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Implementation of Generalized Regression Neural Network to Establish a Relation between Vibration Parameters and Time of Vibration for Welded Joints

J.Kalpana[1] Dr. S.V.Ramana[2] P.Govinda Rao[3,] Dr. V.ChittiBabu[4]
K Santa Rao[5]
[1]PG Student, [2]Professor, [3,4]Associate Professor, [5]Assistant Professor Mechanical Engineering Department, GMRIT, Rajam

Abstract: *This paper presents 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 are used as vibration parameters. Hardness of the welded joint is considered as one of the mechanical properties of the welded joint.*

Keywords*:* *Vibratory welding, Neural Networks, Hardness*

I. Introduction

In manufacturing industries, welding is widely used for metal joining process. Metal arc welding is the most flexible fusion welding and one of the most widely used welding process. The welding joints prepared by arc welding process generally offers good strength and hardness properties. The mechanical vibrations into the weld specimen during welding process improve the weld joint properties significantly. The enhancement in the welded joint properties can be altered by varying the vibration parameters.

Though there exist literature describes the phenomenon of improving the welded joint strength properties, the relation between vibration parameters and the weld joint properties has not been established. Hence the present work is aimed to build a relation between vibration parameters and weld joint properties from the experimental data. Generalised Regression Neural Network is used to build the model.

General regression neural network GRNN is a type of supervised network, and has been widely accepted for its excellent ability to train rapidly on sparse data sets. GRNN usually performs better and faster in continuous function approximation.

II. Related Work

Hardness is the Resistance of a material to deformation, indentation, or penetration by means such as abrasion, drilling, impact, scratching and/or wears. The relative toughness of the mild steel or base metal is affected by many variables including: the chemical analysis, micro structural constituents, and strength or hardness level and grain size [11].

Heat treatable steels [12] have improved strength along with good properties of toughness and fatigue strength. In situations when tensile strength and the yield strength of structural steels don’t satisfy the design requirements, there is a need for heat treatable steels with higher carbon content. The improved strength allows the production of lighter structures, i.e. the usage of thin sheets. The problems that usually occur in welding of steels with higher carbon content are the following: weld cracking, weld metal porosity, high hardening of the weld metal, and cracking of the base material in HAZ [13]. The application of laser welding in industry is constantly increasing. The most important advantages of laser welding over other procedures include: high welding speed, small or no deformations of the welded parts, and high quality of the welded joint. Laser welding of steels with higher carbon content, such as heat-treatable steels has not yet been applied in high-volume production [13].

Arc welding [14] differs regarding the power density and the volume of heat input into the material. High power density in laser welding allows welding with lower specific heat input than in other welding, which results in very high cooling rates [15]. The cooling rates in arc welding are faster than other welding, so that a lower value of maximum hardness in the welded joint is expected. In vibratory welding, stirrer produce a disturbance in weld pool during solidification. After completion of nucleation, the solidification process will continue with nucleus growth. Increasing the growth rate will reduce the grain size of metal. In welding, as the heat source interacts with the material, the severity of thermal excursions experienced by the material varies from region to region, resulting in three distinct regions in the weldment [11].

Jijin Xu, Ligong Chen and Chunzhen Ni [4] described about the effects of the vibratory weld conditioning on the residual stress and distortion in multipass girth-butt welded pipes and also discussed about how vibratory weld conditioning reduce the residual hoop stresses at the outer surface and the radial distortion significantly. The improvement of welded structure’s properties fatigue damage resistance, stress corrosion cracking and fracture resistance due to vibratory weld conditioning is also well discussed.

Lakshminarayanan A.K. and Balasubramanian. V [5] described about improvement in tensile properties of 409M ferritic stainless steel welded joints in comparison with base metal. Ductility and impact toughness of welded joints also tested for the welded joints. Lu Qinghua, Chen Ligong and Ni Chunzhen [6] discussed about the applications of vibration during submerged arc multi-pass welding to improve welded valve quality. The reduction in residual deformation and stress due to vibratory weld conditioning is discussed. The enhancement of the impact property in the weld metal due to vibratory weld conditioning is described.

