Al-Nahrain Journal for Engineering Sciences **NJES** 26(2)131-137, 2023
http://doi.org/10.29194/NJES.26020131

Optimization of Friction Stir Spot Welding Parameters of Al6061T6 by Hybrid Approached

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Paper History:

Received: 24th Apr. 2023

Revised: 13th May 2023

Accepted: 15th May 2023

Abstract

The most important way for joining the non-welding aluminum alloy is Friction stir spot welding. Three parameters effect on efficiency of welding: tool shape, rotational speed, and plunged time, are chosen to study for welding 6061T6 aluminum alloy. Each of the above parameters has three variables as: pin shapes (square, cylinder, and hexagonal), plunged time (50, 70,100) sec and rotational speeds (710, 1120, 1800) rpm hybrid approach which is consist of the experiment run, neural network and social spider optimization is used to optimize the welding conditions by finding the maximum ultimate force. The best condition of the weldments is (square, 710rpm, 100sec) with maximum shear force 4740N. The best results obtained from hybrid optimization with experimental results; with discrepancy of 2%.

Keywords: Friction Spot Welding, Hybrid Approach, Neural Network , Spider Optimization, Ultimate Force, Experiment Run

اختيار ظروف اللحام الاحتكاكي النقطي المثلى لسبائك الالمنيوم ٦٠٦١ باستعمال طريقة هجينة

رشا محمد حسين, سامح فريد حسن, اياد مراد طخاخ, محسن عبد الله الشمري

الخلاصة:

ان من اهم طرق ربط سبائك الالمنيوم الغير قابلة للحام هي عملية اللحام باللحام الاحتكاكي النقطي. ثلاث عوامل مهمة مؤثرة على عملية اللحام الاحتكاكي النقطي لسبائك الالمنيوم ٦٠٦١ تمت دراستها وهي شكل اداة اللحام ,السرعة الدورانية, زمن الغرس. كل عامل من العوامل اعلاه تم اختيار ثلاثة متغيرات له: شكل اداة اللحام:(مربع ,اسطواني , سداسي) , زمن الغرس (٥٠, ٧٠, ١٠٠) ثانية واخيرا السرعة الدورانية (٧١٠, ١١٢٠, ١٨٠٠) دورة في الدقيقة. الطريقة الهجينة المستعملة هنا تتكون من تجارب عملية تم ادخالها وبرمجتها بشبكة الخلايا العصبية وثم تم تعشيقها مع خوارزمية العنكبوت الاجتماعية من اجل ايجاد ظروف اللحام التي تولد اعلى قوة التحمل. ان افضل ظروف لحام تم الحصول عليها هي (شكل الاداة مربع ,٧١٠دورة في الدقيقة, ١٠٠ثانية) حيث كانت اعلى قوة هي ٤٧٤٩ نيوتن. وان اعظم نسبة تباين تم الحصول عليها بمقارنة نتائج العملي والطريقة الهجينة هي ٢%.

1. Introduction:

Aluminum alloys are considered to be lightweight metals which are used in different industrial applications such as automotive, aerospace. There are various methods are used for joining the sheets of an aluminium alloys such as resistance spot welding, friction stir welding, friction stir spot welding shown in Fig.1 and laser spot welding. The main disadvantages of the conventional resistance spot are large heat distortion, poor weld strength. [1]

Arunchai et al. [2] used artificial neural network (ANN) to predict the welding process quality of an aluminum alloys. The main parameter that was predicted by the ANN was the shear strength. The magnitudes of the shear strength as well as the input data parameters that related to the welding process were delivered to the RSW process. The obtained result

NJES is an **open access Journal** with **ISSN 2521-9154** and **eISSN 2521-9162**

of the welding quality was equal to 95% and this matter indicated that the using of ANN in the prediction process was successful.

