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Influence of machining parameters on taper square areas during slant type taper profiling using wire electric discharge machining

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Influence of machining parameters on taper square areas during slant type taper profiling using wire electric discharge machining

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Abstract. The oblique/ tapered machining is a unique method in wire electric discharge machining to get taper profiles difficult to machine materials. These profiles have many applications like dies, nozzles, inserts, cutting tools and other components. In the present study, a simple square profile is machined using a slant type fixture to achieve a tapered profile made of Hastelloy X. A simple square is machined at different slant angles to get a 0°, 15° and 30° tapered profiles. This paper aims to study the effects of the machining parameters like wire guide distance, wire offset, corner dwell time and cutting speed override on the area of machined profiles. Both scanning electron microscope and coordinate measuring machine were used to measure the areas of 1mm and 5mm. It is observed that as the wire guide distance and cutting speed override increases the area decreases. Whereas in case of wire offset, as offset increases the areas also increase and corner dwell time doesn't affect on the area. As the angle increased the area also increased leading to bigger taper profiles.

1. Introduction

Wire electric discharge machining (WEDM) is an electrothermal 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]. The tapered cutting is unique machining used in dies, forming cutters, splicing moulds, vanes and blades etc. [7, 8]. During traditional taper cutting, there are many 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 [9-11]. Many kinds of research have been made to improve the material, mechanism and machining ways. Manoj et al. [12] have highlighted the effect of taper angles on different response parameters which was produced with a unique fixture. Naveed et al. [13] reported optimization of machining complex profile which involves curved features and inclined surfaces. It was observed that there was a 33.3% reduction in angular error, a 14.3% reduction in radial error, a 12% increase in cutting speed and a 14.4% reduction in surface roughness of workpiece.

Sharma et al. [14] have machined a complex profile slot where the surface and metallurgical effects of machining parameters were highlighted. Firouzabadi et al. [15] have reported convex, concave corner radii error in corner profiling for different corner angles and achieved a reduction of 17% in residual material thickness in convex curvatures. Werner [16] explored a method in machining curvilinear profiles on wire-electric discharge machines. The optimal machining parameters were found by modern CAD/CAM systems and tool travel study. Bisaria H and Shandilya P [17] has claimed that at lower pulse parameters, the corner error for 60°, 90°, and 120° profile was decreased by 43.38%,

31.12%, and 29.04%, respectively compared to high parameters. Mouralova et al. [18] explored the profile and area parameters of WEDMed aluminium. They have identified optimal parameters giving best surface quality and least kerf width. Wang et al. [19] machined micro gear profile with 50 µm wire and less than 1.5 µm machining error with an excellent surface (Ra= 0.9 µm). Mandal et al. [20] have employed wire offset value for making the wire travel in a proper path and it was also used to compensate the overcut value. Chaubey and Jain [21] have machined bevel and helical gears and showed that WEDM is the most economic and sustainable alternative. Dodun et al. [22] made an attempt to improve geometrical accuracy in corner machining of thin parts. It was concluded that the thickness and profile angle of the workpiece also plays a vital role in machining accuracy.
From the literature, it can be observed that profile accuracy was very important while component manufacturing. In the present study, a unique slant fixture was employed which avoids the disadvantages in conventional taper operation in WEDM. Many disadvantages like bending of wire, angular inaccuracies, wire break, guide wear etc. occurs in conventional machining of tapered profiles. The effect of different input parameters on a square profile was studied at different taper profiles at 0°, 15° and 30° angles. A simple square profile was used in machining of Hastelloy X using WEDM. The input parameters such as wire guide distance (WDG), corner dwell time (CDT), wire offset (WO) and cutting speed override (CSO) were used.

2. Workpiece and procedure

Hastelloy X is a nickel-based superalloy that provides a good balance of high- temperature strength, oxidation resistance, and fabricability. It has wide applications as transition ducts, combustor cans and liners, injector nozzles, flame holders, exhaust struts and many hot gas path components. The composition of the as-received alloy is shown as in table 1 which was tested and verified with the aid of optical emission spectrometry (SpectraMax 130779).

Table 1. Chemical composition of Workpiece.

%	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Fe%	Co%	W%	Ni%
Composition	0.06	0.21	0.65	0.027	0.01	20.65	8.24	18.05	0.69	0.29	50.88

2.1. Experimental Procedure

The profile to be machined has to be programmed in the WEDM process, the wire traces in the workspace where the workpiece was clamped. The sparks from the wire melt the workpiece forming a profile. The square profiles of different dimensions namely 1mm, 3mm and 5mm were machined for the investigation as shown in fig. 1. The programming was performed using computer numerically controlled software called ELCAM. The Zinc coated copper wire of diameter 0.25mm was used as an electrode that traces the profile. The deionized water was employed as dielectric fluid throughout the study. The machining was performed with the aid of slant fixture in order to achieve a tapered profile. The fig. 1 (a) shows the workpiece rotated at 0° and 30° slant angles attached to fixture. This whole setup with Hastelloy X workpiece was fastened to the WEDM table as shown in fig. 1 (b).

