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Machining and forecasting of square profile areas using artificial neural modelling at different slant angles by WEDM.

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Abstract. Wire electric discharge machining non-conventional process that removes materials by thermal erosion. Tapering in WEDM has many applications in machining accurate geometric profiles. In the present investigation, a slant type taper machining was performed to produce taper profiles with the help of the slant fixture. The machining parameters such as wire guide distance, corner dwell time, wire offset and cutting speed override was employed to find the variation in the taper profile area. A simple square profile of 1mm, 3mm and 5mm was machined at different slant angles namely 0°, 15° and 30°. It was observed that each parameter yielded different profile areas. The artificial neural network was used for the forecasting the areas of 1mm, 3mm and 5mm square for different parameters. The optimum artificial neural network model was experimentally validated and the errors were ranging from 0-10%.

1. Introduction

Wire electric discharge machining (WEDM) is an electro-thermal process where the sparks are generated between the workpiece and electrode due to high potential difference. It is a non-contact machining process where all the conductive and hard materials can be precisely machined [1-3]. This forms a versatile way for machining for different materials like nickel, titanium alloys, composites etc. which can be used in many for complex machining [4-6]. Nickel-based superalloy which possesses a challenge for machining due to its high-temperature strength and low thermal diffusivity [7, 8]. Using Conventional machining for these alloys may cause surface defects and damages recorded both on the tool and as well as in workpiece [9, 10]. So wire EDM is the most promising machining techniques as it depends only on the conductivity of the material. The tapered cutting is unique machining used in dies, forming cutters, splicing moulds, vanes and blades etc. [11, 12]. During traditional taper cutting, there are many disadvantages as a flexible wire electrode is bend to an angle. Many researchers like Kinoshita et al. [13], Plaza et al. [14], Sanchez et al.[15] has identified the disadvantages like wire guide wear, friction, wire breakage, angular inaccuracies, poor surface due to insufficient flushing etc. have been observed during taper machining of materials.

Artificial neural network (ANN) is a versatile method that is used for both optimisation [16, 17] and prediction/forecasting. Some of the researchers like Manoj et al. [18] have attempted a different approach to obtain taper and have predicted profile areas for a triangular profile at different taper angles by an (ANN). Singh and Misra [19] have concluded ANN with a back-propagating neural network gives

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accurate results in the prediction of material removal rate and surface roughness than response surface method. Saha et al. [20] have used ANN for prediction of cutting speed and surface roughness while WEDM of tungsten carbide-cobalt (WC-Co) composite material. Sarkar et al. [21] have predicted trim cutting speed, average surface roughness and dimensional sift using ANN model like Bayesian regularization and early stopping method and an effective cutting speed which gives maximum productivity and surface finish was selected.

The tapering operation in WEDM was used in machining of many complex parts for various applications. In the present investigation, Hastelloy-X is used as investigating material. Hastelloy-X is used in different applications like turbine parts, flame holders, turbocharger impellers etc. which requires slant or taper form of machining. For obtaining taper structure, a unique slant fixture was employed for machining of tapered profiles. This slant fixture avoids the bending of wire, inaccuracies, guide wear etc. as in traditional taper machining. A simple square profile was used slant in the machining of Hastelloy-X using WEDM at 0°, 15° and 30° slant angles. The input parameters such as wire guide distance, corner dwell time, wire offset and cutting speed override were used. ANN was employed for the prediction of taper areas at all the slant angles for different parameters. The model was experimentally validated for intermediate parameters.

