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Research Article

Comparison of RSM and RA with ANN in predicting mechanical properties of friction stir welded aluminum pipes

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Abstract

Aluminum can't successfully be arc welded in an air environment, due to the affinity for oxygen. If fusion welded in normal atmosphere oxidization readily happens and this outcome in both slag inclusion and porosity in the weld, greatly reducing its mechanical properties. This work presents a systematic approach to develop the suggestion model by three (ANN), response surface methodology (RSM) and regression analysis (RA) 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 rotation speed, welding speed and material thickness. The results obtained through regression analysis and response surface methodology were compared with those through artificial neural networks.

KEY WORDS : Friction stir welding, Aluminium pipe, Regression analysis, Response surface methodology, Artificial neural network

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Introduction

The aluminium and its alloys are increasingly used in many important manufacturing areas, such as the automobile industry, aeronautic and military, because of their lowdensity and good mechanical properties, however, the welding of aluminum and its alloys has always represented a great challenge for designers and technologists (Zhou *et al*., 2006).

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 (Su *et al*., 2003).

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 aroutine, 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

Table A : 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 B : 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

welding techniques (Ambrogio *et al.*, 2006; Davies *et al.*, 2005 and Grant *et al.*, 2006). The welds are generated by the concerted action of frictional heating and mechanical perversion due to the rotating tool. The maximum temperature amount to is of the order of 0.8 of the melting temperature (Klingensmith *et al.*, 2005).This work constructs a mathematical model for predicting some mechanical properties of Al 6061 alloy friction stir welded pipe joints. These properties are the ultimate tensile strength, percentage of elongation and hardness.The model is developed by three methods: artificial neural networks (ANN) using software, response surface methodology (RSM) and regression analysis (RA). The model parameters are tool rotational speed, welding speed and material thickness. This work develops also a cost model to predict the cost of Al 6061 alloy friction stir welded pipe joints based on usual cost parameters.

EXPERIMENTAL PROCEDURE

Material :

The chemical composition and mechanical properties of Al 6061 aluminum pipe parts used in the present study as deliveredby the Miser Aluminum company are given in Tables (A-B).

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 (Zeng *et al.*, 2006). The tool pin penetration depth was suggested to be at least about 90 per cent of the work piece thickness. We used three tools with flat shoulder, tools was fixed on the axis of friction stir welding pipes. In the present study the tool length (L) (2,3 and 4 mm), were 50 mm and two different pin length pin diameter (d) 1mm and shoulder Diameter (D) (10 mm).

Design and constructed :

Setup friction stir welding: constructed apparatus is mounted on the drilling press machine bed to the two workpieces of the studied materials which will be welded by friction stir welding technique, (Fig. A). Showing illustration, drawing,

Fig. A : Friction stir welding machine

and construction setup friction stir welding for pipe parts.

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 scorefrom 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 anultimate 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.

EXPERIMENTAL FINDINGS AND ANALYSIS

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. 1 and 2) 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. 1 : Exit pin

Fig. 2 : 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, the percentage of elongation and joint efficiency of the FSW joints have been evaluated. At each condition, three specimens are tested and anaverage 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. 3-5).

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 good tensile properties comparable to that of a less material thickness see (Fig.6-8).

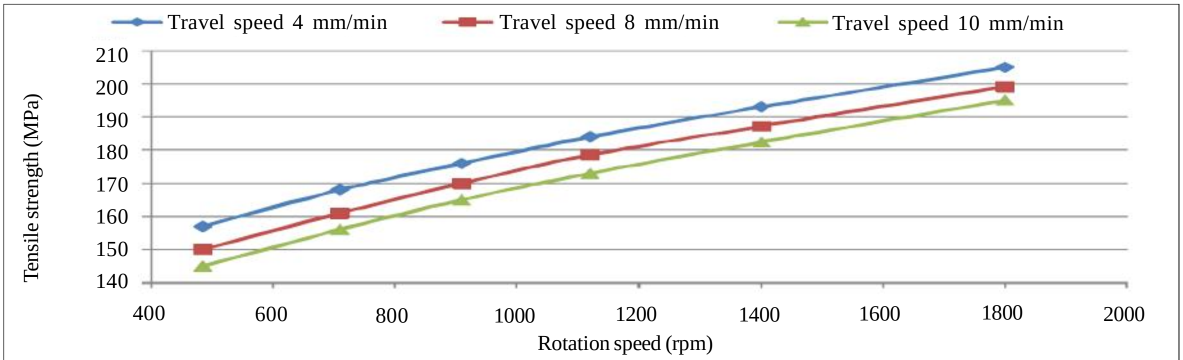

Fig. 3 : **Relation between ultimate tensile strength and rotational speed of AL 6061 (thickness 2 mm)**

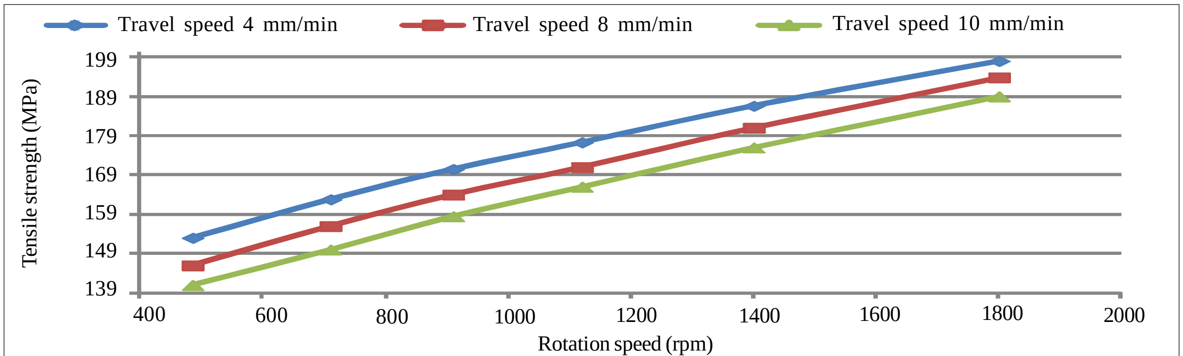

Fig. 4 : **Relation between ultimate tensile strength and rotational speed of AL 6061 (thickness 3 mm)**

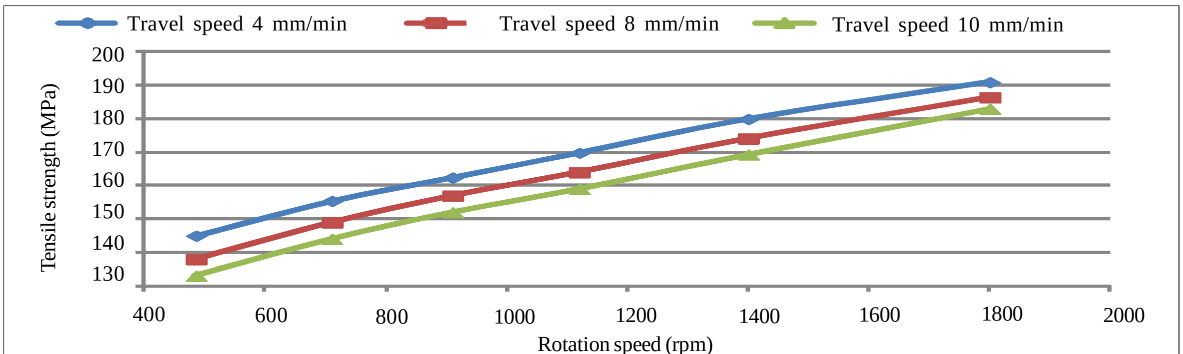

Fig. 5 : **Relation between ultimate tensile strength and rotational speed of AL 6061 (thickness 4 mm)**

