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Machining of Inconel 718 using WEDM and Cutting Parameters Optimization

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Abstract:

In the manufacturing industries, machining of super alloys are evolving rapidly in response to surging production demands, making the strategic design of these processes essential for sustainable expansion. The application of superalloys like Inconel alloys and Ni-Cr based alloy increase in various sectors like aerospace, automobile etc. Machining of superalloy is hard to cut hence WEDM is preferred for cutting, but the selection of input parameter is challenging task. Hence, integrating Multiple Criteria Decision Making (MCDM) into manufacturing industries is critical to support enduring growth. This research work presents an integrating AHP–VIKOR methodology has been for utilized for selection of multiple conflicting criteria. This novel framework determines a well-balanced combination of run order, serving as a compromise solution within a decision-making environment characterized by conflicting criteria. In this work, Machining of Inconel 718 Superalloy using Wire-cut Electric Discharge Machining (WEDM), total of 16 machining run orders are evaluated as decision alternatives. The results of mathematical techniques provide compromise solution that considers various criteria for the machining of Inconel 718. The proposed method is designed to be versatile and can be extended to other selection and ranking challenges across diverse industrial contexts.

Keywords: *Wire-cut Electric Discharge Machine, Sustainable planning; Multi-criteria decision analysis; AHP; VIKOR*

Introduction

Due technological advancements and increasing global demand, manufacturing processes are rapidly adopting to encourage for sustainable industrial development. For sustainable manufacturing process, controlling of machining parameters are challenging for the advance material and superalloys which are difficult to machine. Non-traditional machining techniques play a pivotal role in meeting the challenges of machining advanced materials. The Electric Discharge Machining (EDM) and Wire Electrical Discharge Machining (WEDM) provides an effective solution for precision machining of hard-to-cut materials.

EDM is a contactless spark erosion process. This machine is capable to generate complicated design with high precision and tolerance any difficult-to-cut advanced engineering materials irrespective of their physical and mechanical properties [1-2]. It can competently cut high carbon steels, titanium and their alloys, hybrid Metal Matrix Composites, superalloys (Inconel alloys and super alloy). EDM found extensive range of metal cutting in many of the die making industry, automotive industry, aerospace industry, defence, nuclear and medical industries [3]. Due to hardness, toughness, and low thermal conductivity it is hard to machine using conventional machine.

Wire Electrical Discharge Machining

The working principle of WEDM is similar to conventional EDM process involving the erosion effect produced by electric discharges. The WEDM is a non-conventional machining process that operates on the principle of the electro-thermal concept, where material cutting occurs through the spark erosion technique. In this process, an electric wire is used as a tool that passes through the workpiece at a small distance of 0.025-0.050 mm in the availability of dielectric fluid [4]. High-frequency sparks are generated, and the material is eroded from the specimen through melting and vaporization. The diameter of electric wire (zinc-coated brass, brass, copper, reusable molybdenum etc.) is generally between 0.10 to 0.30 mm used as electrode [5]. The dielectric fluid is generally used as deionized water with high pressure, which helps to remove the debris available between the tool and workpiece and also works as a coolant [6]. Figure 1 shows the working of WEDM.

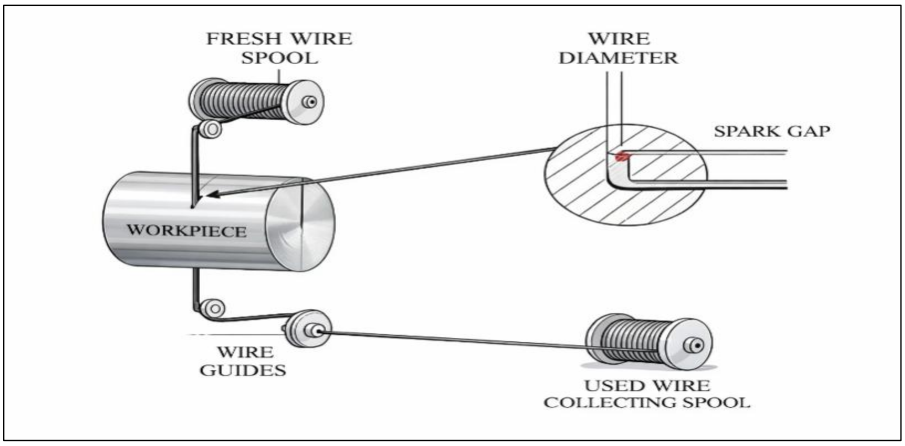

Figure 1: Working principle of Wire Electrical Discharge Machining

WEDM Parameters

The Input parameters of WEDM are Pulse-on(T_{on}), Pulse-off (T_{off}), Servo Voltge (SV), Wire Tension (W_t) and Current (I_c). T_{on} is the time period in which electric spark takes place, T_{off} is the period between successive electric spark' I_c Current flowing through the conducting tool wire to generate high temperature, SV is maintaining the gap between electrode wire and work piece. The W_t is the force applied to stretch the wire during machining for consistent cutting [7-8].

