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Integration between Artificial Neural Network and Responses Surfaces Methodology for Modeling of Friction Stir welding

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ABSTRACT

The objective of this work was to 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 with different thickness 2 ,3 and 4mm,five rotational speeds (485,710,910,1120 and1400) RPM and a traverse 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

Keywords - Friction stir welding, Aluminum pipe, Response surface methodology, artificial neural network

I. INTRODUCTION

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]. 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 The Welding Institute (TWI) [2], 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 processes 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 mechanical deformation due to a rotating tool. The maximum temperature reached is of the order of 0.8 of the melting temperature [6].

A large number of research papers are available in the literature on various aspects of friction stir welded aluminum alloy such material flow, development of microstructure and mechanical properties in friction stir welding for plates and sheets, but the research papers that done in cylindrical parts by using friction stir technique are quite rare.

II. EXPERIMENTAL PROCEDUERS

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

Table (1) Chemical composition (wt. %) of Al 6061

Weight %	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
6061	Bal	0.4	0.70	0.15	0.15	0.9	0.04	0.25	0.15

Table (2) the mechanical properties of Al 6061

Alloy	σ_{UTS} M pa	EL%	VHD
6061	252.690	8	86

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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. [9].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 in the spindle of the drilling. In present study the tool length (L), were50mm, and three different pin lengths (2,3and4mm), pin diameter (d) (1mm) and shoulder Diameter (D) (10mm) a shown fig (1).

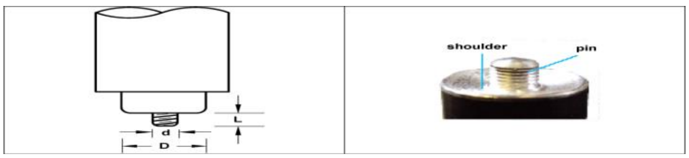


Fig (1).friction stir welding tool dimensions.

III. FRICTION STIR WELDING PROCESS

Two tubes to be welded were butted up against each other and clamped down using the fixture. Rotational velocity and translational velocity of the tool are set in the adapted milling machine. The tool is then rotated and then slowly plunged into a work piece along the interface of the sheets. The tool creates frictional heat in the work piece until the material becomes plasticized. Heat generated by the mechanical mixing process and the adiabatic heat within the material cause the stirred materials to soften without reaching their melting point. This is a major advantage of friction stir welding. Once the material becomes plasticized the tool traverses along a weld line to bond the two materials together Plasticized material is deformed around the tool and is forged into place by the substantial downward axial force of the tool shoulder. Material then consolidates into the weld joint at the trailing edge of the tool leaving a solid phase bond between the two pieces Fig (2).

Fig (2).Drilling press machine

Tensile Testing:

Tensile testing, also known as tension testing, is a fundamental 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 %) [7].

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 Vickers hardness (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 [8].

IV. 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, see Fig. (3) shows the surface appearances of the weld the interface between the recrystallized 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 (3). Surface view

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 friction stir welding (FSW) joints have been evaluated. At each condition three specimens are tested and average of the results of three specimens were measured, it can be Inferred that the rotational speed and thickness are having influence on tensile properties of the friction stir welding (FSW) joints show in Fig. (4-9).

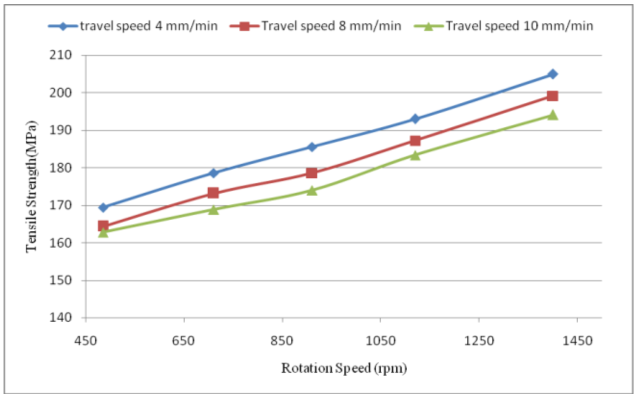


Fig. (4) Relation between ultimate tensile strength and rotational speed of Al6061 (thickness 2 mm)

