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Kerf width analysis of wire electrical discharge machining of titanium alloy

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Abstract

Wire Electrical Discharge Machining (WEDM), is a machining technique that utilizes electro-thermal principles to remove material from workpieces. It achieves material melting and vaporization by generating controlled and discrete sparks between a conductive work surface and a wire electrode. The process parameters involved in WEDM can significantly impact the machining results. This study focuses on four input process parameters: A: Gap Voltage (GV) ranging from 40 to 70V, B: Pulse on time (Ton) ranging from 2 to 8 microseconds, C: Pulse off time (Toff) ranging from 10 to 16 microseconds, and D: Wire Feed (WF) ranging from 1 to 4m per minute. These parameters are considered variables that can be adjusted to achieve desired machining outcomes. To conduct the experiments and analyses, the researchers employed a Taguchi-based Design. The Taguchi method is a statistical approach for designing experiments and optimizing processes by considering various factors and levels. By utilizing this method, the researchers conducted tests to investigate the effects of the process parameters on the output, which in this case is the kerf width. An analysis of variance (ANOVA) was performed to determine the significance of each factor and assess their influence on the kerf width. ANOVA helps identify the key factors that contribute most significantly to the observed variation in the output. Finally, the study employed single objective optimization techniques to achieve the minimum kerf width for titanium alloy. The optimization methods are used to find the optimal combination of process parameter settings that would result in the desired outcome of minimizing the kerf width. By utilizing this approach, the study aims to

understand the impact of process parameters on the machining of titanium alloy using WEDM and optimize the parameters to achieve the desired outcome of minimum kerf width.

Introduction

Titanium and nickel-based alloys are important in various industries due to their unique properties and wide-ranging applications. These alloy groups offer exceptional mechanical, chemical, and thermal characteristics, making them sought-after materials for critical applications. However, they also present challenges in terms of machining due to their high strength and low thermal conductivity. Titanium alloys exhibit excellent strength-to-weight ratio, corrosion resistance, and biocompatibility. These alloys are lightweight yet possess high tensile strength, making them ideal for applications where weight reduction is crucial. Titanium alloys are widely used in aerospace, automotive, medical, and marine industries. Among the titanium alloys, Ti6Al4V holds particular importance. It is a widely used alloy consisting of 90% titanium, 6% aluminium, and 4% vanadium. The specific properties of Ti6Al4V include high strength, excellent corrosion resistance, and good weldability. Its properties make it suitable for applications such as aircraft components, gas turbines, biomedical implants, and structural components subjected to high mechanical stress [1], [2]. However, Ti6Al4V is challenging to machine due to its low thermal conductivity, high chemical reactivity at elevated temperatures, and tendency to work harden during machining processes [3]. Nickel-Based Alloys: Nickel-based alloys often referred to as superalloys, exhibit exceptional heat resistance, high strength, and excellent corrosion resistance. These alloys retain their mechanical properties at elevated temperatures, making them suitable for applications in gas turbines, jet engines, power generation, and chemical processing industries. Nickel-based alloys are known to withstand extreme environments, including high-temperature and corrosive conditions. The machining of nickel-based alloys presents difficulties due to their high strength, low thermal conductivity, and work-hardening tendency. The high strength of these alloys increases cutting forces and tool wear, while their low thermal conductivity results in poor heat dissipation, leading to heat build-up during machining. These factors make machining nickel-based alloys challenging and require specialized tooling and machining techniques to achieve optimal results. In general, titanium and nickel-based alloys are crucial in various industries due to their exceptional properties and diverse applications. Ti6Al4V, a notable alloy from the titanium group, offers a combination of high strength, corrosion resistance, and weldability. It finds applications in aerospace, medical, and other demanding industries. While these alloys pose challenges in machining due to their unique characteristics, overcoming these difficulties is essential to harness their full potential in manufacturing processes. Advanced machining techniques, tooling, and expertise are necessary to effectively machine these alloys and meet the stringent requirements of their applications. Electrical Discharge Machining (EDM) and WEDM play a crucial role in the machining of titanium alloys. These techniques offer several advantages for working with titanium, known for its high strength, low thermal conductivity, and chemical reactivity. The importance and need for EDM and Wire-EDM in machining Ti alloys are Complex Geometries, Hardness and Heat Resistance, and Minimal Material Loss [4], [5].