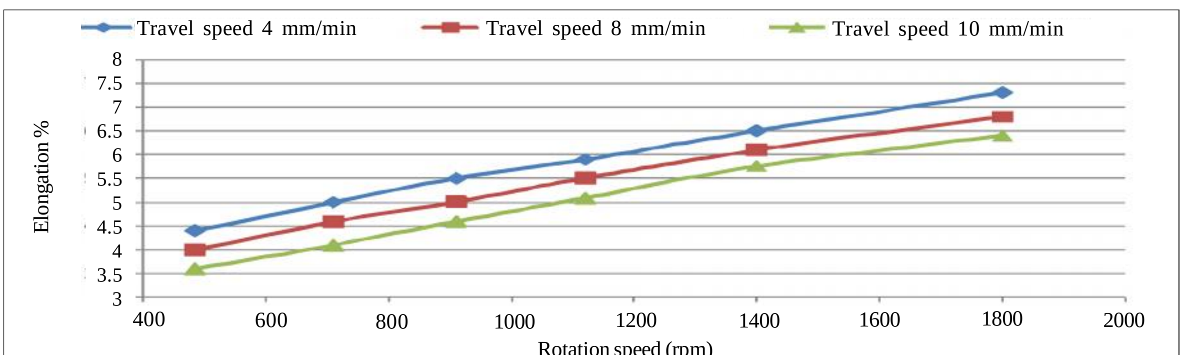

Fig. 6 : **Relation between elongation and rotational speed of AL 6061 (thickness 2 mm)**

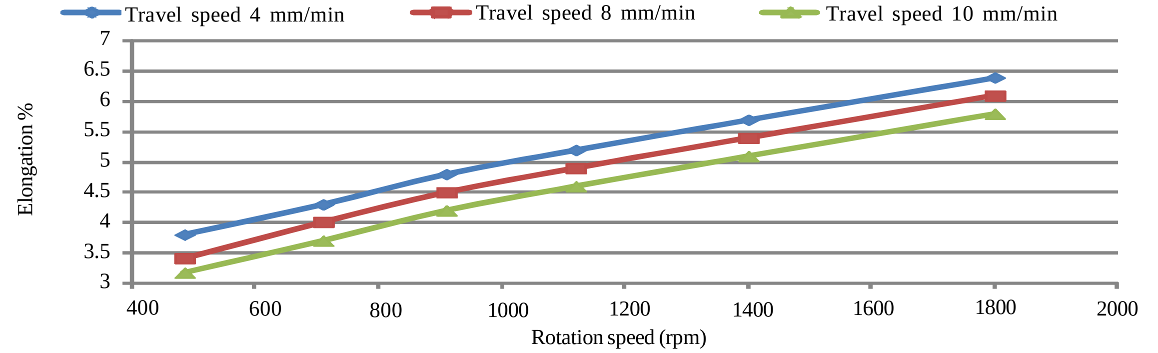

Fig. 7 : Relation between elongation and rotational speed of AL 6061 (thickness 3 mm)

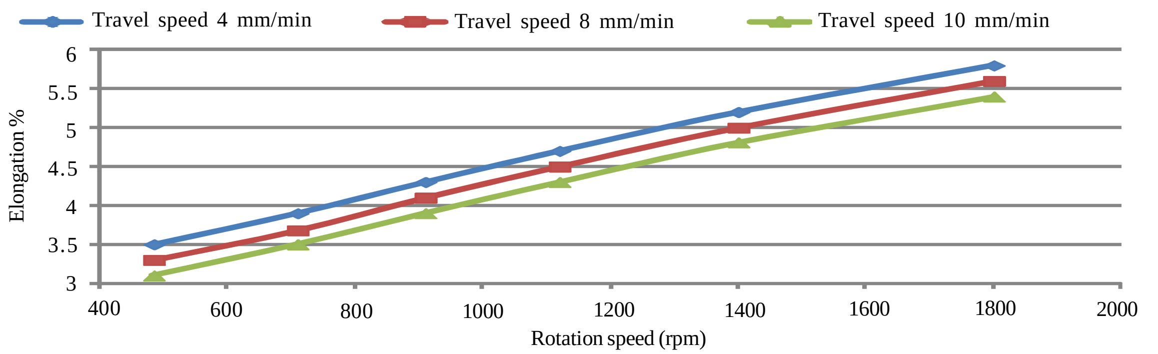

Fig. 8 : Relation between elongation and rotational speed of AL 6061 (thickness 4 mm)

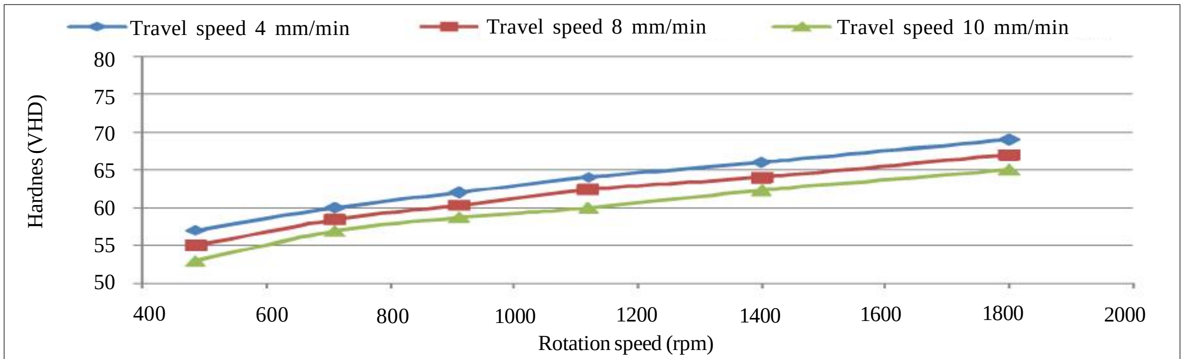

Fig. 9 : Relation between hardness and rotational speed of AL 6061 (thickness 2 mm)