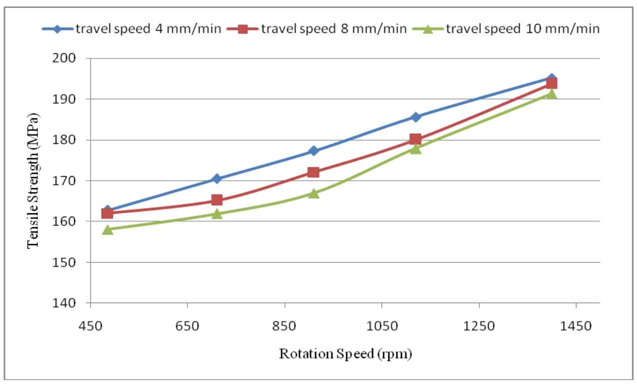


Fig. (5) Relation between ultimate tensile strength and rotational speed of Al6061 (thickness 3 mm)

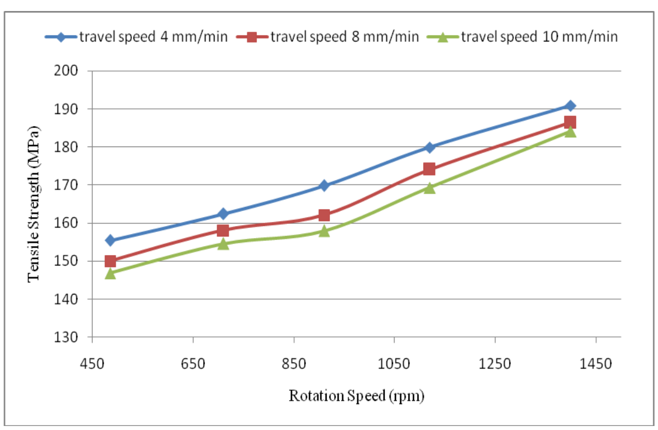


Fig. (6) Relation between ultimate tensile strength and rotational speed of Al 6061 (thickness 4mm)

Elongation Results

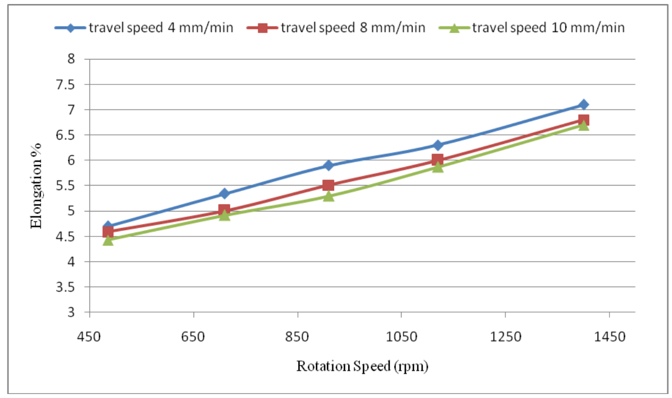


Fig. (7) Relation between elongation and rotational speed of Al 6061(thickness 2mm)

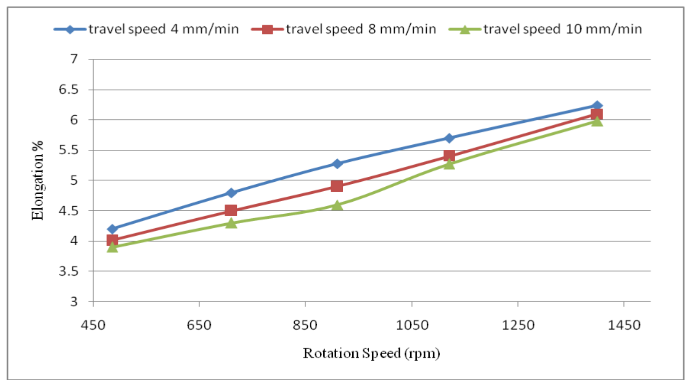


Fig. (8) Relation between elongation and rotational speed of Al 6061(thickness 3mm)