The output response parameters of WEDM are Material Removal Rate (MRR), Surface Roughness (SR), Cutting Velocity (Vc), and Kerf Width (KW). MRR is rate of removal of materials from work-piece during machining. SR measures flatness after machining that shows surface quality. Vc is the speed at which the conducting tool wire moves through the work piece. KW represents as the gap between the two side cuts as wire moves through the work piece. Hou et al. [9] implemented the surface characteristics of Nickle-Titanium shape alloy all together with damage of surface, ability of shape recovery, and hardness where roughness decreases from 2.79 µm to 0.12 µm.

K.H. Ho [10], highlight that WEDM attains high precision and satisfactory finishing but the obstacles like Vibration, Wire Breakage, and low MRR may decrease the efficiency and correctness of WEDM. Numerous studies have been done on cutting of Inconel 718 and similar types of alloys by using WEDM. In several research works, it has been stated that the input parameters such as T_{on}, T_{off}, SV, and Wire Feed (WF) have a substantial impact on the machining rate, SR, and recast layer thickness [11]. Reducing flushing pressure creates debris accumulation between workpiece and wire electrode that deteriorating surface quality [12]. The output responses like SV, peak current (I_p), and T_{on} yields the recast layer at the machining area which has been extensively observed [13].

Karsh and Singh [14] works on the cutting of Inconel 625 using Taguchi Orthogonal Array to determine the optimum machining variables of WEDM. The machining variables designated for the machining are T_{on}, T_{off} and I_p, whereas the output parameters are SR. The result revealed, Ton is the greatest significant factor for SR, while the impact of I_p is expressively less.

Kumar et al. [15], inspected the impact of vital machining parameter on Wire Wear Ratio (WWR) and MRR during the cutting of Titanium using WEDM. Response Surface Methodology methodology has been utilized to frame a predictive model, with the designated input parameter for cutting i.e. T_{on}, T_{off} , I_p, spark gap voltage, WF, and WT. The outcome specifies that MRR higher when the T_{on} and I_p, are increases, but it also rises wire wear; longer T_{off} decreases the spark efficiency and MRR. Later, Kumawat et al [16] studied machining of EN-31 Steel, to develop a triangular contour via WEDM. Taguchi technique are utilized for design of experiment, ANOVA is utilized for identifying the importance of machining parameters on the output responses. The machining variables chosen for the cutting are T_{on}, T_{off}, I_p, and WF, while the output response is MRR. The outcome designates that Ton and WF rate are the extremely significant parameter of MRR. Similarly, Binoj et al. [17] investigated the optimization of WEDM cutting parameters for the Ni alloy and subsequently generates a predictive model for MRR. Taguchi OA have been utilized by using multiple regression analysis to demonstrate experimental associations between input variables and MRR, aiding prediction of machining responses. This shows that Ton is the major active factor, along with I_p and T_{on} for generating MRR.

Experimental Setup

The experimental work is carried out by using Electronica Sprint-cut machine for the machining of Inconel 718 superalloy, experimental setup is shown in Figure 2. A Zinc coated Brass wire of 0.25 mm diameter is utilized as tool for the machining and the de-ionized water is utilized as dielectric fluid to flush the debris available between wire electrode and specimen.

