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Estimating Hardness and Tensile Strength of Vibratory Dissimilar Welded Joint using Machine Learning Technique

J.Kalpana[1], T.V.Madhusudhana Rao[2], V.V.Rama Reddy[3], P.Govinda Rao[4*], Satish Pujari[5]

[1]Dept. of Mechanical Engineering, Baba Institute of Technology and Sciences, Visakhapatnam

[2] Dept. of CSE, Vignan's Institute of Information Technology, Visakhapatnam, India

[3,5]Dept. of Mechanical Engineering, lendi Institute of Engineering and Technology, Vizianagaram

[4]Dept. of Mechanical Engineering, Avanthi's Research and Technological Academy, Bhogapuram, India

Abstract

This paper explores the extension work of past investigators, in which weld joints were produced using vibratory weld technique. This process yields the uniform and fine grain configurations due to dynamic solidification in the weld pool, which in turn enhances the tensile strength and hardness of the weldments. In this investigation, frequency of vibration has been considered as input parameter and ultimate tensile strength and hardness as output parameters in order to develop the regression model for estimating hardness and tensile strength of vibratory dissimilar welded joints.

Key words: Vibratory welding, frequency, hardness, tensile strength and regression technique

1. Introduction

Regression is one of the Machine Learning techniques for finding functional relationships among variables. The relation among the variable is given in the form of an equation or a model linking the dependent variable and predictor variables. In the current work, input variable is frequency at which the specimens to be welded and output variable is mechanical property. In such a way that regression equations have been developed for hardness and tensile strength with respect to frequency of specimens to be welded.

It is denoted that the response variable by Y and the independent variables by $X_1, X_2, \ldots, Xp$, where p states the number of independent variables. The actual relationship between Y and $X_1, X_2, \ldots, Xp$, may be approximated with regression technique is

$$Y = f(X_1, X_2 \ldots, Xp) + \epsilon_1$$

where E is presumed to a random error presenting the variance in the approximation. It is accounted for the failure of the model to fit the data with exactness. The

function $f(X_1, X_2, \ldots, Xp,)$ gives the relationship between Y and $X_1, X_2, \ldots,$

Xp.

Further, An example is given as the linear regression model

$$Y = \beta o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \epsilon_1$$

Where $\beta o, \beta_1 \ldots, \beta p$ are called the regression coefficients, are unknown constants to be found from the data. It is followed that the it is used notational convention of representing unknown parameters by Greek letters.

The independent variables are also named by other names such as predictor variables, factors, carriers and regressors. The nameindependent variable, although usually used that it is the least preferred, because of it is in practice the predictor variables may not be often independent of each other.

Rao P. G. et al., [1] developed vibratory welding system for enhancing the mechanical properties of welded joints.

Rao P. G. et al., [2] reported that from last few decades, vibratory welding techniques have been used for improving the mechanical properties of weldments. Previous results showed that welded test specimens under vibratory conditions exhibited improvements in mechanical properties than the conventional arc welding. In this present work, vibratory set-up has been developed for inducing mechanical vibrations during welding operation. The designed vibratory set-up produces the required frequency with amplitude and acceleration in terms of voltages. In the current investigation, weld specimens were prepared while varying the two input parameters: voltage and time of vibration. And the remaining process parameters such as travel speed, current, and other electrode parameters were kept constant. Metallurgical properties showed that refined microstructure has been achieved for the vibratory welded specimens. The refined grain structure is responsible for the improvement in flexural strength, ultimate tensile strength, impact strength, and hardness of the vibratory weld pieces.

Rao P. G. et al., [3] reported that previous researches have been devoted to development of vibratory setup for inducing mechanical vibrations into the weld pool during welding process. The designed vibratory setup produces the required frequency with suitable amplitude and acceleration in terms of voltages. This helps in producing uniform and fine grain structure in the welded joints which results in an improvement in the mechanical properties of the weld pieces at heat affected zone. This paper presents the development of a smart prediction tool by implementing generalized regression neural network to establish a relation between vibration parameters such as input voltage to the vibromotor, time of vibration and impact strength of vibratory weld joints. In order to validate the feasibility of the developed prediction tool, a comparison is made with the experimental results.