Munsi A S M Y, Waddell A J and Walker C A[7] discussed about the effect of vibratory stress on the welding microstructure and residual stress distribution of steel welded joints. The 25 percent improvement in hardness of weld joint is also discussed. Shigeru Aoki, Tadashi Nishimura and Tetsumaro Hiroi [8] discussed about a method for reducing the residual stress using random vibrations during welding. The residual stress in the quenched butt-welded joint is measure by paralleled beam X-ray diffractometer with scintillation counter.

Tewari S P and Shanker A.[9] described about improvements on yield strength, ultimate tensile strength and breaking strength on shielded metal arc welded joints due to vibratory conditions like longitudinal vibration and frequency. The drop in percentage of elongation due to the vibratory conditions is discussed. Weglowska. A, and Pietras A[10] described the influence of the welding parameters on the mechanical properties of vibration welded joints such are tensile properties and microscopic behaviour of dissimilar grades of nylons.

Dirk Tomandl and Andreas Schober[1] discussed about modified general regression neural network, which can be applied for common practical problems. Supervised training algorithms are proposed for training of neural network. Donald F. Specht[2] described about a one pass learning algorithm with well parallel structure named as the general regression neural network (GRNN), which can train sparse data in a multidimensional measurement space. The general regression neural network provides estimates of continuous variable and converges to the underlying linear or non linear regression surface. The parallel network form is superior in learning the dynamics of a model and also for prediction. Any non linear regression problem can be modelled with this algorithm. Hsien-Yu Tseng[3] described about implementing the general regression neural network to create approximate models to relate the spot welding parameters , weld joint strength and power required to prepare the weld joint. And implementation of optimisation algorithm on the neural approximation model to find out the economic design.

In the present study, welding is performed along with the vibrations for improving the mechanical properties of the base material. Physical experiments have been conducted on the homogeneous welded joints by providing vibrations during the welding period. Thereby, implementation of Generalized Regression Neural Network to establish a relation between vibration parameters and properties of vibration welded joints.

III. Experimental work

Vibration equipment setup

A platform to place the specimen is equipped with four springs along each the corner. The vibration platform is prepared by attaching a vibro motor to the vibration table set. A dimmer stat, voltmeter and ammeter are attached to the vibro motor to generate the vibrations. Fig.1a and Fig1b show the experimental setup.

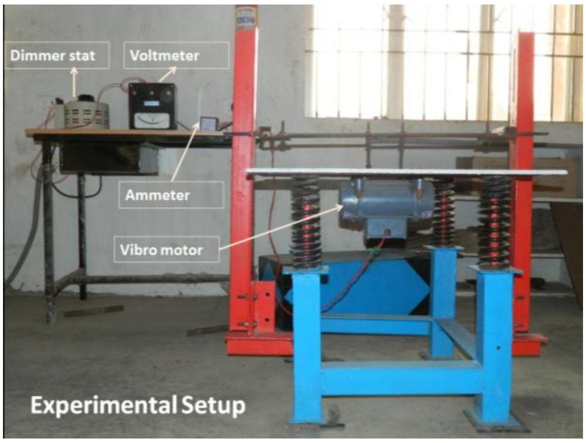


Fig.1a Vibration platform equipment setup

Fig.1b Vibration platform surface plate

Vibratory Setup for Welding

With an aim of improving the mechanical properties of weld joints through inducing of favourable changes in the weld microstructures, an auxiliary vibratory set up capable of inducing mechanical vibrations into the weld pool during manual metal arc welding is designed and developed. Different frequencies and with different amplitude are applied along the weld length, just trailing behind the welding arc so that weld pool could be mechanically stirred in order to induce favourable micro structural effects. This setup produces the required frequency with the amplitude in terms of voltages.

Weld joint Specimens Preparation

Mild Steel of 5mm. thickness is used in the current investigation, it is composed of (in weight percentage) 0.9% Carbon (C), 7.5-10.0% manganese (Mn), 1.00% Silicon (Si), 17.0-19.0% Chromium (Cr), 4.0-6.0% Nickel (Ni), 0.06% Phosphorus (P), 0.03% Sulphur (S), and the base metal Iron (Fe).

Steel plates are placed on the vibration platform and power is supplied to the vibration equipment. Specimen welding is represented in Fig.2

Fig.2. Welding the specimen using vibrations

The joints prepared by using arc welding using vibration equipment is represented in Fig.3

Fig.3. Butt welded joint prepared by vibratory welding

Measurement of Hardness

The Rockwell Hardness test is probably is the most widely used method of hardness testing. Rockwell testers use much smaller penetrators and loads than does the Brinell tester. Hardness is measured at the center of the weld bead for different welded specimens prepared under different voltages of vibrometer and times of vibration. Example of one specimen is shown in Fig.4.

