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STUDY ON BREAKING LOAD OF SINGLE LAP JOINT USING HYBRID JOINING TECHNIQUES FOR ALLOY STEEL AISI 4140 AND MILD STEEL: TAGUCHI AND NEURAL NETWORK APPROACH

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Abstract: The present investigation carried out to analyze the breaking load of single lap joint using hybrid joining techniques for alloy steel AISI 4140 and mild steel as base material by experimentally and optimized by Taguchi method and neural network. The six samples of lap joints were prepared namely: bolted joint (BJ); adhesive joint (AJ); welded joint (WJ); bolted-welded joint (BWJ); adhesive-welded joint (AWJ) and adhesive-bolted joint (ABJ). The breaking load of the joints in terms of breaking load and elongation were evaluated for each joint. The effect of the adjustment attached to the joint on the breaking load and elongation were evaluated. Taguchi method was applied for given input parameters and L4 design of experiments was used. The breaking load and elongation were taken as output response. The predicted values by Taguchi method were used as target values in neural network fitting curve. Neural network fitting tool was used to check whether the obtained values were near the target value or not. Based on the achieved results, the maximum breaking load and elongation were found for bolted-welded joint.

Keywords: lap joint, fracture load, elongation, Taguchi method, Neural network.

1. Introduction

The various methods of joining (like bolting, riveting, adhesively, etc) for mechanical parts and other components play a significant role in determining the breaking strength and performance of the joints [1-3]. It has been reported in the literature that the bolted joints are known for its strength but these joints have a main disadvantage due to drilled holes. This causes the earlier fatigue due to development of the stress and strain concentration [4-6].

Hoang-Ngoc et al. [7] simulated the single lap bonded and the hybrid (adhesive/bolted) joints with a flexible adhesive. The adhesive shear stress was homogeneous in the overlap. The peeling stress decreased considerably as the free surface of the specimen was approached. In peeling stress, the effect of adhesive compressibility on the joint stiffness as well as adhesive stress distribution was significant. The fatigue life of hybrid joints was found higher than the simple bolted joints.

Dang Hoang et al. [8] investigated the failure mode analysis of a bolted single lap joint of the Aluminum alloy 6082 T6 under tension-shearing. They investigated that the failure modes depend on the number and disposition of the bolts. The torque has little influence on the failure mode of the bolted joint. Li et al. [9] carried out the experimental study on failure modes of the composite riveted joints under both quasi-static and dynamic loading conditions. The loading rates have significant effect on failure mode. The failure modes may change with increasing loading rate. The total energy absorbed by joints increases with increasing loading rate whereas the rivet rotation decreases with increasing loading rate thus reduce the joint strength.

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Samaei et al. [10] investigated experimentally and numerically fatigue crack growth of Aluminum alloy 2024-T3 single lap simple bolted and hybrid (adhesive/bolted) joints. The effective stress intensity factor range decreases with increasing the clamping force which leads to the longer fatigue life. The hybrid joint with high clamped force showed the longer fatigue life as compared to that of simple bolted joint. Sadowski et al.[11] the paper deals with experimental investigations of steel adhesive double lap joints (DLJ) reinforced by rivets. The analysis of riveted, adhesive and hybrid (adhesive and rivet) joints showed that the two stage fracture process of double lap adhesive joints by rivets introduced by riveting improve both the static strength and the stiffness of joint. The energy absorption (hybrid joint) was increased by 35% as compared to that of riveted joint. Lambiase and Di Ilio [12] investigated the suitability of mechanical clinching for production of hybrid metal–polymer joints. During joining of metal polymer by clinched joint, the preheating time and preheating temperature of hot air plays an important role. Moderate preheating (55-130^{o}C) and low preheating time showed the better results in terms of low joining time, no crack formation as compared to that of conventional joining process.

Kelly [13] investigated the strength and fatigue life of hybrid (bonded/bolted) joints with carbon-fiber reinforced plastic. The hybrid joints with high strength failed catastrophically in net-section mode whereas for low strength the failure occurs in a non-catastrophic bearing mode. Fu and Mallick [14] study on the static and fatigue performance of hybrid joints in a structural reaction injection molded composite. They reported that the performance of the hybrid joint depends on the washer design. The hybrid joints have more static breaking load and better fatigue life than the adhesive joints. In FSW process, the properties of the joint like hardness, Young's modulus, yield stress affected by input parameters (applied pressure, filler content, rotational speed) as reported by many researchers[15-18]. The metal matrix composite plate shows good surface roughness [21].