Rao P. G. et al., [4] designed a vibrating table that produces the required frequency with suitable amplitude and acceleration in terms of voltages. This helps in producing a uniform and fine grain structure in the welded joints, which results in an improvement of the bending strength of the welded joints. This paper presents the implementation of the Generalized Regression Neural Network (GRNN) to establish a relation between vibration parameters such as the input voltage to the vibromotor, the time of vibration, and the bending strength of the vibratory welded joints. In order to validate the feasibility of the developed prediction tool, a comparison is made with the experimental results.

Rao P. G. et al., [5] stated that vibration techniques have been used in welding for improving the mechanical properties of metals in the last few decades. In the present work vibratory setup has been used for inducing mechanical vibrations into the weld pool during welding. The designed vibratory setup produces the required frequency with the amplitude and acceleration in terms of voltages. An increase in the flexural strength of the weld pieces in to the heat affected zone (HAZ) has been observed. The increase in mechanical properties is attributed to, as the weld pool solidifies, grains are not only limited in size but also dendrites are broken before they grow large in size. Refined microstructure has been observed. The above mechanism is responsible for the improvement in flexural strength of weld pieces welded with vibratory setup compared to without vibration during welding.

J.Kalpana et al., [11, 22] presented implementation of Generalized Regression Neural Network to establish a relation between vibration parameters and properties of vibration welded joints. During the welding of metals along with mechanical vibrations, uniform and finer grain structures can be produced. This increases the toughness and hardness of the metals, because of solidification effects at the weld pool surface. So, physical experiments have been conducted on the homogeneous welded joints by providing vibrations during the welding period. The voltage used to generate the vibration and the time of vibration is used as vibration parameters. Hardness of the welded joint is considered as one of the mechanical properties of the welded joint.

Rao P. G. et al., [6] reported that vibration techniques have been used in welding for improving the mechanical properties of metals in the last few decades. In the present work vibratory setup has been used for inducing mechanical vibrations into the weld pool during welding. The designed vibratory setup produces the required frequency with the amplitude and acceleration in terms of voltages. An increase in the impact strength of the weld pieces in to the heat affected zone (HAZ) has been observed. The increase in mechanical properties is attributed to, as the weld pool solidifies, grains are not only limited in size but also dendrites are broken before they grow large in size. Refined microstructure has been observed. The above mechanism is responsible for the improvement in impact strength of weld pieces welded with vibratory setup compared to without vibration during welding.

Rao P. G. et al., [7] stated that the residual stresses in welded structures produced by vibratory welding process has been discussed. Material properties, material manufacture, and structural geometry, welding process, treatments after welding and service conditions have been considered to analyse residual stress distributions. Plate butt welds, circumferential butt welds and weld cladding are the best examples to analyse residual stress distributions. Entire manufacturing and service history of the vibratory welded structure and its component materials are required for better understanding and analysing the improvement in prediction and reduction of residual stresses. Microstructure of can be refined when the welded joints prepared with the presence of vibration. In this study, mechanical vibrations were given to the weld specimens during welding for identifying its effect on the hardness, metallurgical structure and residual stress of the material. Residual stresses were found to diminish in response to vibration whether it was applied during welding or after welding. Also grain growth process in the weld was increased.

Rao P. G. et al., [8] mentioned that vibration techniques have been used in welding for improving the mechanical properties of metals in the last few decades. In the present work vibratory setup has been used for inducing mechanical vibrations into the weld pool during welding. The designed vibratory setup produces the required frequency with the amplitude and acceleration in terms of voltages. An increase in the tensile strength of the weld pieces in to the heat affected zone (HAZ) has been observed. The increase in mechanical properties is attributed to, as the weld pool solidifies, grains are not only limited in size but also dendrites are broken before they grow large in size. Refined microstructure has been observed. The above mechanism is responsible for the improvement in tensile strength of weld pieces welded with vibratory setup compared to without vibration during welding.

Rao P. G. et al., [9] reported that welded joints are used for construction of many structures. Welding is a joining or repair process which induces high residual stress field, which combines with stresses resulting from in-service loads, strongly influencing in-service behavior of welded components. When compared with stresses due to service loads, tensile residual stress reduces crack initiation life, accelerates growth rate of pre-existing or service-induced defects, and increases the susceptibility of structure to failure by fracture. Also, welding residual stresses are formed in a structure as a result of differential contractions which occur as the weld metal solidifies and cools to ambient temperature. Previously some of the methods like heat treatment and peening kind techniques were used for reduction of residual stress. However, those methods need special equipment and are time consuming. In this, we are proposing a new method for reduction of residual stress using vibration during welding. For this Mechanical vibrations will be used as vibration load. In this work, Finite Element Method (FEM) will be used for assessment of welding residual stresses and comparison of experimental results with FEM results for Mild steel butt welded joints.