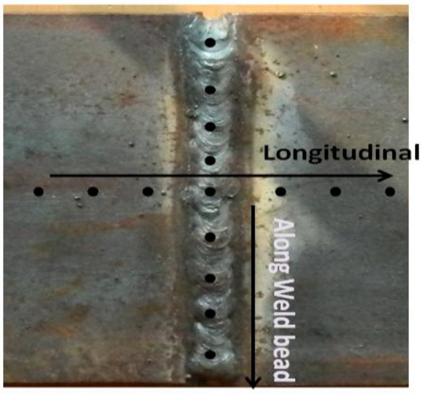
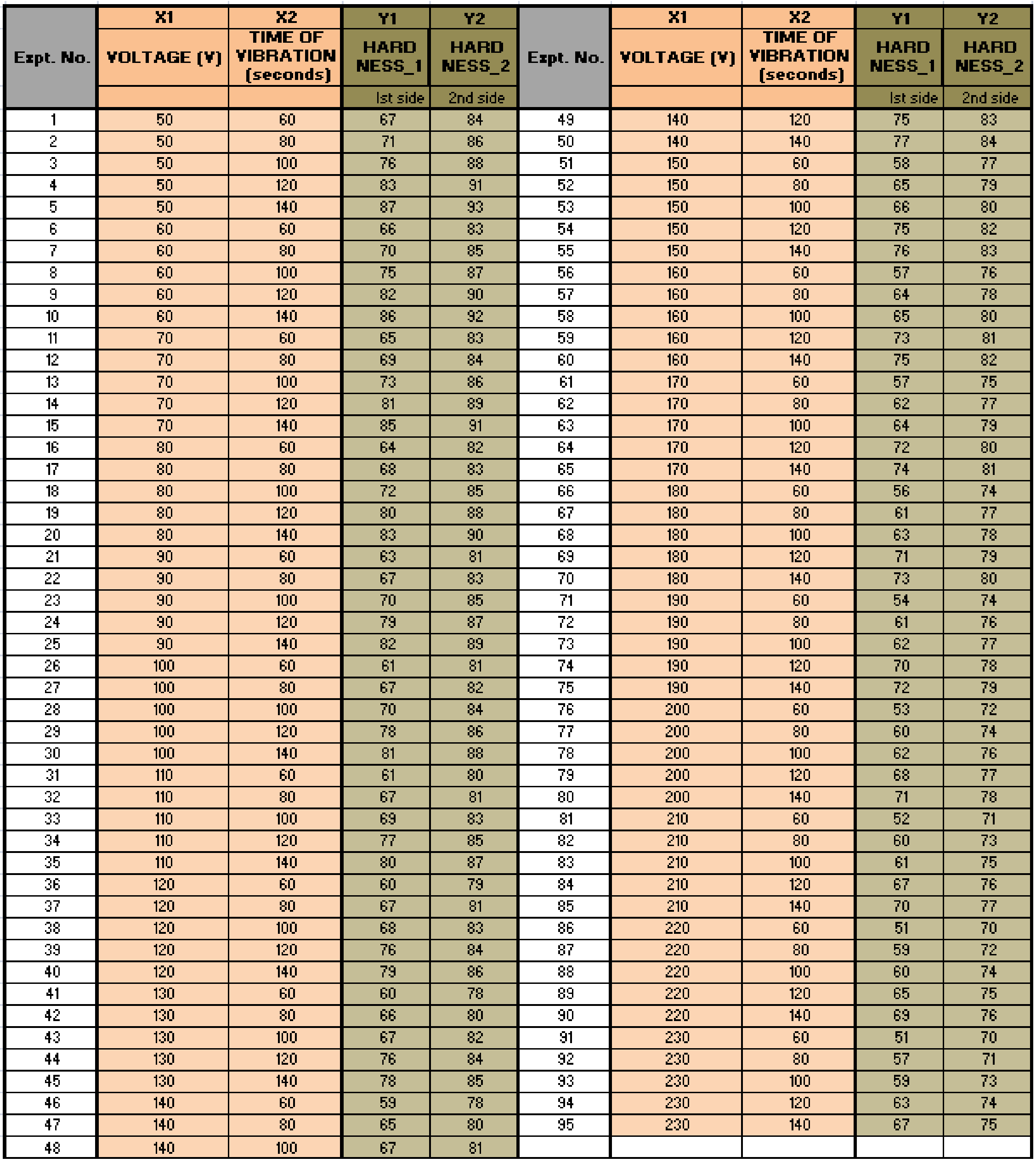


