



## Discretization and artificial neural network approach in resistance spot welding of aluminium alloy AA6063 T6 sheets used in automotive applications

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### Abstract

The present research work investigates the approach for predicting the mechanical properties – tension shear; nugget diameter; direct tension; torsion shear for a resistance spot weld of aluminum 6063 T6 sheets of 0.5 mm. In this study, the discrete analysis viz., finite element method; finite difference method was used to predict the parameters for experimentation and heat affected zone. Various levels of the three important spot welding parameters - weld force, weld current and weld time were selected to be used for analysis and experimentation. In order to validate the numerical results a series of experiments were carried out and the mechanical properties were measured. The results obtained with the experimentation were used to build up a back propagation, artificial neural network model for the mechanical properties prediction. The results revealed that the combination of these two developed models – discretization and artificial neural network can accurately and rapidly predict the mechanical properties for a resistance spot weld.

**Keywords:** resistance spot weld, finite element method, finite difference method, artificial neural network, aluminum alloys, heat affected zone

### 1. Introduction

For many years, resistance spot welding (RSW) is the principle joining method used in automotive industries. On an average a typical body of a car contains 4500 spot weld joints <sup>[1]</sup>. The joint in RSW method is made by the generation of heat due to the resistance offered by the work pieces for current flow and simultaneously applying the force (pressure). The electrodes are made of Copper and they conduct the weld current where the weld is to be made and they also serve to apply force on to the weld spot area to form a strong joint. The heat for joining the parts in RSW is an effect of the heat generated because of electrical resistance of welding circuits according to Joule-Lenz Law.

$$Q(t) = \int_0^t I(t) \cdot R \cdot dt$$

Where:

Q	–	Generated heat,
I	–	welding Current,
R	–	Electrical resistance of welding circuit,
T	–	Welding time.

In automotive industry, the usage of Aluminium alloys has been significantly increased as a requirement for light weight and highly fuel efficient vehicles. The principle characteristics of Aluminium alloys such as high strength to weight ratio and corrosion resistance makes it preferable choice over traditional

mild steel material for manufacturing automobile body structure <sup>[2]</sup>.

The use of discretization techniques will reduce the main costs associated with the experimental tests. Finite element method (FEM) and finite difference method (FDM) are the discretization methods used and along with artificial neural networks (ANNs), it is considered as an effective approach for solving complex problems. In recent years, the use of ANNs in modeling resistance spot welds has attracted the attention of researchers.

Y. Cho, *et al.*, <sup>[2]</sup>, study of effect of various welding parameters in aluminium RSW using a systematic two stage, sliding level design of experiment approach. Kancha Sammaiah, *et al.*, <sup>[3]</sup>, study was made on direct and indirect RSW on low carbon steel, under optimum welding condition from the experiments for single spot, double spot in series and zig-zag spot for the direct and indirect spot welding gave very good tension shear breaking loads, yield stress and working stress for lap joints cold rolled carbon steel sheet of 0.5mm thickness for tension shear applications. A. Ambroziak, *et al.*, <sup>[4]</sup>, Study was made on aluminium alloys are more frequently used in automotive industry especially as an alternative material for car-bodies. R.S. Florea, *et al.*, <sup>[5]</sup>, This study reveals that the welding process parameters have a great influence in the quality of the RSW joints. Davood Afshari *et al.*, <sup>[6]</sup> predicted the nugget size in resistance spot welding with a combination of a finite element analysis and an artificial neural network. However, the paper ignores the

strength of the weld which is also dependent on the nugget diameter experimental prototype test shall be recommended. B.D.Y. Sunil *et al.*, [7], predicted the ANN in the RSW optimum process parameters for the maximum tension shear criteria. Finite Element procedures were developed for heat affected zone prediction [8-10] in weld joints.

**2. Discretization Techniques**

Discretization techniques (FEM, FDM) are utilized in the present study involved in RSW operations. Due to the complexity of the spot welding process and the extensive connections between the different fields like mechanical, thermal, electrical, metallurgical, etc., a simulation of these operations is very difficult [6]. Heat affected zone (HAZ) is the portion of the parent material which has been heated above the critical temperature but has not melted. It is the area of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by welding. The heat from the welding process and subsequent re-cooling causes this change in the area surrounding the weld. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process [11].

In this study, a finite element model was used for simulating the spot weld in structural analysis while finite difference model was used for simulating in thermal analysis. To create the finite element model for the simulation of spot welding of aluminum 6063 T6, the commercial ANSYS16.0 software and the APDL environment were used while for create the finite difference model, the commercial MATLAB R2007b software and the FDM code were used.