The aim of the present study is to analyze the breaking load and elongation in single lap joints by using various techniques. Taguchi method was used to predict the response in terms of breaking load and elongation and further use of these values as input parameters to find the best fit curve by the neural network approach.

2. MATERIALS AND METHOD

2.1 Material and lap joint preparation

Alloy steel (AISI 4140) and mild steel (low carbon steel) were selected for a single lap joint and various joining techniques were used to find out the breaking load of a single lap joint. The samples of lap joint were designed according to the ASTM D 1002. The dimensions of the lap joint are shown in the Fig. 1.

As shown in the Fig. 1 the lap length of joint (in shear area) was selected 25 mm and 50 mm and the total length of the lap joint were 202.8 mm (lap length 25 mm) and 227.8 mm (lap length 50 mm). In welded joint, a single lap welded joint of alloy steel and mild steel plates was prepared by using arc welding. The specimens were designed according to the ASTM standards. A bolted joint was prepared by drilling the plates, nut and bolts were used for preparing a single lap joint according to the ASTM A307. The size of the bolts was taken 9 mm diameter. Cyanoacrylate adhesive was used for joining the plates. Cyanoacrylate commonly sold under the trade names as "Super Glue" and "Krazy Glue". The curing time of the adhesive was 24 hours. The thickness of the adhesive was kept 0.5 mm in all the joining techniques.

The drill were done on the plates then cyanoacrylate adhesive was used for joining the plates with the help of the bolts as shown in the Fig. 2(a). The hybrid joint of weld-bolted joint as shown in Fig. 2 (b) was formed by drilling on the plates. A vertical drilling machine was used to drill holes of 9 mm diameter.

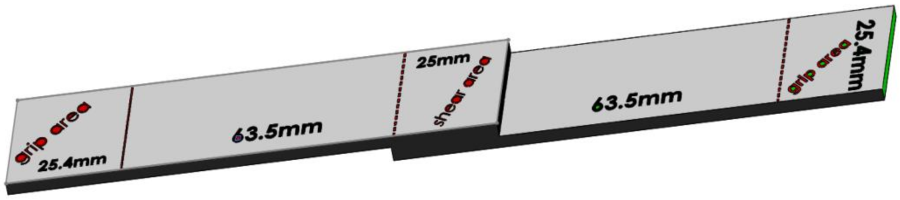

Fig. 1.0 show the dimension of the single lap joint

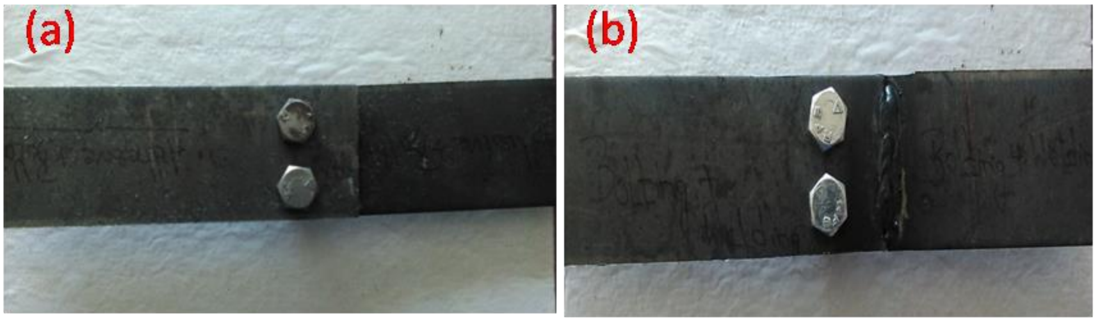

Fig. 2 Photograph of hybrid joints (a) adhesive-bolted joint (b) bolted-welded joint

2.2 Mechanical Testing

2.2.1 Breaking load

Tensile testing of the hybrid joint was carried out according to ASTM D 1002. The tests were conducted on a tensile testing machine (HEICO -HL-590, New Delhi, INDIA). Each value reported is the average of three specimen tests. The extension rate was kept constant at a rate of 10 mm/min for each specimen.