Fig.4. Locations for hardness testing on the welded joint

For different combinations of voltage and time of vibration, weld specimens are prepared and tested for hardness on both of the sides. The experiments are carried out at 95 different combinations and the results are tabulated in Table.1.

Table.1 Welded joints hardness values experimental data



Expt. No.	X1	X2	Y1	Y2	Expt. No.	X1	X2	Y1	Y2
	VOLTAGE (V)	TIME OF VIBRATION (seconds)	HARD NESS_1	HARD NESS_2		VOLTAGE (V)	TIME OF VIBRATION (seconds)	HARD NESS_1	HARD NESS_2
			Ist side	2nd side				Ist side	2nd side
1	50	60	67	84	49	140	120	75	83
2	50	80	71	86	50	140	140	77	84
3	50	100	76	88	51	150	60	58	77
4	50	120	83	91	52	150	80	65	79
5	50	140	87	93	53	150	100	66	80
6	60	60	66	83	54	150	120	75	82
7	60	80	70	85	55	150	140	76	83
8	60	100	75	87	56	160	60	57	76
9	60	120	82	90	57	160	80	64	78
10	60	140	86	92	58	160	100	65	80
11	70	60	65	83	59	160	120	73	81
12	70	80	69	84	60	160	140	75	82
13	70	100	73	86	61	170	60	57	75
14	70	120	81	89	62	170	80	62	77
15	70	140	85	91	63	170	100	64	79
16	80	60	64	82	64	170	120	72	80
17	80	80	68	83	65	170	140	74	81
18	80	100	72	85	66	180	60	56	74
19	80	120	80	88	67	180	80	61	77
20	80	140	83	90	68	180	100	63	78
21	90	60	63	81	69	180	120	71	79
22	90	80	67	83	70	180	140	73	80
23	90	100	70	85	71	190	60	54	74
24	90	120	79	87	72	190	80	61	76
25	90	140	82	89	73	190	100	62	77
26	100	60	61	81	74	190	120	70	78
27	100	80	67	82	75	190	140	72	79
28	100	100	70	84	76	200	60	53	72
29	100	120	78	86	77	200	80	60	74
30	100	140	81	88	78	200	100	62	76
31	110	60	61	80	79	200	120	68	77
32	110	80	67	81	80	200	140	71	78
33	110	100	69	83	81	210	60	52	71
34	110	120	77	85	82	210	80	60	73
35	110	140	80	87	83	210	100	61	75
36	120	60	60	79	84	210	120	67	76
37	120	80	67	81	85	210	140	70	77
38	120	100	68	83	86	220	60	51	70
39	120	120	76	84	87	220	80	59	72
40	120	140	79	86	88	220	100	60	74
41	130	60	60	78	89	220	120	65	75
42	130	80	66	80	90	220	140	69	76
43	130	100	67	82	91	230	60	51	70
44	130	120	76	84	92	230	80	57	71
45	130	140	78	85	93	230	100	59	73
46	140	60	59	78	94	230	120	63	74
47	140	80	65	80	95	230	140	67	75
48	140	100	67	81					

GRNN Model Preparation

For the present work, the experimental data is used to create a GRNN model, The voltage and time of vibration are used as input parameters(X1,X2) and the hardness values on both the sides(Y1,Y2) are considered as output parameters. GRNN estimate the hardness values for any combination of time of vibration and voltage values.

From the weld joint experimental data 76 experimental data is considered randomly to create the GRNN model.