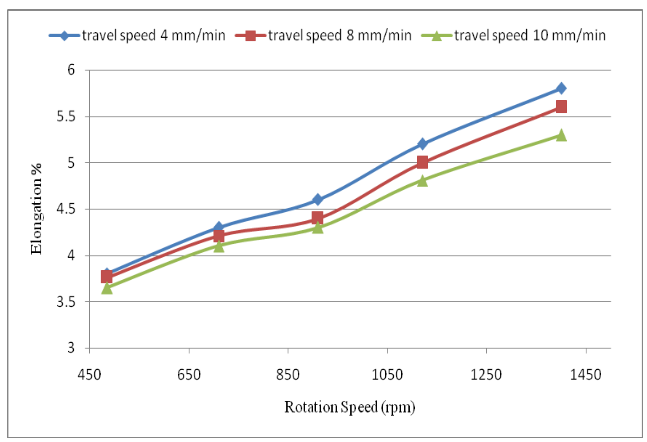


Fig. (9) Relation between elongation and rotational speed of Al 6061(thickness 4mm)

The joints fabricated at high rotational speed (1400RPM) exhibited superior tensile properties compared to other joints. Similarly, the joints fabricated with high material thickness are showing a good tensile properties comparing to that of a less material thickness [17].

Hardness measurement of the joints

Hardness measurement was taken a cross the base metal (BM), has affect zone (HAZ) and nugget zone (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 speed, which effect the dynamic recrystallization as well as the dynamic recovery at the thermal mechanical affect zone (TMAZ) . In general, the Hardness decreases from the base metal towards the weld centerline show in Fig. (10-12).

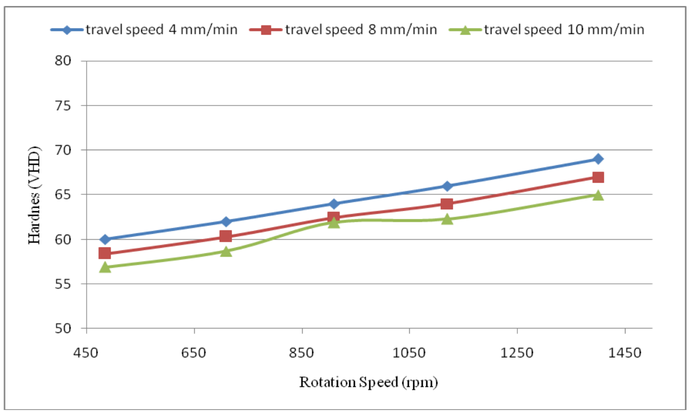


Fig. (10) Relation between hardness and rotational speeds of Al6061 (thickness 2mm)

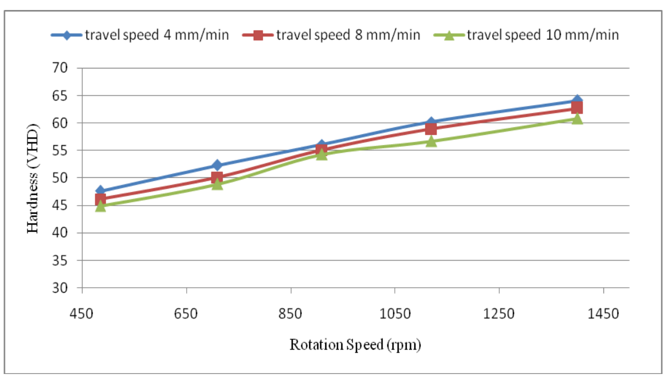


Fig. (11) Relation between hardness and rotational speeds of Al6061 (thickness 3mm)