2. Experimental Details

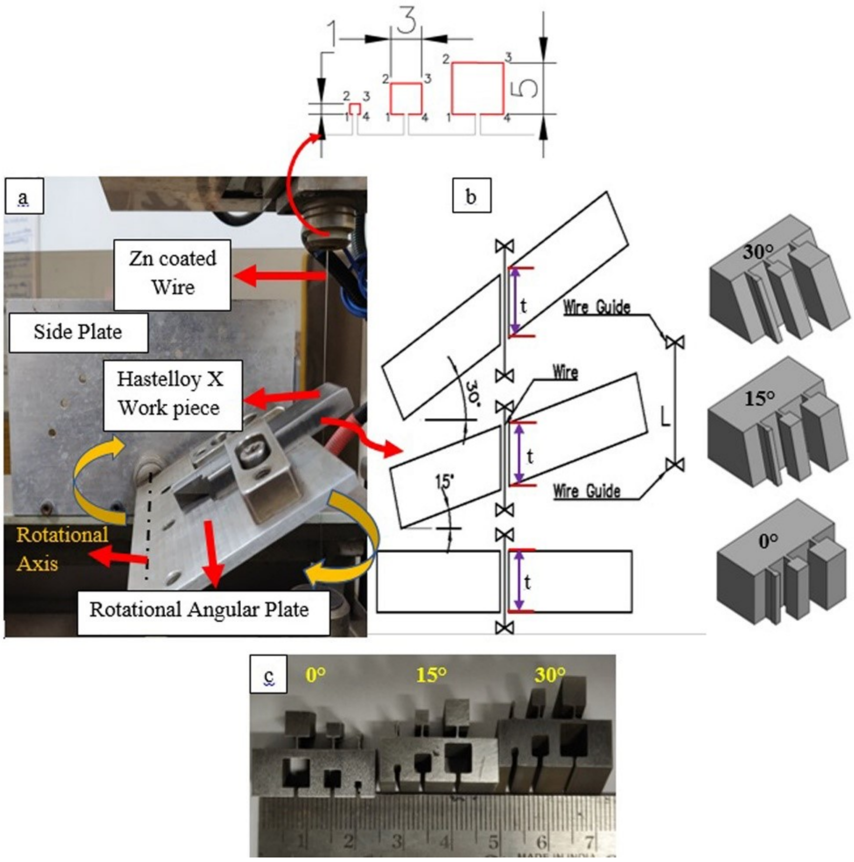

Figure 1. Experimental methodology.

Fig.1 shows the method followed to achieve the tapering with help of in-house developed fixture. The fixture made of aluminium H9 series was made to rest on the WEDM table. The Electronica 'ELPULS 15' made WEDM was employed. The zinc-coated copper wire as the electrode and deionized water as the dielectric medium was made used to machine Hastelloy-X. The workpiece placed in the rotating angular plate which is locked to the required angle. The angular plate is fixed to the fixture resting on WEDM table as shown in fig.1. The programmed profile is coded and uploaded to the CNC of WEDM so the wire guide movement follows the shape. The different angles were achieved as shown in fig. 1

(b) and the orthogonal view of the tapered components can also be seen. The fig.1 (c) shows the tapered components of 10mm cut at different angles.

3. Parameters

The input parameters like wire guide distance, corner dwell time, wire offset and cutting speed override were made use as machining parameters. Based on the initial experiments and machining capabilities theses parameters were defined as in table 1 [18, 22, 23]. As the interactions were insignificant or having a minimal effect on the area, therefore L16 orthogonal array was used. For each angle, 16 components were machined and areas of each 1mm, 3mm and 5mm squares were measured by Scanning electron microscope (SEM), Image J software and co-ordinate measuring machine (CMM).

Table 1 WEDM Parameters

Constant Parameters				
EDM Parameters	Settings			
Pulse off time (µs)	44			
Servo Feed (mm/min)	20			
Wire Feed (m/min)	6			
Pulse on time (µs)	115			
Servo voltage (V)	40			
Machining Parameters				
	40	50	60	70
Wire guide distance (mm)	75	85	95	105
	100	110	120	130
Cutting speed override (%)	31	54	77	100
Wire offset (µm)	0	40	80	120
Corner dwell time (s)	0	33	66	99

4. Results and Discussion

Table 3 shows the recorded areas and predicted areas at different machining parameters. The optimal neural network in fig.2 was decided by test runs consisting of numerous combinations of hidden and output layers. The neural network (type: feed forward backprop) was used to train, test and validate the data for 1mm, 3mm and 5mm square areas. From the 48 iterations, the ANN toolbox in Matlab takes 70% for training, 15% for validation and 15% for testing the model. Back-propagation neural network was employed for training of ANN optimal network [24]. The logarithmic-sigmoid function was employed for the hidden layer and pure-line function was used for the output layer. The mean square error (MSE) performance function with a combination of 5-10-1-1 architecture was employed as shown in fig 2. The regression plots in Fig.3 and R values from table 2 shows the training, testing and validation of the optimal model.