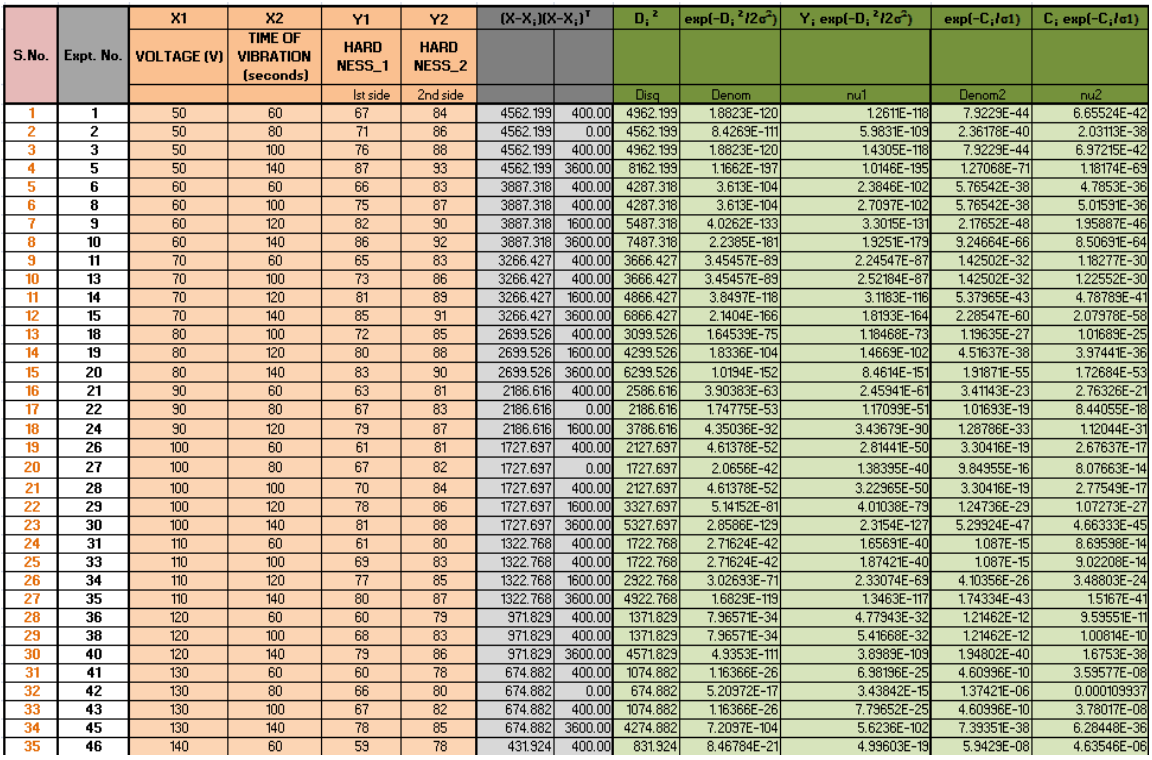
$$\hat{Y}(X) = \frac{\sum_{i=1}^{n} Y_i \exp\left(-D_i^2/2\sigma^2\right)}{\sum_{i=1}^{n} \exp\left(-D_i^2/2\sigma^2\right)} \qquad (1)$$

Where (Xi , Yi) is a sample of (X, Y) input parameters, $D^2_i = (X- X_i)^T (X- X_i)$, and σ is the smoothing parameter. As a pre-processing step in GRNN, the scaling factors are calculated from the standard deviation values of input parameters presented in Table.2.

	X1	X2
STANDARD DEVIATIONS	55.50659831	28.839544
SCALING FACTORS	0.519569653	1

Table.2 Scaling factors and Standard deviation values for input parameters.

A smoothing parameter σ is determined for the computation purpose. By trial and error method two different values are chosen for (Y1 and Y2) two hardness values. In the equation (1), $2\sigma^2$ for Hardness_1 is 9 and for Hardness_2 is 25.

