MUTIL-OBJECTIVE OPTIMIZATION – A TOPSIS APPROACH FOR OF EDM MACHINING OF BIOMATERIALS

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ABSTRACT

The increasing requirement for less wear and corrosive materials in biomedical, medical equipments application drives the development of new advanced smart metal matrix composites (SMMC). It is important to enhance the performances, life cycle and reliability of the biomedical and medical devices. A new, shape memory alloy is used as the reinforcement for making smart composite materials, to augment the properties such as ductility and toughness without compromisingthe corrosion resistance. The aluminium and NiTi is used to fabricate NiTi reinforced aluminum smart composites via powder metallurgy (PM) process. To understand the fundamental effect of NiTi on aluminum, the composites are fabricated for varying compositions. To disclose the efficacy of the fabrication process, the composites tested for physical and mechanical properties. The following basic terms density, porosity, hardness, and compression strength is studied and discussed. The augmentation of NiTi gains the compressive strength of the smart composites to certain extent which is significantly higher than pure aluminum. The density of the composites is slightly increased compared to pure aluminum; porosity is less than 5% irrespective of the reinforcement level. The problem persists with smart composite material is, it is very difficult to make into final shape by traditional machining process. In this work smart composites are machined to understand the machinability characteristics and investigates the influence of various Electric Discharge Machine (EDM) process parameters on machining quality such as Surface Roughness (R_a) and material removal rate (MRR). TOPSIS method is used to model the process and output of the same is presented.
Keywords: *Aluminum, NiTi, Mechanical Properties, EDM, Surface Roughness, MRR, TOPSIS*

1. Introduction

MMC shows increase in mechanical, tribological and damping properties as compared to matrix alloy but often suffer from inferior fracture toughness [1,2]. Aluminium Metal Matrix Composites (AMCC) is one of the prominent materials owing to its exceptional stiffness and wear resistance properties, compared to unreinforced aluminium alloys [3]. Within the available

MMC, Particulate Metal Matrix Composites (PMCC) possess excellent fabrication benefits and marked as cost-effective process. There are good number of evidences available to describe the benefits PM process in fabricating the PMMC and the most commonly used particulates are SiC, B_4C, SiO_2, Al_2O_3, Bauxite, Corundum, Granites and Silimanite [4-5]. The other benefit of PM process is low sintering temperature related to conventional melting process, it alleviates the formation of intermetallic compounds, thus produce products good in dimensional accuracy and tolerance [6-7]. Bekir et al. [8] used Al_2O_3-SiC as reinforcement and compared the effect of casting and PM method on the quality of AMCC and found that fabrication of hybrid composites by PM process is superior than casting process [8]. The influence of graphite soft reinforcement and SiC hard reinforcement in aluminum alloy is studied to understand the PM processing capability by Mahdavi et al. [9]. PM process is capable of making hybrid composites with lesser porosity, but compaction pressure, sintering time and sintering temperature plays a significant role. The augmentation of particulates increases the hardness of MMC by negotiating the toughness property.

Machining of PMMC is very difficult in nature because of its complex structure, abrasivesize and shape. Aforementioned difficultyleads to excessive cutting tool wear in traditional machining process. Some of the nontraditional machining process are upright to handle the aforesaid issues, since, in most of the process cutting tool do not have direct contact with workpiece materials [10]. Among the wide variety of nontraditional machining process, EDM finds its place because of its capability in making complex shapes in dies and biomedical components [11]. In EDM process, the material is removed by melting and evaporation, the melting temperature process depends upon the EDM machining parameter such Voltage (V), Current (I), pulse on time and off time. In case of EDM machining of Al-SiC MMC, it is observed that spark produced between the electrode and workpiece melts the matrix and reinforcement materials [12], and it is observed that the temperature in the machining zone varies between 8000 to 12000^0 C [13].