Yahya et al. [3] studied experimentally the FSSW of dissimilar materials consisting of AA5754-H22 and AA2024-T3 alloys with thickness 1.6 and 1.5. The experimental process was carried out with various welding parameters such us: tilt angle, dwell time, tool rotation speeds, and tool plunge depth with different magnitudes. The selection of the best magnitudes of the welding parameters was done by using Taguchi technique. The best results of the FSSW process were occurred at 0(deg)/ 5(s)/ 1500(rpm)/ 2.65.

Saleh et al. [4] applied Taguchi technique based on Taguchi's L9 orthogonal array to evaluate the optimal values of the FSSW parameters experimentally. The basic parameters of the FSSW are the plunge depth, rotational speed, dwell time, and plunge rate. The results of the Taguchi technique showed that the best welding efficiency occurred at 2000 rpm, 0.9 mm , 8 seconds and 10 mm/min.

Basma et al. [5] examined experimentally the effect of the T6, T4 and FSSW parameters on both of the microstructure and shear load on an AA6061-O aluminum alloy. Taguchi technique adopted to predict the parameters of FSSW. The primary parameters that were selected are the dwell time and the tool rotational speed. It was concluded that by increasing the dwell time the grain size of stir zone increased and the magnitude of the shear load of the welding joints after the heat treatment (T6) is smaller than after the heat treatment (T4).

Abbas et al. [6] studied experimentally the effect of the shoulder diameter, rotational speed, welding direction, tapered pin geometry, and tilting angles on the welding efficiency of the FSW of (2024-T3) aluminum alloy. Taguchi method was utilized to evaluate the optimal values of the welding parameters that lead to the best welding efficiency condition according to the yield and tensile strengths. It was found that the best yield and tensile strengths magnitudes at shoulder diameter (14 mm), rotation speed (1400 rpm), welding direction (3 passes), rotation speed (1400 rpm), tilting angle (3°), and linear speed (40 mm/min).

Muna et al. [7] presented experimentally FSSW to weld a sheet of pure copper alloy with a sheet of Al alloy (AA5754-H114) having a thickness equal to (2 mm). It was used Taguchi technique based on the design of experiment to predict the suitable welding parameters. It was found that the maximum shear forces magnitudes obtained when the plunging time, rotational speed, equal to (90 sec) and (1000 rpm) respectively.

Seshu Kumar [8] applied experimentally the FSSW process on a nylon 6A and polycaprolactam polymer composite plates. It was tested the hardness of welded joints and the ultimate tensile strength under various process parameters such us: the feed rate as well as the tool rotational velocity. It was utilized Taguchi method to select the optimum process parameters values. It was found that the maximum ultimate tensile strength and the hardness for the 1500 rpm and feed rate at 30 mm/min.

Onur et al. [9]. Employed grey relational analysis (GRA) as well as Taguchi technique to obtain the optimum FSSW parameters used to weld an Al alloy. The efficiency of the FSSW was measured according to the tensile shear strength magnitude. It was concluded that the maximum tensile shear strength equals to(122.16 MPa) at (1500 rpm) tool speed, (2.6 mm) pin height, and welding time was 10 s. The microstructural investigation on the deformed crystallization in FSW of Al7075-T651 plate is discussed in [10].

Maha et al. [11] presented theoretically and experimentally the effect of the static and dynamic parameters on the strength of the FSW process. It was utilized fuzzy logic control (FLC) to select the best welding process parameters. A comparison was made between the theoretical results that was obtained from the FLC and the experimental results and it was concluded that there is a difference about 7%.

Suriya [12], solved the problem of FSSW of dissimilar materials consisting of Al5052 aluminum and Ti-4V-6Al titanium alloys. Taguchi technique was applied to select the optimum values of the welding process parameters. The primary parameters that were adopted are dwell time, feed, and the tool rotational speed. While the analysis of variance (ANOVA) was utilized to optimize the S/N ratio of shear force to obtain the best welding efficiency.

