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Proceeding Paper

The 3D Taper Profile Machining of Superalloys and Composites Using WEDM: A Review †

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Abstract: Wire electric discharge machine (WEDM) is a process used popularly in microsystems, tool and die industries, medicine, transportation, and spacecrafts to create intricate portions with high dimensional accuracy and surface finish. It is employed to process superalloys and materials made of composites which are conductive and strong materials. From the literature, an analysis of the WEDM process on different materials revealed that there were many variables involved and that each process parameter influences the different response variables. The removal process of a spark discharge for an inclined angle during the cutting of 3D profiles has different applications. Also, types of dielectric fluid, and the influence of wire material, diameter and pressure, wire tension, feed, Ton, Toff, current, and voltage on machining characteristics—like kerf, MRR, wire wear, surface finish and its characteristics, dimensional deviations, and corner errors—and on a variety of materials like Inconel, nickel, titanium, WC, steels, and other superalloys and composites (MMCs and CMCs) during taper WEDM were reviewed.

Keywords: three-dimensional profile machining; superalloys and composites; process parameter and responses

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1. Introduction

The current trends of industries are challenging and represent a major task with regard to machine materials, and complicated designs with a good surface finish. We want to use advanced techniques to create complicated profiles for use in the military sector, in aircrafts, and in space technology. Some research works were carried out to overcome the machining of hard-to-machine materials including intricately shaped profiles using a WEDM consuming tungsten, molybdenum brass and copper wires.

Taper cutting is achieved by applying a relative motion between the two guides. The maximum angle is achieved by the thickness of the material used and the behavior of the wire. When making vertical cuts on a workpiece, the wire is kept vertical. However, when taper cutting is required, the wire is inclined by adjusting the positions of upper and lower wire guides in relation to the vertical, as shown in Figure 1. WEDM cuts successfully achieve corner machining precision by setting restrictions and cutting speed based on the number of trim cuts on the workpiece on all sides to improve corner accuracy. A special feature of the WEDM process is taper cutting, which enables the production of any draught-tapered pieces with various cross-sections and taper angles. Since the upper and lower guides are not vertical, the wire tension is high and hence the frequency of wire breakage is higher than with normal vertical cutting. Flushing efficiency is lower than with simple vertical machining. The forces during machining or stiffness vary in upper and lower guides and hence there is a chance for error in the corner accuracy. A review of normal WEDM on different materials is available in the existing literature. However, the literature has revealed that there is only a small amount of published research on the WEDM taper-cutting operation so far.

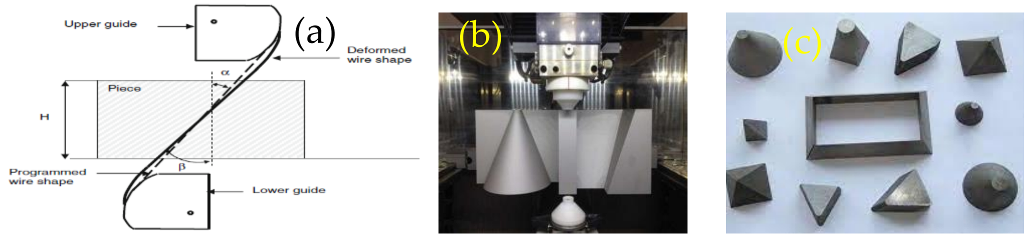

Figure 1. (**a**). Location of the wire during (programmed and actual) taper cutting in WEDM [1]. (**b**). Typical photo of WEDM taper cutting. (**c**). WEDMed 3D tapered samples.

Importance of the WEDM Process

Metal wires of diameter 0.03–0.35 mm are normally used as WEDM electrodes. WEDM can process production parts in a single step, saving time and money and dramatically enhancing production efficiency. Figure 1b shows the typical taper workpiece produced using the WEDM process. Figure 1c shows the various 3D tapered samples machined using WEDM, and these can be used as patterns/tools for creating dies.

Figure 1c shows typical samples produced using WEDM and these pieces can also be used to duplicate, using mold in casting, or repair rare or difficult-to-find auto parts. This can reduce the cutting waste from pricey materials (such as gold, silver, or expensive alloy materials) and aid in creating small, tapered holes, very narrow grooves, or three-dimensional designs to correctly fit existing parts and mitigate the high tolerances and material limits present in the aeronautical and medical fields.

2. Literature Review on 3D Taper Machining of Different Materials

Anmol Singh Verma et al. [2] performed the WEDM process on five 5-axis CNC machines to cut the taper of tool steel EN 31 using 0.25 mm brass for the taper cut up to 22°/80 mm. The MRR increased because of more energy being produced per spark as the spark period increased and the pulse duration (Ton) increased. Using the Taguchi–Grey Relation Analysis (TGRA), Hao Yan et al. [3] studied the design and development of two different big taper-cutting six-bar linkage mechanisms that could provide wire electrode guidance and dielectric fluid tracking spray. Executing numerous cuts enhanced the mechanism and reduced the roundness inaccuracy of taper cutting (taper 20°, thickness 40 mm). The wire-guiding technique was chosen, which causes an angular error but no wear.