Electrode diameter, rotational speed of the electrode, size and shape of the particulate have significant role to achieve the desire MRR, out of the aforesaid parameters, the electrode diameter is the key parameter and trailed by rotational speed of the electrode which decides the MRR. Size of the particulate have major effect on electrode wear, increase in electrode wear is noted while machining with large particulate size reinforced composites [14]. It found that increase in tool wear resistance provides high melting temperature to remove the material. Subsequently, the electrode wear in one of the performances deciding factor in EDM process, the selection of appropriate electrode material is also crucial factor [15]. The experimental studies to understand the behavior of electrode material while machining of Al-SiC composites, it found that copper performed well with less tool wear than the tungsten and brass materials [16]. Hocheng et al. studied the formation and size of the crater wear in MMC workpiece material which decides the MRR. The size of the crater wear depends upon the discharge energy and subsequently the discharge energy depends on current and pulse on time. It is noted that increase in discharge increase the crater size of the Al-SiC composites [17]. R_a also plays important role in EDM machining, it is observed that, discharge current, pulse-on time, and duty cycle have significant role in deciding the R_a of MMC [18]. From the literature, it is understood that most of the nontraditional machining operation are performed in Al-SiC composites, and very few literatures are available in Al_2O_3. In this work an attempt is made to understand the effect of EDM machining parameter on NiTi reinforced aluminum smart composites.

2. Materials and methods

NiTi and aluminum is used as the matrix and reinforcement materials to fabricate the smart composites through PM route. Average particle size of NiTi and aluminum material is ≤45 μm and bought form Coimbatore Metals, Coimbatore, India. The required sample of smart composites containing 0 to 5 wt. % NiTi is prepared by suitably selected PM process parameters. The following steps are followed to ascertain the quality samples; mixing and blending of powder in ball mill to ensure the homogeneity, preheating the powder in nitrogen atmosphere to remove the moisture, loading the powder in the compaction die, compaction is done in UTM machine by applying compaction pressure of 300 kPa, the green sintered composites ejected from the die and sintered for 60 min at 550^0C under nitrogen-controlled atmosphere. The green compact is removed from the die and sintered smart composite is shown in Fig.1.

Fig. 1 Fabricated and Sintered Composites

ASTM Standard D-792 is used to determine experimental density and compared with theoretical density by rule of mixture. ASTM B777 is used to measure the compressive strength of the sintered composites. The size of the specimen is maintained as diameter 9.53 mm and length as 25.33 mm. The experiment is repeated twice to ensure the process accuracy and average value of the composite is reported. Vickers micro hardness measuring machine with a load and time of 0.4903N and 30 sec is used to measure the hardness. The measurements are taken at four different areas and average hardness is reported. JEOL JSM-6840 LV scanning electron microscope is used to study particle distribution in the matrix materials.

2.1 Machining of composites

Sparkonix ZNC EDM Model S-50 is used to perform the planned experiments. Fig. 2 shows the experimental setup used for performing EDM machining operation. Kerosene is used as dielectric fluid medium with a flushing pressure of 1.0 kgf/cm^2 to conduct the experiments. The follwing parameters are selected based on the importance and contribution in EDM process, such as peak current, pulse on time, voltage, and other important parameter is wt.% of reinfocement. The selected levels of process parameter and wt.% reinforcement is shown in Table 1. MRR and R_a of the experiment is measured after 30 min. of each machining process. Each experiment is repeated twice to measure the MRR and R_a. MRR is calculated based on difference in the weight. Electronic weighing machine with an accuracy of 0.0001 mg is used to measure the initial and final weight.

Table 1. EDM and Material Process Parameter and its Levels

Level	1	2	3
Peak Current (A) in Amps	5	10	15
Pulse on Time (B) in sec	40	50	60
Voltage (C) in V	200	500	1000
wt.% of reinforcement (D) in gm	0	3	5

R_a is measured by stylus type surface roughness measuring device (model SRT 6120), the cut-off length is maintanied as 0.8 mm, and repeated twice in two locations. The average of two observations is reported for each experiment.

(a) (b)

Fig. 2 (a) Specimen (b) Elecrode

2.2 Mutiobjective Optimization by TOPSIS

TOPSIS idenified as one of the relaiable process to select the optimcal combination of machining paramater. The concept of Techniques for Order of Preference by Similarity to Ideal Solution (TOPSIS) is proposed by Huang and Yoon in 1981 and further develped by Yoon 1987. The aim of the proposed method is to select the best alternative from the group of data sets. The best alternative should be positioned near to the ideal solution and must far away from the worst alternative. To achieve this, the proposed algorthim should have unique characteristics to manage the poor results in one category of data sets can be compansated with better category of dataset. The idea behind the technique is to chose the aternative which have shortest distance position to ideal solution and far away from the negative ideal solution. The uniqueness of the TOPSIS method is; ability to compensate the poor result in one criteria with the other good result in another criteria. To find the most suitable EDM machining condition, the following steps are followed:

The decision matrix is framed as per the experimental runs and its criteria represented by Eq.1.