**3. Experimental methods and conditions**

Experiments were carried out on Aluminium Alloy Al 6063 T6 sheet of 0.5mm thickness which is having a very good application for thin sheet fabrication. The chemical composition and mechanical properties are presented in Table 1 and Table 2. The dimensions of the sheets that were used are 75 mm × 25 mm × 0.5 mm, Fig. 1. Fig. 2 shows the drawing of the samples under study. Before spot welding, each sheet was cleaned mechanically with emery paper of 180 and 220 grade; and the welding process was performed by using the different levels of weld parameters that have been obtained by the design of experiments, trials were conducted on a 200KVA 3-phase 415 V 50 Hz hydraulic operated resistance spot welding machine, at Ordnance Factory Medak, Sangareddy (Dist), Telangana State, India. The welding conditions were based on the recommendations by AWS [12] in order to achieve the minimum nugget size and avoid an expulsion in welding.

**Table 1:** Chemical composition of specimen

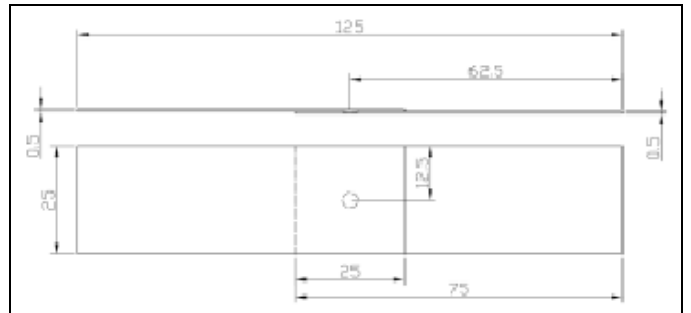
Element	Si	Cu	Mn	Mg	Cr	Zn	Ni
<b>Nominal Composition</b>	0.4	0.1	0.1	0.7	0.1	0.1	0

**Table 2:** Typical Mechanical Properties of specimen

S. No	Details of Properties	Units
1	Tensile strength	241.31MPa
2	Yield Strength	213.73MPa
3	Elongation	12%
4	BHN	73



**Fig 1:** Sample Test Specimen for RSW



**Fig 2:** Dimensions of tensile shear test specimen

RSW samples were produced over a range of weld force (F), weld current (C), and weld time (T) parameters, Table 3a.

**Table 3a:** Process parameters for experimentation

Test sample	Process parameters		
	Weld force (N)	Weld current (A)	Weld time (Cycles)
TS1	1765	21000	2
TS2	1961	21000	2
TS3	1765	24000	2
TS4	1961	24000	2
TS5	1765	21000	4
TS6	1961	21000	4
TS7	1765	24000	4
TS8	1961	24000	4

The weld samples were subjected to overlap tensile shear testing, coach peel testing, direct tension testing and torsion shear testing.

**4. Artificial neural network**

A multilayer back propagation feed forward ANN which was implemented and trained using Neural Network Toolbox in MATLAB R2007b 7.5 version package has been used for this study. All the pattern recognition and classification tasks can be performed with a three-layer BPN, even though BPNs may have many layers [11]. For training the ANN the Bayesian regularization algorithm (called trainbr in MATLAB) was used. Bayesian regularization is a function which trains the network and updates the weight and bias values according to Levenberg-Mar-quardt optimization. It determines the correct combination by minimizing the combination of squared errors, so as to produce a network that generalizes well.

The learning system of the ANN is similar to the training of the biological nervous system. A supervised learning mechanism was utilized in the training of the ANN in this research. Thus each input should come with its respective desired output. The inputs are 3 component vectors, a

component for each of the weld parameters, F, C and T. The target is the corresponding tensile shear strength of the RSW joint that is obtained from the respective input.

**Table 3b:** Process Parameters for ANN.

Weld Force (N)	Weld Current (A)	Weld Time (Cycles)
1765	21000	2
1863	21000	2
1961	21000	2
1765	22500	2
1863	22500	2
1961	22500	2
1765	24000	2
1863	24000	2
1961	24000	2
1765	21000	3
1863	21000	3
1961	21000	3
1765	22500	3
1863	22500	3
1961	22500	3
1765	24000	3
1863	24000	3
1961	24000	3
1765	21000	4
1863	21000	4
1961	21000	4
1765	22500	4
1863	22500	4
1961	22500	4
1765	24000	4
1863	24000	4
1961	24000	4

**5. Results & Discussion**

Since the loading criteria has to be studied for the lap joint failure, the FEM & FDM analysis and experiment & ANN studies are employed for better understanding of the process parameters and mechanical properties of the weld.