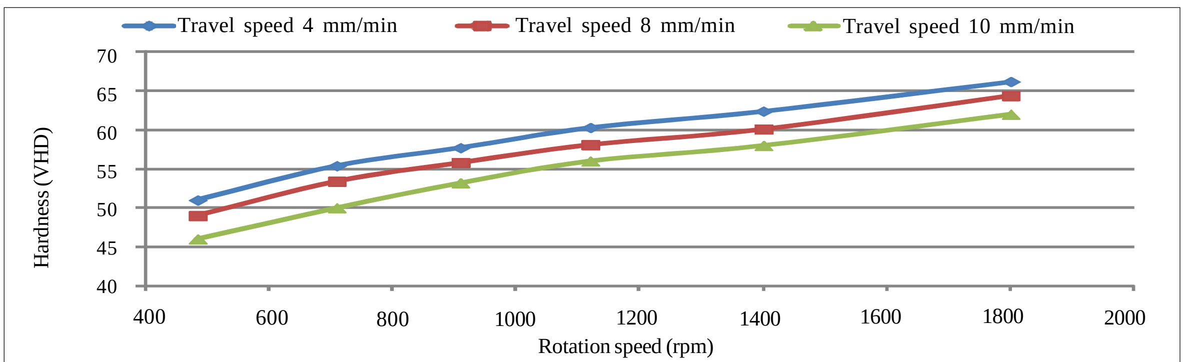

Fig. 10 : Relation between hardness and rotational speed of AL 6061 (thickness 3 mm)

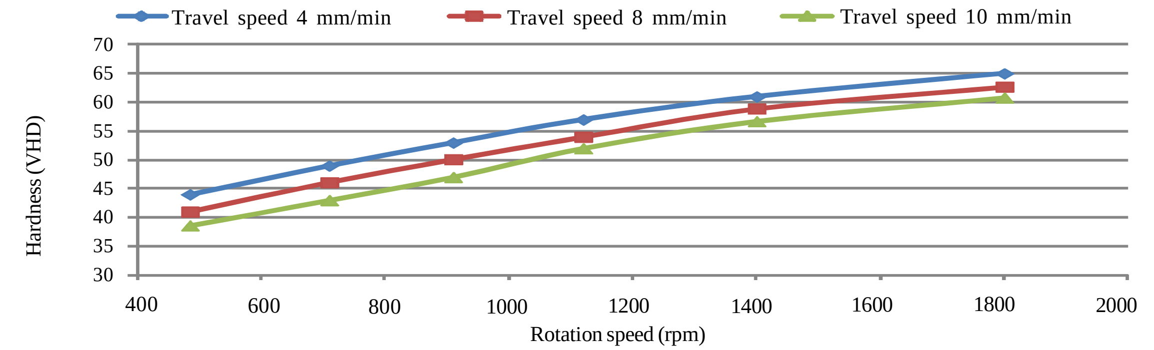

Fig. 11 : Relation between hardness and rotational speed of AL 6061 (thickness 4 mm)

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 centreline increases by increasing the rotational speed. Such observation could be understood in the light of relative increasein the degree of plastic deformation an frictional heat generatesat higher rotational speeds, which effect the dynamic crystallization as well as the dynamic recovery at theTMAZ. In general, the hardness decreases from the base metal towards the weld centreline show in (Fig. 9-11).

Mathematical modeling :

Regression analysis :

The tensile strength of the joints is the function of rotational speed, welding speed 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 co-efficients a, b, and c are linear terms (Kanakaraja and Hema, 2013) .

MINITAB 15 software packages are used to calculate the values of these co-efficients for different responses. After determining the co-efficients, the mathematical models are developed. The developed final mathematical model equations in the coded form are given below :

Tensile strength = 162 + 0.0364 (N) -7.05 (T) - 1.44 (F)

Elongation % = 4.89 - 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. (12-14). The observed values and predicted values of the responses are scattered

Table 1 : Estimated regression co-efficients of mathematical models (Al 6061)

Regression co-efficients	Tensile strength	Elongation %	Hardness
k	162	4.89	62
A	0.036	0.001	0.009
B	7.05	0.542	3.67
C	-1.44	-0.067	0.604

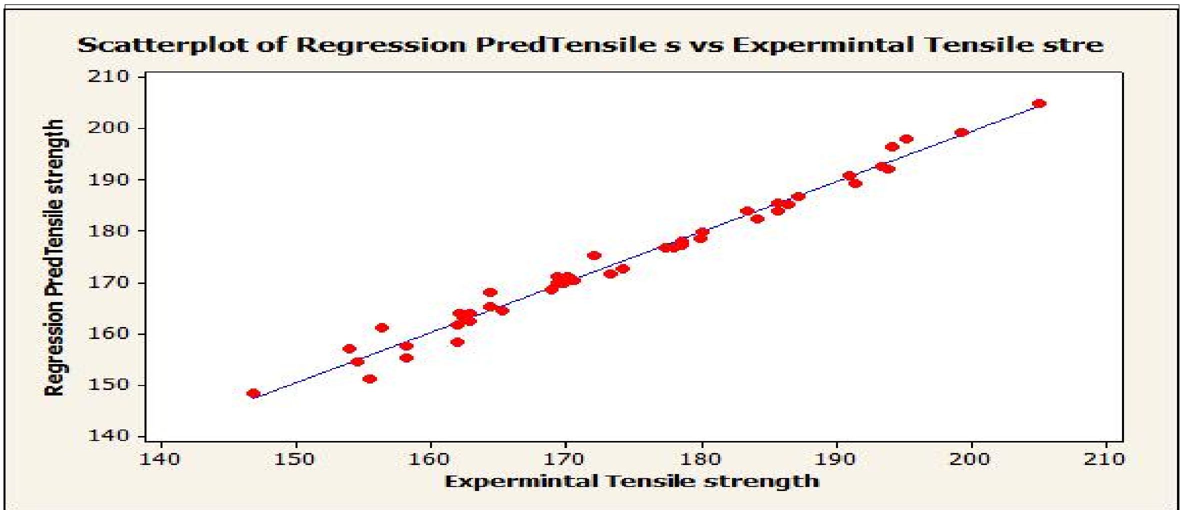

Fig. 12 : Relation between exprimental tensile strength and predicted rensile stregth

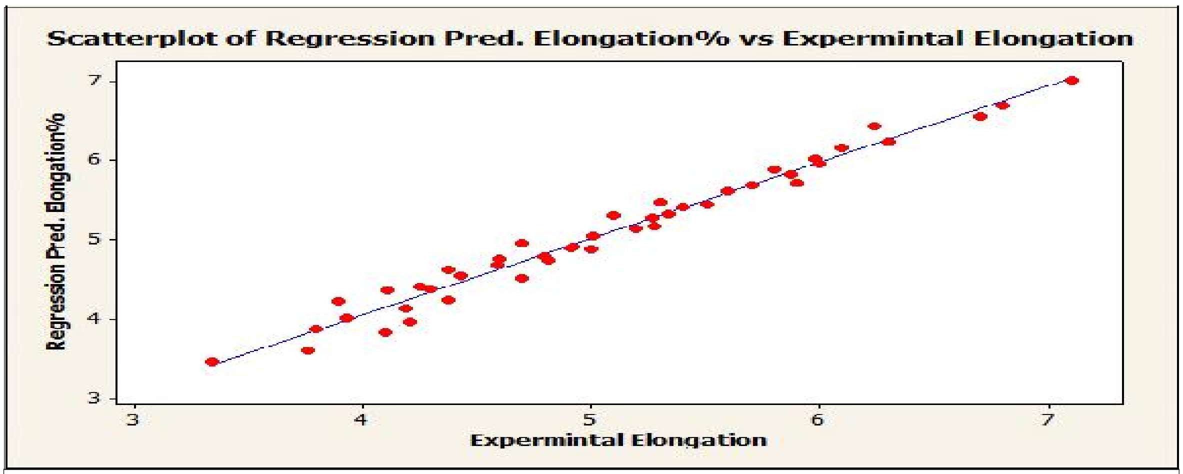

Fig. 13 : Relation between exprimental elongation per cent and predicted elongation per cent