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12.....} & x_{1n} \\ x_{21} & x_{22} & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix} \quad (1)$$

In decision matrix, X_{ij}express the output performance meausred during the experiments with their corressponding units. Since, MRR and R_a is measured with diffetent unit measurement system, it is very difficult to process the data; therefore it is necssary to convert into comparable units. To obtain the comparable units; MRR and $R_a$are normalized by Eq. 2.

$r_{ij} = X_{ij}$ √∑ X_{ij} $2mi$=1, (2)

where i = 1, 2.....9; j = 1 & 2, i = number of expreiment and j = number of parameter

The weight factor for each performance is taken as 0.5 and same is used to compute the weighted normalized matrix is established by the Eq. 3.

$V_{ij} = w_i \times r_{ij}$ (3)

where i = 1, 2…..9 and j = 1 & 2, w_j represents weight for each performance (1) and (2).

The nearest ideal solution from the all the experimetnal run is established by Eqn.3.

$D^+ = (D_1 +, D_2 +, \ldots.. D_n^+)$ for maximum values

$D^- = (D_1 -, D_2 -, \ldots.. D_n^-)$ for minimum values

The distance between the ideal solution (positive) and ideal solution (negative) is computed by Eq. 4

$S_i^+ = \sqrt{\sum} (D_{ij} - D_j^+)^2 mi$=1 (4)

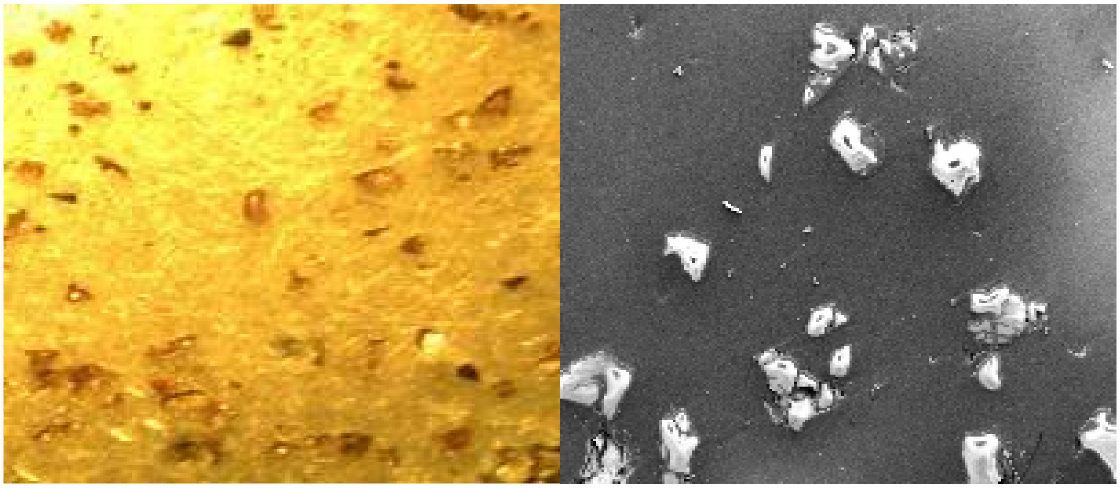
$S_i^- = \sqrt{\sum} (D_{ij} - D_j^-)^2 mi$=1

The closest coefficient value of each experiment is computedby Eqn.5

$$C_{ci} = \frac{s_i^+}{(s_i^+ + s_i^-)} \quad (5)$$

3. Result and Discussions

To ascertain the distribution of NiTi reinforcement particulates in aluminium matrix, the fabricated composites are cut into desired shape, size, polished and are inspected under optical and SEM. Fig. 3 (a) and (b) shows the opticaland SEM micrograph 5 % NiTi reinforced aluminium smart composites, it is understood NiTi particles are well distributed throughout the aluminium matrix and spacing between the reinforcements are also more or less uniform. It indicates there is no evidence of agglomeration of NiTi particles.



(a) (b)

Fig. 3 (a) and (b) Optical and SEM micrograph

Augmentation of NiTi particles over aluminum matrix increases the density of the smart composites, because addition of high density partlcles increase the density. In this case, the porosity of the composite is in the range of 3 to 5 %. Fig. 4 shows the trend of increasing in density of the composites. The reason for less porosity is proper selection compaction pressure, sintering time and tempearture. The other reasons could be due to particle size of the reinforcement of particle size and shape, since the selected particulate sizes are more or less uniform for reinforcment and matrix material.