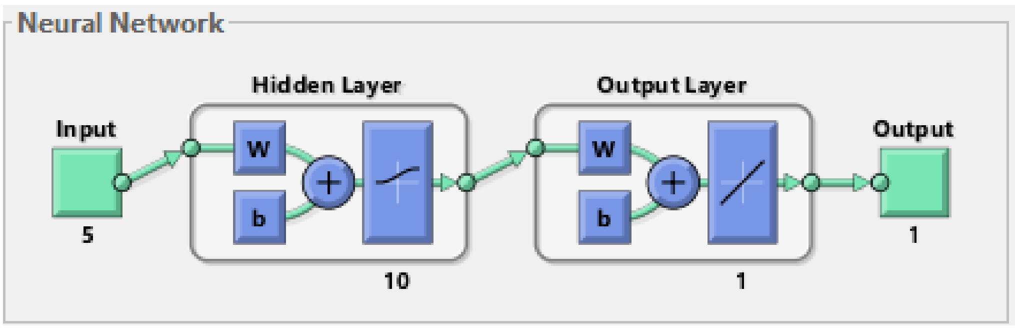

Figure 2. Optimum neural network for used for forecasting.

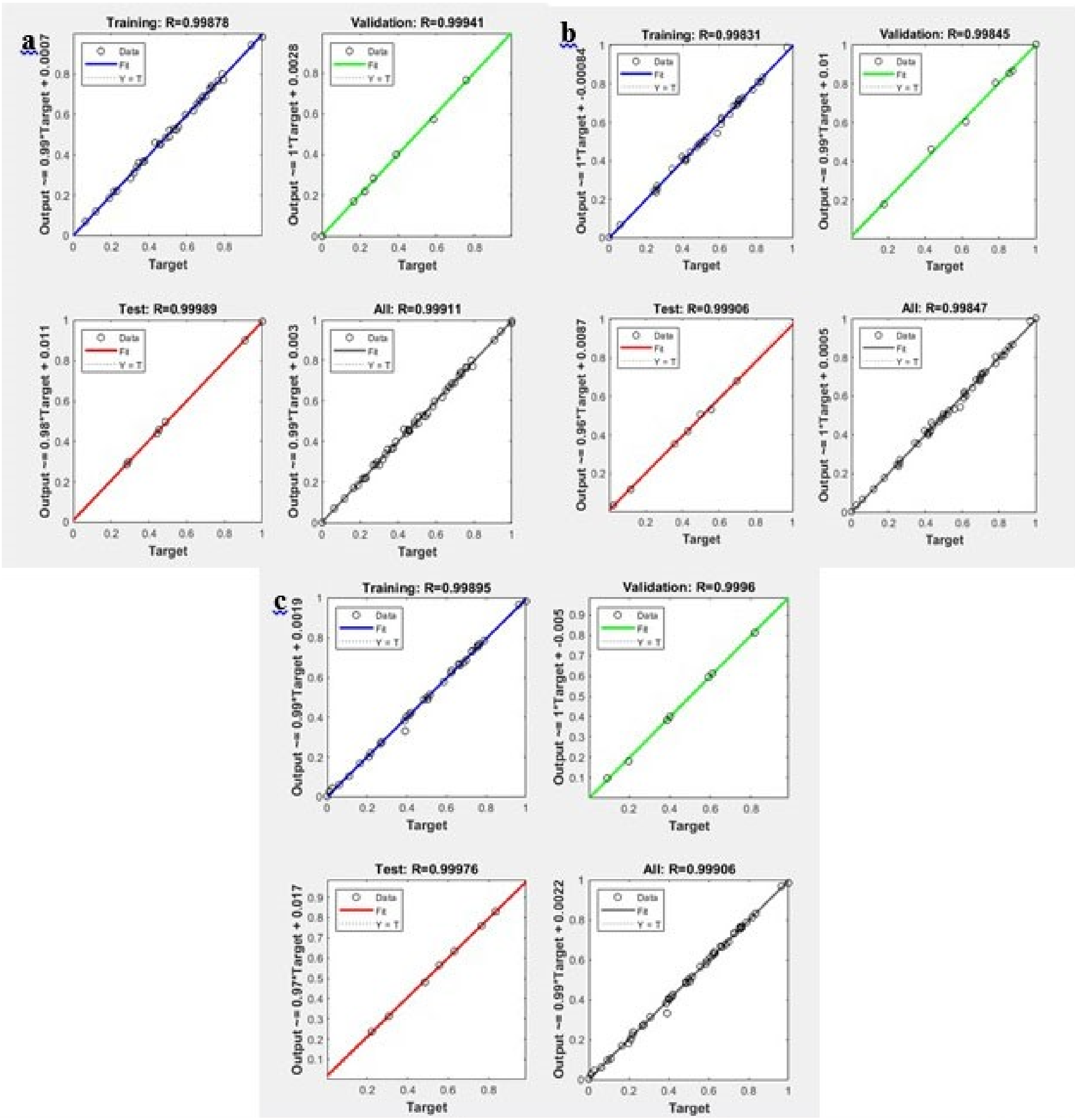

Figure 3. Regression Plots for (a) 1mm (b) 3mm and (c) 5mm square profiles.

Table 2 R values from Regression plot

Sl. No.	**Square Areas**	**Training**	**Validation**	**Testing**	**All (R)**
1	1mm	0.99878	0.99941	0.99989	0.99911
2	3mm	0.99831	0.99845	0.99906	0.99847
3	5mm	0.99895	0.9996	0.99976	0.99906

Table 3 Machining and estimation of profile areas

Sl. No.	WDG (mm)	CDT (s)	WO (µm)	CSO (%)	Slant Angle	Predicted Area of the square in mm²			Area of the square in mm²		
						1mm	3mm	5mm	1mm	3mm	5mm
1	40	0	0	31		0.783	7.594	23.108	0.773	7.66	23.086
2	40	33	40	54		0.767	7.619	22.865	0.786	7.622	22.969
3	40	66	80	77		0.982	8.364	23.207	0.986	8.265	23.112
4	40	99	120	100		1.041	8.640	24.097	1.059	8.797	24.131
5	50	0	40	77		0.695	7.394	22.347	0.690	7.392	22.323
6	50	33	0	100		0.660	7.193	22.025	0.664	7.194	21.914
7	50	66	120	31		1.029	8.603	24.279	1.033	8.689	24.284
8	50	99	80	54		0.768	8.221	23.437	0.765	8.249	23.432
9	60	0	80	100	0°	0.696	7.647	22.989	0.701	7.672	23.032
10	60	33	120	77		0.826	8.224	23.671	0.822	8.138	23.633
11	60	66	0	54		0.589	7.014	21.922	0.588	6.989	21.826
12	60	99	40	31		0.796	7.710	22.398	0.806	7.676	22.425
13	70	0	120	54		0.935	8.152	23.394	0.938	8.206	23.392
14	70	33	80	31		0.857	8.011	22.786	0.865	7.956	22.766
15	70	66	40	100		0.536	6.913	22.130	0.529	6.877	22.13
16	70	99	0	77		0.460	6.797	21.775	0.460	6.787	21.754
17	75	0	0	31		0.951	8.981	25.497	0.953	9.019	25.486
18	75	33	40	54		0.947	8.878	25.383	0.957	8.872	25.369