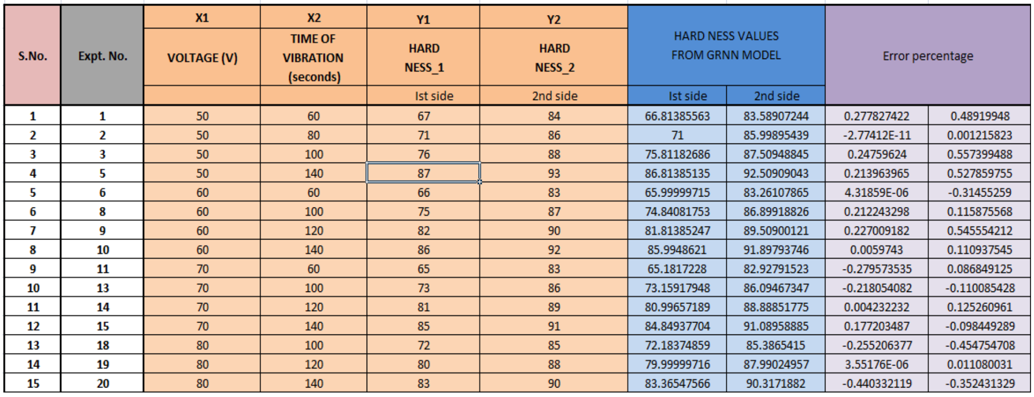


S.No.	Expt. No.	X1	X2	Y1	Y2	$(X-X_i)(X-X_i)^T$		D_i^2	$\exp(-D_i^2/2\sigma^2)$	$Y_i \exp(-D_i^2/2\sigma^2)$	$\exp(-C_i/\sigma1)$	$C_i \exp(-C_i/\sigma1)$
		VOLTAGE (V)	TIME OF VIBRATION (seconds)	HARD NESS_1	HARD NESS_2							
				Ist side	2nd side			Disq	Denom	nu1	Denom2	nu2
1	1	50	60	67	84	4562.199	400.00	4962.199	1.8823E-120	1.2611E-118	7.9229E-44	6.65524E-42
2	2	50	80	71	86	4562.199	0.00	4562.199	8.4269E-111	5.9831E-109	2.36178E-40	2.03113E-38
3	3	50	100	76	88	4562.199	400.00	4962.199	1.8823E-120	1.4305E-118	7.9229E-44	6.97215E-42
4	5	50	140	87	93	4562.199	3600.00	8162.199	1.1662E-197	1.0146E-195	1.27068E-71	1.18174E-69
5	6	60	60	66	83	3887.318	400.00	4287.318	3.613E-104	2.3846E-102	5.76542E-38	4.7853E-36
6	8	60	100	75	87	3887.318	400.00	4287.318	3.613E-104	2.7097E-102	5.76542E-38	5.01591E-36
7	9	60	120	82	90	3887.318	1600.00	5487.318	4.0262E-133	3.3015E-131	2.17652E-48	1.95887E-46
8	10	60	140	86	92	3887.318	3600.00	7487.318	2.2385E-181	1.9251E-179	9.24664E-66	8.50691E-64
9	11	70	60	65	83	3266.427	400.00	3666.427	3.45457E-89	2.24547E-87	1.42502E-32	1.18277E-30
10	13	70	100	73	86	3266.427	400.00	3666.427	3.45457E-89	2.52184E-87	1.42502E-32	1.22552E-30
11	14	70	120	81	89	3266.427	1600.00	4866.427	3.8497E-118	3.1183E-116	5.37965E-43	4.78789E-41
12	15	70	140	85	91	3266.427	3600.00	6866.427	2.1404E-166	1.8193E-164	2.28547E-60	2.07978E-58
13	18	80	100	72	85	2699.526	400.00	3099.526	1.64539E-75	1.18468E-73	1.19635E-27	1.01689E-25
14	19	80	120	80	88	2699.526	1600.00	4299.526	1.8336E-104	1.4669E-102	4.51637E-38	3.97441E-36
15	20	80	140	83	90	2699.526	3600.00	6299.526	1.0194E-152	8.4614E-151	1.91871E-55	1.72684E-53
16	21	90	60	63	81	2186.616	400.00	2586.616	3.90383E-63	2.45941E-61	3.41143E-23	2.76326E-21
17	22	90	80	67	83	2186.616	0.00	2186.616	1.74775E-53	1.17099E-51	1.01693E-19	8.44055E-18
18	24	90	120	79	87	2186.616	1600.00	3786.616	4.35036E-92	3.43679E-90	1.28786E-33	1.12044E-31
19	26	100	60	61	81	1727.697	400.00	2127.697	4.61378E-52	2.81441E-50	3.30416E-19	2.67637E-17
20	27	100	80	67	82	1727.697	0.00	1727.697	2.0656E-42	1.38395E-40	9.84955E-16	8.07663E-14
21	28	100	100	70	84	1727.697	400.00	2127.697	4.61378E-52	3.22965E-50	3.30416E-19	2.77549E-17
22	29	100	120	78	86	1727.697	1600.00	3327.697	5.14152E-81	4.01038E-79	1.24736E-29	1.07273E-27
23	30	100	140	81	88	1727.697	3600.00	5327.697	2.8586E-129	2.3154E-127	5.29924E-47	4.66333E-45
24	31	110	60	61	80	1322.768	400.00	1722.768	2.71624E-42	1.65691E-40	1.087E-15	8.69598E-14
25	33	110	100	69	83	1322.768	400.00	1722.768	2.71624E-42	1.87421E-40	1.087E-15	9.02208E-14
26	34	110	120	77	85	1322.768	1600.00	2922.768	3.02693E-71	2.33074E-69	4.10356E-26	3.48803E-24
27	35	110	140	80	87	1322.768	3600.00	4922.768	1.6829E-119	1.3463E-117	1.74334E-43	1.5167E-41
28	36	120	60	60	79	971.829	400.00	1371.829	7.96571E-34	4.77943E-32	1.21462E-12	9.59551E-11
29	38	120	100	68	83	971.829	400.00	1371.829	7.96571E-34	5.41668E-32	1.21462E-12	1.00814E-10
30	40	120	140	79	86	971.829	3600.00	4571.829	4.9353E-111	3.8989E-109	1.94802E-40	1.6753E-38
31	41	130	60	60	78	674.882	400.00	1074.882	1.16366E-26	6.98196E-25	4.60996E-10	3.59577E-08
32	42	130	80	66	80	674.882	0.00	674.882	5.20972E-17	3.43842E-15	1.37421E-06	0.000109937
33	43	130	100	67	82	674.882	400.00	1074.882	1.16366E-26	7.79652E-25	4.60996E-10	3.78017E-08
34	45	130	140	78	85	674.882	3600.00	4274.882	7.2097E-104	5.6236E-102	7.39351E-38	6.28448E-36
35	46	140	60	59	78	431.924	400.00	831.924	8.46784E-21	4.99603E-19	5.9429E-08	4.63546E-06