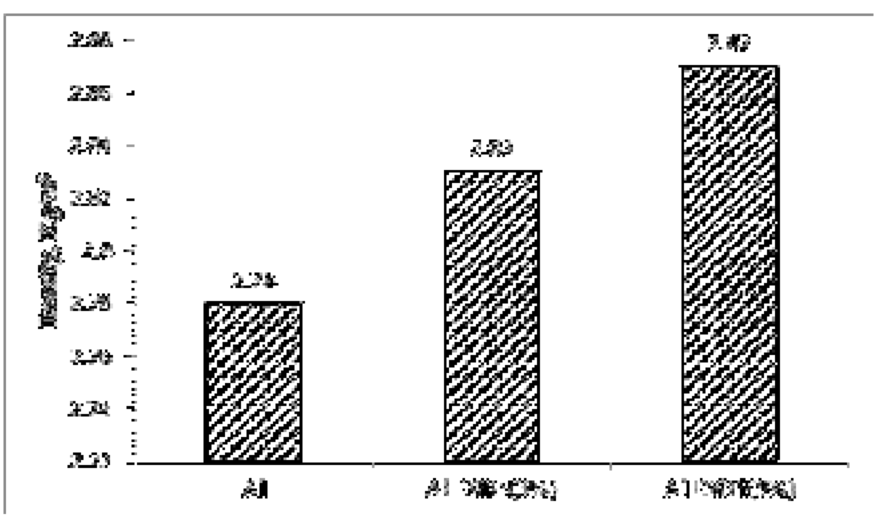


Fig. 4. Density of the reinforced and unreinforced composites

From Fig. 5 it is evident that, as the percentage of NiTi particles is increased from 0 to 5 wt. %, the hardness of the smart composite intensified monotonically and meaningfully to nearly one time advanced to original value. Interfacial contact between the NiTi and aluminium and uniform distance between the reinforcement could be one of the reasons for obtaining higher hardness. The existence of reinforcement particulates arrests the free movement of atom thus resist the propagation of cracks; it could be other reasons for increase in hardness. Augmentation of higher wt.% reinforcement reduces the space between the particulates which weakens the binding between the matrix and reinforcement materials. Aforementioned are the reasons for increasing compressive strength also, the trend of increasing in compressive strength is shown in Fig. 6. However, the augmentation of hard NiTi particles into the aluminium causes the smart composites to become brittle rather ductile in nature.