Effertz et al. [13], studied experimentally Refill Friction Stir Spot Welding of an Al alloys. Taguchi technique used to optimized the process parameters, plunge depth, plunge time and rotational speed in order to obtain the highest Ultimate Lap Shear Force (ULSF) of 2024-T3 Aluminum Alloy similar joints optimum parameter combination (Rotational Speed = 2,310 rpm, Welding Time = 5.3 s and Plunge Depth = 2.6 mm). also taguchi technique is used to optimized the FSSW Al-Li AA8090 butt joined, and the maximum UTS of 220 MPa is obtained [14].

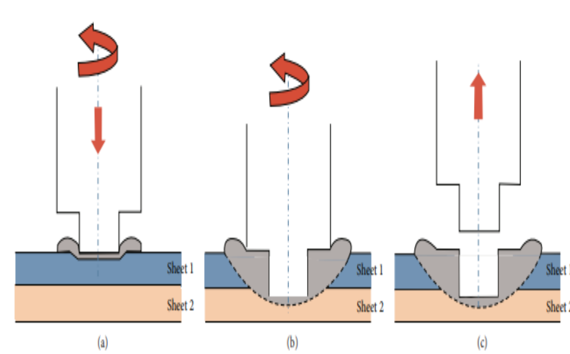


Figure (1): Schematic illustration of FSSW process (a) plunging, (b) stirring, and (c) retracting, [1]

The current study is deal with the optimization of similar friction stir spot welding of Al6061T6 by using original hybrid method consist of three stages, first nine experimental run, second construct relation between the inputs and the related output, third optimization by Social Spider optimization.

2. Experimental set up

2-1 material selection

The sheets of aluminum alloy with thicknesses of (2 mm) for Al6061-T6 were used in this work, The base material was chemically analyzed by spectrometer apparatus. The results of chemical composition for two kinds of aluminum plates are given in Table1 compared with [17].

Table (1): Standard and actual chemical compositions of AA6061-T6 aluminum alloy

Materials	6061T6 [test]	Standard
Si	0.617	0.4 -0.8
Fe	0.328	<0.7
Cu	0.236	0.15-0.4
Mn	0.054	<0.15
Mg	0.999	0.8 -1.2
Cr	0.217	<0.25
Zn	0.005	<0.15
Ti	0.032	0.04 -0.35
Al	Bal.	Bal.

The test specimens were cut by using a water jet machine with ASTM E8M -04 ,then the specimen's tensile test is testing by a universal testing machine with maximum capacity (50KN) to find mechanical properties. Three reading for Vickers Macro hardness are taken at load 294N to find the hardness.

2-2 welding procedure

The similar welding process were done by the friction stir spot welding of two aluminum plates (6061-T6) lab joint done with welding tool of tool steel X12 for three different pin shapes (cylinder, square, and hexagonal) with (6mm diameter and 3.7mm length) and cylindrical shoulder of dimensions (18mm diameter and 3cm length) . Two aluminum plates with dimension (100*25*2) mm were firmly clamped with a fixture of mild steel as shown in Fig.2. After the dwell time about 20 sec to plasticize the plates, the pin started to weld. Three different rotational speeds and plunged time were chosen as shown in Tables 2 and 3 using experimental procedure.

Table (2): The FSSW parameters and their levels

Parameter	Rotational speed (rpm)	Plunged time (sec)	Tool shape
Level 1	1800	40	Hexagonal (1)
Level 2	1120	70	Square (2)
Level 3	710	100	Cylinder (3)