2.3 Taguchi Method

Taguchi method uses special design of orthogonal array to study the entire parameters space with only a small number of experiments [19]. An orthogonal array is formed using Taguchi method to study the entire parameter space with small number of experiments. Numbers of levels used in this setup are two as shown in Table 1 and the degree of freedom of the parameters is one.

Table 2 shows the design of experiments. The varying parameters are lap length, adjustment thickness and adjustment length. The results of tensile tests on single lap joints were analyzed. The output response were breaking load of the joint during tension and elongation at the breaking load. The L4 orthogonal array was formed. Taguchi gives importance to the response variation using S/N ratio, which results in minimizing the quality characteristic variation caused due to the uncontrollable parameters. The equation (1) was used to find the S/N ratio indicates higher is better. The equation (2) was used to find the S/N ratio indicates lower is better. In the Taguchi method, the S/N ratio is used to determine the deviation of the performance characteristic from the desired value [20].

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\right)\sum_{i=n}^{n}\frac{1}{y_i^2} \tag{1}$$

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\right)\sum_{i=n}^{n} y_i^2 \quad (2)$$

Table 1 Test parameters with levels

Sl.No.	Parameter	Levels	Level[1]	Level[2]
1	Lap length(mm)	2	25	50
2	Adjustment thickness(mm)	2	0.25	0.50
3	Adjustment length(mm)	2	100	125

Table 2 Design of Experiments

Sl.No.	Design of experiments	Lap length (mm)	Adjustment thickness (mm)	Adjustment length (mm)
1	L1	25	0.25	100
2	L2	25	0.50	125
3	L3	50	0.25	125
4	L4	50	0.50	100

2.4 Neural network

The Neural network tool is used in MATLAB, fitting curve option is chosen to check how much the output results vary from the target values. In this method mean tensile load obtained for various joints is taken as input whereas the maximum value of tensile load is taken as the target value. Neural Network signifies how much the load values are deflecting from its target values.

Neural network fitting curve was applied for Taguchi predicted values and actual values obtained after tensile test. The Taguchi predicted values were taken as target values and the obtained values from the tensile test were taken as input. Once a neural network is 'trained' to a good level it can be used as an analytical tool on other data. To do this, the user no longer defines any training runs and allows the network to work in forward propagation mode only.

3. RESULT AND DISCUSSIONS

3.1 Breaking load of hybrid joints

Four types of single lap joints were formed namely; (a) alloy steel AISI 4140 with alloy Steel AISI 4140 Lap joint (b) alloy steel AISI 4140 with mild steel Lap joint (c) mild steel with mild steel Lap joint.

3.1.1 The breaking load for conventional and hybrid single lap joints

There are six types of lap joints made namely: bolted joint (BJ); adhesive joint (AJ); welded joint (WJ); bolted-welded joint (BWJ); adhesive-welded joint (AWJ) and adhesive-bolted joint (ABJ). The breaking load was evaluated and shown in the Fig. 2. The breaking load of the AJ was the lowest as compared to the BJ and WJ, whereas the breaking load was increased for all hybrid joints (BWJ; AWJ and ABJ). The breaking load was decreasing for all hybrid joints (BWJ; ABJ and AWJ) for material used as AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS respectively as shown in the Fig. 2. It was found that the maximum breaking load was achieved for hybrid joint made by bolted-welded joint (BWJ) for two type of materials used (AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS). The highest breaking loads of BWJ were achieved of 51.83 kN, 48.60 kN and 53.56 kN for AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS materials respectively. Whereas the lowest value of breaking load were found for ABJ as 34.43 kN, 33.4 kN and 32.8 kN for AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS materials respectively. The fracture locations of the three joints were different. It was observed that the fracture location for AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS were 13.24 mm, 12.46 and 10.29 mm from the centre of the shear zone. It has observed that the breaking load of the WJ is slightly better than ABJ for all type of materials used as seen from the Fig. 3.