**5.1 FEM Analysis Results**

Maximum load criteria were simulated as per experimental setup. The results indicate the failure load which can be utilized for the selection of parameter ranges for conducting experiments. The results for analysis of tension shear were tabulated in Table 4. It was observed that the tension shear load failure range is from 275N to 830 N. The results for analysis of torsion shear were tabulated in Table 5. It was observed that the torsion shear load failure range is from 0.06 N-m to 1.37 N-m. The results for analysis of direct tension were tabulated in Table 6. It was observed that the torsion shear load failure range is from 280 N to 360 N.

**Table 4:** Tension shear results in FEM.

Force (N)	Tension Shear (N/mm <sup>2</sup> )			Remarks
	XY	YZ	XZ	
5	0.88	0.2	0.8	
70	9.2	4	11.5	Design load with FOS 4
100	17.7	5.7	16.6	
275	48.8	15.7	45.5	Design load without FOS 4
400	71	22	66	
700	124	40	116	Min. failure load
800	142	4.6	132	
830	151	48.5	140.7	Max. failure load

**Table 5:** Torsion Shear Results in FEM.

Force (N)	D (mm)	M (F x d)	Torsion Shear (N/mm <sup>2</sup> )			Remarks
			XY	YZ	XZ	
5	12.5	62.5	9.1	6.3	5.4	Design load with FOS 4
15	12.5	187.5	27	19	16	
25	12.5	312.5	45	31	27	Design load without FOS 4
30	12.5	375	55	38	33	
70	12.5	875	127	89	77	Min. failure load
90	12.5	1125	164	114	88	
110	12.5	1375	200	140	121	Max. failure load

**Table 6:** Direct Tension Results in FEM.

Force (N)	Tensile Strength (N/mm <sup>2</sup> )	Remarks
5	4.5	
25	22.5	Design load with FOS 4
60	54	
110	99	Design load without FOS 4
220	198	
280	251	Min. failure load (failure initiation)
320	287/70	
360	323/105	Max. failure load

Since the weld quality and strength are completely related to the process parameters, the FE analysis and FDM studies are employed to better understand the weld zones. Fig. 3a shows a typical temperature distribution of a spot welded FE model. Three distinct zones are clearly observed: the base metal (BM); the heat-affected zone (HAZ) and the fusion zone (FZ) or the nugget. The result indicates that heat affected zone (HAZ) is within 0.1 mm.

**5.2 FDM analysis results**

Thermal analysis was performed using FDM which revealed that the temperature distribution in the material is in accordance with the FEM thermal results. Fig. 3b shows the thermal analysis results obtained from the FDM.