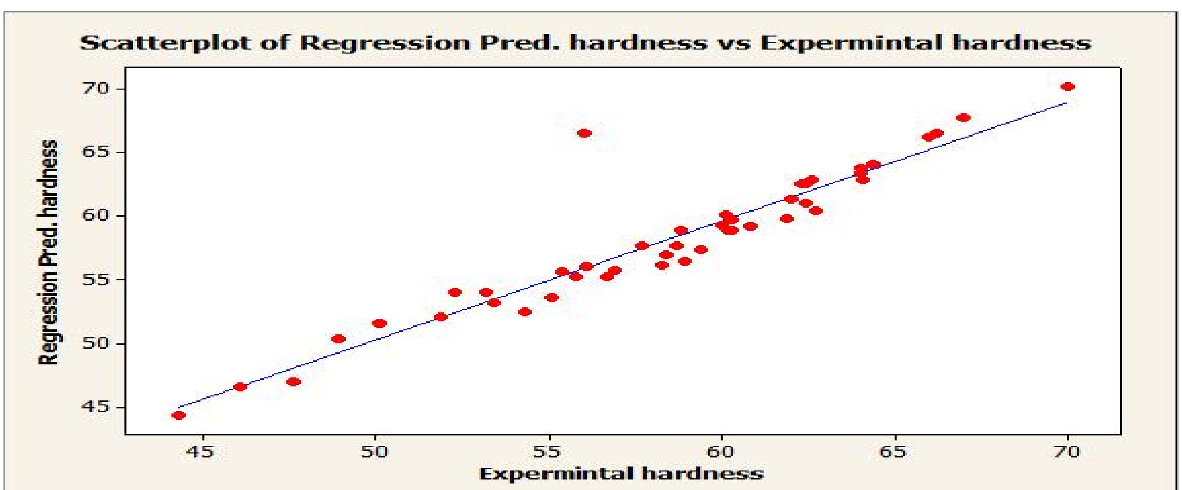

Fig. 14 : Relation between exprimental hardness and predictred hardness

close to the 45° line, indicating an almost perfect fit of the developed empirical models (Plaintively *et al.*, 2011 and Zhang and Friedrich, 2003).

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 co-efficients a, b, and c is linear terms (Kanakaraja and Hema, 2013; Ramasamy *et al.*, 2002 and Kim *et al.*, 2003).

Design-Expert 6.0.8 software packages is used to calculate the values of these co-efficients for different responses and is presented in Table 2. After determining the co-efficients, the mathematical models are developed see (Fig.15-18). The developed final mathematical model equations in the coded form are given below:

Tensile strength(MPa) = 161.03+ 0.03N-7.1 T +0.71F +8.1E-004 N^2 -3.3T^2 - 0.10F^2 -8.3NT-0.2973NF-0.17368TF

Elongation%=3.7+3.4E-003 N-0.62T+0.041F-2.0E-004N^2-1.8E-005T^2+9.8E-003F^2-3E-007NT+0.04NF-8.8E-003TF

Hardness (VHD)=63.96+0.011N-7.87 T-0.8F-4.0E-003N^2-4.06E-004T^2+0.15F^2-5.1E-006NT-0.4NF - 0.10202TF

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

Optimization of parameters of FSW on responses :

One of the most substantial objectives of this realization was to maximize the tensile strength ,elongation per cent and hardness of friction stir welded joints pipes of Al 6061 and also, find the optimum process parameters from the suggestion model developed. We feel that numerical optimization such describes multiple response methods called desirability this method used to solve multiple response optimization problems, combines multiple responses into a dimensionless measure of performance called the overall desirability function. The desirability ranges between 0 and 1. The suggestion model predicted optimal results from above technique are a tensile strength, elongation per cent and hardness that can be obtained, are 205 Mpa, 7.1 per cent and 69, respectively.The acquired desirability value of 0.766.

Table 2: Estimated regression co-efficients of mathematical models (RSM) (Al 6061)

Regression co-efficients	Tensile strength	Elongation%	Hardness
b_0	+116.74726	+3.79137	+63.96119
b_1	0.038318	+3.499E-003	+0.011332
b_2	-7.123	-0.62850	-7.87798
b_3	+0.71808	+0.041501	+0.83819
b_{11}	+8.0E-004	-2.080E-004	+4.8E-003
b_{22}	-1.30 E-004	-1.80E-005	-4.3E-004
b_{33}	0.10660	+9.894E-003	+0.1533
b_{12}	-8.3985	-3.048E-007	-5.3E-006
b_{13}	-0.2973	+0.041691	-0.44497
b_{23}	-0.17368	-8.891E-003	-0.10202

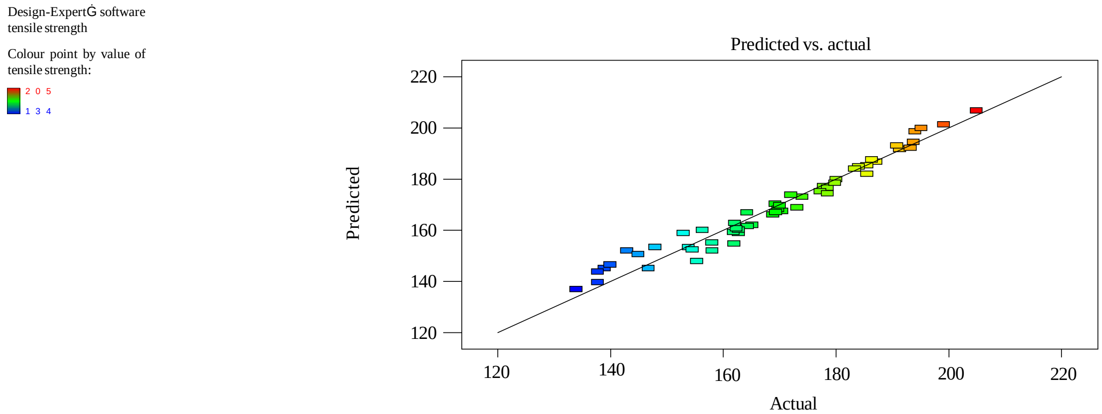

Fig. 15 : Relation between experimental tensile strength and predicted tensile strength

