engineering proceedings

Proceeding Paper

Wire EDM Process of AISI 431 Martensitic Stainless Steel: A Machinability Investigation †

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† Presented at the International Conference on Processing and Performance of Materials, Chennai, India, 2–3 March 2023.

Abstract: The wire EDM process for AISI 431 martensitic stainless steel involves meticulously investigating its machinability. This study explores the intricate details of the machining process, considering factors such as material characteristics and cutting conditions. A steep increase of 51.59% in pulse on time was observed following enhanced material removal. As servo voltage and pulse-off decreased, surface roughness decreased by 24.31%. The aim was to increase the efficiency and precision of the wire EDM process for this AISI 431 stainless steel grade. The investigation shows valuable insights for manufacturing applications, especially in surgical instruments, orthopedic implants, and medical casing. The findings will enhance the performance and quality of AISI 431 martensitic stainless steel components.

Keywords: SS 431; surface roughness; hardness; surface morphology; WEDM

Citation: Chandrasekaran, B.; Sampath, S.; Anbalagan, A.; Paneerselvam, V.; Karthick, V. Wire EDM Process of AISI 431 Martensitic Stainless Steel: A Machinability Investigation. *Eng. Proc.* **2024**, *61*, 27. https://doi.org/10.3390/engproc2024061027

Academic Editors: K. Babu, Anirudh Venkatraman Krishnan, K. Jayakumar and M. Dhananchezian

Published: 3 February 2024

1. Introduction

The wire EDM process has emerged as a pivotal technology in the manufacturing industry, facilitating the precise shaping of materials that are often challenging to machine using conventional methods [1]. In particular, AISI 431 martensitic stainless steel has greater attention in the field of engineering and manufacturing due to its exceptional combination of hardness, corrosion resistance, and mechanical properties [2]. This investigation delves into the intricate shapes of the wire EDM process applied to AISI 431 martensitic stainless steel, primarily focusing on evaluating its machinability. This research aims to uncover the optimal parameters and methodologies to enhance the precision and efficiency of manufacturing components from AISI 431 stainless steel [3]. This study contributes to the broader understanding of advanced machining techniques and their application in key industrial materials, ultimately advancing the field of medical and automobile sectors. The literature reveals that a limited amount of work has been performed using WEDM to machine AISI 451 alloys. This investigation presents the optimal process parameters for machining AISI 451 alloys to achieve higher material removal with good surface quality. AISI 451 alloys are machined using the RSM-BBD optimization technique as part of the wire EDM process [4]. An SEM analysis was used to characterize the machined surface, and the hardness variation in the machined alloy was measured using the micro-Vicker.

2. Materials and Methods

2.1. AISI 431 Martensite Alloy and Its Chemical Composition

In this work, the AISI 431 steel plate was purchased and cut into a 100 mm × 30 mm size for the WEDM process. The chemical composition was initially tested using a positive material identification (PMI) tester.

2.2. Wire EDM of AISI 431 Steel

Wire EDM (Model: Excetex) was used to machine the SS 431 alloy. This machine's wire electrode had a diameter = 0.25 mm (brass). The input parameters of the pulse off-time (T_{off} = 10–12 range), servo voltage (SV = 40–50 range), and pulse on time (T_{on} = 8–10 range) were considered in the machining of the AISI 431 steel. The parameter ranges were determined in accordance with the machine's limitations and valid literature [5].

2.3. Measurement of MRR, SR and Micro-Hardness

The SS 431 alloy's weight was measured using a weighing balance before and after machining. During the machining, the time of each cut was noted. The MRR of the machined sample was computed using Equation (1) [6]. The material removal rate was an essential output parameter for manufacturing precision components. As a result, this machining effort aimed to achieve good surface quality.

$$MRR\ (\mathrm{mm}^3/\mathrm{min}) = \frac{W_1 - W_2}{\rho \times t} \times 1000 \tag{1}$$

W_1 and W_2 refer to weight before and after WEDM, AISI 431 density (ρ) = 7.80 g/cm^3. The surface roughness (SR) was measured using the tester SJ-210. The hardness was measured using the micro-Vicker. The measured SR and MRR for the set of 15 combinations are outlined in Table 1. Design Expert 13.0 was used for optimization of the experiments.

Table 1. Machining response values of the AISI 431 alloy for various experiments.

Run	T_{on}, µs	SV, V	T_{off}, µs	MRR, mm^3/min	SR, µm
1	9	45	11	4.506	3.583
2	9	40	12	3.912	3.214
3	8	50	11	2.723	2.027
4	9	50	10	4.812	3.941
5	9	40	10	5.061	4.187
6	10	45	10	6.591	5.172
7	9	45	11	4.402	3.609
8	9	50	12	3.533	2.873
9	10	50	11	5.833	4.438
10	10	45	12	5.416	4.379
11	9	45	11	4.292	3.472
12	10	40	11	6.184	4.945
13	8	40	11	3.086	2.266
14	8	45	12	2.469	1.798
15	8	45	10	3.279	2.662

3. Results and Discussion

3.1. Statistical Study of the MRR on the AISI 431 Steel

Figure 1a shows that the MRR increases steadily from 2.924 mm^3/min to 6.041 mm^3/min as the T_{on} increases from 8 µs to 10 µs. The increased discharge intensity at a high pulse on time leads to greater metal removal from the work surface [6]. As shown in Figure 1b, with an increase in T_{off}, the MRR reduced from 4.907 mm^3/min to 3.804 mm^3/min. Due to decreases in the discharge rate at the high T_{off}, the surface roughness decreased, resulting in improved surface quality but less material removal.