Table.3 GRNN model for weld joint database

GRNN Model Calibration

The GRNN model created for 76 random experiment values are tested for two different sets of used experimental data and un-used experimental data. The calibrated data for the first 15 sets are represented in Table.4. The deviations in the GRNN computed values from the used experimental values are also captured in Table.4. The deviations are plotted in Fig.5.



S.No.	Expt. No.	X1	X2	Y1	Y2	HARD NESS VALUES FROM GRNN MODEL		Error percentage	
		VOLTAGE (V)	TIME OF VIBRATION (seconds)	HARD NESS_1	HARD NESS_2				
				Ist side	2nd side	Ist side	2nd side		
1	1	50	60	67	84	66.81385563	83.58907244	0.277827422	0.48919948
2	2	50	80	71	86	71	85.99895439	-2.77412E-11	0.001215823
3	3	50	100	76	88	75.81182686	87.50948845	0.24759624	0.557399488
4	5	50	140	87	93	86.81385135	92.50909043	0.213963965	0.527859755
5	6	60	60	66	83	65.99999715	83.26107865	4.31859E-06	-0.31455259
6	8	60	100	75	87	74.84081753	86.89918826	0.212243298	0.115875568
7	9	60	120	82	90	81.81385247	89.50900121	0.227009182	0.545554212
8	10	60	140	86	92	85.9948621	91.89793746	0.0059743	0.110937545
9	11	70	60	65	83	65.1817228	82.92791523	-0.279573535	0.086849125
10	13	70	100	73	86	73.15917948	86.09467347	-0.218054082	-0.110085428
11	14	70	120	81	89	80.99657189	88.88851775	0.004232232	0.125260961
12	15	70	140	85	91	84.84937704	91.08958885	0.177203487	-0.098449289
13	18	80	100	72	85	72.18374859	85.3865415	-0.255206377	-0.454754708
14	19	80	120	80	88	79.99999716	87.99024957	3.55176E-06	0.011080031
15	20	80	140	83	90	83.36547566	90.3171882	-0.440332119	-0.352431329