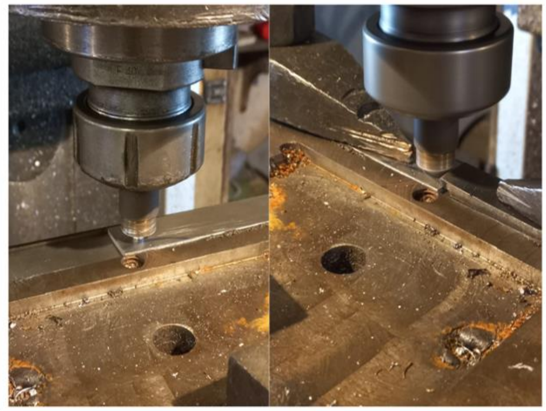


Figure (2): Fixture of sample to welding

Table (3): The experimental tests for the welding process

Experiment No.	Rotational speed (rpm)	Plunged time (sec)	Tool shape
1	1800	40	Hexagonal (1)
2	1120	70	Hexagonal (1)
3	710	100	Hexagonal (1)
4	1120	40	Square (2)
5	710	70	Square (2)
6	1800	100	Square (2)
7	710	40	Cylinder (3)
8	1800	70	Cylinder (3)
9	1120	100	Cylinder (3)

After the FSSW are done for each case the tensile test is done to find ultimate tensile strength to find the welding efficiency from equation

$$\text{Efficiency of joint} = \frac{\text{tensile stress of welded plate}}{\text{tensile stress of based metals}} * 100\% \quad (1)$$

The samples after welding are shown in Fig. 3

Figure (3): Samples after welding

3. Hyprid optimization method

ANN is formed by three layers (input layer, hidden layers, output layer), three inputs are introduced to the ANN and one output with six neuron in one hidden layer that is the structure of the feed forward network. Normalization is done on the input and output to get best result by reduce the space of solution. The function that is used to train the hidden layer is called bipolar continuous activation function (tansig), and for output layer unipolar continuous activation functions (logsig) is used. As shown in Fig.4.[15]

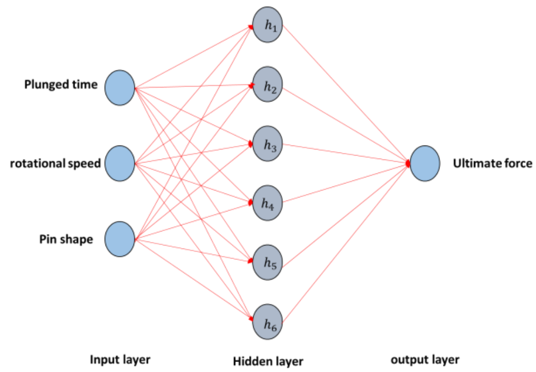


Figure (4): Neural network for the output- input relation.

The applying (tansig) to each neuron in the hidden layer as: [16]

$$\mathrm{out}(h_i) = \frac{2}{1+\exp^{-\lambda\,\mathrm{net}(h_i)}} - 1 \quad \text{......(2)}$$

The applying (logsig) to each neuron in the hidden layer, as:

$$\mathrm{out}(o_i) = \frac{1}{1+\exp^{-\lambda\,\mathrm{net}(o_i)}} \quad \text{......(3)}$$

The Social spider optimization (SSO) algorithm is a type of a swarm algorithm that has the foundation for the simulation of involving mutual assistance in working toward the performance of social spiders. [18]

The proposed process followed in calculations and the present problem solving operations is adopted this algorithm. This methodology assumed two different visions, such as spider's males and females. The mathematical formula that has been used for evaluating female spiders (Nf) is [17]:

$$N_f = floor\,[(0.9 - rand0.25).N_s] \quad \text{......(4)}$$

Where (rand) represents random number within a value between (0-1) and (floor) is considered to be a mapping from real to integer number, and (NS) is the spiders total number. the numbers of male spiders have been computed as [19,20]:

$$N_m = N_s - N_f \quad \text{......(5)}$$

The equation that used for evaluating the weight of each spider is written as [17]

$$w_i = \frac{J(s_i)-\mathrm{worst}_s}{\mathrm{best}_s-\mathrm{worst}_s} \quad \text{.......(6)}$$

Where J(si) can be defined as the value of the fitness which obtained from the position of the spider (si) with respect to the objective function (Jf). The range (r) of the mating operation in the SSO can be defined as the radius that is relay on the search space size and it is evaluating as below

$$r = \frac{\sum_{j=1}^{n} P_j^{high} - P_j^{low}}{2n} \quad \text{......(7)}$$

P_j^{high}, P_j^{low} are the lower and upper bond of the initial parameters, the flow chart of the method used is shown in Fig.5. The comparison is done with other researches to check the quality of this optimaztion method for finding the optimal conditions. As shown in Table4.