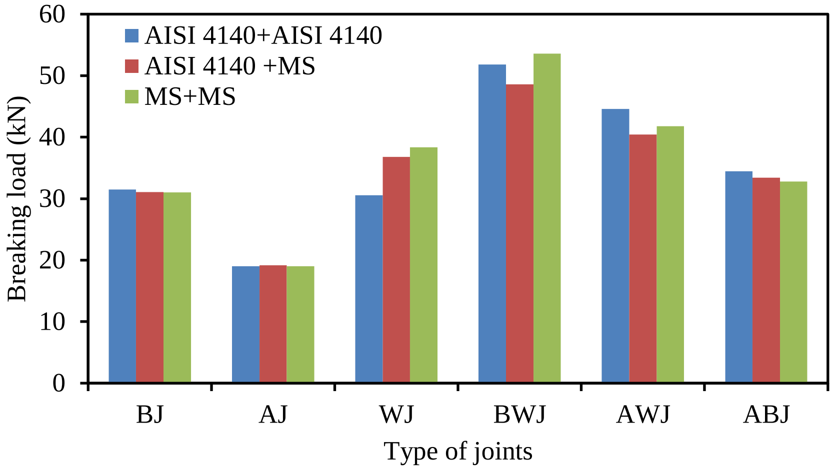

Fig.3 the breaking load for conventional and hybrid single lap joints

3.1.2 The elongation for conventional and hybrid single lap joints

Figure 4 show the elongation for conventional and hybrid single lap joints for various material compositions. Adhesive joint show the lowest elongation as compared to other joints whereas the elongation of BWJ and AWJ were on higher side. The value of elongations of BWJ was 5.21mm, 5.32 mm and 5.73 mm for AISI 4140+ AISI 4140; AISI 4140+Mild Steel (MS) and MS+MS materials respectively. The possible reason of higher elongation of this joint is due to higher breaking load for all type of materials. The hybrid joints (BWJ, AWJ and ABJ) show higher elongation as compared to that of conventional joints (BJ, AJ and WJ) as seen in Fig. 4. The hybrid joints have higher breaking load and higher elongation.

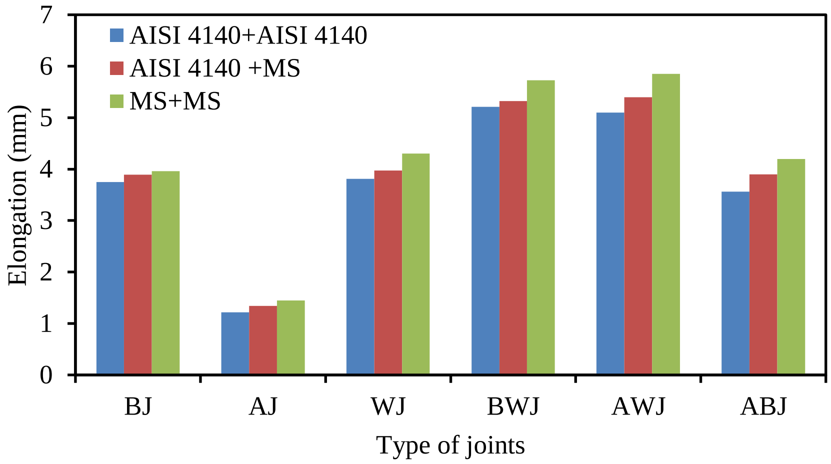

Fig. 4 Shows the elongation for conventional and hybrid single lap joints

3.2 Optimization using Taguchi Method

The joints with adjustment showed an increase in the breaking load. Using Taguchi method bolted-welded joint and adhesive – bolted joint with adjustment were optimized. Three input parameters such as lap length (100 mm and 125 mm), adjustment length (125 mm and 100 mm) and adjustment thickness (0.25 mm and 0.50 mm) were varied. The two levels were taken and L4 matrix was formed. As per the constraints four designs of experiments were prepared. The Taguchi design of experiment was performed on Minitab software. Table 3 shows the common parameters used in design of experiments and the value of breaking load and elongation were taken as input value. Table 4 shows the response table for signal to noise ratio-output response as breaking load and elongation. Table 2 shows the ranking of each parameter. If rank one was given to a certain parameter this indicates that parameter has more influence on the breaking load.

