Materials Today: Proceedings 27 (2020) 1943–1946

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Investigation of cutting speed, recast layer and micro-hardness in angular machining using slant type taper fixture by WEDM of Hastelloy X

Ranjit Joy, I.V. Manoj *, S. Narendranath

Department of Mechanical Engineering, National Institute of Technology Karnataka, Mangalore 575025, India

ARTICLE INFO

Article history:
Received 19 July 2019
Accepted 4 September 2019
Available online 3 October 2019

Keywords:
Angular machining
Slant type taper fixture
Hastelloy X
Cutting speed
Recast layer thickness
Micro-hardness

ABSTRACT

Wire electric discharge machining (WEDM) is a thermo-electric spark erosion process that can machine any difficult to cut materials. Taper cutting in WEDM is a unique feature that has many problems such as taper angular inaccuracies, wire cut and distribution of dielectric fluid during machining. In the present research work, angular machining is performed for generating a tapered component using a novel slant type taper fixture which overcomes the disadvantages of taper cutting in WEDM. The machining was performed on Hastelloy X at various angles namely 0°, 30° and 60° with different parameters in the machining range. The behaviour of cutting speeds for Taguchi's L9 set of experiments at 0°, 30° and 60° angle of tilt in machining was reported. The cutting speed is ranging from 0.16 mm/min to 2.49 mm/min during angular machining. From the SEM micrographs, the highest average recast layer thickness for highest cutting speed parameter was 26.4 μm at 0° and for the lowest cutting speed parameter, it was measured 6.4 μm lowest at 60° compared to the remaining angle of cut. The variation of micro-hardness at 0°, 30° and 60° tapered components at the highest cutting speed parameter were measured using Vickers micro-hardness test. The lowest Vickers hardness was found to be 167Hv at 0°. However further it is increased to 173Hv and 180Hv at 30° and 60° angle of cut respectively.

1. Introduction

Wire Electric discharge machining (WEDM) is one of the non-traditional machining processes that are capable of machining any conductive hard materials like titanium alloys, shape memory alloys, nickel-based superalloys, die steel etc. It is a spark eroding process where the sparks are developed by the high potential between tool and workpiece, which melts the workpiece to form a cut. Then the dielectric fluid impinges the melting region providing instant cooling to the workpiece and it helps to remove the debris. As WEDM is one of the precise processes for machining complex geometry, it has many applications in aircraft, tooling, chemical and defence industries.

Newton et al. have investigated machining parameters that affected the characteristics of surface morphology, recast layer, residual stress and hardness in Inconel 718 [1]. Sharma et al. have reported on material removal rate, surface roughness, variation in recast layer and hardness of Inconel 706 for different WEDM parameters [2]. Roy et al. have investigated different machining parameters on material removal rate, surface roughness and recast layer material of TiNiCu shape memory alloys [3]. Soni et al. have investigated on surface crack density, microhardness and XRD analysis for machining of $Ti_{50}Ni_{49}Co_1$ Shape Memory Alloy at different cutting speed parameters [4]. Tapering or angular machining is a unique feature in wire EDM. Kinoshita et al. initially of all had developed a linear model for taper machining, highlighting the flaws of normal taper cutting in WEDM [5]. Yan et al had reported a new servo mechanism than the traditional mechanism for the tapering process. The surface texture of the servo mechanism gave better surface integrity and improved accuracy compared to the traditional mechanism [6]. Martowibowo et al. have investigated material removal rate, surface roughness and taper angle through Taguchi method in taper motion of WEDM [7]. Sanchez et al. have investigated process parameters influencing the angular error and formulated a finite elemental model, to describe the mechanical behaviour of soft wires in taper cutting of WEDM [8]. In the present research work, an innovative method has been employed for taper

* Corresponding author.
E-mail address: vishalmanojvs@gmail.com (I.V. Manoj).