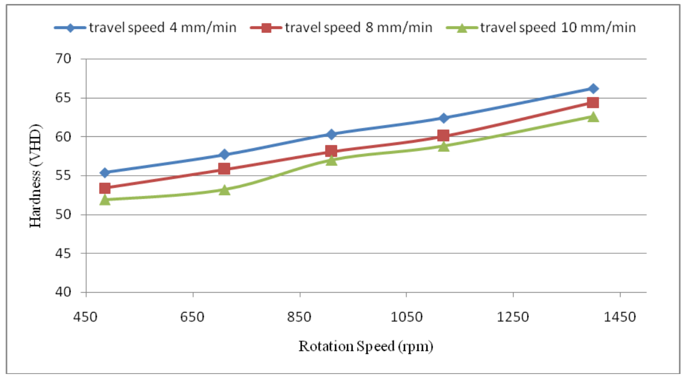


Fig. (12) Relation between hardness and rotational speeds of Al6061 (thickness 4mm)

Development of mathematical model by Response surface methodology

Was the work of a mathematical model using the response surface methodology Tensile stress ,the percentage of elongation and hardness of the joints is the function of rotational speed, travel speed, and material thickness and it can be expressed as

$$\mathbf{Y = f(N, T, F)} \qquad \textbf{Eq. \#1}$$

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

$$\mathbf{Y = K + aN + bT + cF + a^2N^2 + b^2T^2 + c^2F^2 + + abNT + acNF + bcTF} \qquad \textbf{Eq. \#2}$$

Where k is the free term of the regression equation, the coefficients a, b, and c is linear terms, the coefficients a^2, b^2, and $c^2$are quadratic terms, and the coefficients ab, ac and bc are interaction terms [10-11]

Using the Design-expert 6.0.8Software has been selected three factors and is calculated on the basis of the equation Eq. #2 as shown in table 3 and the final mathematical model equations for the tensile strength, the percentage of elongation and hardness is as follows in equation (Eq. #3, Eq. #4 and Eq. #5)

Regression Coefficients	Tensile Strength	Elongation%	Hardness
k	+62.39160	+0.11243	+3.65275
a	+0.011057	+2. 0E-004	+0.025121
b	+7.64223	-0.13778	+8.55206
c	+57.18147	+2.66333	+16.07271
a^2	+1.311E-005	+4.178E-007	-1.3141E-007
b^2	-0.29328	+0.041946	-0.16743
c^2	-12.89176	-0.69039	-3.21203
ab	-8.0323E-004	+2.540E-004	-4.487E-003
ac	+3.2659E-003	+3.302E-004	3.5366E-004
bc	+1.17397	+0.11406	+0.29049

Table (3): Estimated response surface methodology of mathematical models (Al 6061

Tensile strength $=62.39160+0.011057\,N+7.64223\,T+57.18147\,F+1.31951E\text{-}005N^2-0.29328\,T^2-12.89176\,F^2-8.03623E\text{-}004\,NT+3.26569E\text{-}003\,NF+1.17397\,TF$ **Eq. #3**

Elongation $=0.11243+2.25160E\text{-}004\,N-0.13778\,T+2.66333F+4.17148E\text{-}007\,N^2+0.041946\,T^2-0.69039F^2+2.59840E\text{-}004\,NT+3.35002E\text{-}004NF+0.11406\,TF$ **Eq. #4**

Hardness $=3.65275+0.025121N+8.55206\,T+16.07271\,F-1.31741E\text{-}007\,N^2-0.16743\,T^2-3.21203\,F^2-4.48117E\text{-}003\,NT+3.53166E\text{-}004\,NF+0.29049\,TF$ **Eq. #5**

Was drawing the relationship between the experimental values (actual) and predicted values using response surfaces methodology show 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 [12-13].

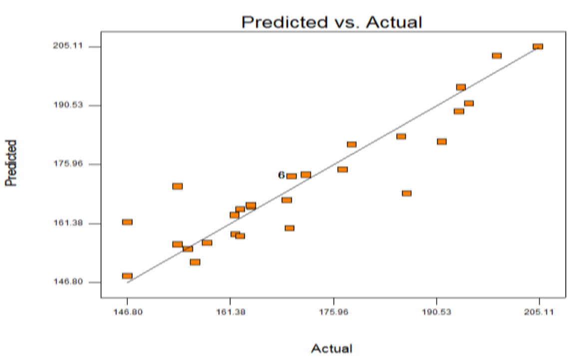


Fig. (13) Relation between actual tensile strength (experimental data) and predicted

