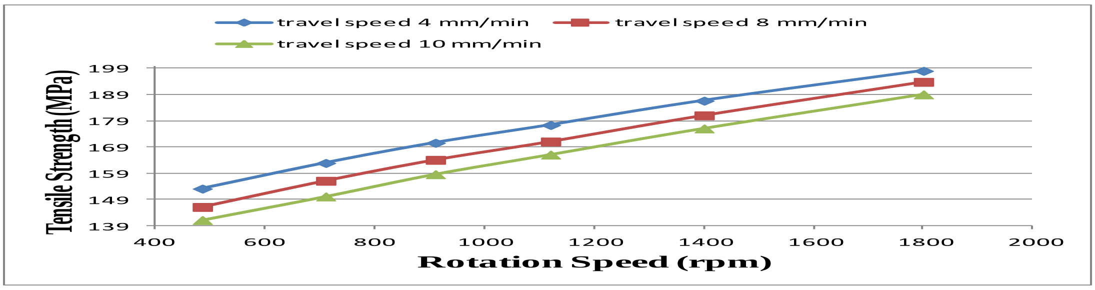

Fig. (5) Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 3mm)

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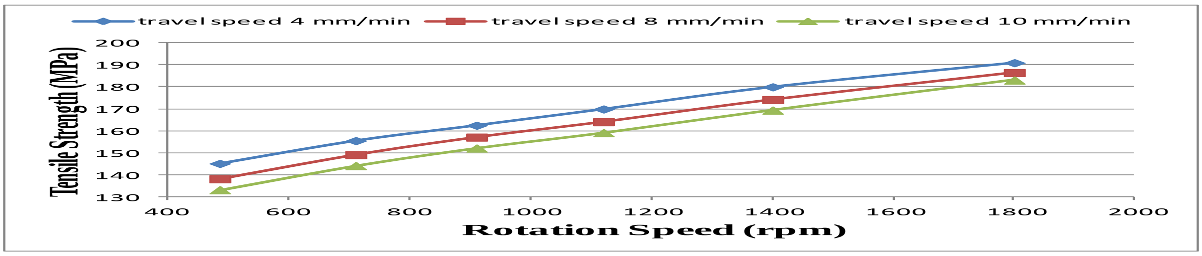

Fig. (6) Relation between ultimate tensile strength and rotational speed of Al6061 (at thickness 4mm)

Elongation Results

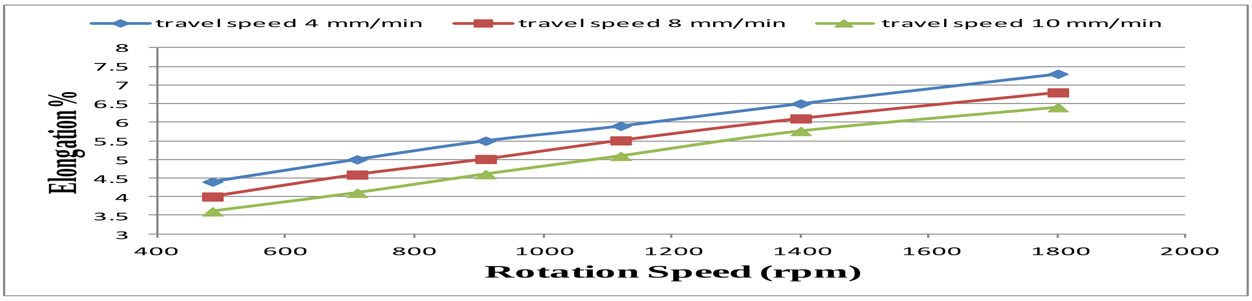

Fig. (7) Relation between elongation and speed of Al 6061 (at thickness 2mm)