https://doi.org/10.1016/j.matpr.2019.09.021
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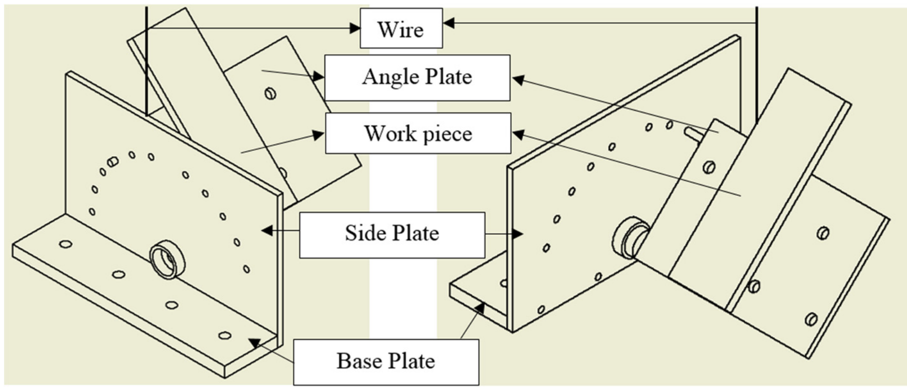

Fig. 1. Slant type taper fixture.

Table 1
Machining parameters.

Trial No.	T_{ON} (μs)	SV (V)	WF (m/min)	SF (mm/min)
1	105	40	6	10
2	105	50	7	15
3	105	60	8	20
4	115	40	7	20
5	115	50	8	10
6	115	60	6	15
7	125	40	8	15
8	125	50	6	20
9	125	60	7	10

or angular machining that could compensate for the disadvantages of taper machining. Hastelloy X was used as the work material and angular machining was carried out with the aid of slant type taper fixture leading to tapered surface of angles 0°, 30°and 60°.

2. Materials and methods

2.1. Experimental method and parameters

The WEDM used was of make Electronica model ECOCUT ELPLUS 15 from Electronica India Ltd. Pune, India and the deionized water was employed as dielectric fluid. The workpiece was Hastelloy X and tool was a zinc-coated copper wire of 0.25 mm. Hastelloy X which is a nickel-chromium-iron-molybdenum superalloy having application in transition ducts, combustor cans, spray bars and flame holders, afterburners, tailpipes and cabin heaters. The angular machining was achieved with the help of a slant type taper fixture as shown in Fig. 1. It mainly consists of a base plate which is fixed on a table of WEDM and angle is provided to the angular plate by the side plate where the Hastelloy X piece was fixed. The angular machined work surface of 5 mm thickness at 0°, 30° and 60° was machined at different parameters.

By the preliminary experiments that were conducted to decide the parameters, for the workpiece and tool combination. Taguchi's L9 orthogonal array was used for carrying out the experimental runs as shown in Table 1. The pulse on time (Ton), servo voltage (SV), wire feed (WF) and servo feed (SF) were considered for angular machining in Hastelloy X.

3. Results and discussion

3.1. Experimental method and parameters

The Hastelloy X was machined using WEDM at different machining parameters. Fig. 2 shows different cutting speeds that

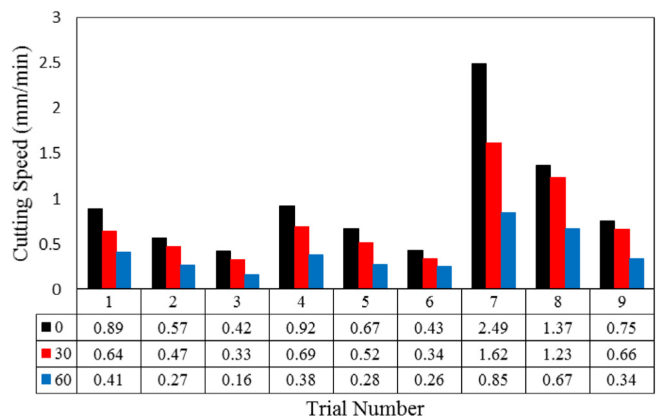

Fig. 2. Cutting speed variation at different angles.