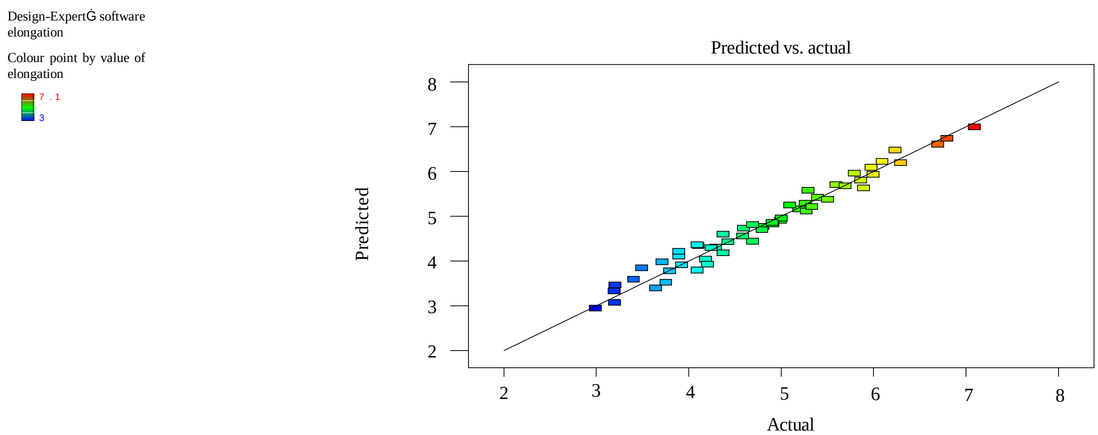

Fig. 16 : Relation between experimental elongation per cent and predicted elongation per cent

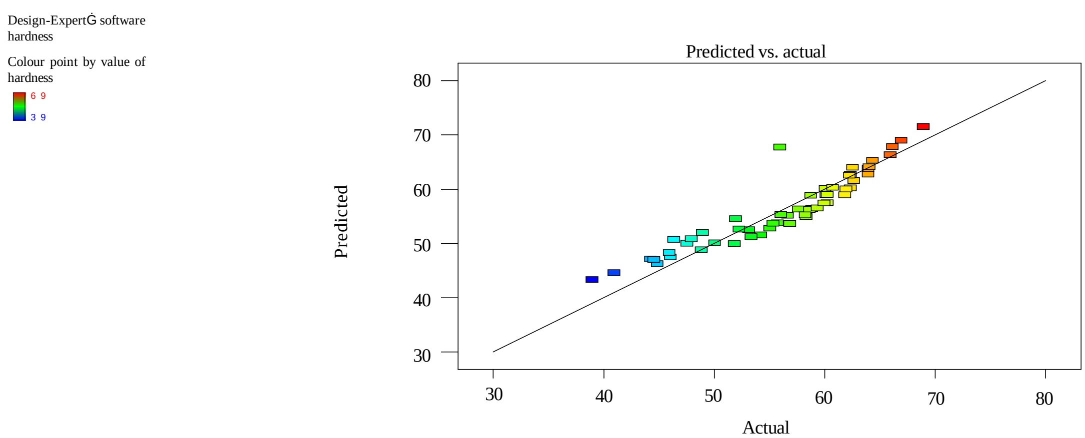

Fig. 17 : Relation between experimental hardness and predicted hardness

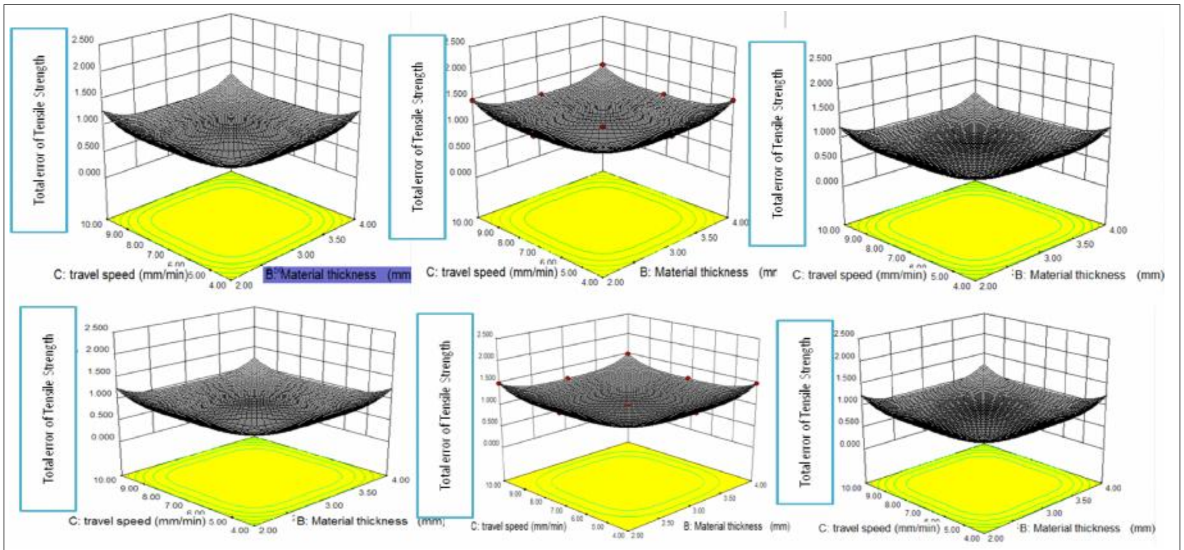

Fig. 18 : **Relation between standard errors of tensile strength, travel speed and material thickness of A16061 (At rotational speeds 485-1800 RPM)**