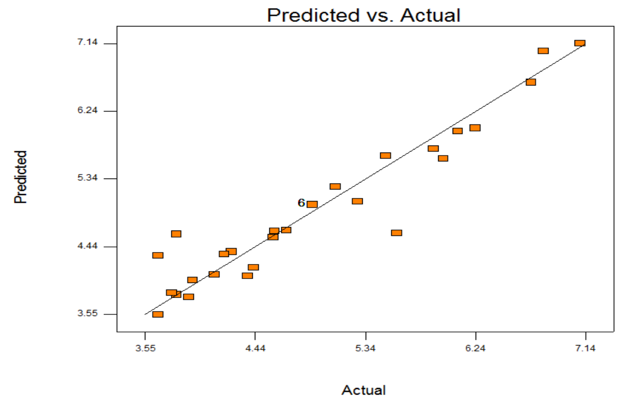


Fig. (14) Relation between actual elongation% (experimental data) and predicted

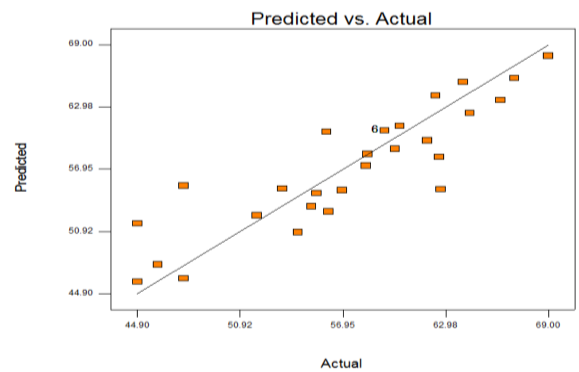


Fig. (15) Relation between actual hardness (experimental data) and predicted

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 improved with numerical optimization techniques. The topology architecture of feed-forward three-layered back propagation neural network is illustrated in Fig. 16 below.

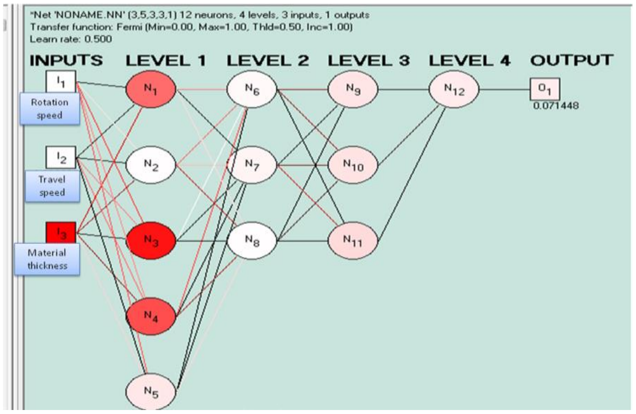


Fig. (16) Propagation artificial neural network

The Network's output is the output of the last level's neurons. Each neurons output equation is calculated as

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

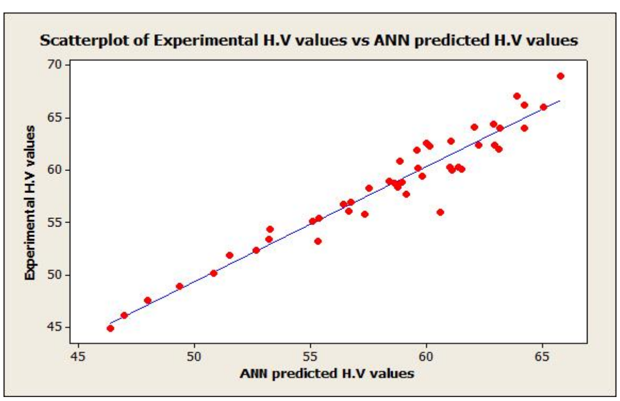
O_n is the neuron's output, n is the number of the neuron,