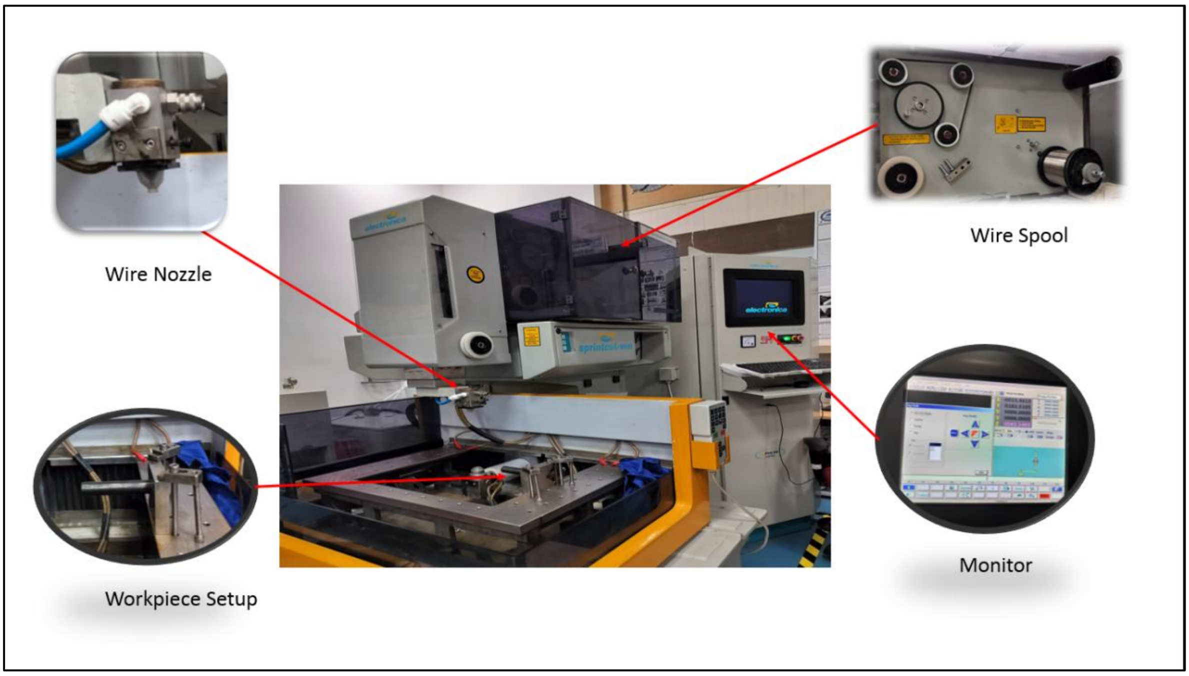

Figure 2: Sprintcut WEDM experimental setup

For the cutting process Table 1 shows the input parameters and MRR, SR and CV are the response parameters. Table 2 represents the results the machining of Inconel 718 using WEDM.

Table 1: Parameters of Wire EDM machine for machining

S. No.	Input Parameter	Units	Symbol	Level			
				1	2	3	4
1	Pulse-on Time	µ-s	T_{on}	106	112	118	120
2	Pulse-off Time	µ-s	T_{off}	62	58	54	50
3	Wire Feed	m/min	WF	5	6	7	8
4	Spark Voltage	Voltage	SV	30	40	50	60

Table 2: Experimental results of machining using WEDM

Alternatives	Input Parameter				Response Parameter		
Run order (A)	T_{on} **(μs)**	T_{off} **(μs)**	WF **(m/min)**	SV **(V)**	MRR **(mm³/min)**	SR **(μm)**	V_c **(mm/min)**
1	106	62	5	30	0.602	1.626	0.482
2	106	58	6	40	0.635	1.682	0.513
3	106	54	7	50	0.690	1.271	0.502
4	106	50	8	60	0.746	1.264	0.712
5	112	62	6	50	0.811	2.304	0.759
6	112	58	5	60	0.802	2.534	0.758
7	112	54	8	30	1.396	2.462	1.353
8	112	50	7	40	1.624	2.244	1.592
9	118	62	7	60	1.022	2.462	1.23
10	118	58	8	50	1.447	3.155	1.345
11	118	54	5	40	1.821	2.552	1.88
12	118	50	6	30	2.180	2.992	2.124
13	120	62	8	40	1.763	2.55	1.635
14	120	58	7	30	1.529	3.144	1.42
15	120	54	6	60	1.042	2.986	1.256
16	120	50	5	50	1.485	2.733	1.373

Some MCDM methods are AHP, TOPSIS, VIKOR, Elimination and Choice Translating Reality (ELECTRE), etc. [18]. On the basis of relative position, AHP model assesses some criteria by organizing them in pairwise comparison matrix and ranking them in order. Earlier, Singh and Nachtnebel [19] have utilized AHP model with a view of sustainability. TOPSIS technique positions alternatives based on their relative distances from Positive and Negative ideal results for enhancing sustainability [20]. Sinha and Chaturvedi [21] presented an combined outline of Pinch knowledge and TOPSIS for sustainable planning. The VIKOR technique focuses on ranking and choice of several substitutes having inconsistent features by giving a Compromise Solution which is nearest to ideal [22].