Rao P. G. et al., [10] improved mechanical properties of steels, vibration techniques have been used in the last few decades. During the welding of metals along with mechanical vibrations, uniform and finer grain structures can be produced. This increases the toughness and hardness of the metals, because of solidification effects at the weld pool surface. As the weld pool solidifies, grains are not only limited in size, but dendrites growing perpendicular to the fusion line are restricted. While the process is going on, dendrites can be broken up before they grow to become large in size. Hence, the microstructure of the weld metal is improved during the solidification process. In this work, we employed a dynamic solidification technology, by applying mechanical vibrations during the ‘Arc welding’ process. Analyses have been carried out for mild steel pieces having 5 mm. of thick butt joints. The results obtained from the current study pointed out that the butt welded joints fabricated with vibratory condition are found to possess relatively high hardness, without any considerable loss in its ductility.

J.Kalpana et al., [12] presented the amplitude effect on tensile strength of welded joints produced with vibratory dissimilar TIG (Tungsten Inert Gas) welding process. In this study, new vibratory setup has been developed with two metal engravers for inducing mechanical vibrations to the specimens to be welded. Metal engravers are capable to produce different amplitudes of specimens by adjusting the knob provided on the metal engravers. Finally, analysis has been carried out on the effect of vibration amplitude on tensile strength of welded joints.

Rao et al. [13-33] proposed dynamic solidification technique during welding has been proposed to prompt the mechanical vibrations during welding of butt welded joints. It was presumed that butt welded joints arranged under vibratory conditions had high hardness with no loss of its ductility. Authors utilized the vibratory setup to affect the mechanical vibrations to the weld pool amid welding. Because of vibratory welding process, change of mechanical properties has been observed. It was inferred that the refined microstructure component was in charge of the change of impact strength, tensile strength, flexural strength and hardness of butt welded joints of mild steel plates. Authors observed that post weld vibratory treatment will not influence the crystal structure, the increase in all properties are related to the crystal structure only. Finally, General regression neural network technique (GRNN) based tool has been developed for estimating impact strength and hardness for given input parameters. GRNN is a proven prediction tool applied for various manufacturing applications including welding.

Dutta and Dilip [34] modelled a Conventional regression based on experimental data of a TIG welding process, to find its input-output relationship. A large training database for neural network was created at random, by varying the input variables within their respective range and responses were calculated for each combination of input variables by using the response equations obtained through the above conventional regression analysis. The performances of the conventional regression analysis approach, a back propagation neural network (BPNN) and a genetic-neural system (GA-NN) were compared on some randomly generated cases (experimental), which are different from the training cases.

Ganjigatti et al.[35] made an attempt to establish input output relationship in MIG welding process through regression analyses carried out both globally (i.e. one set of response equation for the entire range of variables) as well as cluster wise. It is important to mention that second approach make use of the entropy based fuzzy cluster. The investigation was based on the data collected through full factorial design of experiments. Results of the above two approaches were compared and the cluster wise regression analysis was found to perform a slightly better than the global approach in predicting weld bead geometry parameters.

Campbell et al. [36] used artificial neural network for the prediction of key weld geometries using GMAW with alternating shielding gases. A comparison showed that the experimental and the predicted geometries were matched closely.

Though there exists the literature that describes the phenomenon of enhancing the weld joint properties, the relation between vibration parameters and the weld joint properties tensle strength and hardness have not been developed. Hence the present work is concentrated for building a relation between vibration parameters and properties of welded joints. Finally, regression analysis has been used to build this model.

2. Regression Equation for Hardness

In the present case, frequency treated as the input parameter (X_1) and Hardness (Y_4) as the output parameter.

Hardness Equation 5th Order

$Y = C(0) + C(1)*X_1 + C(2)*X_1\verb|^|2 + ,,,$

Coefficients

C(0) = -1735.09947118

C(1) = 12.2588598212

C(2) = -0.0325977011485

C(3) = 4.29325626693e-005

C(4) = -2.79758701899e008

C(5) = 7.2173107656e-012

Correlation coefficient is 1

Standard error about the line = 5.25036538542e007

For developing above equation, two sets of data are required for regression analysis: training data set and validation data set. From the prepared welded joints of 21, 17 sets are chosen randomly for training while the rest of them, 4 in numbers, are taken for validation. The training data set and the validation data set including percentage of error deviation are given in Tables 1 and 2 respectively.