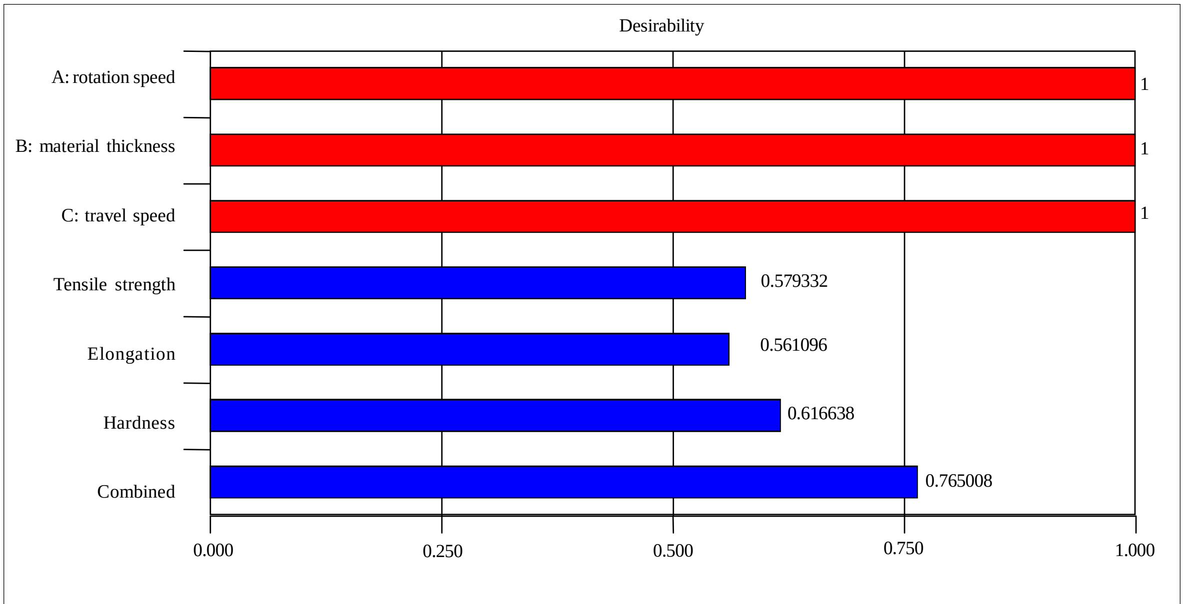

Fig. 19 : **Optimization of parameters of FSW on responses**

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 mode is the version framework of the information processing system. It is composed of a big number of much-interconnected processing elements (neurons) working in conformity 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 (Kanakaraja and Hem, 2013; Arcakhoglue *et al.*, 2004; Zhang and Friedrich, 2003; Khourshid and Sabry, 2013 and Khourshid

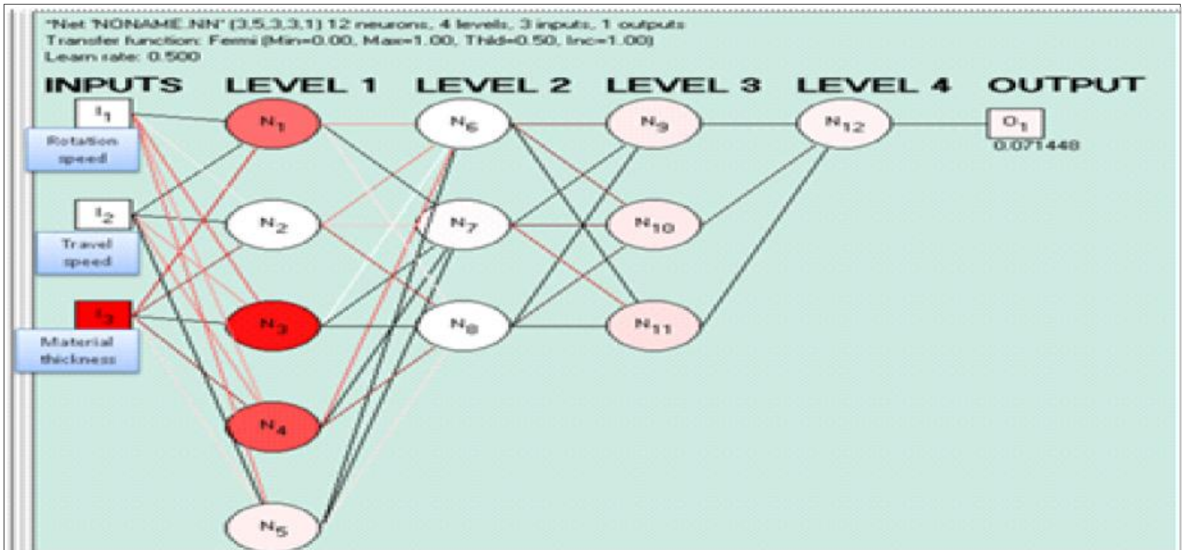

Fig. 20 : Propagation artificial neural network

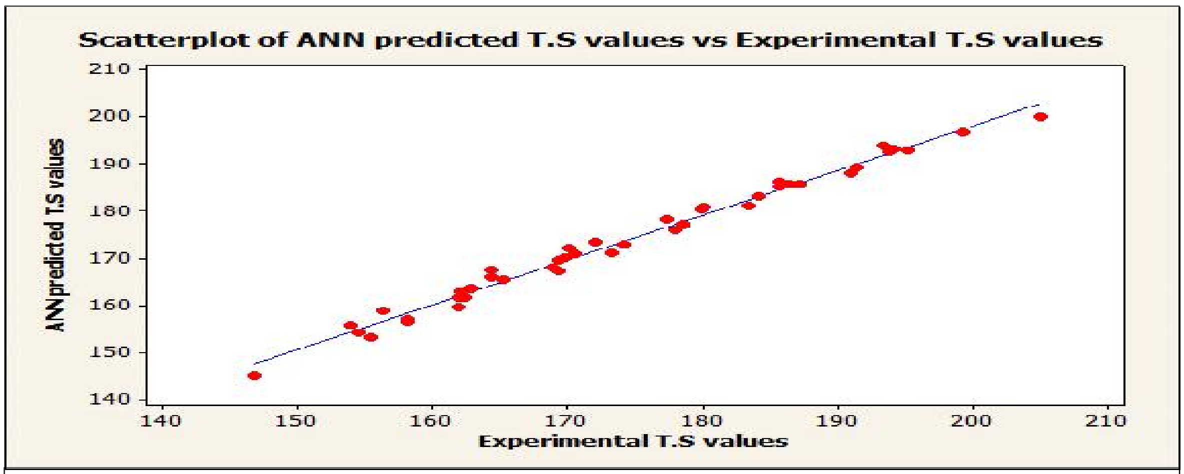

Fig. 21 : Relation between exprimental tensile strength and predicted tensile strength

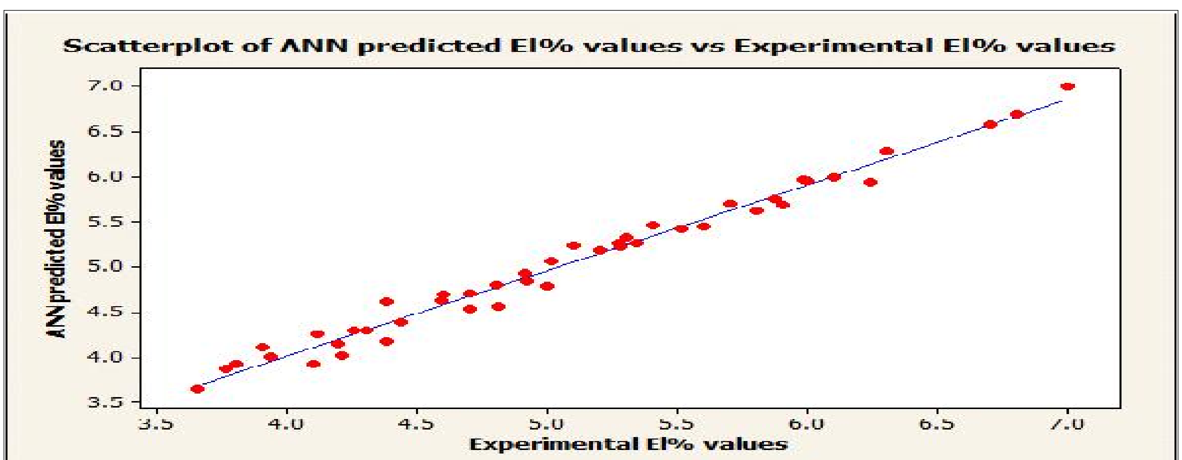

Fig. 22 : Relation between exprimental elongation per cent and predicted elongation per cent