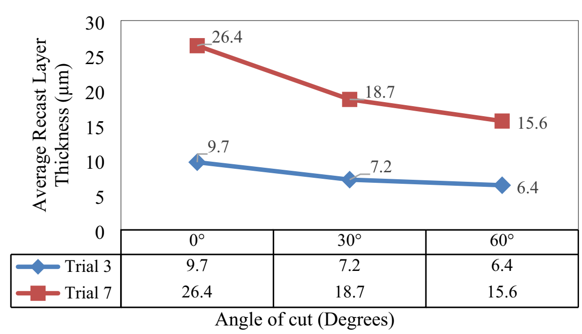

Fig. 3. Variation of average recast layer thickness at 0°, 30° and 60° angular machining.

were recorded at various parameters for 0°, 30° and 60° angle of cut. The trial 3 yielded the lowest cutting speed and trial 7 recorded the highest cutting speed at all the angle of cut. Trial 3 has a recorded lowest cutting speed of 0.16 mm/min at 60° and Trial 7 generated the highest cutting speed i.e. 2.49 mm/min at 0° slant angles. The cutting speed depends on pulse on time and servo voltage. As the pulse on time increased the number of sparks also increased. Hence the discharge energy increases the melting of the work surface, thus increasing the cutting speed. The servo voltage affects adversely on sparking, as the servo voltage was increased the spark gap enlarged. So the discharge energy is decreased which led to a reduction in cutting speed [9]. For all 9 parameters, the cutting speed decreases as the angle of cut increases due to the increase in cutting thickness. As the cutting

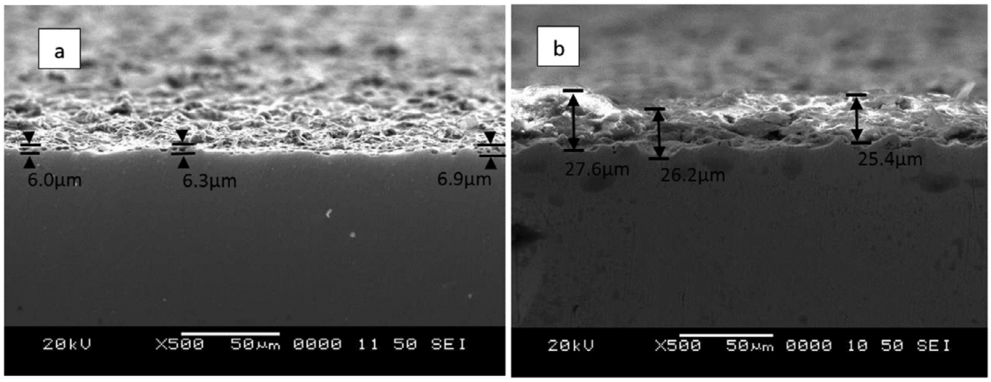

Fig. 4. SEM micrograph of (a) lowest average recast layer and (b) highest average recast layer.

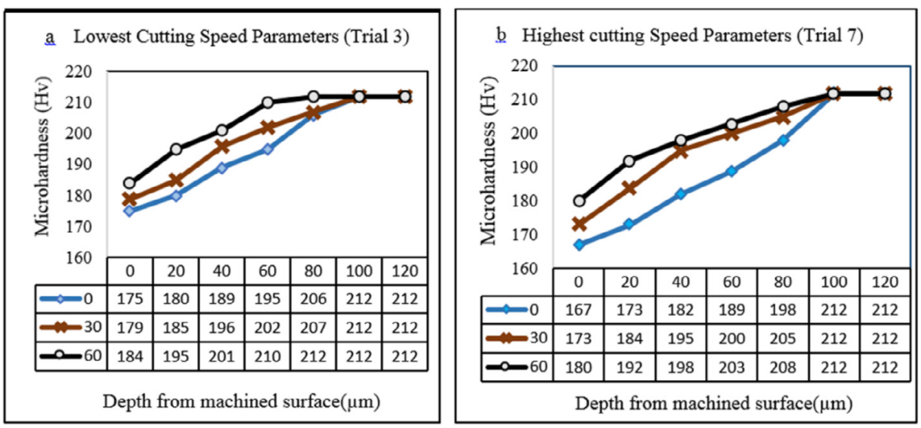

Fig. 5. Variation of hardness at different angle of cut for (a) Lowest cutting speed parameters (b) Highest cutting speed parameters.

thickness (job height) increases the amount of material that has to melt near the sparking region also increases, in turn, decreasing the cutting speed [8].