19	75	66	80	77		1.163	9.262	25.633	1.166	9.261	25.612
20	75	99	120	100		1.241	9.532	26.444	1.239	9.454	26.431
21	85	0	40	77		0.854	8.512	24.698	0.855	8.555	24.723
22	85	33	0	100		0.849	8.306	24.203	0.833	8.293	24.213
23	85	66	120	31	15°	1.200	9.557	26.565	1.198	9.603	26.584
24	85	99	80	54		0.957	9.224	25.807	0.926	9.218	25.832
25	95	0	80	100		0.891	8.848	25.294	0.881	8.905	25.332
26	95	33	120	77		0.987	9.263	25.971	1.006	9.262	26.033
27	95	66	0	54		0.766	8.187	24.093	0.751	8.214	24.126
28	95	99	40	31		0.995	8.518	24.827	0.986	8.484	24.825
29	105	0	120	54		1.106	9.126	25.834	1.100	9.094	25.792
30	105	33	80	31		1.026	8.914	25.212	1.049	8.872	25.166
31	105	66	40	100		0.699	8.393	24.352	0.709	8.411	24.330
32	105	99	0	77		0.644	7.994	23.781	0.640	8.012	24.154
33	100	0	0	31		1.251	9.106	25.893	1.253	9.160	25.946
34	100	33	40	54		1.260	9.232	26.221	1.247	9.192	26.205
35	100	66	80	77		1.477	9.745	26.723	1.476	9.765	26.760
36	100	99	120	100		1.534	10.21	27.772	1.539	10.20	27.869
37	110	0	40	77		1.205	8.799	25.644	1.215	8.862	25.582
38	110	33	0	100		1.127	8.581	24.754	1.143	8.594	24.845
39	110	66	120	31	30°	1.521	10.16	27.672	1.538	10.09	27.656
40	110	99	80	54		1.291	9.544	26.411	1.316	9.549	26.384
41	120	0	80	100		1.181	9.164	26.239	1.181	9.172	26.209
42	120	33	120	77		1.285	9.634	26.838	1.276	9.638	26.863
43	120	66	0	54		1.078	8.479	24.739	1.091	8.489	24.728
44	120	99	40	31		1.286	9.135	25.570	1.286	9.146	25.563
45	130	0	120	54		1.432	9.703	26.400	1.440	9.706	26.433
46	130	33	80	31		1.323	9.414	26.359	1.309	9.456	26.381
47	130	66	40	100		1.023	8.443	24.901	1.009	8.447	24.915
48	130	99	0	77		0.955	8.187	24.222	0.950	8.187	24.195