Table 1 Training data set with Error Deviation for Hardness

Expt. No	Frequency (Hz)	Hardness (RHN)	Hardness from Regression (RHN)	% Error Deviation
1	600	94	94.02285317	-0.02431
2	620	94	94.26204926	-0.27878
3	640	95	94.44680529	0.58231
4	680	95	94.84278611	0.165488
5	700	94	95.10482424	-1.17534
6	720	96	95.41959191	0.604592
7	740	96	95.78088617	0.228244
8	780	96	96.582738	-0.60702
9	800	97	96.98369931	0.016805
10	820	98	97.35753757	0.655574
11	840	99	97.68748815	1.32577

12	860	96	97.96298838	-2.04478
13	900	99	98.35602592	0.650479
14	920	98	98.50839095	-0.51877
15	940	99	98.68150398	0.321713
16	960	99	98.93738407	0.063248
17	1000	100	100.0624465	-0.06245

Table 2 Validation data set with Error Deviation for Hardness

Expt. No	Frequency (Hz)	Hardness (RHN)	Hardness from Regression (RHN)	% Error Deviation
1	660	94	94.62925375	0.669419
2	760	96	96.17484886	0.182134
3	880	97	98.18244908	1.21902
4	980	98	99.36088096	1.388654

The deviations in the output values predicted by regression analysis for the training data set and the validation data set are graphically represented in Fig. 1 and Fig. 2 respectively.