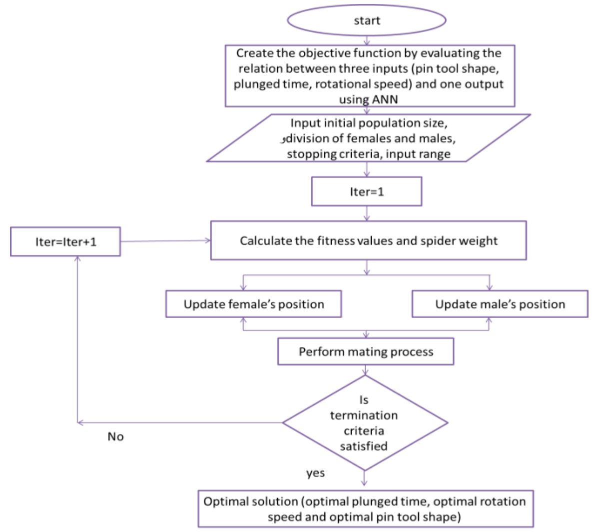


Figure (5): Flow chart for current method

Table (4): The verification of current method with other researches

	Weld> speed (rpm)	Plunged time (sec)	Third param.	Fourth param.	Optimal output
Ref. [Saleh,2016]	2000 rpm	8	plunge depth=0.9mm	plunge rate=10m m/min	Tensile shear = 9.57 kN
Current method	1900	8.3	0.92	11	10KN
Ref. [Onur,2021]	1500	10	Pin height=2.6mm	-	Ultimate stress=122.16MPa
Current method	1450	9.5	2.65	-	132.16MPa
Ref. [Suriya,2022]	3500	10	feed = 2 mm rev–1	-	shear force = 2.83 kN
Current method	3450	9.8	1.9	-	3KN

4. Result and discussion

4-1 Mechanical properties

After tensile test is done on three samples of two kinds of aluminum alloy the mechanical properties are found as listed in Table5.

Table (5): Mechanical properties of aluminum alloy

	Young modulus (GPa)	ultimate stress (MPa)	Maximum elongation (%)	Hardness (HV)
6061T6	68	310	15	98.25

4-2 FSSW results

The ultimate shear stress of welding plates is calculated, as shown in Table 6

Table (6): The experimental results for FSS similar welding of (AL6061T6)

Exp. No.	Rational speed (rpm)	Plunged time (sec)	Tool shape	Ultimate force (N)	Ultimate stress (MPa)	Efficiency of joint
1	1800	40	Hexagonal 1	2710	110	35%
2	1120	70	Hexagonal 1	2430	98.66	31.6%
3	710	100	Hexagonal 1	3110	126.27	40.7%
4	1120	40	Square 2	2840	115.3	37.2%
5	710	70	Square 2	4580	185.95	60%
6	1800	100	Square 2	2570	104.3	33.6%
7	710	40	Cylinder 3	2400	97.44	31.4%
8	1800	70	Cylinder 3	2570	104.34	33.65%
9	1120	100	Cylinder 3	4550	184.73	59.6%

From the above curves it can be seen for Al6061 when the plunged time is increased the ultimate force is increased too because the heat generation during the welding is increased and plasticized the zone well. The rotational speed affected in opposite for 6061 welding plate the ultimate shear force decrease when rotational speed increased because of heat generation depending on rotational speed and increased too much.

For tool shape affects, the square shape of pin is given the minimum shear force, because the blasting effect of sides and it is smooth profiles combined with appropriate time 70 sec for generate the required heat generation. The curves for the effect of parameters are shown Fig.6,7 and 8. Also it can be seen for low time the ultimate force is small because the small amount of heat generation that produced.

