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Multi-objective optimization in wire-electro-discharge machining of TiC reinforced composite through Neuro-Genetic technique

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ABSTRACT

This paper proposed a Neuro-Genetic technique to optimize the multi-response of wire electro-discharge machining (WEDM) process. The technique was developed through hybridization of a radial basis function network (RBFN) and non-dominated sorting genetic algorithm (NSGA-II). The machining was done on 5 vol% titanium carbide (TiC) reinforced austenitic manganese steel metal matrix composite (MMC). The proposed Neuro-Genetic technique was found to be potential in finding several optimal input machining conditions which can satisfy wide requirements of a process engineer and help in efficient utilization of WEDM in industry.

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1. Introduction

A newly developed TiC reinforced austenitic manganese steel matrix composites are now-a-days used in producing components where wear resistance is a major concern. TiC reinforced composites are also the effective materials for producing thermal fatigue erosion-resistant components and high performance tooling [1]. However, the full potential of these materials is hindered by the high machining cost. This is because of the excessive tool wear of the conventional machine tools due to the abrasion of the hard TiC particles (3200 HV) present in the material [2]. As a result the dimensional accuracy of the components is lost. Consequently, the machinability of TiC/austenitic manganese steel composite is now considered to be an important area of manufacturing science requiring urgent attention.

As the material removal of WEDM is not affected by hardness of the electrically conductive composite, hence, it could be an alternative manufacturing process for machining such difficult-to-machine hard materials. The potential of electro-discharge machining process for machining other MMCs was already well accepted [3–5].

The presence of nonconductive TiC particles in the composite and the formation of ferric oxide (Fe_2O_3) make the WEDM process very much unstable. The generation of abnormal sparks such as arcing, short circuit, etc. leads to such instability. It is, thus, complicated to model the process by analytical approach based on the physics of this process. Moreover, in general, there is no perfect parametric combination exists that can simultaneously result in both higher cutting efficiency and higher dimensional accuracy (hence, it is multi-objective optimization, see Section 4). Therefore, selection of optimal parametric combination for obtaining better cutting performance is a challenging task in WEDM while machining the aforesaid composite. And hence, any attempt to model and optimize the process would be useful.

Two of the most important output parameters which govern cutting performance of WEDM are cutting speed and kerf width. Kerf width (see Fig. 1) determines dimensional accuracy of the machined components. Lower the kerf width, higher will be the dimensional accuracy.

Any optimization technique requires an objective function which determines the functional relationship between input and output decision variables. Similarly, for optimization of WEDM process parameters, several techniques have been implemented to determine the functional relationship between input and output WEDM process variables. Once the functional relationship is established, several methods have been adopted to optimize the process parameters. Scott et al. [6] developed a factorial design model and finally non-dominated solutions were obtained by explicit enumeration and dynamic programming. Liao et al. [7] used a regression model and subsequently the optimal machining parameters were

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Table 1
Chemical composition (in wt%) of the austenitic manganese steel matrix and 5 vol% TiC reinforced austenitic manganese steel matrix composite.

Materials	C	Mn	Si	Al	Cr	S	P	Ti	Fe
Matrix	1.23	11.53	0.418	0.46	0.29	0.008	0.019	–	balance
Composite	4.06	10.95	0.35	0.45	0.32	0.03	0.04	4.70	balance

obtained by feasible-direction non-linear programming method. Sarkar et al. [8] used a back-propagation neural network (BPNN) and obtained optimal solutions using constraint, and Pareto optimization algorithm. A feed forward neural network and simulated annealing were used by Tarng et al. [9]. The optimization was done by simple weighting method. Saha et al. [10,11] used several soft computing and regression techniques to model the process while machining WC-Co composite materials. There are also available some research works which used fuzzy multi-objective optimization approach for solving some management problems [12,13].

The authors in their previous work [14] already determined the functional relationship of WEDM process parameters by RBFN technique while machining TiC reinforced composite material. The superiority of RBFN technique over other modeling techniques, cited above was also mentioned in their work.

In spite of the fact that, in multi-objective optimization, multiple solutions are to be obtained, most of the researchers used either simple weighting method by converting multi-objective into a single-objective or a constraint optimization method. The limitation of simple weighting method is that it is very much sensitive to the weight vectors and needs prior knowledge to the problem [15,20]. On the other hand, a constraint optimization method provides a single solution at a time while keeping the other objective at a desired level. As in the real world situation user may require different alternatives in decision making; therefore, the above methods need to be solved number of times as the requirement changes [15,20].