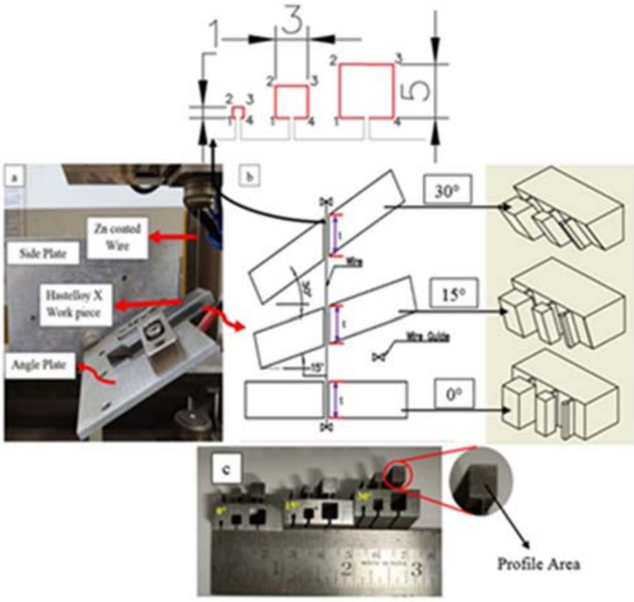

Figure 1. (a) Workpiece at different slant angle by slant fixture (b) Slant Fixture (c) Area of the profile.

3. Results And Discussion

3.1. Variation of areas at different parameters

The parameters were chosen based on the initial experiments [23, 24]. As there were 4 input parameters and from the initial experiments, the interactions were very low. So Taguchi's L_{16} orthogonal array was used for the investigation. The 1mm square was measured using the Image J software form the SEM images obtained from 'JEO JSM-6368OLA'. The 5mm squares were calculated from coordinate measuring machine (CMM) 'TESA VISIO 200'. Table 2 shows various profiles areas machined at different slant angles. The 'Minitab' software was employed to get ANOVA and main effects plots.

Table 2. Slant Areas at Different Parameters for Different Angles.

Sl. No.	WDG (mm)	CDT (s)	WO (µm)	CSO (%)	Area in mm ² 1mm	5mm
			0°			
1	40	0	0	31	0.773	23.086
2	40	33	40	54	0.786	22.969
3	40	66	80	77	0.986	23.112
4	40	99	120	100	1.059	24.131
5	50	0	40	77	0.690	22.323
6	50	33	0	100	0.664	21.914
7	50	66	120	31	1.033	24.284
8	50	99	80	54	0.765	23.432
9	60	0	80	100	0.701	23.032
10	60	33	120	77	0.822	23.633
11	60	66	0	54	0.588	21.826
12	60	99	40	31	0.806	22.425

13	70	0	120	54	0.938	23.392
14	70	33	80	31	0.865	22.766
15	70	66	40	100	0.529	22.13
16	70	99	0	77	0.460	21.754
			15°			
17	75	0	0	31	0.953	25.486
18	75	33	40	54	0.957	25.369
19	75	66	80	77	1.166	25.612
20	75	99	120	100	1.239	26.431
21	85	0	40	77	0.855	24.723
22	85	33	0	100	0.833	24.213
23	85	66	120	31	1.198	26.584
24	85	99	80	54	0.926	25.832
25	95	0	80	100	0.881	25.332
26	95	33	120	77	1.006	26.033
27	95	66	0	54	0.751	24.126
28	95	99	40	31	0.986	24.825
29	105	0	120	54	1.100	25.792
30	105	33	80	31	1.049	25.166
31	105	66	40	100	0.709	24.330
32	105	99	0	77	0.640	24.154
			30°			
33	100	0	0	31	1.253	25.946
34	100	33	40	54	1.247	26.205
35	100	66	80	77	1.476	26.760
36	100	99	120	100	1.539	27.869
37	110	0	40	77	1.215	25.582
38	110	33	0	100	1.143	24.845
39	110	66	120	31	1.538	27.656
40	110	99	80	54	1.316	26.384
41	120	0	80	100	1.181	26.209
42	120	33	120	77	1.276	26.863
43	120	66	0	54	1.091	24.728
44	120	99	40	31	1.286	25.563
45	130	0	120	54	1.440	26.433
46	130	33	80	31	1.309	26.381
47	130	66	40	100	1.009	24.915
48	130	99	0	77	0.950	24.195

3.2. ANOVA table and Main Effects plot for areas at different angles

The ANOVA and main effect plots were formulated as shown in table 2. Fig. 2, 3 and 4 show the main effect plots for different dimensions and at various slant angles. Table 3 shows the ANOVA analysis of areas with percentage contribution. From the ANOVA and main effects plot, the WO is the most significant and highest contributing factors compared to all the input parameters on the area. It was noticed that as the WO increases the area of the square profile also increases due to the increase in offset. Similar effects were also observed by Mandal et al. [20] and Kanlayasiri and Jattakul [25]. The ANOVA table also shows the contributing factors. It can be noticed that the error percentage of contribution was very low (0-3%). The WDG was the next highest contributing parameter followed by the CSO parameter on the area at different slant angles. The CDT parameter was the least influential and contributing factor for different slant areas [23].