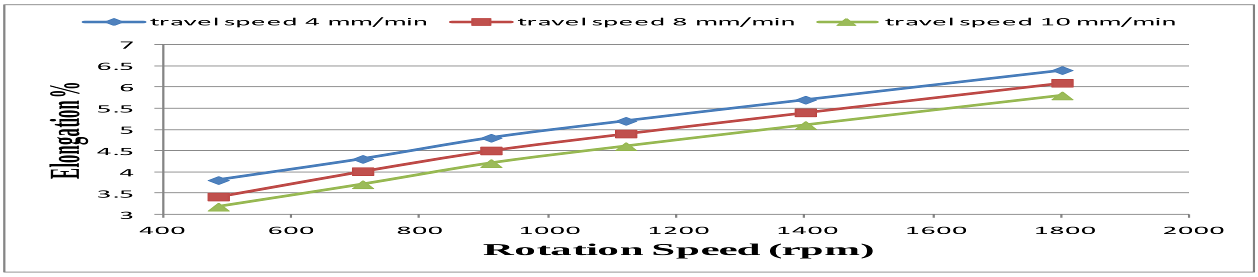

Fig. (8) Relation between elongation and speed of Al 6061 (at thickness 3mm)

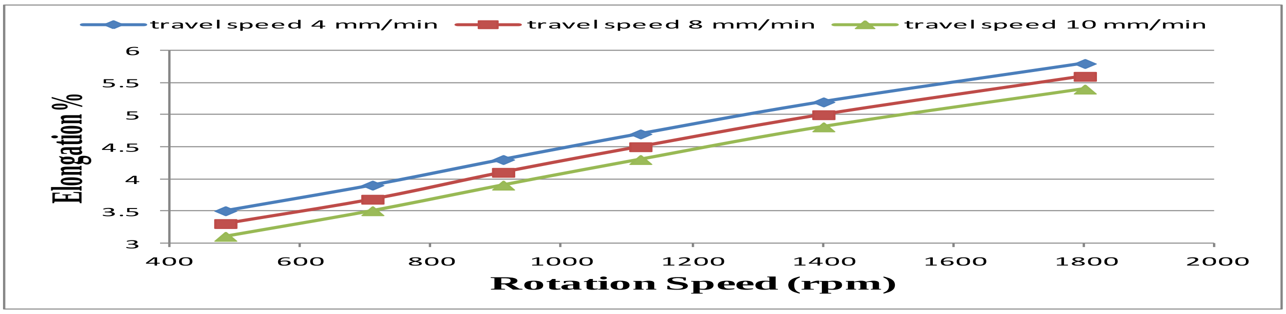

Fig. (7) Relation between elongation and speed of Al 6061 (at thickness 4mm)

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Hardness Results

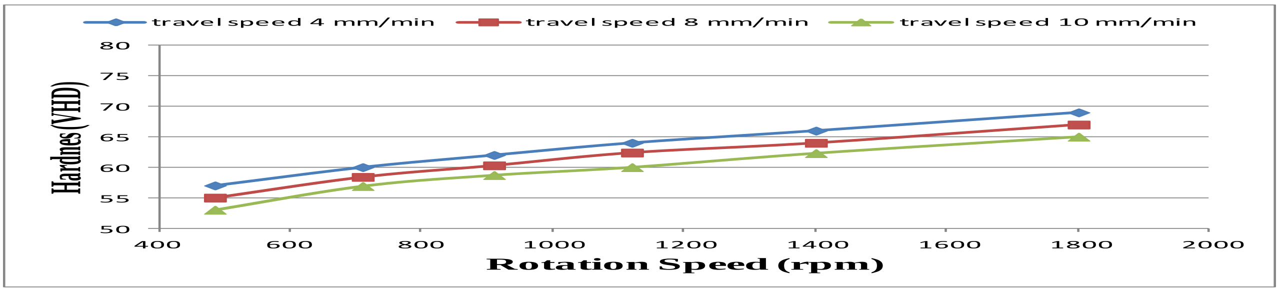

Fig. (10) Relation between hardness and speed of Al 6061 (at thickness 2mm)