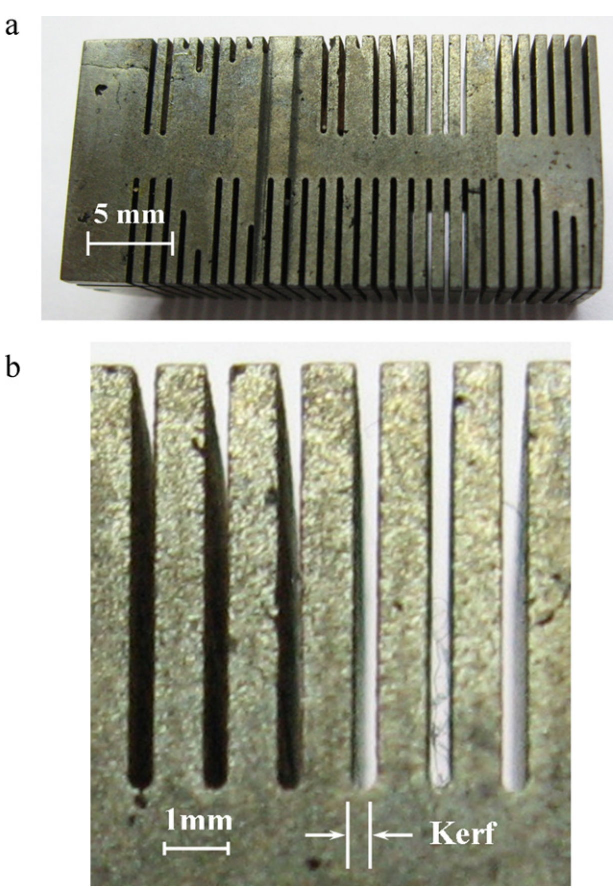

Fig. 1. (a) Work piece after wire-EDM showing kerf width and (b) close view of a kerf width.

On the other hand, as NSGA-II works with a population of points, a number of Pareto-optimal solutions (defined in Section 4) may be captured using this technique. Therefore, a decision maker can have several alternatives which can be used whenever requirement changes. There is available very little research which used NSGA-II on WEDM. Kanagarajan et al. [16] developed a regression model to correlate EDM process parameters with MRR and surface roughness while machining WC/Co composite. And finally hundred non-dominated solutions were obtained by regression model based NSGA-II technique. Saha et al. [17] used Neuro-Genetic technique to optimize the process while machining WC-Co composite. There are also available some research works which used Neuro-Genetic technique to solve single objective optimization problem [18,19]. From the literature, it could be noticed that, there is no work available which hybridizes RBFN and NSGA-II to optimize WEDM process while machining TiC reinforced composite. And hence, the objective of this research is set to find out the Pareto-optimal solutions for WEDM process by RBFN based NSGA-II while machining TiC reinforced composite. To accomplish this goal, following steps need to be followed: (a) Experimenting, (b) Measuring process performances (c) correlating input and output decision variables by RBFN and (d) integrating RBFN with NSGA-II to obtain Pareto-optimal solutions. It is worthy to mention that, as the functional relationship of WEDM process parameters has already been established in the author's previous work [14], hence, no discussion will be provided here on this point. The readers are recommended to refer reference [14] for detailed discussion on RBFN technique used for modeling the process. This paper deals with only on the optimization results obtained from combining developed RBFN model and NSGA-II.

2. Experimental study

Experiment was performed on Electra Maxicut-523 CNC WEDM machine, manufactured by Electronica Machine Tools Limited, India. 5 vol% TiC/austenitic manganese steel in-situ metal matrix composite was considered as the work-piece material. The detailed chemical composition of the Fe matrix and its composite is listed in Table 1. Based on the existing literature, four input process parameters such as pulse on-time (T_{on}), pulse off-time (T_{off}), average gap voltage (V_g), and wire feed-rate (W_f) were varied to see their effects on cutting speed and kerf width. Experiment was carried out based on the orthogonal and uniform-precision rotatable central composite design of experiments with five levels for each parameter. The details of the design of experiments are shown in Table 2. The constant machining condition is given in Table 3. The cutting

Table 2
Machining parameters and their levels based on central composite design.

Process parameter	Level/code				
	−2	−1	0	+1	+2
T_{on} (μs)	6	8	10	12	14
T_{off} (μs)	5	15	25	35	45
W_f (m/min)	2	3	4	5	6
V_g (V)	50	56	62	68	74

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