Table 3. Slant Areas at different parameters for different angles.

Sl. No.	**Factor**	**DF**	**Area 1mm²**		**Area 5mm²**	
			Sum of squares	**% Contribution**	**Sum of squares**	**% Contribution**
			0°			
1	WDG	3	0.0960	21.27	1.4734	16.01
2	CDT	3	0.0004	0.10	0.0569	0.62
3	WO	3	0.2683	59.78	6.8701	74.67
4	CSO	3	0.0458	10.20	0.4186	4.55
5	Error	3	0.0387	8.65	0.3818	4.15
			15°			
1	WDG	3	0.0961	21.39	1.6550	17.46
2	CDT	3	0.0005	0.13	0.0844	0.89
3	WO	3	0.2685	59.74	6.9577	73.41
4	CSO	3	0.0473	10.52	0.4618	4.87
5	Error	3	0.0370	8.22	0.3184	3.36
			30°			
1	WDG	3	0.1006	22.40	3.150	19.86
2	CDT	3	0.0029	0.65	0.012	0.08
3	WO	3	0.2664	59.33	11.887	74.94
4	CSO	3	0.0407	9.06	0.692	4.36
5	Error	3	0.0384	8.55	0.121	0.76

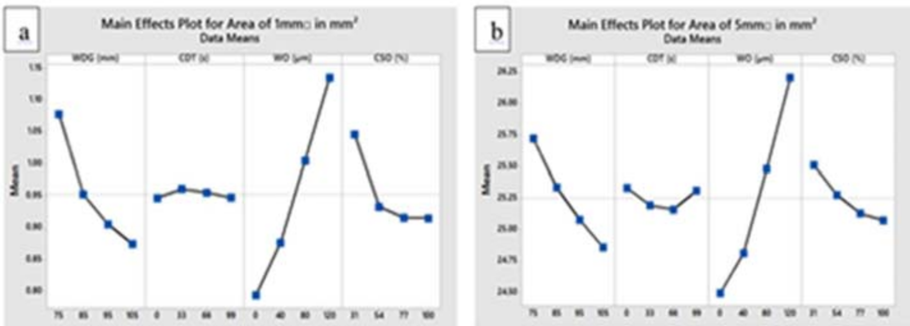

Figure 2. Effects plots of areas (a) 1mm and (b) 5mm at 0°.

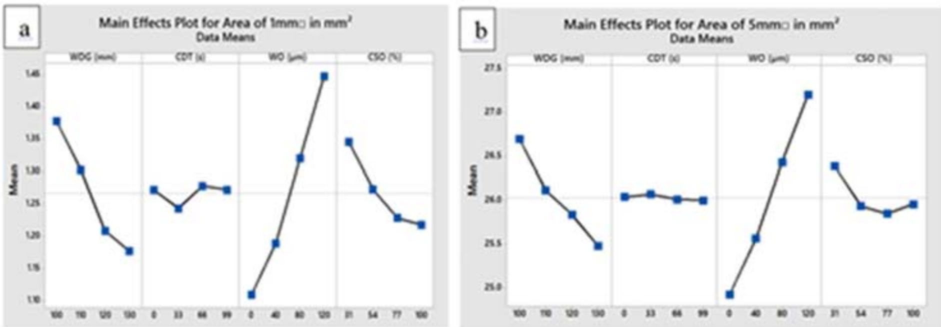

Figure 3. Effects plots of areas (a) 1mm and (b) 5mm at 15°.

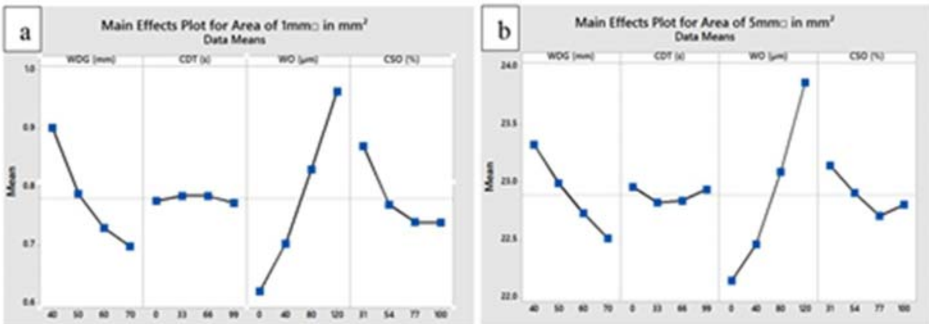

Figure 4. Effects plots of areas (a) 1mm and (b) 5mm at 30°.

