Recent Advances in Machining of Composites and Super Alloys by Using Wire-EDM. A Review

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1 Introduction

1.1 Composites

Aluminum-based composites possess low density and high strength which makes them suitable for wide range of industrial applications [1, 2]. Metal matrix composites (MMC) must have at least two constituent parts, i.e., one constituent is metal and other can be metal or non-metal. Matrix is usually a lighter metal like aluminum, which exhibits capability to support reinforcement. Further, particles or fiber could also be as reinforcement. MMC's are being widely used in many industrial sectors due to various desirable properties such as better tribological and corrosion behavior, high strength, wear resistance, low thermal coefficient, good mechanical properties at elevated temperature but they possess poor machinability [3–5]. The composite materials are suitable for nuclear power plants as well [6]. The classification of composites materials is shown in Fig. 1 [7].

The reason of poor machinability of composite materials is the presence of hard reinforcement particle which cause hindrances while machining which in turn increases tool wear. Machining of MMCs is very difficult by using conventional machining processes. [4, 8]. To fulfill this gap non-conventional machining technique got more importance, among them wire electrical discharge machining (WEDM) is best suited for giving better machining profiles in composite materials [8]. WEDM is non-contact machining process and can machine any conducting material regardless of hardness and strength of the material being machined [9]. In order to achieve better machining performance, various mathematical models and statistical models

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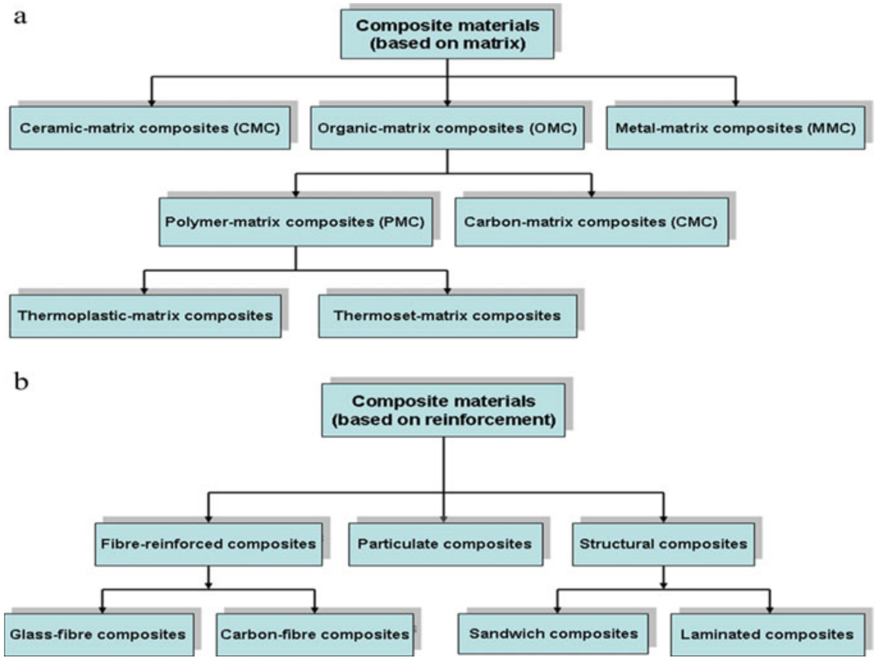

Fig. 1 Classification of composites, **a** based on matrix **b** based on reinforcement [7]

are used by researchers to establish the relation between process parameters and response variables [10].

1.2 Super Alloys

One of the best materials used in last few decades for high temperature application is super alloy. Super alloys show better performance in high temperature applications like jet and rocket engines where the temperature reaches around 12,000 °C to 14,000 °C [11]. Nimonic super alloys possess high specific strength and thereby used in various aero engine components [12]. The chemical composition of Nimonic super alloys is 38–76% nickel, 27% chromium and 20% cobalt, and some more components are needed such as tungsten (W), tantalium (Ta) and Molybdenum (Mo) to enhance its properties [13]. Super alloys are classified as in Fig. 2 [14]. Inconel 718 is age-hardened nickel–chromium-based super alloy having better mechanical and tribological properties and retains its mechanical properties in the range of −423 °F to 1300 °F. It also exhibits good weldability to resist with post-weld cracks. Inconel 718 is difficult to be machined by conventional processes. To efficiently machine such alloys, non-conventional machining process needs to be adopted, and WEDM is generally preferred to machine high strength super alloys [15].