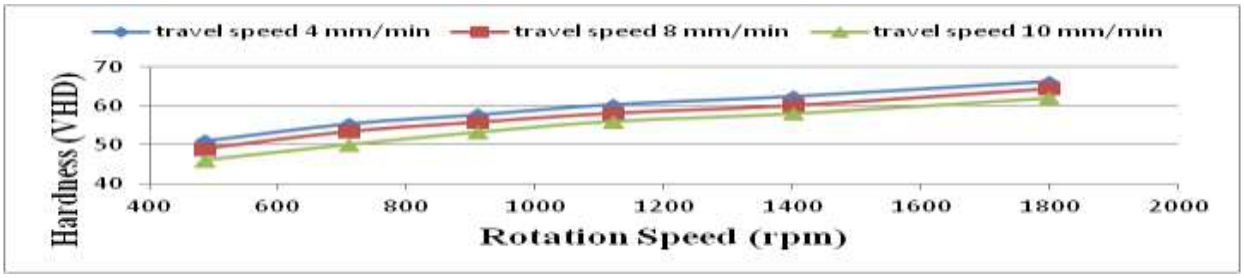

Fig. (11) Relation between hardness and speed of Al 6061 (at thickness 2mm)

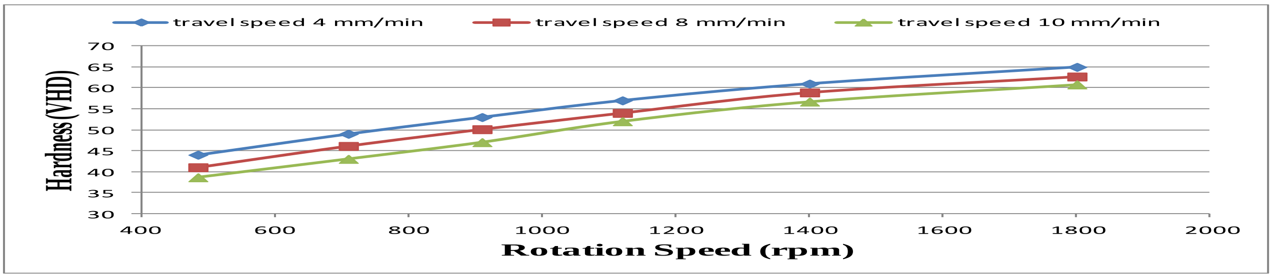

Fig. (12) Relation between hardness and speed of Al 6061 (at thickness 2mm)

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).

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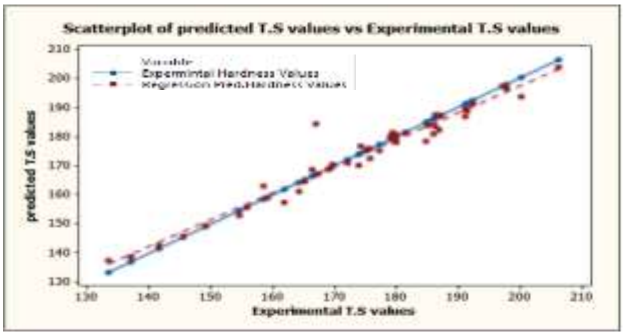
MATHEMTICAL MODLING



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 [11]

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

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responses are scattered close to the 45° line, indicating an almost perfect fit of the developed empirical models [9-10].

Fig. (13) Relation between experimental tensile strength and predicted tensile strength