3.3. Effect of WO on area

The WO parameter is the most significant and contributing factor (59.33-74.94%) influencing the area during machining. It can be observed from the main effects plot that as WO parameter increases the area also escalates. This phenomenon is noticed due to the increase in offset distance during profiling for all dimensions and at all the slant angles. This leads to wire machining higher circumference than the programmed profile [25]. Fig. 2, fig. 3 and fig. 4 shows a clear increase in the area of the profile offset distance increases (WO parameter increases). There was small variation noticed at 40µm. These variations in the area were observed due to the vibrations in the wire during profiling [26]. As the slant angle increases, workpiece thickness also increases which increases the wire vibrations [24]. This leads to variations in machining the area of the taper profile.

3.4. Effect of WDG on area

From the ANOVA table and main effect plot, the WDG parameter is the next contributing factor affecting the area. As the WDG parameter increases the wire lag also increases due to the flexible nature of wire [25]. Therefore as the WDG increases the area reduces. From fig. 2 (b) and fig. 3 (b) it can be observed as the WDG increases the areas reduces. There were variations noticed in fig. 2 (a) at 50mm, fig. 3 (a) at 85mm and fig. 4(a), (b) at 120mm. These variations were due to the phenomenon of the increase in vibrations due to the change in wire length and flushing [24, 27].

3.5. Effect of CSO on areas

It can be noticed that as the cutting speed override increases the area decreases. The cutting speed override controls the cutting speed of the wire without varying the parameters during machining. At higher cutting speed the corner error increases and there is a decrease in areas [28]. The cutting speed after a certain limit was limited to influence on the profile which after remains constant [29]. A similar trend can be identified in fig. 2, 3 and 4 main plots. There was a slight increase from 77% to 100% in fig 2(b) and 4(b) due to the variation in vibrational forces due to sparking at different cutting parameters [27, 30]. These vibration forces cause irregular random vibrations which affect the areas while profiling. It also indicates after a certain speed the areas will not further decrease.

3.6. Variation of areas at different angles

It can be observed from the fig.5 that as the slant angle increases, the area increases for both 1mm and 5mm square profiles. This observed due to slant angles provided by the fixture while machining. As the slant angle increases as shown in fig. by tilting the slant fixture, the material available for machining also increases. Although the profile traced by the wire remains the same due to the slant/tilting of workpiece increases the area of profile [23, 31].

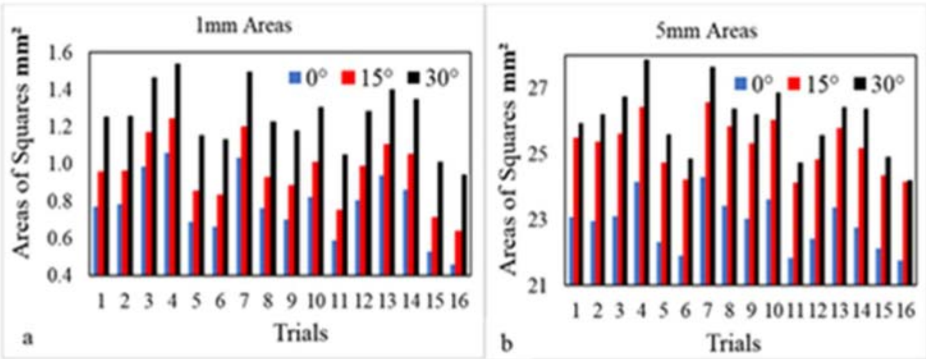

Figure 5. Variation of (a) 1mm and (b) 5mm square areas

4. Conclusion

From the above experiments carried out with slant angle, wire guide distance, corner dwell time, wire offset and cutting speed override as input parameter and area as a response parameter. The future scope of this research can be by knowing the overcut and effects of input parameters. WO parameter can be optimized for different profiles and can be machined with required tolerances without any finishing operation. The following conclusions can be drawn.

1. During slant type taper profiling, the WO parameter was the most significant parameter having contributing factor ranging from 59.33-74.94% and CDT parameter was the most insignificant parameter.
2. There was a decrease ranging from 4.54-18.89% in the area as WGD increased at all the angles. After 77% of CSO parameter, the area remains nearly constant indicating cutting speed doesn't affect the area.
3. As the angle was increased from 0° to 30°, there was a maximum increase in the area ranging from 15.87-85.45%% in square profiles.

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