Table 4 shows the validation parameters that were chosen randomly and machined. Table 5 shows the error percentage that was calculated for ANN predicted values comparing the experimental values. The machined components were measure and the areas were recorded. From the optimal model, the predicted areas were generated by loading the machining parameters to the model. It can be observed that the errors varied from 0-9.16% in case of prediction from ANN.

Table 4 Validation parameters for the optimum ANN model

Sl. No.	WGD (mm)	CDT (s)	WO (μm)	CSO (%)	Slant Angle (Degree)
1	55	40	100	45	0°
2	80	45	180	80	0°
3	90	50	75	65	15°
4	120	60	150	50	15°
5	115	80	50	90	30°
6	145	20	130	70	30°

Table 5 Variation of ANN predicted and experimental areas

Sl. No	Area of the square in mm²								
	1mm			3mm			5mm		
	ANN Predicted areas	Measured areas	Error %	ANN Predicted areas	Measured areas	Error %	ANN Predicted areas	Measured areas	Error %
1	0.977	0.903	7.574	8.7	8.34	4.138	25.698	23.344	**9.160**
2	0.915	0.927	1.311	7.869	8.621	9.556	24.899	23.807	4.386
3	0.957	0.948	0.940	9.846	9.016	8.430	27.89	25.562	8.347
4	0.998	0.95	4.810	9.449	9.051	4.212	26.564	25.306	4.736
5	1.296	1.216	6.173	9.757	8.942	8.353	24.289	25.466	4.846
6	1.22	1.224	**0.328**	9.079	9.815	8.107	25.586	26.245	2.576

5. Conclusions

The taper was be achieved from a slant type taper fixture a unique way different from the traditional method. The areas were machined on Hastelloy-X and the following conclusions can be drawn.

1. The ANN with BPNN algorithm gave the most effective of the method for forecasting the areas as the errors vary from 0-5% irrespective of dimensions.
2. The ANN optimal models have been validated experimentally having validation errors varying from 0-9.16%.

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