3.2.1 Optimizing bolted-welded joint with adjustment

Bolted- welded joint with adjustment is made according to the design experiment as discussed in the above table. A single lap joint was made using alloy steel AISI 4140 with mild steel and tensile test was done on this joint, the values of breaking load and elongation at break point were recorded. In Taguchi method, the equation 1 was used to evaluate the S-N ratio. In our study, higher S/N ratio was preferred for both the outputs (elongation and breaking load). It has been seen from Fig. 5 that the variation in the lap length is maximum from the mean line whereas the variation in the adjustment length is minimum. The variation in any parameter about the mean line indicates more sensitivity on the output response (breaking load and elongation). In this case the lap length is more sensitive parameter as compared to the adjustment length and adjustment thickness.

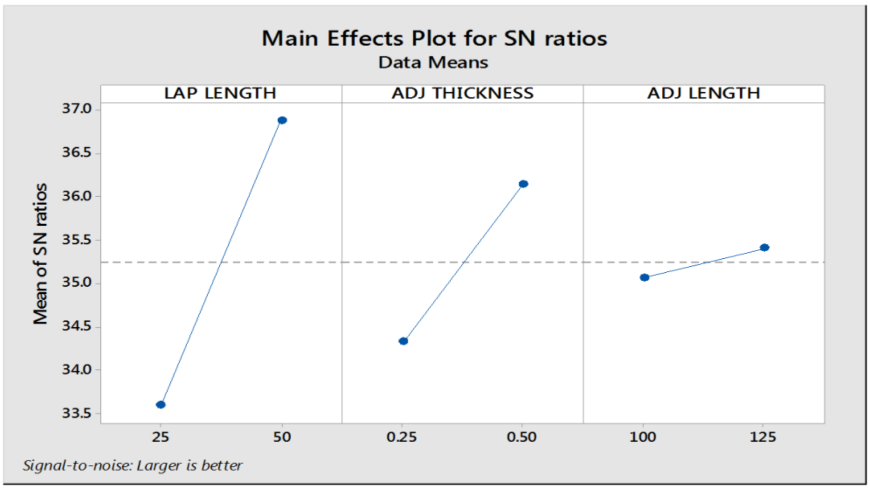

Fig. 5 Shows signal to noise ratio curve, output response- breaking load

Table 3 Design of experiments for breaking load and elongation as input value

Sl. No.	Common parameters for Design of Experiments			Design of Experiment breaking load as input value		Design of Experiment elongation as input value	
	Lap length (mm)	Adjustment Thickness (mm)	Adjustment Length (mm)	Breaking Load (kN)	S/N ratio	Elongation (mm)	S/N ratio
1	25	0.25	100	42.21	32.50831	6.41	16.13716
2	25	0.50	125	54.12	34.66716	9.22	19.2946 2
3	50	0.25	125	64.13	36.14122	10.20	20.1720 1
4	50	0.50	100	75.96	37.62769	10.51	20.4320 5

The bolted-welded joint was optimized and the output parameter was the elongation length. The elongation is mostly affected by lap length and adjustment thickness causes minimal affect on the elongation length. Table 3 indicates the design experiment and the input value of elongation, the table also indicates the S/N ratio. Table 4 indicates ranking of each parameter. Figure 6 shows the S/N ratio curve, maximum value of S/N ratio indicates maximum variation.

Table 4 Response table for signal to noise ratio-output response as breaking load and elongation.

Level	Response value for signal to noise ratio-output response (breaking load)			Response value for signal to noise ratio-output response (elongation)		
	Lap Length (mm)	Adjustment Thickness (mm)	Adjustment Length (mm)	Lap Length (mm)	Adjustment Thickness (mm)	Adjustment Length (mm)
1.	33.59	34.32	35.07	17.72	18.15	18.28
2.	36.88	36.15	35.40	20.30	19.86	19.73
Delta	3.30	1.82	0.34	2.59	1.71	1.45
Rank	1	2	3	1	2	3