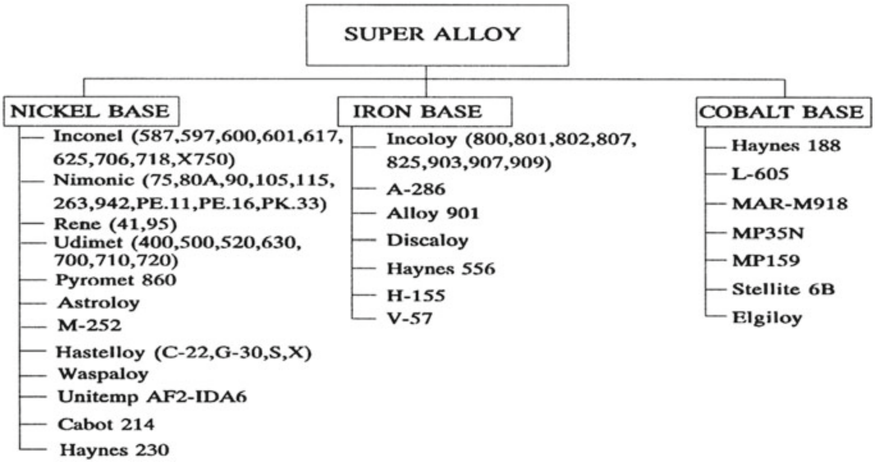

Fig. 2 Classification of super alloys [14]

Titanium-based alloys exhibit good mechanical properties like creep resistance, fatigue strength, wear resistance, functional and structural strength at elevated temperature and are thereby used in multiple applications like aerospace, ballistics, machine components, automobiles. Due to its cost, it should be handled with great effort and processing like fabrication, machining operations must be chosen carefully. WEDM is an easy and economical machining process to machine any grade of super alloys and titanium alloys [16].

2 Literature Survey

See Table 1.

3 Latest Techniques for Machining Composites and Super Alloys Using WEDM

WEDM comprises number of response variables and among them material removal rate (MRR) and surface roughness (Ra) are important that affect the productivity and surface texture of manufacturing components. From the literature survey, it is clear that most of the research has been done on MRR and Ra. The MRR refers to the amount of material removal which depends upon polarity of wire electrode as well. Higher MRR is attained by the negative polarity of wire electrode and positive polarity of work piece.

Table 1 Recent studies on composites and super alloys, using WEDM

Investigator	Work material, machining process and method used	Process/input parameters	Response/output variables	Research finding
Kumar et al. [17]	Al-SiC-B_4C composites, WEDM	Current (12Ae20A), pulse on time (100mse120 ms), wire feed (6 mm/m and 10 mm/m) and composition of B4C w%	(RSM), kerf width & cutting speed	RSM method was used which gives current = 20 A, POT = 108.6 ms, B_4C = 5.65% & wire feed rate = 10 mm/min as significant parameters. Also, gives kerf = 0.271 mm & max cutting speed = 4.76 mm/min
Manikandan et al. [18]	Incoloy 825, 603XL,600, Monel K400 super alloy, WEDM, SEM	POT, voltage, PFT, wire feed and mean current	Perpendicularity, straightness and Ra	Monel K400 produced better significance over other super alloys
Vellingiri et al. [19]	LM13 and LM13/SiC alloys, WEDM	POT, PFT and Current	MRR and Ra	Better hardness and tensile strength, POT (30–40 ms), PFT (4–10 ms) and current (Ip, 1–3 A) for better MRR and Ra
Sing et al. [20]	AA7075/SiC, WEDM, Fuzzy logic modeling	POT, PFT and Peak Current	MRR and Ra	Influencing parameters for AA7075 + 5wt%SiC, POT for Ra. PFT for MRR. And Influencing parameters for AA7075, PFT for Ra and peak current for MRR
Kavimani et. al. [21]	AZ31 + (0.2–0.4) %r-GO@ (10–30) % SiC, WEDM	POT, PFT, Wire Feed Rate	MRR and Ra	POT increases Ra, Hybrid technique can be used

(continued)

Table 1 (continued)

Investigator	Work material, machining process and method used	Process/input parameters	Response/output variables	Research finding
He et al. [22]	2D C/SiC Composite, WEDM	POT, PFT and No. of tubes	Mach. speed (Cs) and Ra	Fibber orientation has got more significant effect on the Ra than machining speed
Ishfaq et al. [23]	SS316 and mild steel, WEDM	WP orientation, hight of one layer, voltage of servo, PON, wire dia, wire feed and pressure ratio	Spark gap	Wire dia. and pressure ratio contribute 71% and 16%, respectively, to the spark gap
Sing et al. [24]	MWCNT alumina composites, WEDM, SEM	POT, Peak current, Wire speed	Ra and MRR	MRR increases with POT, current. Wire speed also influences
Sing et al. [24]	MWCNT alumina composites	POT, Peak current, Wire speed	Allowance	Multi-pass WEDM shows steep decrease in surface roughness
Nain et al. [25]	Aeronautics super alloy, WEDM, Fuzzy logic and BP-ANN	POT, PFT, IP, SV, WT and WF	Ra and waviness	The variable POT, interaction between POT and PFT, wire tension and spark gap voltage have influenced Ra. The waviness is influenced greatly by POT and PFT and spark gap voltage
Goyal Ashish [26]	Inconel 625 super alloy, WEDM, SEM, TAGUCHI & ANOVA	Tool electrode, current intensity, POT, PFT, wire feed and tension	Ra and MRR	POT, electrode and current are the input parameters affecting Ra and MRR
Yusoff et al. [27]	Ti-48Al intermetallic alloys, WEDM, ANN & multi-GA	POT, PFT, feed rate, peak current and servo voltage	MRR, Ra, Vc and Dk	The approach, OrthoANN, reduced ANN experimentation time and optimization by integrated with multi-GA