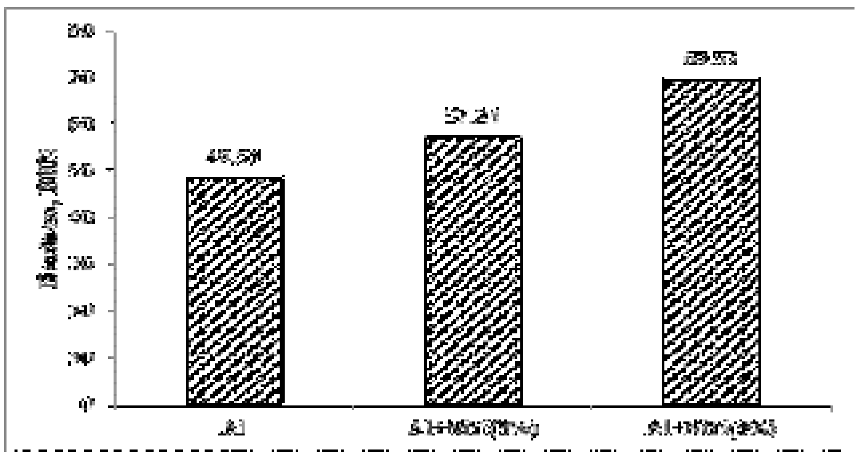


Fig. 5. Hardness of the composites

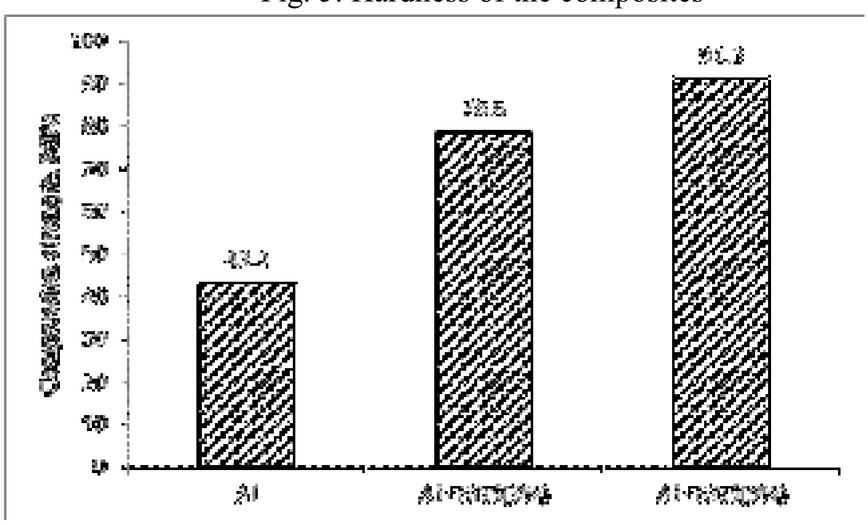


Fig. 6. Compression Strength of the composites

3.1 Optimization of machining parameter

The experimental data set is developed based L_9 orthogonal array and it is used to perform the optimization studies. The experimental data set is used to frame the decision matrix as mentioned in Eq.1. EDM machinng parameters are current, pulse on time, votlage, and material properties is % wt. reinforcement and MRR and R_a is considered as output performances. Table 2 shows the experimental plan and its results.

Table 2. Experimental reuslts and their runs

A	B	C	D	R_a	MRR	(r_{ij})	(r_{ij})	(D_i^+)	(D_i^-)	C_i	Rank
5	200	40	0	5.50	9.9E-06	0.09	0.08	0.10	0.072	0.41	7
5	500	50	3	7.42	1.0E-05	0.13	0.09	0.08	0.075	0.50	5
5	1000	60	5	8.10	6.3E-06	0.14	0.05	0.06	0.111	0.67	2
10	**200**	**50**	**5**	**9.75**	**1.3E-05**	**0.17**	**0.00**	**0.06**	**0.172**	**0.75**	**1**
10	500	60	0	7.15	3.5E-05	0.12	0.30	0.26	0.148	0.36	8
10	1000	40	3	11.14	1.5E-05	0.19	0.13	0.07	0.1	0.58	3
15	200	60	3	11.38	2.7E-05	0.19	0.23	0.18	0.126	0.41	6
15	500	40	5	14.47	1.8E-05	0.25	0.16	0.12	0.152	0.57	4
15	1000	50	0	10.24	2.2E-05	0.35	0.37	0.17	0.08	0.33	9

Eq. 2 is employed to normalize the MRR and R_a (j = 1 & 2) and the results are presented in Table 2. Eq. 3 is employed to compute the weighted normalized matrix. The weight factor for each performance is taken as 0.5 and results of weighted normalized matrix is given in Table 3. The closeness among ideal positive and negative ideal solution is estimated by Eq. 4. The results of ideal positive and negative idea solution are presented in Table 2. Closeness coefficient values of the MRR and R_a (j = 1 & 2) is performed by Eq. 4 and it is listed in Table 2. The output performances are ranked based on their closeness coefficent values and it is presented in Table 2. The output performances are crosswise in nature, it can be conceivable to separate the result of EDM machining parameters at different levels. The ideal positive solution are desirable for better MRR and R_a. The highest closeness coefficient value is closer to get maximum MRR and minium surface roughness.The average closeness coefficient value for MRR and R_a is calculated for level 1-3 by averaging the experiment results. Correspondingly, the average values for 4-6 and 7-9 level is also calculated and presented in Table 2. From the average value of each level EDM optimal machining parameters is selected based on the highest value of closeness coefficient value. From Table 2, the optimal combination of machining parameters are MRR and R_a are set at level A_2, pulse on time at level B_1, Voltage C_2 and % of reinforcement at level D_3.

4. Conclusion

The following points are observed from the experimental results;

- PM process is capable of making smart composites with accepted porosity level of lesser than 5%.
- Augmentation of NiTi reinforced particulates improves the hardness and compressive strength of the composites nearly one time to matrix material value.
- EDM machining parameter plays viral role in deciding the MRR and R_a of the smart composites, among the selected parameter higher current could provide sufficient discharge energy to melt and evaporate the reinforcement and matrix material.
- Augmentation of NiTi particulate increase the machinability characteristics of the composite materials, due to the ductile nature of the smart composites.
- The optimal machining conditions derived from TOPSIS method identified as $A_2B_1C_2$ and D_3.

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