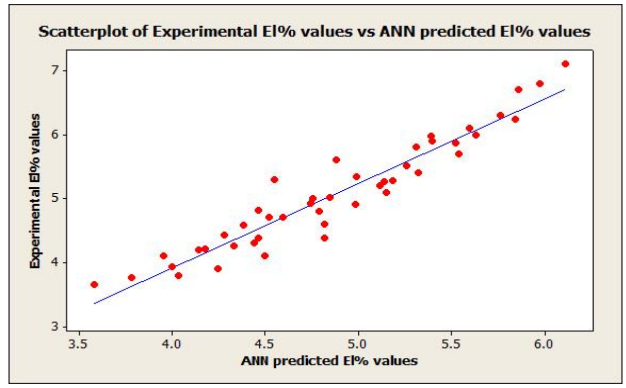
I_k are the neurons inputs, k is the number of inputs,

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.17





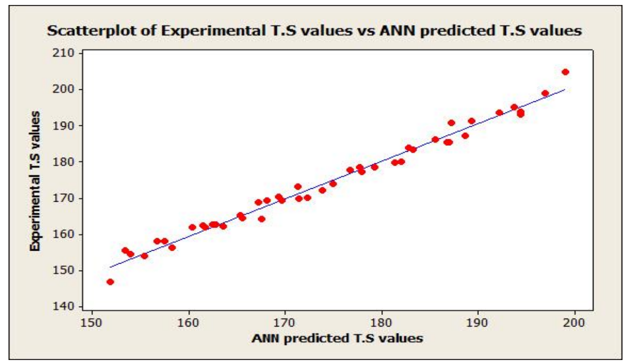
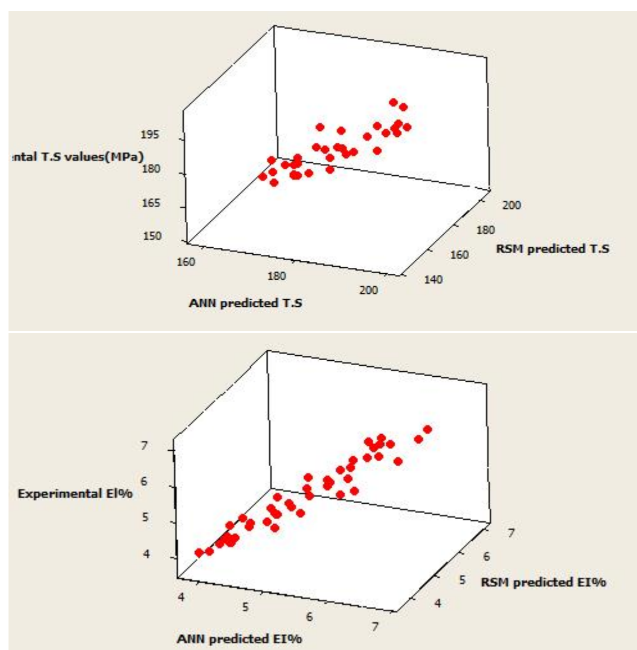


Fig. (17) Scatter diagram for aluminum 6061 pipe using artificial neural network (ANN)

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



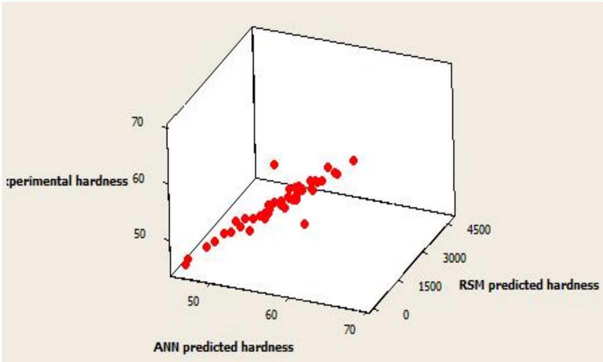


Fig (18) Relation between response surface methodology and hardness artificial neural network

V. CONCLUSION

1- The friction stir welding (FSW) efficiency increases with increase rotational speed and decrease travel speed and material thickness
2- All fractures of friction stir welded specimens were occurred in the weld nugget.
3- The artificial neural network model and response surface methodology model have been proved to be successful in terms of agreement with experimental results ratio respectively 93.5% and 90%.

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