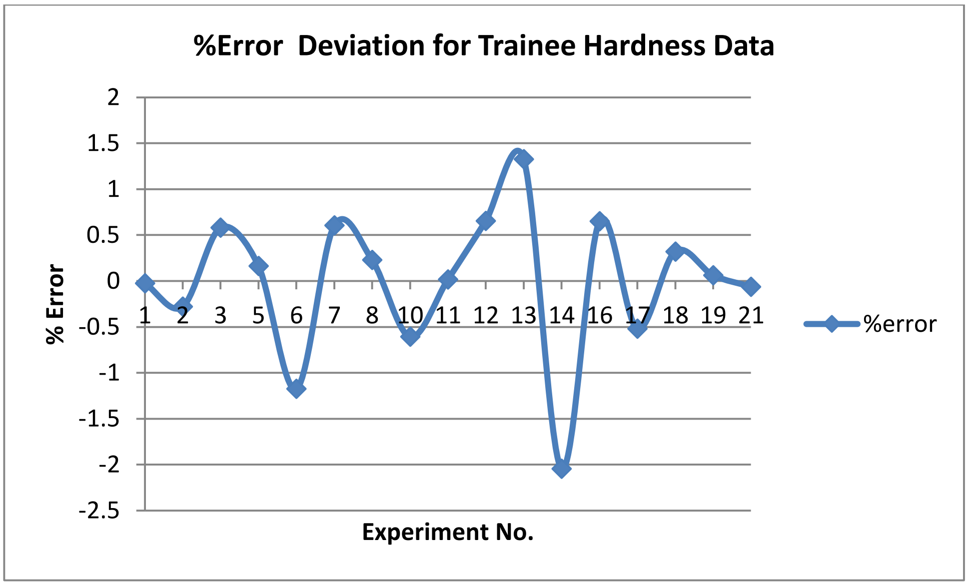

Fig. 1 Error percentage of training dataset for hardness

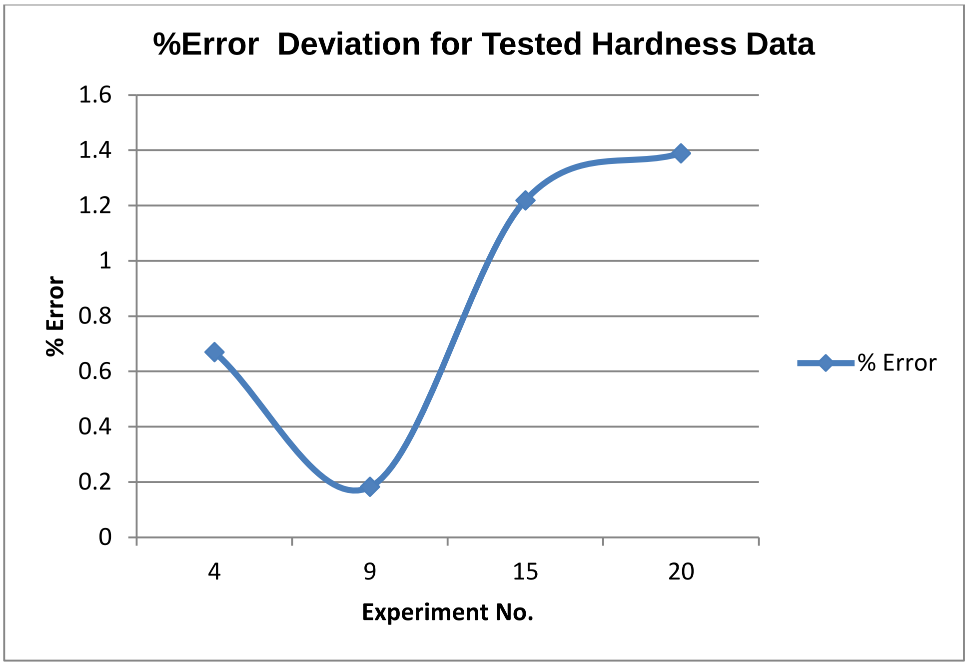

Fig. 2 Error percentage of validation dataset for hardness

The proposed regression equation for hardness has predicted the values with 97.5% accuracy for the training dataset implying that the deviations from the actual values fall within ±2.5% limits. The validation data set is predicted with 98.4% accuracy making regression a worthy equation for prediction of hardness strength

3. Regression Equation for Tensile Strength

In the present case, frequency treated as the input parameter(X_1) and the Tensile Strength (Y_1) as the output parameter.

Tensile strength Equation 1st order is

$$\mathbf{Y_1 = C(0) + C(1)*X_1}$$

Where Coefficients

C(0) = 392.947381224

C(1) = 0.149445600532

Correlation coefficient is

0.999899762397

Standard error about the line =0.271892009429

For developing above equation, two sets of data are required for regression analysis: training data set and validation data set. From the prepared welded joints of 21, 17 sets are chosen randomly for training while the rest of them, 4 in numbers, are taken for validation. The training data set and the validation data set including percentage of error deviation are given in Tables 3 and 4 respectively.

Table 3 Training data set with Error Deviation for Tensile strength

Expt. No	Frequency (Hz)	Tensile Strength (Mpa)	Tensile Strength from Regression (Mpa)	% Error Deviation
1	600	482.78	482.6147415	0.034231
2	620	485.69	485.6036536	0.017778
3	640	488.56	488.5925656	-0.00667
4	680	494.21	494.5703896	-0.07292
5	700	497.12	497.5593016	-0.08837
6	720	500.89	500.5482136	0.068236
7	740	503.67	503.5371256	0.026381
8	780	509.34	509.5149496	-0.03435
9	800	512.89	512.5038616	0.075287
10	820	515.78	515.4927737	0.055688
11	840	518.23	518.4816857	-0.04857
12	860	521.23	521.4705977	-0.04616
13	900	527.34	527.4484217	-0.02056
14	920	530.45	530.4373337	0.002388
15	940	533.86	533.4262457	0.081249
16	960	536.34	536.4151577	-0.01401
17	1000	542.23	542.3929818	-0.03006

Table 4 Validation data set with Error Deviation for Tensile strength

Expt. No	Frequency (Hz)	Tensile Strength (Mpa)	Tensile Strength from Regression (Mpa)	% Error Deviation
1	660	491.45	491.581478	-0.02675
2	760	506.45	506.526038	-0.01501
3	880	524.34	524.45951	-0.02279
4	980	539.78	539.40407	0.069645

The deviations in the output values predicted by regression analysis for the training data set and the validation data set are graphically represented in Fig. 3 and Fig. 4 respectively.