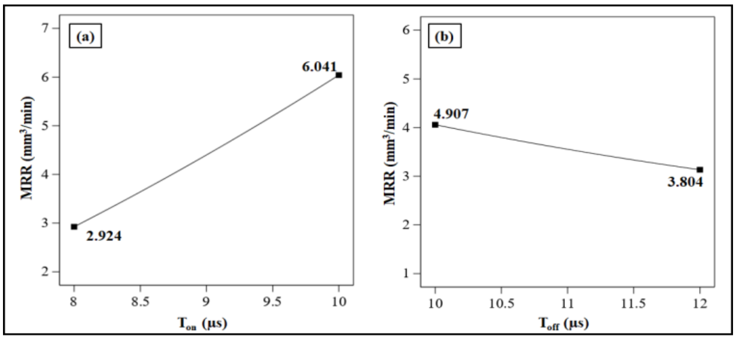

Figure 1. (**a**,**b**) Parmetric effect of surface plots on the MRR.

3.2. Statistical Study of the Surface Roughness (SR) of the AISI 431 Steel

Figure 2a shows that the SR increases from 2.188 µm to 4.733 µm with an increasing T_{on}. The extended pulse on time increases spark energy and melts and evaporates more material-resolidified metal on the machined surface, increasing surface roughness [7]. As T_{off} increases, surface roughness reduces, as shown in Figure 2b. The longer the T_{off}, the less work it takes for the material to melt, allowing for dielectric fluid flushing to quickly remove it from the machining zone and reduce surface roughness [8].

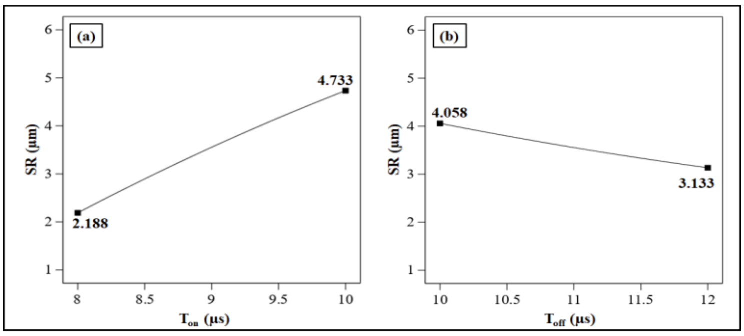

Figure 2. (**a**,**b**) Parmetric effect of surface plots on the SR.

3.3. WEDM Parametric Optimization

The optimum level of machining parameters is shown in Table 2. Figure 3a depicts the microhardness of the AISI 431 alloy at different parameters; high-level machining parameters increased the microhardness. The optimal values show better results compared to other parameters. Similarly, Figure 3b shows the SEM image of the optimal value WEDMed surface, which clearly shows less accumulation of debris with fewer surface defects.

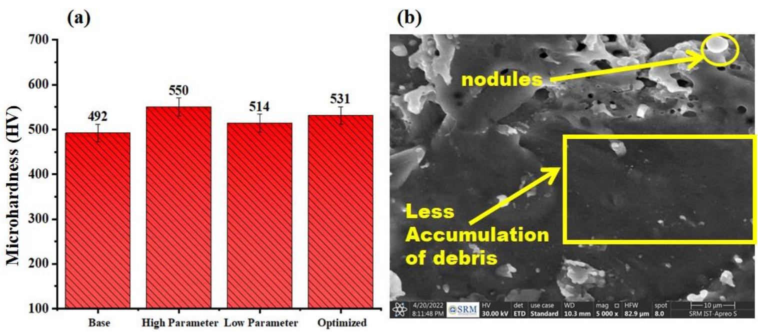

Figure 3. (**a**) Microhardness; (**b**) SEM graph of optimal WEDM parameters.

Table 2. The optimum level of WEDM parameters.

Optimized Level			Predicted Values		Experimental Values		% of Error	
T_{on}	SV	T_{off}	MRR	SR	MRR	SR	MRR	SR
9	50	11	4.606	3.636	4.421	3.488	4.18	4.24

4. Conclusions

Machining AISI 431 using WEDM and a longer pulse duration removes more material due to more significant discharge power generation, leading to quicker melting and material vaporization. Although the SR rises with a pulse on time, it can be decreased by an increasing T_{off} and servo voltage, resulting in a reduced amount of material being removed from the cutting surface. The machined surface had a higher hardness than the unmachined work sample, and this value was increased by increasing the T_{on} value. This is owing to the development of a recast layer and the rapid cooling of the dielectric fluid. Machining with optimal parameters produces less debris and a smoother surface.

Author Contributions: Conceptualization, B.C., S.S., A.A., V.P. and V.K.; methodology, B.C. and S.S.; software, B.C.; validation, investigation, B.C., S.S., V.P. and V.K.; resources, B.C. and S.S.; data curation, B.C., S.S. and V.P.; writing—original draft preparation, V.P. and V.K.; writing—review and editing, B.C., A.A. and S.S.; visualization, S.S.; supervision B.C. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available on request.

Conflicts of Interest: The authors declare no conflict of interest.

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