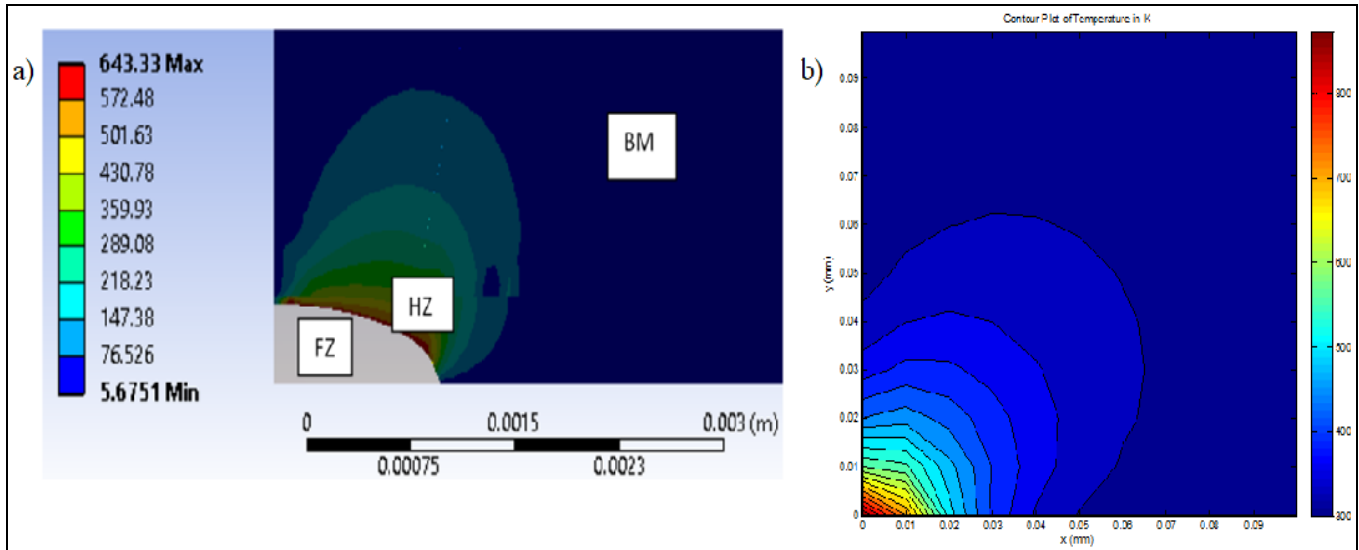


Fig 3: Temperature Distribution with (a) ANSYS (FEM) (b) MATLAB (FDM)

**5.3 Experimental test results**

The experimental test results revealed that the failure loads are as expected with FEM. Different mechanical tests viz., tension shear, torsion shear, direct tension and the peel test for measuring the nugget size were conducted for the samples which showed the results as tabulated in Table 7. FE model presented in the study illustrates the steps of the load failure criteria. To validate the FE model results, the model was compared with the data obtained with the experimentation as

indicated in Table 8. The FEM results (tension shear, torsion shear, direct tension) are compared with the actual experimental test results for 8 samples. The FEM results indicate that the presented model has a good accuracy. Fig.4 is the comparison of experimental and Ansys results. Fig. 4a shows the typical setup for the testing method of RSW joint in a UTM of 5 ton capacity. Fig. 4b shows the failed sample in tension shear load. Fig. 4c is the FEM analysis result which showed the failure of joint at around 750 N.

Table 7: Experimental results for the mechanical properties.

Test sample	Tension shear load (N)	Torsion shear load (N-m)	Direct tension load (N)	Nugget Diameter (mm)
TS1	331	0.49	221	2.99
TS2	593	1.17	397	3.56
TS3	467	1.27	260	3.53
TS4	485	1.37	237	3.61
TS5	434	0.98	311	3.4
TS6	425	0.98	229	3.88
TS7	524	0.78	234	3.25
TS8	470	0.93	258	3.49

Table 8: FEM vs Experimental Results.

S. No	Analysis	FEM result	Experimental result
1	Tension Shear Load (N)	275 - 830	330 - 600
2	Torsion Shear Load (N-m)	0.06 - 1.37	0.49 - 1.37
3	Direct Tension (N)	280 - 360	221 - 397

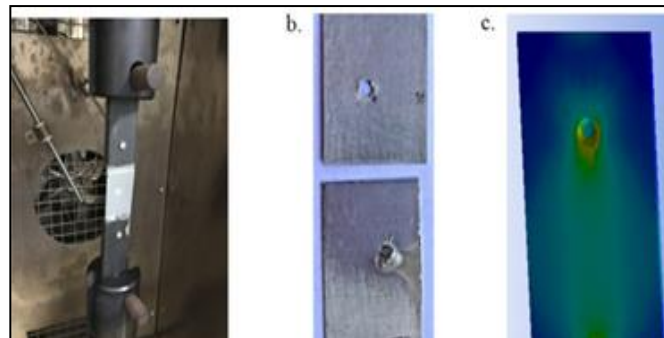


Fig 4: (a) Tension shear experimental setup (b) Test sample after failure (c) FEM (Ansys) failure weld

### 5.4 Artificial neural network results

Of the 27 sets of parameters presented in Table 3b, eight experimentation test cases (Table 3a) were selected and used for training the ANN, and further for all ANN was implemented. The 27 ANN test results were plotted against the

8 experimental results of test samples from Fig 5-8. The ANN results demonstrate within 10% of the experimental results. Hence, ANN is found to be the best approach for multi test case prediction on accordance with experimental results.