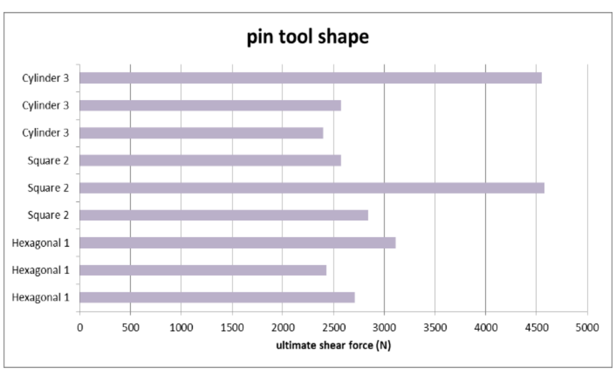


Figure (6): The effect of pin tool shape of ultimate shear force

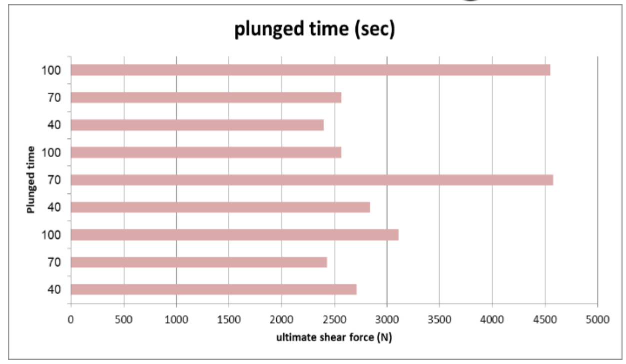


Figure (7): The effect of plunged time of ultimate shear force

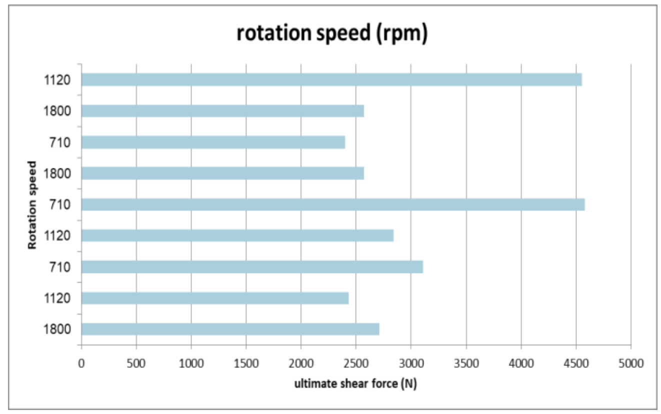
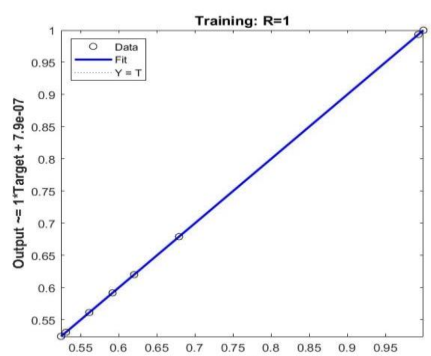


Figure (8): The effect of rotation speed of ultimate shear force

The above results are the input for the new hybrid method used to find the optimal conditions. The neural network performance for the current case are shown in Fig.9, and performance index for social spider optimization is shown in Fig.10