(continued)

Table 1 (continued)

Investigator	Work material, machining process and method used	Process/input parameters	Response/output variables	Research finding
Mandal et al. [28]	Nimonic C 263, WEDM	R- cut, F- cut, Grinding & post Grinding	Ra, Rz, Rt and Rsk	The average Ra is as minimum as 0.024 µm after recast layer, and new surface is generated along with compressive residual stress 500 MPa
Garg et al. [29]	Nickel-based super alloys, WEDM & RSM	POT, PFT, spark gap voltage & wire feed	Cutting speed, gap current and Ra	Significant parameters are POT and PFT, with minimum spark gap voltage, and wire feed is insignificant
Nain et al. [30]	Udimet-L605 super alloy, WEDM, Taguchi, GRA	POT, PFT, Peak current, Spark gap voltage, Wire tension and feed	MRR and Ra	Spark- gap voltage, POT, interaction POT x PFT and wire tension are optimum variable for Ra while POT, spark gap voltage and PFT are optimum variables for MRR

To increase MRR, the discharge current should be increased. Surface roughness (Ra) is one of the parameters of surface integrity and it depends on the type of contact friction, deformation and accuracy. The machined component should have good surface quality for mainstream applications. Figure 3a and b shows the SEM image of machined composite material by WEDM and illustrates the 3D-Topography of machined surfaces. Figure 4 shows SEM images of the WEDMed surfaces of super alloy Monel K400 [14]. Among various unconventional machining techniques, WEDM is most preferred one and plays the vital role in machining of complex shape, precision shape components, intricate shapes, making dies, micromachining, etc. The major challenge for researchers now a days is the efficient machining of high temperature composite materials and super alloys. Various researchers concluded that the WEDM process parameters which significantly affect the machining performance during machining of super alloys and composites materials are (POT), (PFT), servo voltage and peak current. For better machining performance, these process parameters need to be optimized to obtain desired surface integrity, MRR and kerf.

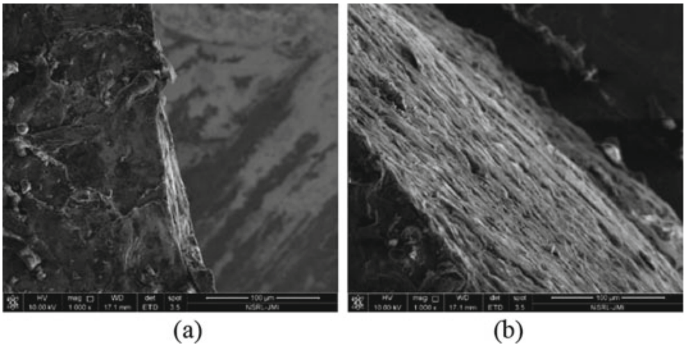

Fig. 3 **a** SEM image of WEDM machined edge. **b** SEM image of WEDM machined surface

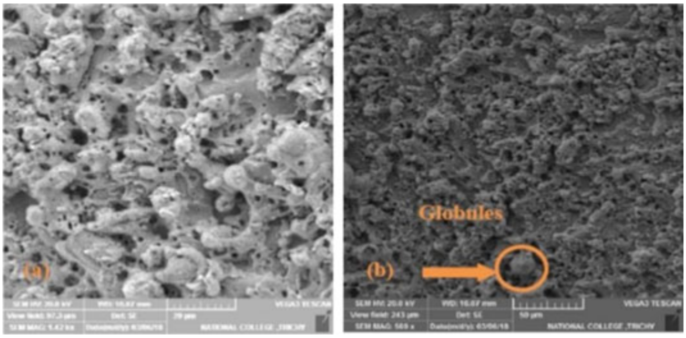

Fig. 4 SEM image of WEDMed surface of Monel K400 [18]

4 Conclusions and Future Scope

The machining of composites materials and super alloys is difficult by using conventional methods and this arises the need of non-conventional machining methods. One of the most convenient machining processes for precise machining of composite materials and super alloys is Wire electric discharge machining. WEDM is an efficient process for precise and micro level machining of composites and super alloys. Literature reveals that the WEDM process parameters significantly affect the surface integrity/roughness, MRR and kerf during machining of super alloys and composites materials. The process parameters which significantly affect the machining performance are (POT), (PFT), servo voltage and peak current. As per this study these process parameters need to be optimized to obtain desired productivity and quality of the machined component.

In future machining of insulating composites and ceramics can be done on WEDM. Furthermore, surface quality can be enhanced along with high temperature machining performance.

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