Suresh et al. [4] examined the influence of different WEDM process parameters on machining quality when taper-cutting HSS. They analyzed important process variables impacting the surface roughness (Ra). Outcomes have shown that the improvement in the typical Ra is obtained after taper cutting during machining using a brass wire of ϕ 0.25 mm with an increase in Toff. Pramanik et al. [5] investigated errors like circularity, cylindrical, and diameter errors in a Ti_6Al_4V alloy during WEDM where the wire tension, Ton, and flushing pressure were all variable. Using the DOE and traditional analysis, the way variables affect whole mistakes was investigated. Uday Kiran et al. [6] studied the effects of rake angle, wire feed, and standoff distance on responses, such as attempting to cut the time, angular error, and Ra, to find the optimum values of each variable that generate the best cutting conditions. The tests were designed using response surface methodology (RSM).

Rakhshanda Naveed et al. [7] analyzed the geometrical correctness, trimming rate, and machined surface of a challenging tapered profile. The effects of WEDM factors, Ton/off duration, wire tension (WT), and voltage (V), were examined. The workpiece and wire were WC-cobalt composite strip and brass, respectively. Kashif Ishfaq et al. [8] investigated the feature of WEDM on Al6061 alloy. They observed that the wire tension had increased and the corner mistake was worse. As a result, there was an increase in heat flow and material degradation at the corners.

BijayaBijetaNayak et al. [9] showed that the B_4C-reinforced aluminum matrix composite could be machined well during WEDM taper cutting. A unique combination setting has also been used to reduce angular error and Ra value. Sadananda Chakraborty et al. [10] studied the comparison between GRA and GRA-principal component analysis (PCA) in WEDM performance on Ti_6Al_4V using chromium powder mixed dielectric, and it was discovered that GRA-PCA is superior to GRA for optimization. The most critical elements for Ra are Toff and V, while the most essential factors for powder concentration are Ton and pulse length.

Jayakumar and Suresh [11–13] used two wire materials (brass and zinc-coated brass) to examine the effects of current (I), Ton, Toff, and V on the WEDM of the SS304 in terms of MRR and kerf. They also conducted the WEDM of SS304 with rough and trim cuts to increase machinability. The electrode was 0.25 mm ϕ brass wire. They also analyzed the impact of the same wire materials with WEDM parameters of I, V, Ton, and Toff time on SS 304 to evaluate Ra, the hardness of the machined surface, and the thickness of the recast layer.

The next part of the paper presents discussions on the WEDM of various superalloy workpieces, wire electrode materials, different WEDM parameters, and corresponding output responses. The major findings of recent research works are presented in the form of a table (Table 1) for an easily accessible overview.

Table 1. Summary of research on WEDM of different materials with responses.

S.No.	Author and Year	Materials	Process Parameters	Performance Measures	Findings	Ref. No.
1.	Manoj et al. (2020)	WP: Hastelloy X. Zinc-coated Cu.	Ton, V, Wire and servo feed	Cutting thickness, Ra, slant angle, surface crack density.	The slant angle is influenced by wire vibration.	[14]
2.	Manoj and Narendranath (2020)	WP: Hastelloy X. Zinc-coated Cu.	Toff, Wire feed Ton, V	Cutting speed, override, wire offset, dwell time.	WEDM parameters and slant angle influence the profiles.	[15]
3.	Sadaf Zahoor et al. (2021)	IN718 superalloy. Zn-coated Cu.	Wire tension, Ton, Toff, V and wire feed	Ra, dimensional deviation, and cutting speed,	The optimal solution: 2.6 g WT, 2.9 µs Ton, 22.4 µs Toff, 54.6 V.	[16]
4.	Arulselvan Subbura et al. (2021)	Inconel 825, copper wire	Ton, Toff, WT, Taper angle (1°, 3° and 5°)	MRR, Ra, taper error.	40 µs Toff, 0.6 µs Ton, 12 N, and 1° yielded good responses.	[17]
5.	Manoj and Narendranath. (2021)	Hastelloy-X. Wire: Zn-coated Cu.	Toff, Wire feed, Ton, V, I, flushing pressure	Profiling speed and area, Ra, hardness and recast layer	Profiling speed influences accuracy and tapers circular profiles.	[18]
6.	Manoj and Narendranath. (2022)	WP: microfer 4722. Wire: brass	Toff, Ton, V, wire feed, Angle (0° to 30°)	Profiling speed and error, Ra, recast layer thickness, hardness	Residual stress decreased as the slant angles were raised to 30°.	[19]
7.	Yesong Wang et al. (2023)	WP: Cr12 steel, Wire: molybdenum.	Pulse width, Ton and I.	Error analysis, attitude and angular error.	A decrease in the positioning error reduces the volumetric error.	[20]

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