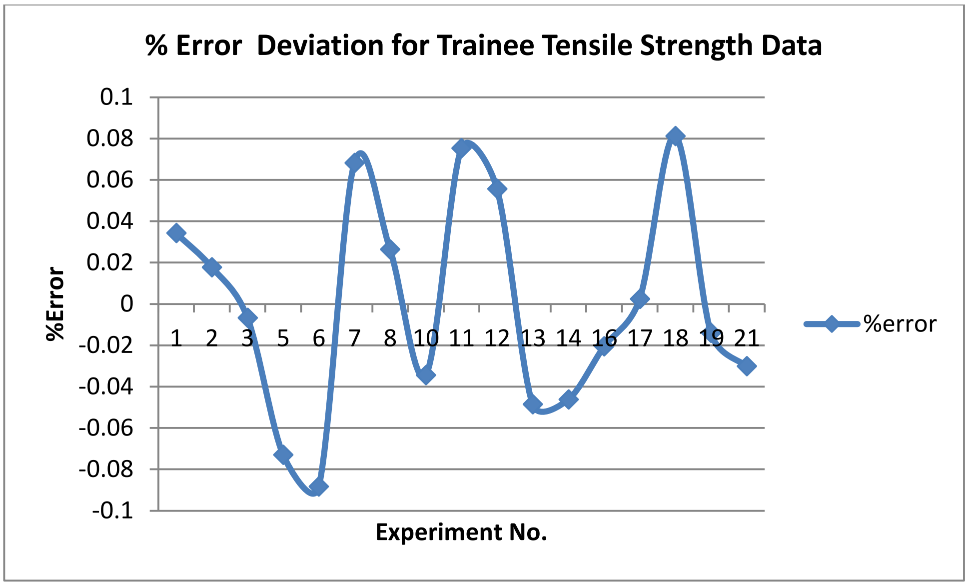

Fig. 3 Error percentage of training dataset for tensile strength

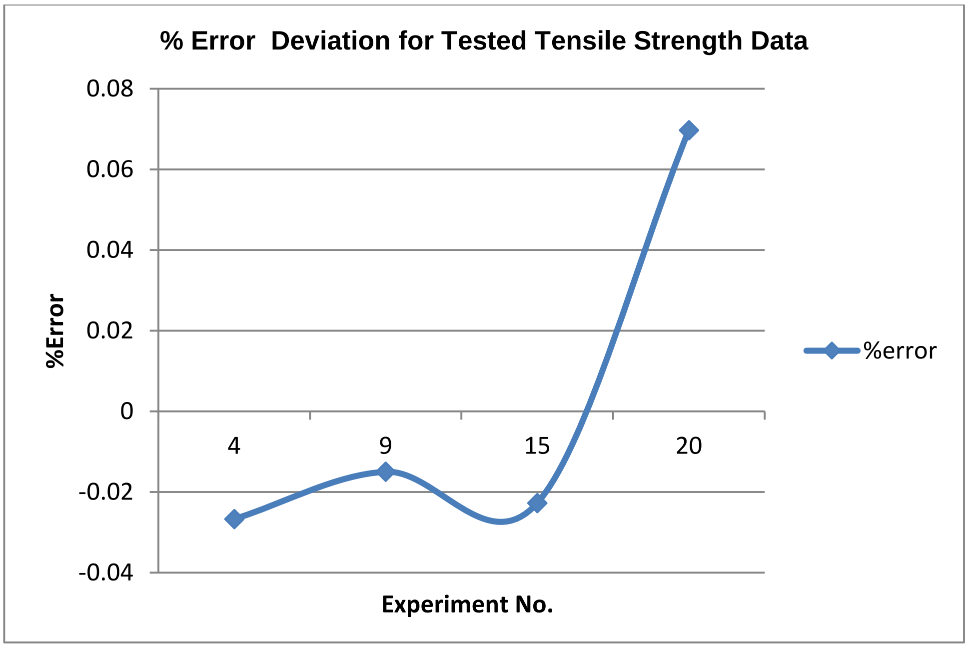

Fig. 4 Error percentage of validation dataset for tensile strength

The proposed regression equation for ultimate tensile strength has predicted the values with 99.9% accuracy for the training dataset implying that the deviations from the actual values fall within ±0.1% limits. The validation data set is predicted with 99.96% accuracy making regression a worthy equation for prediction of tensile strength.

Conclusions

A regression technique has been used to establish a relation between the chosen input vibration parameter (frequency) and the mechanical properties tensile strength and hardness of vibratory weld joints. In order to validate the feasibility of the developed prediction tool comparison is made with the experimental results. The regression technique has predicted the results for the mechanical properties with an accuracy of around 98%. Hence, the developed equations are to be used to find unknown values of hardness and tensile strength of weld joints without conducting actual tests.

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