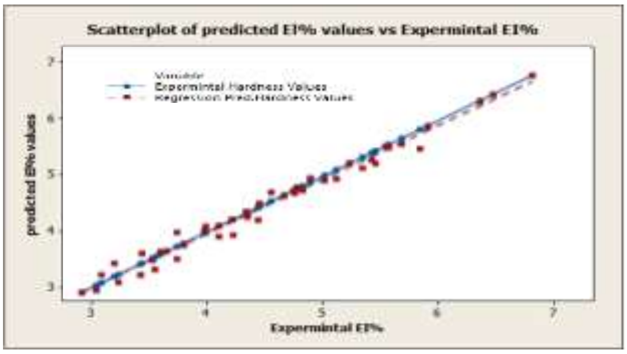

Fig. (14) Relation between experimental elongation% and predicted elongation%

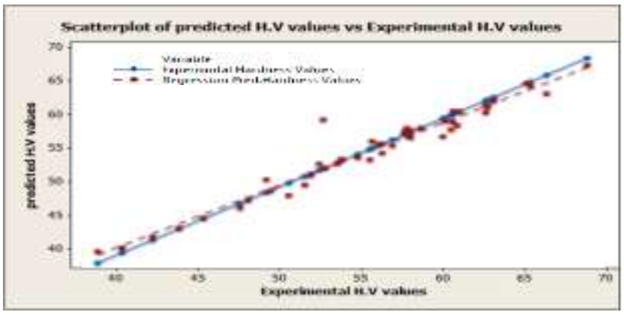

Fig. (15) Relation between experimental hardness and predicted hardness

Response surface methodology

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

$Y = K+ aN + bT + cF + a^2N^2 + b^2T^2 + c^2F^2+ + abNT + ac\ NF +bc\ TF$

Where k is the free term of the regression equation, the coefficients a, b, and c are linear terms [11-13]

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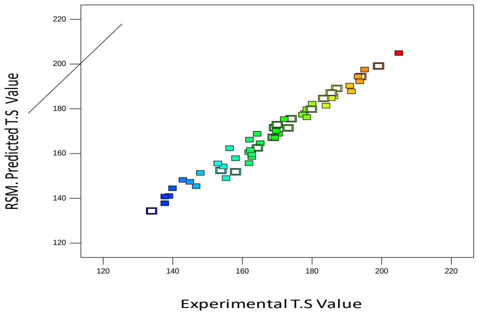
Coefficients	Tensile Strength	Elongation %	Hardness
b_0	141.5	3.7	+50.44
b_1	0.06	3.78E-003	0.02
b_2	8.26	0.672	5.1
b_3	0.64	0.04	0.5
b_{11}	1.2E-005	4.09E-007	1.08E-005
b_{22}	0.07	0.05	0.49
b_{33}	0.15	8.44E-00	0.0917
b_{12}	-8.5E-06	-2.0E-004	3.19E-003
b_{13}	2.7E-004	5.8	1.80E-004
b_{23}	+0.13	+0.01	0.92



Design-Expert 6.0.8 Software Packages is used to calculate the values of these coefficients for different responses and is presented in Table 4. After determining the coefficients, the mathematical models are developed see Fig.16-19. The developed final mathematical model equations in the coded form are given below:

Tensile strength (MPa) = 141.5+0.06N -8.26 T +0.64F -1.20E-005N^2 +0.07T^2 -0.15F^2 -8.5E-006NT -2.7E-004NF +0.13TF

Elongation%% =**3.7**+3.78E-003**N** -0.672 **T** +0.04**F** -4.09E-007$\mathbf{N^2}$ +0.05$\mathbf{T^2}$-8.44E-003 $\mathbf{F^2}$ -2.0E-004**NT** **+5.8NF** +0.01**TF**

Hardness(VHD) =**50.4+**+0.02**N --**5.1 **T** +0.5**F -** -1.08E-005$\mathbf{N^2}$ -0.49$\mathbf{T^2}$**-** 0.0917$\mathbf{F^2}$ **-**+3.19E-003**NT** -1.80E-004**NF - 0.92TF**

Table captions appear centered above the table in upper and lower case letters. When referring to a table in the text, no abbreviation is used and "Table" is capitalized.

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Fig. (16) Relation between experimental tensile strength and predicted tensile strength