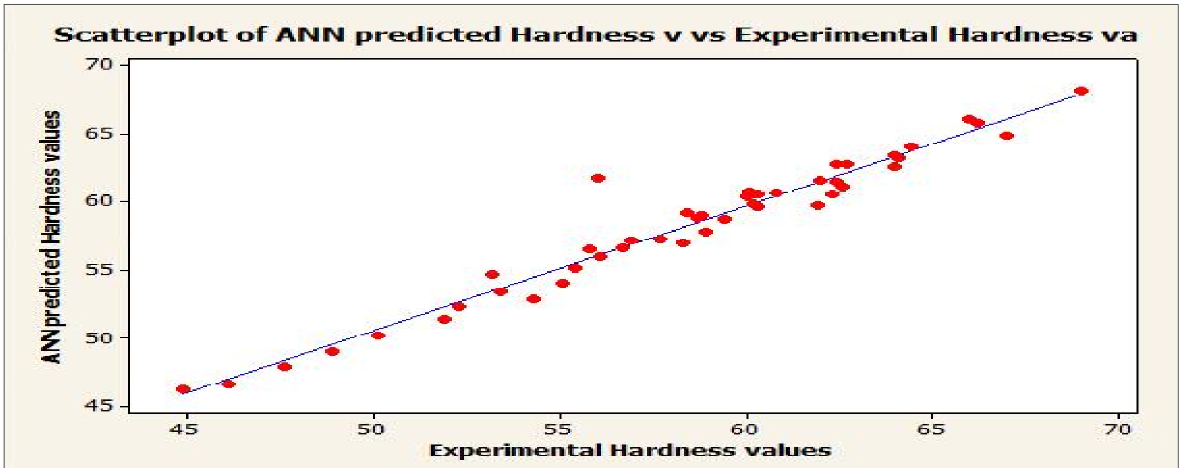

Fig. 23 : **Relation between exprimental hardness and predicted hardness**

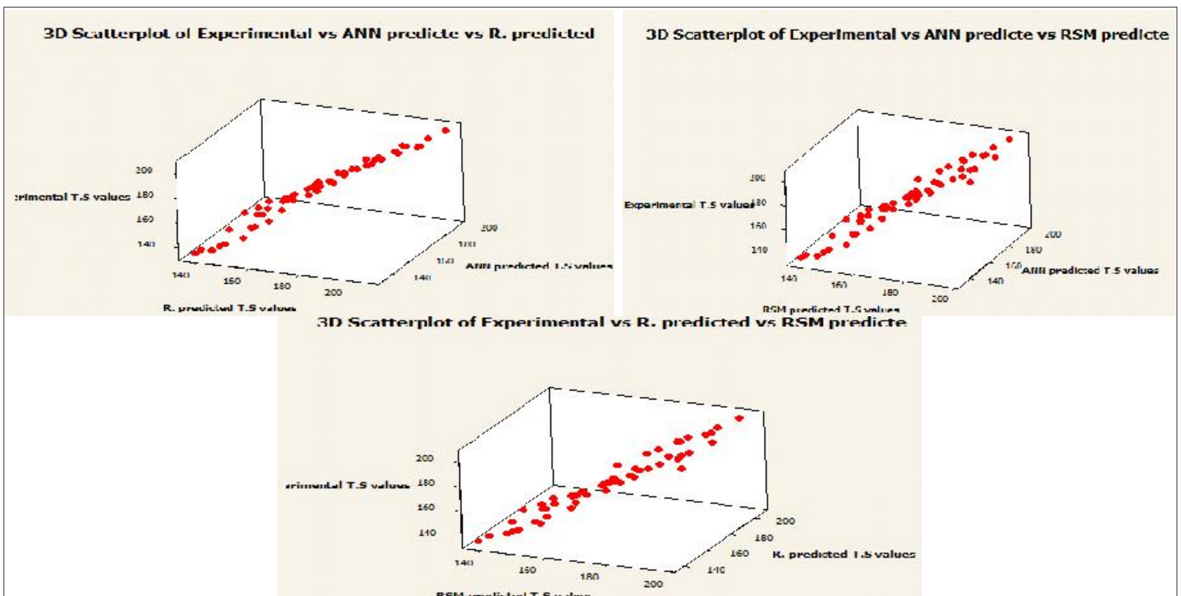

Fig. 24 : **Relation between tensile test measurement and tensile tests predicted (response surface methodology, regression analysis, artificial neural network)**

et al., 2011 and 2015). In this study, 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. 19 and 20.

The equation is calculated as :

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

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

I_k is the inputs of the neuron, k is the number of inputs,

W_{kn} are the weights of the neurons.

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

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.

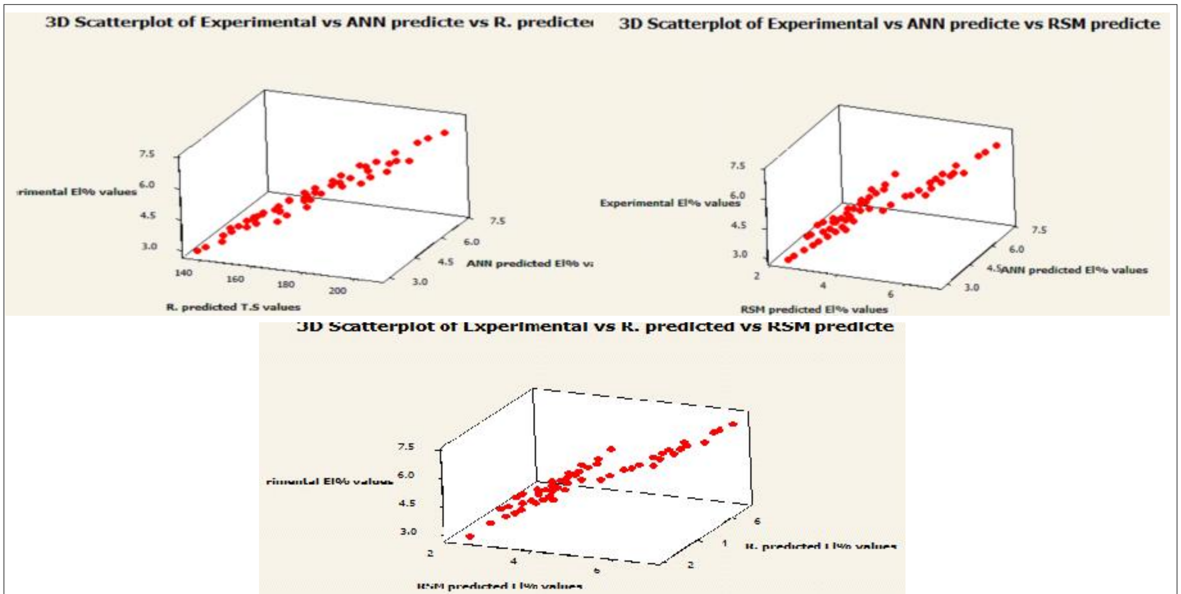

Fig. 25 : **Relation between elongation measurement and elongation predicted (Response surface methodology, regression analysis, artificial neural network)**