Wire EDM is an unconventional machining approach that can work electrically conductive materials whose hardness makes it difficult for conventional machining to handle. It is a spark erosion method where sparks repeatedly generated between a workpiece submerged in a dielectric solution and a thin, continuously moving electrode. The materials melt and evaporate as a result of this repeated electrical spark. Through the dielectric medium, molten debris is removed from the workpiece in this process. Furthermore, cooling machined surfaces is accomplished using this dielectric medium [6]. Modern manufacturing technology includes higher dimensional accuracy for the needed application through precision machining, which is a crucial component. The dimensional precision of the workpiece to be machined is critically dependent on kerf width (KW) [1]. For the product to be of high quality, this dimensional precision or KW was kept as minimal as feasible. The KW, which affects wire diameter in WEDM, might affect the workpiece's dimensional deviation. Additionally, it depends on nonelectrical parameters like WF, WS, and WT as well as workpiece material characteristics, different types of dielectric fluids, and various wire electrode types. It’s also depends on non-electrical parameters such as WF and speed, in addition to electrical factors such as Ton and Toff, Ip and GV. Anshuman Kumar [7] studied the impact of design variables on Inconel 718 alloy response during WEDM. The analysis revealed that Ton is the most important parameter that, by applying more discharge energy, impacts KW, SR, and MRR. KW was increased by the threshold voltage, Ton, and WF, but decreased by an increase in Toff. When Toff increases, the discharge energy decreases, resulting in shallow craters on the workpiece [8]. The largest involvement to the KW comes from Ton (48.25%), next Toff (14.45%) [9]. Ikram et al. [10] used different material thicknesses and optimization strategies for WEDM based on the Taguchi method. For all workpiece thicknesses, SR, KW, and MRR, Ton has the most important parameters at feed rate of 2–6 mm/min. A. Aniza et al. [11] explored how machine feed rate affects WEDM. The machining feed rate is increased, the MRR and SR increase while the KW decreases. Roan et al. [12] investigated how parameters affected the accuracy of titanium alloy (TA) using WEDM. According to the investigation, KW decreases when WT is move up from 400 to 700 gf. KW is also marginally impacted by WF rate (14.1 m/min will produce the narrowest KW). According to earlier research, the performance of a WEDM depends not only on electrical variables like GV Toff, Ip, Ton, and but also on non-electrical variables like WF, WS, and WT as well as the properties of the workpiece's material, the type of dielectric fluid, and the type of wire electrodes [9]. The KW, which is more than the wire's actual diameter, reflects the areas on which melt and vaporization was taken by the moving electrode (wire) due to the effects of consecutive discharges [13]. The average KW can theoretically be calculated by multiplying the wire diameter by the spark gap. The voltage, Ip and Ton which regulate the intensity of discharges and the total spark gap during the wire-EDM process, are found to have a significant impact on the KW [11]. Other factors that affect KW include types of wire material, WF rate and tension, albeit these effects are not as strong as those linked to discharge energy [13]. The KW is minimized for continuous stable discharge and lower discharge energy [14]. Also, it was found that the KW increased as the wire tension decreased. This is primarily caused by the wire electrode's enhanced lateral vibration, which is related to an increase in the lateral concentration of discharges. As a result, increased wire tension results in a more desirable and constant KW. Extremely high tension is not preferred, though, as it increases the likelihood of frequent wire rupture. According to [16] the breadth of the kerf grows as the pulse-on-time does. Taper also appears near the conclusion of the machining process. According to Alias et al. (2012) [11], increases in peak current of 4 to 12 A and pulse-off time of 1 to 5 μs significantly increase KW. But peak current had a bigger impact than pulse-off-time. In terms of machining parameters, 5 μs Ton, 12 A Ip, 6N WT, and speed 4 mm/min were the most effective. With increasing wire tension, the KW at the top and bottom narrow. Because the wire is more flexible and long while the tension is low, more material is removed and more heat is produced, which causes the kerf to spread. In contrast, when stress increases, the wire electrode stiffens and its diameter decreases, which helps to narrow the kerf [16].

Udyaprakash J et al [17] performed WEDM of AMCs to investigate the effects of process parameters and with % of reinforcement on MRR and SR. It has found GV, WF and B4C % has significantly effects on MRR and SR. In an untreated sample, the material removal rate exhibits a trend toward a decrease with rising WFS and SRV and an upward trend with increasing wire tension. With increasing WSF and SRV in the annealed sample, MRR and SR increase, whereas a diminishing tendency is shown with increasing wire tension. When WSF and SRV are increased in a quenched sample, MRR and SR also do, but there is a declining tendency as wire tension is raised [18]. The ANN has been employed for prediction of machining performance of Micro WEDM & WEDM process [19], [20]. According to test results from Palani et al's powder mixed EDM technique, the SR increase is better when Gr nanopowder is mixed with EDM oil [21]. P. Sreeraj investigated the Wire Electrical Discharge Machine (WEDM)'s machining properties, including KW and surface roughness, when machining AMCs. Peak current of 12A, applied voltage of 20V, and WF rate of 5 m/min were determined to be the ideal machining conditions using the MOORA-PCA method [22].

The literature reveals that there is very little research on the machining of titanium alloy. The use ofoptimization in TA machining particularly KW has not been studied. The novelty of present focused on identifying the influences on WEDM process parameters on KW. Therefore, the current effort concentrated on WEDM process optimization for TA using taguchi approach.

Section snippets

Experimental methods

The workpiece is a commercially available TA (Ti-6Al-4V) and the plates length 15 cm, and 1 cm in width thickness 0.5 cm. The chemical compositions of TA is given in Fig. 1. The wire electrodes made of brass materials and its 250 μm diameter. Deionized water based dielectric medium flushed into machining zone. The selection of wire electrode and dielectric medium are based on literature and commercially available. Fig. 1 shows the WEDM process. Fig. 2 shows images of workpiece before and after …

Results and discussion

The experiment's results for KW are shown in Table 2. Fig. 4 depicts the KW for each parameter for mean data at levels 1, 2, 3 and 4. As can be observed in Fig. 4, the KW extends as the pulse timing is becoming more advance. The lower KW found at Voltage 50 V, 2 μs Ton, 12 μs Toff and 1 m/s WF. The KW tends to decrease and then increase while increasing the voltages. It's due to the fact that the discharge energy goes upwith the Ton, and higher energy release causes a larger crater, resulting …

Conclusions

In this study, machining of TA was carried out utilizing Taguchi L16 orthogonal array design in order to explore KW. These result in findings that are presented here.

- By using the Taguchi design of experiments, the tests were carried out to investigate the machining accuracy of a number of different design variables such as GV, pulse on pulse off and WF on relating to KW. …
- GV, Toff and WF has most influencing factors for KW which had 48.8%, 35.21% and 7.5 % respectively, whereas Ton less …

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CRediT authorship contribution statement

Santosh Kumar Sahu: . **M. Vijay Anand:** . **T CH Anil Kumar:** . **Ashok Kumar:** Investigation, Formal analysis, Methodology, Software. **G Shakthi Prasad:** . **V.V Niraj:** . …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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