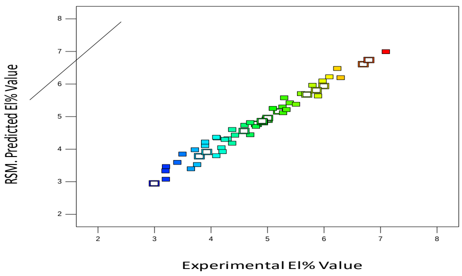


Fig. (17) Relation between experimental elongation% and predicted elongation%

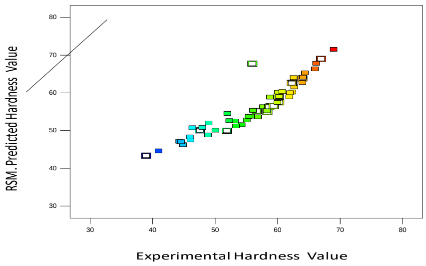
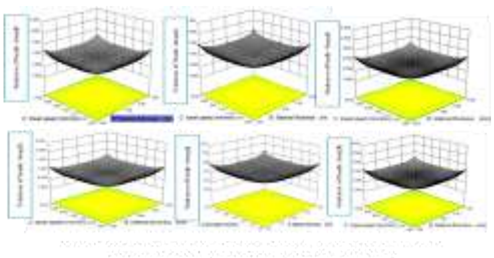


Fig. (18) Relation between experimental hardness and predicted hardness



Fig(19)Relation between stander errors of tensile strength, travel speed and material thickness of Al6061 (At rotational speeds 485- 1800 RPM)

Artificial Neural Network (ANN)

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. Artificial neural network (ANNs), like people, learns by example. An artificial neural network (ANN) is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons [14-16]. In this study, software (pythia) Neural Network is used with a single hidden layer

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improved with numerical optimization techniques. The topology architecture of feed-forward three-layered back propagation neural network is illustrated in Fig. 20 below.

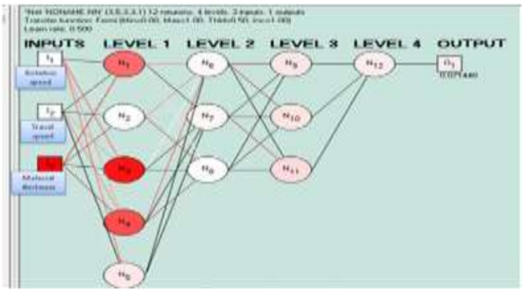

Fig. (20) Propagation artificial neural network

equation is calculated as

$O_n = F(\Sigma I_k * W_{kn})$

O_n is the neuron's output, n is the number of the neuron,

I_k are the neurons inputs, k is the number of inputs,

W_{kn} are the neurons weights.

F is the Fermi function 1/(1+Exp(-4*(x-0.5)))

Software (pythia) has been used for training the network model for tensile strength, the percentage of elongation and hardness prediction. The neural network described in this paper, after successful training, will be used to predict the tensile strength of friction stir welded joints of 6061 aluminum alloy within the trained range.

The results obtained after training and testing O_n artificial neural networks are shown in the Fig.(21-23)

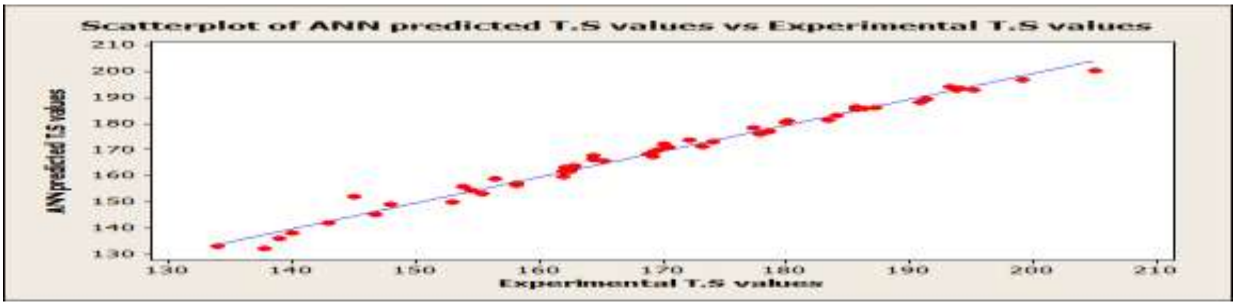

Fig. (21) Relation between experimental tensile strength and predicted tensile strength