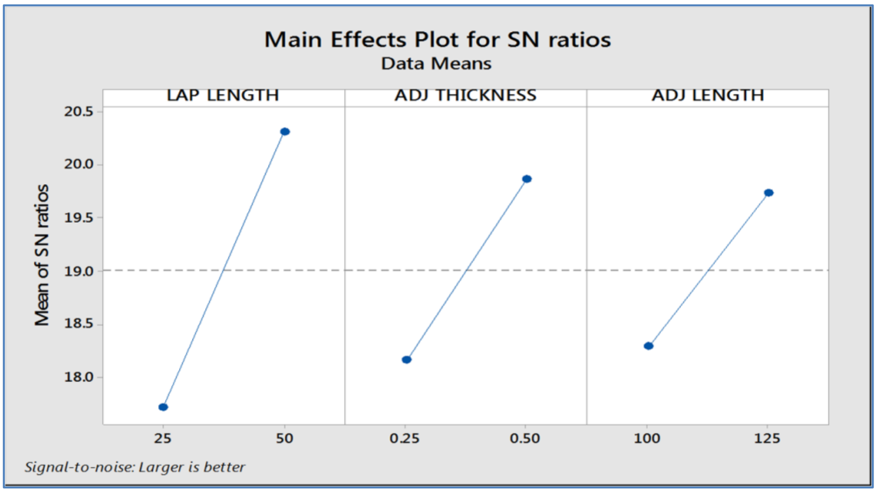

Fig. 6 Shows signal to noise ratio curve, output response- elongation

3.2.2 Predicted Values by Taguchi Method

The predicted values of breaking load and elongation of the samples were obtained for various types of joints. The predicted values of breaking load and elongation are reported here for Taguchi predicted design of experiment (lap length, 50 mm; adjustment thickness, 0.5 mm; adjustment length, 125 mm). For bolted –welded joint with adjustment, the predicted breaking load by Taguchi method was obtained 76.07kN and the S/N ratio 37.9639. The actual breaking load was 75.96 kN. The elongation for the same design of experiment, the S/N ratio 21.8808 and mean-11.76, the predicted value of elongation by Taguchi method was obtained 11.76 mm and the actual elongation value was 10.91 mm.

For adhesive-bolted joint with adjustment, the breaking loads for predicted and actual values were 48.14 kN and 49.64 kN respectively. The elongations for predicted and actual values were 6.185 mm and 5.96 mm respectively. These results show the good closeness between the actual and predicted values of breaking load and elongation.

3.3 Neural Network Fitting Curve Applied to Taguchi Predicted Values

As discussed in the section 2.4, the neural network is applied for Taguchi predicted values and actual values obtained after tensile test. The Taguchi predicted values were taken as target values and the values obtained after tensile test were taken as input. Neural network fitting tool was used to check whether the obtained values were near the target value or not. A total twenty neurons were used to validate the results. The data were divided into test data, validation data and training data. The training data, validation data and test data were taken to be 70%, 15% and 15% respectively. The performance fit for Taguchi predicted and actual values are shown in figure 7.