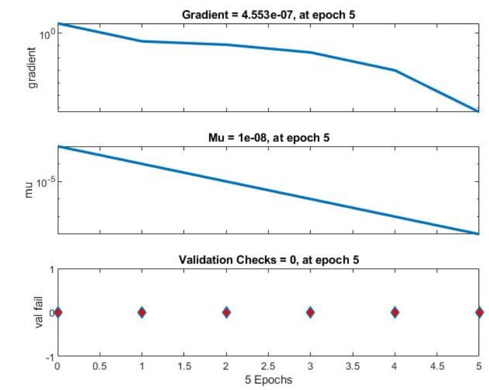


Figure (9): Neural network performance and regration

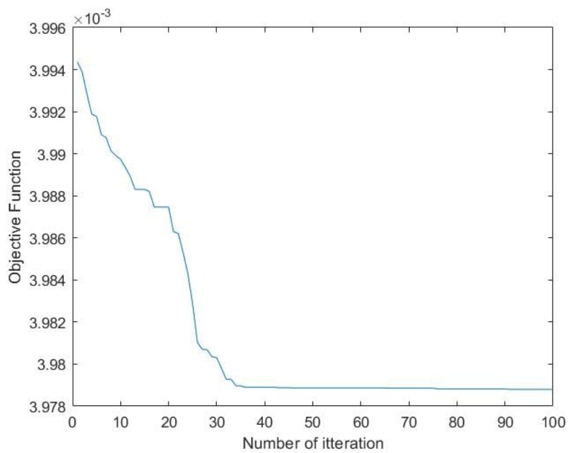


Figure (10): Performance index

The optimal condition that obtained from current method compared with experimental results as shown in Table 7

Table (7): Optimum parameter to get maximum ultimate force of AL6061T6

Plunged time (sec)	100
Rotational speed (rpm)	710
Tool shape	square
Predicted ultimate force (N)	4934.44
Experimental ultimate force (N)	4740
Discrepancy%	4%

The average Vickers micro-hardness of the region (TMAZ) is higher than that of the heat affective zone as shown in Fig.11 because of the precipitation of the coarsened precipitate-hardened. But the two zones (TMAZ, HAZ) showed the lower hardness in the welding zone. The weld nugget zone has the higher hardness due to the recrystallization of grains that occurred according to the maximum temperature reached nugget zone and highly shear stresses induced by tool motion forming the microstructure with small grains and equiaxed microstructure [10]. On the other hand the less hardness value is found in the HAZ at the welded of 6061-T3, and that is the cause of the coarsening of precipitates. The discrepancy in the hardness values in each weld section is due to the complete influences of strain hardening, variation of the dimensions of grain, and the strengthened phase dissolution [7].

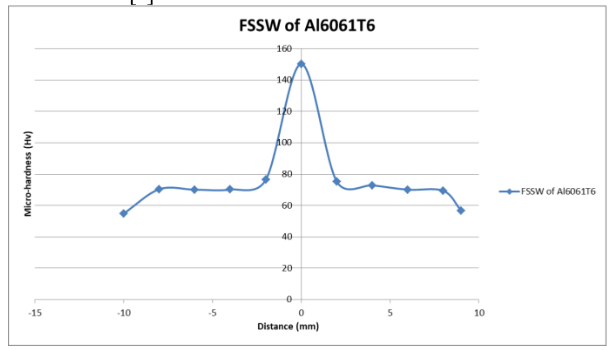


Figure (11): micro hardness across welding zone

5. Conclusion

In this work, the aluminum alloy are welded by using FSSW process for different parameters (rotational speed , plunged time, tool shape) and three levels are used. Social spider optimization with neural network is used to optimize the parameters of welding. The main conclusions are:

1- For Al6061 welded when the plunged time is increased the ultimate force is increased too.
2- The rotational speed affected in opposite the welding alloy, the ultimate shear force decrease when rotational speed increased because of heat generation depending on rotational speed and increased too much.
3- For tool shape affects, the cylindrical shape is given the minimum shear force, because the blasting effect of sides and it is smooth profiles. The maximum tensile force is obtain at square pin.
4- The best results that obtained from new hybrid method with experimental results, with discrepancy of 4%.
5- The weld nugget zone has the higher hardness due to the recrystallization of grains that occurred according to the maximum temperature reached nugget zone and highly shear stresses induced by tool motion and the hardness is high than the material without welding.

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