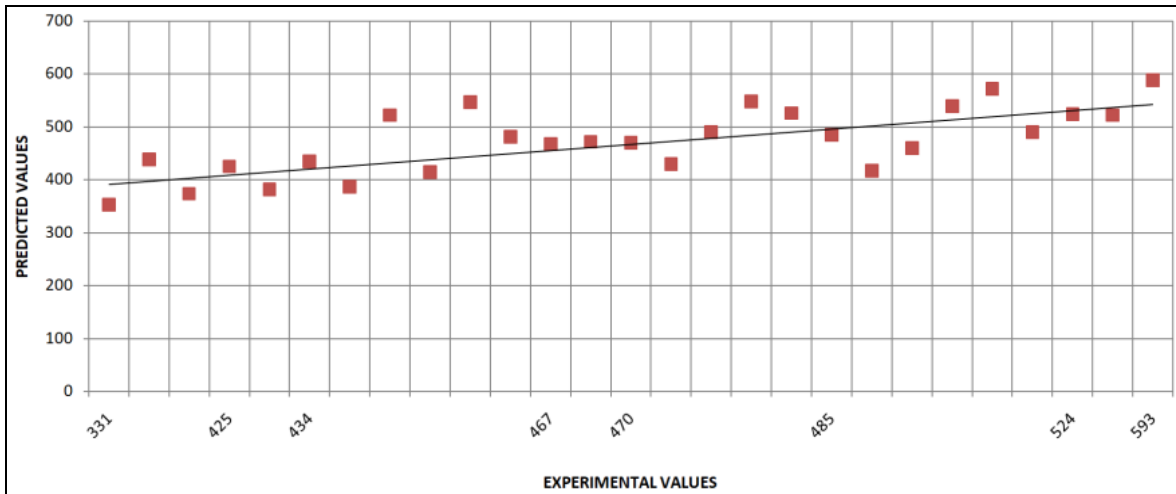


Fig 5: Tension shear experimental vs ANN (N)

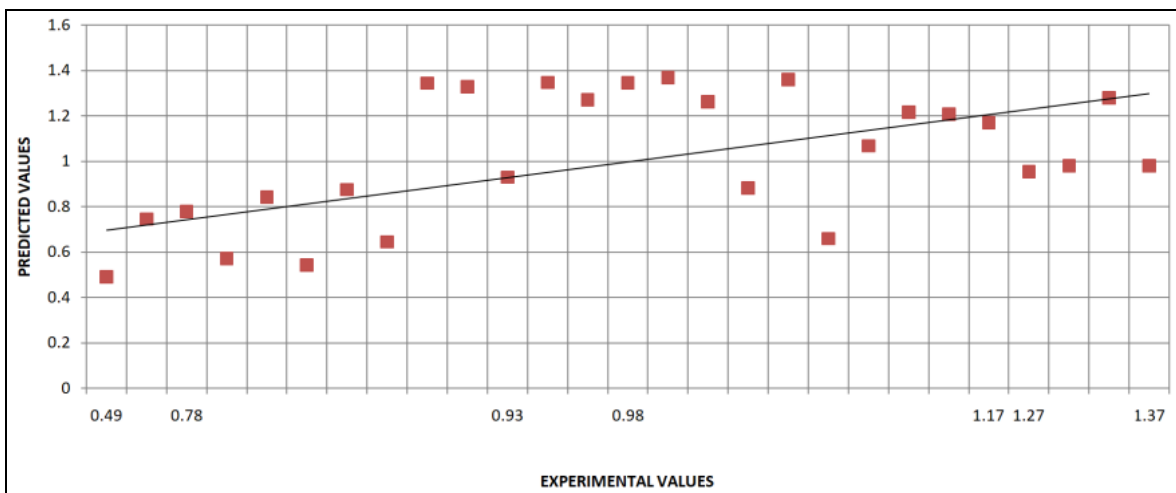


Fig 6: Torsion shear experimental vs ANN (N-m)