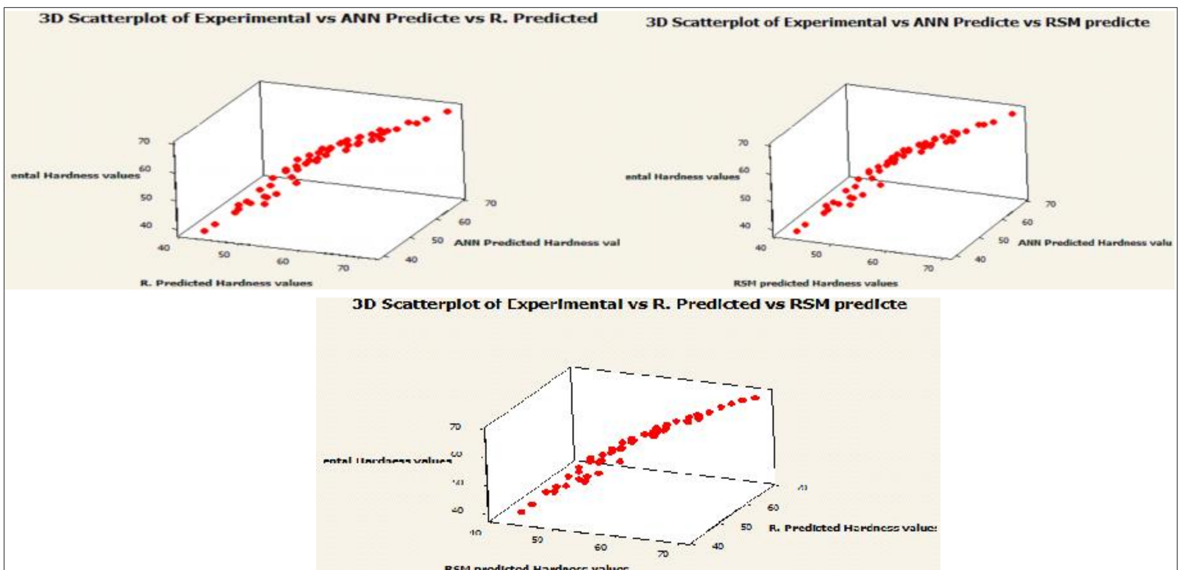

Fig. 26 : **The relation between hardness measurement and hardness predicted (Response surface methodology, regression analysis and artificial neural network)**

The results acquired after exercise and testing on artificial neural networks are shown in the (Fig. 21-23).

The comparative between response surface methodology, regression analysis and artificial neural network for ultimate tensile strength, the present elongation per cent and nugget hardness are presented in (Fig. 17-20).

Conclusion :

– The FSW efficiency increases with decrease the joint efficiency of FS welded (ratio of ultimate tesnsile strength of welded joint to that of the base material was found 80, 79 and 76 per cent in 6061 in thickness 2, 3 and 4 mm.

– A regression analysis model and response surface methodology have been proved to be successful in

term of agreement with experimental results ratio, respectively 90 per cent and 94.6 per cent.
- ANN model has been proved to be successful in terms of agreement with experimental results ratio 96.5%.

REFERENCES

Ambrogio, G., Fratini, L. and Micari, F. (2006). Incremental forming of friction stir welded tailored sheets, In : Proceedings of the 8th Biennial ASME Conference on Engineering Systems Design and Analysis, ESDA2006.

Arcakhoglu, E., Cavusoglu, A. and Risen, A. (2004). Thermodynamic analyses of refrigerant mixtures using artificial neural networks. *J. Appl. Energy*, **78** : 219-230.

Davies, R.W.S., Diamond, P. S., Sklad, S., Wazny, L., Kaunitz, B., Fulbright, D., Waldron and McTernan, K. (2005). Friction-stir-joined aluminum sheet materials for heavy vehicle cab structures, In: Annual Progress Report: High Strength Weight Reduction Materials, 2005.

Grant, G.J., Davies, R.W., Stephens, E.V., Wazny, S., Kaunitz, L. and Waldron, D.J. (2006). The formability of Friction Stir Welds in automotive stamping environments. *SAE Transactions J. Materials & Manufact.,* **114** (5) :619-629.

Kanakaraja, D. and Hema, P. (2013). Comparative study on different pin geometries of tool profile in friction stir welding using artificial neural networks. *Internat. J. Mechanical Engg. & Technol.,* **4** (2): ISSN 0976 – 6340 (Print), ISSN 0976-6359 online.

Khourshid, A.M., Bousaif, T. and Sabry, I. (2011). Welding of cylindrical parts by using Friction Stir Technique. Monufia University.

Khourshid, A. M. and Sabry, I. (2013). Friction stir welding study on aluminum pipe. *Internat. J. Mechanical Engg. & Robotics Res.*, 2013.

Khourshid, A.M., Ahmed, M. El-Kassas and Sabry, Ibraheem (2015). Integration between artificial neural network and responses surfaces methodology for modeling of Friction Stir Welding, *Internat. J. Adv. Engg. Res. & Sci.,* **2** (3): 67-73.

Kim, I. S., Son, K.J., Yang, Y.S. and Karaganda, P. K. D. V. (2003). Sensitivity analysis for process parameter parameters in GMA welding process using factorial design method. *Internat. J. Machine Tools & Manufact.,***43** : 763-776.

Klingensmith, S., DuPont, J.N. and Marder, A.R. (2005). Microstructural characterization of a double-sided Friction Stir Weld on a superaustenitic stainless steel, *Welding J.,* **84** (5): 77–85.

Plaintively, R., Koshy Mathews, P. and Murugan, N. (2011). Development of mathematical models to predict the mechanical properties of friction stir welded AA6351 aluminum alloy. *J. Engg. Sci. & Technol. Rev.,* **4** (1) : 25-31.

Ramasamy, S., Gould, D. and Workman (2002). Design of experiments study to examine the effect of polarity on stud welding. *Welding J.,* **81** : 19- 26.

Su, J.Q., Nelson,T.W., Mishra,R. and Mahoney, M.(2003). Mi-crostructural investigation of friction stir welded 7050- T654 aluminium. *Act Mater.*, **51** (3) : 713- 729, doi:10.1016/S1359-6454(02)00449-4.

Zeng, W. M., Wu, H. L. and Zhang, J. (2006). Effect of tool wear on mechanical properties and acoustic emission of friction stir welded 6061 Al alloy. *Acta. Metallurgica. Sinica.,* **19** (1): 9-19.

Zhang, Z. and Friedrich, K. (2003). Artificial neural networks applied to polymer composites: A review. *J. Composit. Sci.& Technol.,* **63**: 2029-2044.

Zhou, C., Yang, X. and Luan, G. (2006). Effect of root flaws in the fatigue property offriction stirs welds in 2024-T3 aluminum alloys. *Mater Sci.Engg.,* **418** : 155–160.

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