3.2. Variation of average recast layer thickness at different angles

The Fig. 3 shows the variation of recast layer thickness at highest (Trial 3) and lowest (trial 7) cutting speed parameters at different angle of cut. The average recast layer was recorded at highest speed (2.49 mm/min) to be 26.4 µm at 0° slant angle and lowest cutting speed (0.16 mm/min) to be 6.4 µm at 60° slant angle which was measured using JEO JSM-6368OLA scanning electron microscope as shown in Fig. 4(a) and (b). During machining, higher the pulse on time the discharge will also become higher. The sparks generated will be more causing the workpiece to melt at a faster rate. In the case of servo voltage, as the servo voltage decreases smaller will be the spark gap. This increases the number of sparks striking the workpiece which makes the discharge higher and vice versa. A portion of the material melts and it is carried away by the dielectric fluid providing a cooling effect on the workpiece. The remaining material solidifies on the machined surface which forms the recast layer [10]. In the case of angular machining as the angle increases, the cutting thickness also increases. This increases the area that has to be melted to machine the angular cut. In turn, decreasing the recast layer thickness as the heat distribution has to be more. There was 34.02%, 40.91% decrease in average recast layer for trial 3 and trial 7 with increasing angle of cut from 0°, 30° and 60°.

3.3. Variation of micro-hardness at different angles

Wire EDM is a thermo-electric erosion process where the machining is performed by melting the workpiece, the micro-hardness is affected significantly in angular machining. Fig. 5 shows variation of micro-hardness at the highest cutting speed and lowest cutting speed parameters at 0°, 30° and 60° angular cuts. The micro-hardness was measured using 'OMNI TECH MVH-S-AUTO' micro Vicker's hardness tester and the micro-hardness of the base metal was 212Hv. The three sets of micro-hardness were recorded and the average micro-hardness considered for the study. From Fig. 5(a) and (b) the micro-hardness was found to increase as the depth increased. The least micro hardness adjacent to recast layer was found to be 175Hv, 179Hv and 184Hv at 0°, 30° and 60° slant angles for lowest cutting speed parameter as in Fig. 5 (a). The Vickers hardness of 167Hv, 173Hv and 180Hv was found at 0°, 30° and 60° slant angles for highest cutting speed parameter as in Fig. 5(b). This difference in micro-hardness was due to lower and higher discharge energy while machining in WEDM. During machining due to the heating of workpiece, there would be intermediate zone formation which is known as heat-affected zone between the base material and recast layer. This zone has lesser micro-hardness compared to the base metal due to the metallurgical changes during machining [2,4].

It was also observed that 0° angular machined sample showed the least micro-hardness and however the micro-hardness is increased for 30° and 60° angular cut samples in both the parameters. This variation of micro-hardness is observed due to decreased heat-affected zone (HAZ) nearing the recast layer. During angular machining as the angle of cut increases, the cutting thickness also increases. This increase in cutting thickness increased the surface area to be machined, which led to a better distribution of heat generated by discharge energy. This leads to decreasing the recast layer thickness and HAZ on the machined surface.

4. Conclusion

From above the investigation of angular machining in Hastelloy X through slant type taper fixture, the following conclusions were drawn,

1. The cutting speed was found to be the highest 2.49 mm/min at 0° and the lowest of 0.16 mm/min at 60° angular cuts. It was observed that in angular machining the cutting speed decreases with an increase in the angle of cut due to increase in thickness, for all the machining parameters.
2. The average recast layer was observed highest at 0° is 26.7 µm for trial 7 and lowest of 6.4 µm for trial 3 at 60° slant angle. As the angle of cut increases the average recast layer thickness decreases due to the increase in the machining area, causing the distribution of discharge energy in angular machining.
3. The micro-hardness was recorded least 167Hv at 0° for (trail 7) highest cutting speed parameter which increased from 173Hv to 180Hv at 30° and 60° respectively. Similarly, the least hardness was observed 175Hv, 179Hv and 184Hv at 0°, 30° and 60° at (trail 3) lowest cutting parameters in angular machining. This effect was observed due to the variation of heat effected zone for different cutting speed parameters and cutting thickness.

Acknowledgements

We thank Manufacturing Lab, Mechanical Dept., NITK, Surathkal and TEQIP for giving an opportunity for carrying out our research. We are grateful to all the people who directly and indirectly helped in publishing this paper.

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