Table.4. Calibrated data for used experimental data

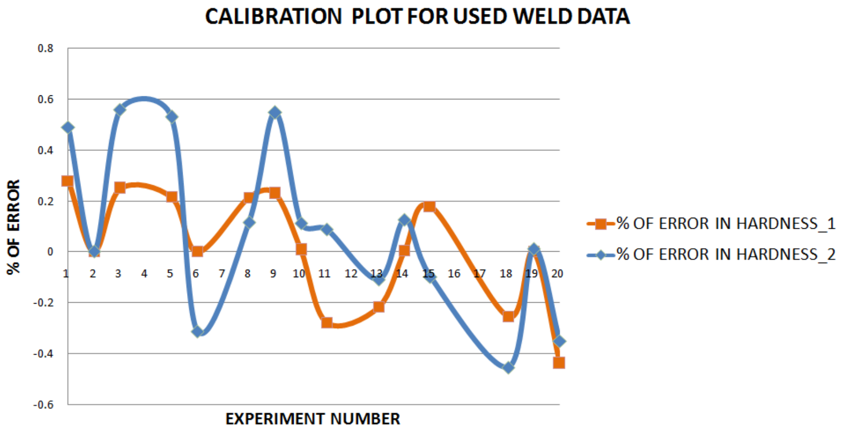


Fig.5 Graphical representation of error percentage

The un-used experimental data for creation of GRNN model is also calibrated for 15 sets are represented in Table.5. The deviations in the GRNN computed values from the un-used experimental values are also captured in Table.5. The deviations are plotted in Fig.6.

S.No.	Expt. No.	X1	X2	Y1	Y2	HARD NESS VALUES FROM GRNN MODEL		Error percentage	
		VOLTAGE (V)	TIME OF	HARD	HARD				
				Ist side	2nd side	Ist side	2nd side		
1	4	50	120	83	91	81.98899236	89.81419765	1.218081494	1.303079511
2	7	60	80	70	85	70.99997537	85.957298	-1.428536242	-1.126232944
3	12	70	80	69	84	68.9994464	84.4202513	0.000802318	-0.500299164
4	16	80	60	64	82	63.99450227	81.99976558	0.008590202	0.000285874
5	17	80	80	68	83	67.00002436	82.87113261	1.470552408	0.155261915
6	23	90	100	70	85	71.00000305	84.50633956	-1.428575783	0.580776986
7	25	90	140	82	89	82.00550077	88.99886402	-0.006708259	0.001276387
8	32	110	80	67	81	66.98911207	81.83943967	0.016250636	-1.036345275
9	37	120	80	67	81	65.99999999	80.29764779	1.492537322	0.867101495
10	39	120	120	76	84	76.98912418	84.85039784	-1.301479186	-1.012378377
11	44	130	120	76	84	75.02175763	83.14910871	1.28716101	1.012965827
12	50	140	140	77	84	77.97823633	84.70115159	-1.270436796	-0.834704279
13	55	150	140	76	83	75.02176366	82.29695192	1.287153075	0.847045874
14	61	170	60	57	75	56.49449923	75.08256612	0.886843457	-0.11008816
15	67	180	80	61	77	61.50550382	76.41247563	-0.828694781	0.763018658

Table.4. Calibrated data for un-used experimental data

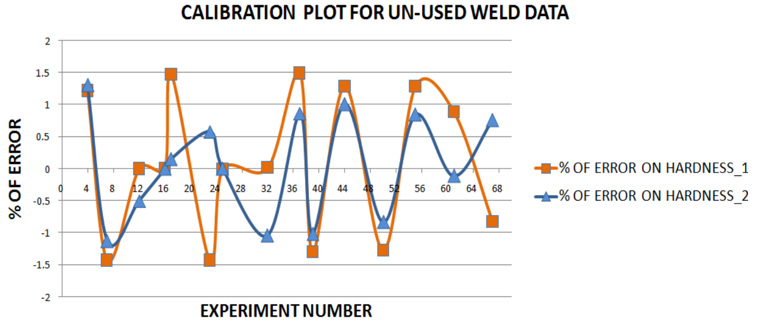


Fig.5 Graphical representation of error percentage for non used experimental data

IV. Conclusions

In the present study, welding is performed along with the vibrations for improving the mechanical properties of the base material. The vibratory welded joints properties, such are hardness values along and across the weldbeed are varying in accordance with vibration time and voltage supplied to generate the vibration. Due to the non linear behaviour relation between the vibration weld parameters and the welded joint hardness properties, GRNN model is created. The proposed GRNN model is highly superior which is computing the values with 99% accuracy for the used experimental values with ±0.5 error and 97% accurate for the un used experimental values with ±1.5.

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