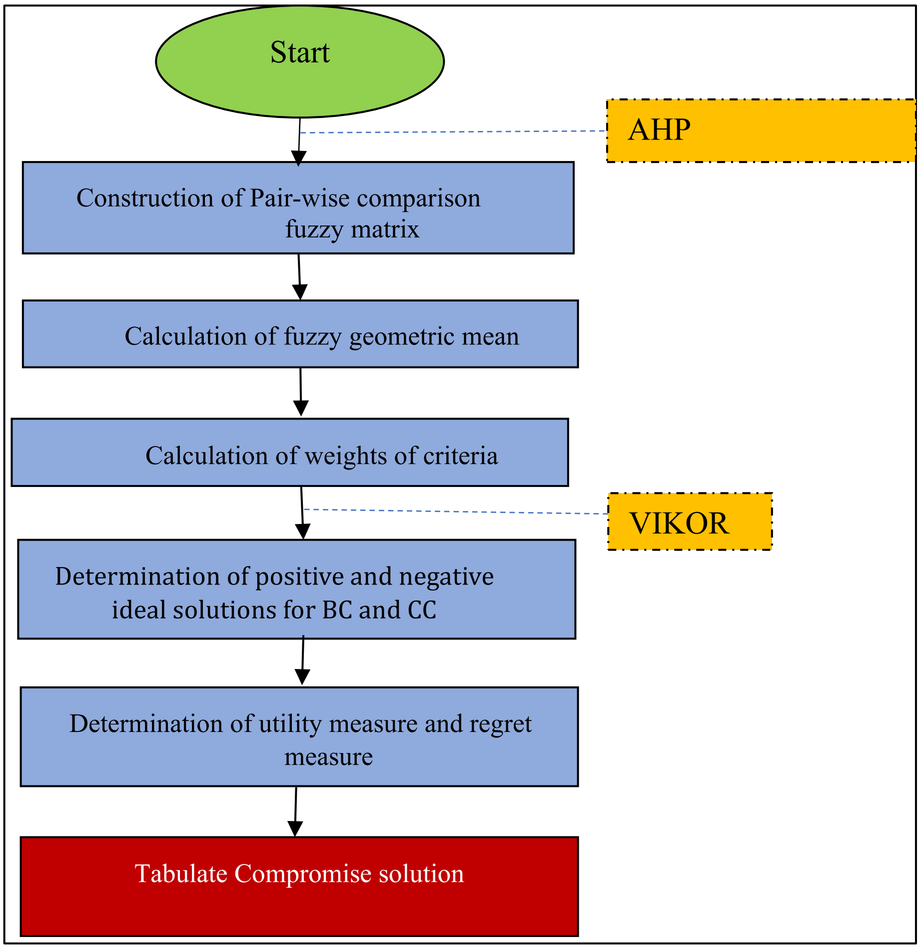

Figure 3: Flowchart of AHP-VIKOR methodology

It presents VIKOR technique that delivers a hopeful result for decision making with high utility and low regret. The Figure 3 shows the MCDM methodology of combined AHP-VIKOR approach for obtaining ranks and compromise solution. After utilizing the proposed methodology of AHP-VIKOR it has been found that, 3 out of 16 run orders are selected in machining of Inconel 718 by WEDM. The developed methodology calculates weight of output responses based on relative importance of criteria in and A12, A11 and A13 are selected as Compromise Solution out of given run orders. These run orders are superior to other run orders which could aid in achieving sustainability by providing optimal output response in machining.

Conclusion

The developed methodology considered for the machining can be utilized with incommensurable and conflicting criteria. It provides a promising solution for conflicting criteria and enhances sustainability. The developed methodology can be utilized in various domain where conflicting criteria are available. In the current experimental work, the most promising value with respect to response parameter is A12. But the value of A12 is no much superior than run order A11 and A13 hence all three run order are the most compromise solution from all run order. This methodology provides a promising solution for conflicting criteria and enhances sustainability which can be further in future for selection of energy projects, production planning and other domains to tackle sustainability issues.

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