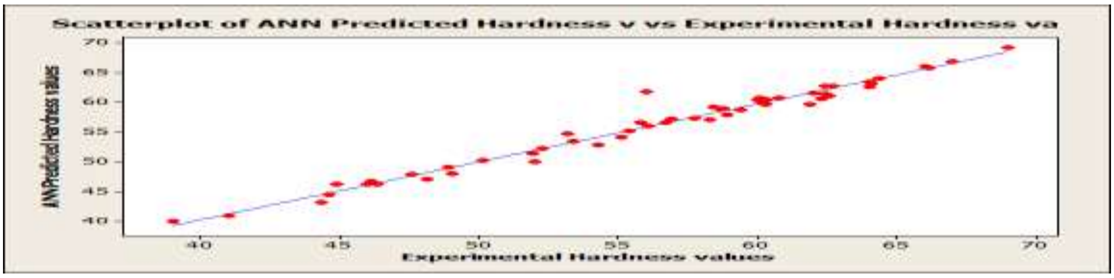

Fig. (22) Relation between experimental elongation% and predicted elongation%

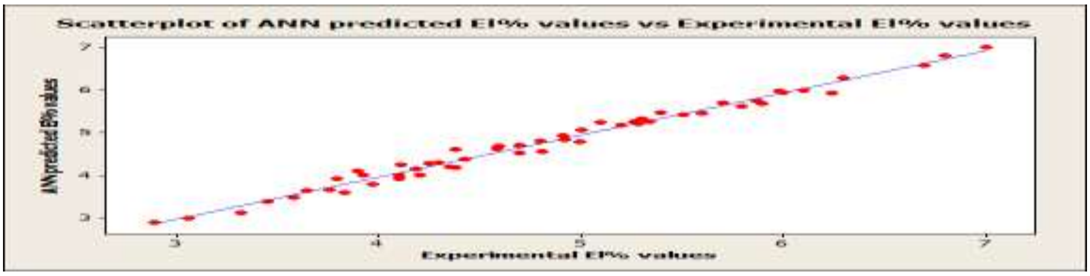

Fig. (23) Relation between experimental hardness and predicted hardness

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The comparative between response surface methodology, regression analysis and artificial neural network for ultimate tensile strength, the present elongation% and nugget hardness are presented in Fig (18-20).

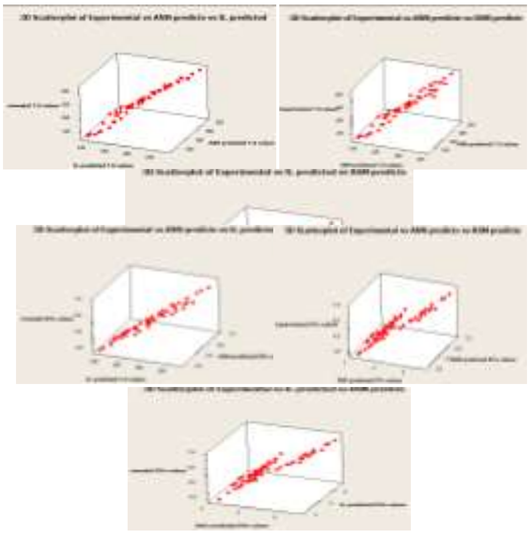

Fig. (24) Relation between tensile test measurement and tensile tests predicted (response surface methodology, regression analysis , artificial neural network)

Fig. (25) Relation between elongation measurement and elongation predicted (Response surface methodology, regression analysis, artificial neural network)

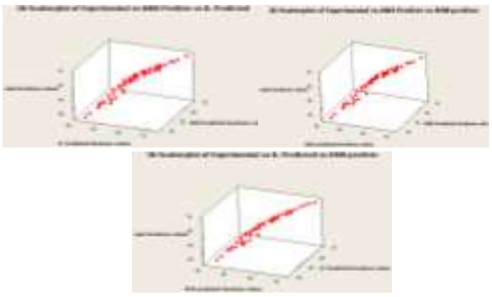

Fig. (26) relation between hardness measurement and hardness predicted (Response surface methodology, regression analysis, artificial neural network)

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.

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5. . A regression analysis model and response surface methodology 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 respectively 94.6% and 90%.

6. ANN model has been developed for the prediction of tensile strength and hardness as a function of rotation speed, material thickness and travel speed. The model has been proved to be successful in terms of agreement with experimental results ratio 96.5%.

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