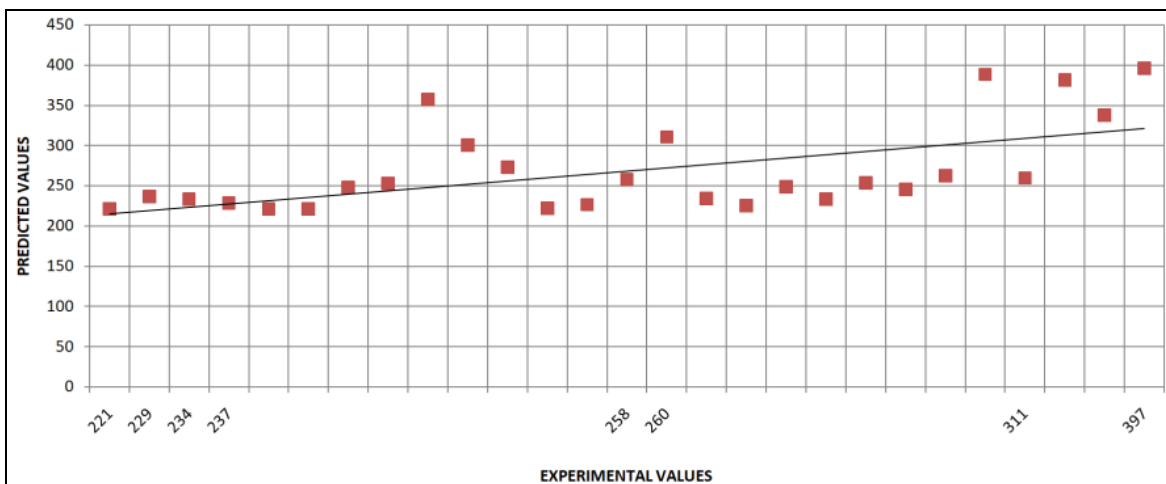
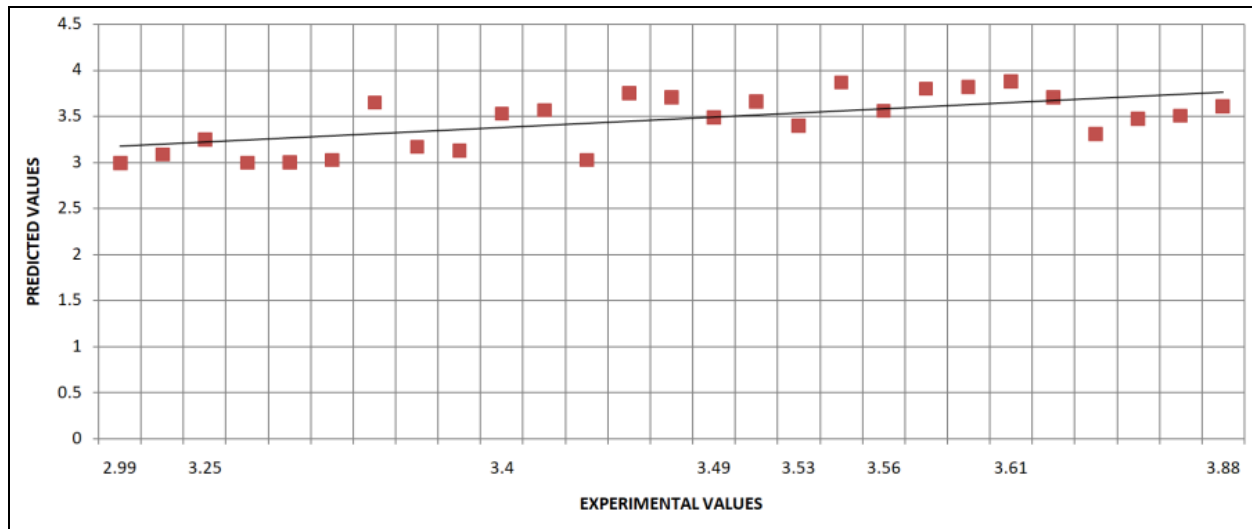


Fig 7: Direct tension experimental vs ANN (N)



**Fig 8:** Nugget diameter experimental vs ANN (mm)

As mentioned before, the welding conditions for obtaining optimum mechanical properties were based on the recommendations by AWS<sup>[12]</sup> in order to achieve tension shear of 593 N, torsion shear of 1.17 N-m, direct tension of 397 N, and nugget diameter of 3.56 mm for the sheets with a thickness of 0.5 mm which is obtained in the test sample TS2. Considering the results obtained from a previous study<sup>[7]</sup>, for aluminium 6063 T6 sheets of 0.5 mm, with a weld-nugget diameter of above 3.5 mm, the spattering of melt during a spot welding operation is predictable. Tables 7 shows the mechanical properties obtained from the experimental tests.

## 6. Conclusions

In this study, the tension shear, torsion shear, direct tension for the spot weld of an aluminium 6063 T6 sheet with a thickness of 0.5 mm was predicted with finite element analysis. The findings obtained from the experimental and analysis results can be summarized as follows:

- The comparison between the FEM results and the experimental results indicates that the presented model has a good accuracy in the prediction of the mechanical properties and that, by using this model, the efficiency of RSW joints can be rapidly investigated.
- The ANN model created using the results of the experimental tests conducted has good accuracy (less than 10%) in the prediction of the mechanical properties, based on the spot welding parameters of the weld force, weld current and weld time.
- After the verification of FEM vs experimental and ANN vs experimental, by the use of the FEM and ANN, the process parameters for RSW can be well predicted, reducing the number of experiments.

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