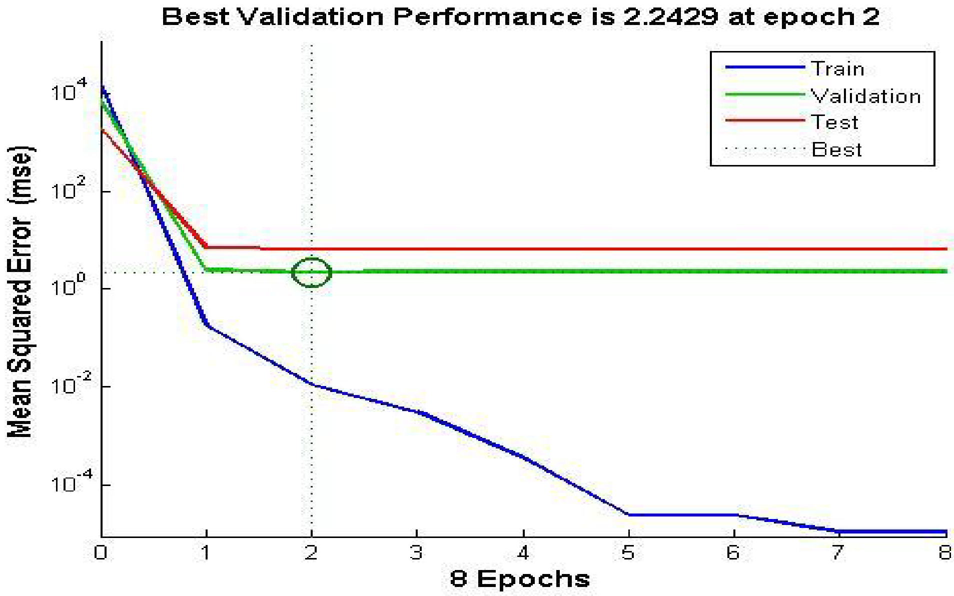

Fig.7 Shows neural network performance fit

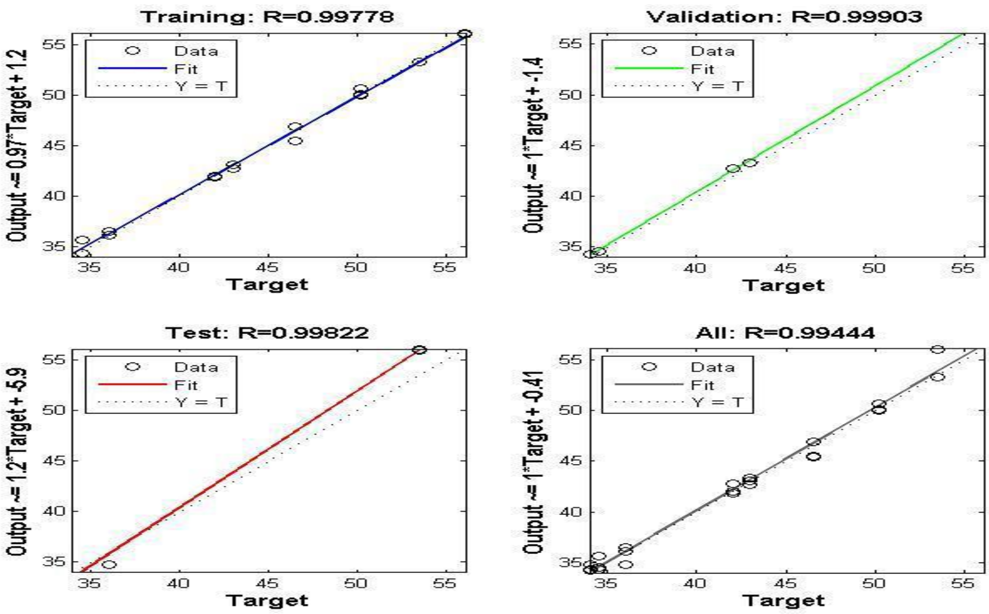

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Fig.8 Shows regression fit for training, validation and testing data.

As seen from the Fig.8, the decrease in the curve indicates how the networks mean squared error decreases as it learns. The blue line indicates the decreasing error on the training data. The green line shows the validation error. Training stops when the validation error starts decreasing. The red line shows the error on the test data. These lines in the Fig. 8, indicates how well the network will generalize to new data. The validation data reached its minimum value at epoch 2 as shown in Fig. 7. The best validation performance value came out to be 2.2429. The red and green lines are almost similar which means less over fitting and a good plot.

4. Conclusions

In this study, the breaking load and elongation at break point of single lap joints Using Hybrid Joining Techniques for Alloy Steel AISI 4140 and Mild Steel as base metal has been investigated. The main process parameters influencing the breaking load and elongation of the joints have been identified. Based on the achieved results, the following main conclusions are summarized below:

- The breaking load of single lap joint lower as compared to that of the hybrid joints, whereas the bolted-welded joint showed the highest breaking load.
- By using the adjustment in the joint, the breaking load of the hybrid joints was increased by 20-30% as compared to that of the joints without adjustment.
- For the breaking load, the S/N ratio -37.9639 and mean -76.07 the predicted breaking load by Taguchi method was obtained 76.07kN and the actual breaking load was 75.07 kN.
- The predicted value of elongation by Taguchi method was obtained 11.76 mm and the actual elongation value was 10.91 mm.
- In neural network, the validation data reached its minimum value at epoch 2 and the best validation performance value came out to be 2.2429. The fitting curve of neural network indicated a good relationship between the input and target values.

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