

Optimization of Wear Phenomenon of Al6061/Gr MMCs using Non-Traditional Optimization Methods

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Abstract.

The tribological properties like wear rate/weight loss plays a significant role when the newly developed metal matrix composites are put in to the service condition. Therefore, deciding the optimal parameters for wear is an important research area. In the present manuscript, two non-traditional optimization algorithms, namely invasive weed optimization (IWO) and particle swarm optimization (PSO) algorithms are used to optimize the said process. The non-linear regression equations developed for as cast and heat-treated Al6061/Gr MMCs using response surface methodology is used for the said purpose. The four independent process parameters, namely sliding velocity, percentage of reinforcement, load and sliding distance are considered to optimize the weight loss during wear test. The performance of the developed optimization algorithms is compared in terms of their ability to produce optimal solution.

Keywords: Weight loss, Al6061/Gr MMCs, PSO, IWO.

1. Introduction

The aluminum-based metal matrix composites (MMCs) are most commonly used in several engineering applications, namely aerospace, automobile and military applications. Researchers had tested several materials such as Al₂O₃, SiC, TiC, B₄C, TiB₂ and ZrC etc. as reinforcement materials and examined for their wear characteristics [1]. In [2], the authors' studied the effect of particle size of Al₂O₃ abrasive particles on wear. It was observed that the infiltration of SiC increased the resistance to wear of Al alloys. Sakip et al. [3] used Taguchi's method to experimentally determine the influence of various factors on dry sliding wear phenomenon of AlB₂/Al composites. Later on, Rajesh et al. used grey-Taguchi method to optimize the wear properties such as wear volume rate and coefficient of friction of Al/SiC [4] and Al/Gr [5] metal matrix composites. The optimized values obtained were verified experimentally. Rao et al. [6] also evaluated the tribological and mechanical properties of Al7075/TiC MMCs with as cast and heat-treated conditions. It was observed that the heat condition had shown an improvement in the properties. Further, Praveen et al. [7] response surface methodology (RSM) to model the wear behavior of LM13/SiC Aluminum MMCs. The process parameters, namely normal load, sliding distance, sliding velocity and silicon carbide were used as the input process parameters and wear rate was used as the response. Not much work is reported on the optimization of wear phenomenon for aluminum metal matrix composites. In [8], genetic algorithm (GA) was used to model and optimize the mechanical properties of Al nanocomposites. Chandrasekaran and Santosh [9] used GA and desirability analysis to optimize the multi response optimization of Al-SiC_p composites. The optimal Pareto optimal fronts related to the higher material rate and desired surface roughness were obtained. In addition to the above approaches, Vinoth et al. [10] used GA to optimize the nonlinear regression equation of wear rate obtained from RSM approach. They considered sliding speed, percentage of silicon and applied load as the input process parameters and wear rate as response. Moreover, Ali et al. [11] used particle swarm optimization (PSO) algorithm to optimize the stir casting process that produce more uniform composites. Further, wear test was conducted on those samples. In the present paper an attempt is made to optimize the wear rate of as cast and heat-treated Al6061/Gr MMCs using PSO and IWO algorithms. The nonlinear regression equation developed from RSM is utilized for the said task.



2 Mathematical Model of Al6061/Gr Wear Process

In the present research, the as cast and heat-treated Al6061/Gr MMCs (ref. to Fig. 1) produced using stir casting process has been considered to conduct the experiments on the pin-on-disc apparatus (ref. to Fig. 2). The independent parameters, namely applied load, sliding distance, percentage of reinforcement and sliding velocity are considered as input process parameters and the weight loss (WL) is considered as the response. The range of input process parameters considered in this study are given in Table 1.



Fig.1 Schematic diagram showing plates of Al6061/Gr composite produced using stir casting route.



Fig. 2 Schematic diagram showing the pin-on-disc wear apparatus.

Table 1: Table showing the ranges of the variables used in the study.

S. No	Factors	Symbol	Ranges	
			Low (-1)	High (+1)
1	Reinforcement (%)	A	3	9
2	Load (N)	B	10	30
3	Sliding distance (m)	C	500	2500
4	Sliding velocity (m/s)	D	1	3

The nonlinear regression equations are developed after conducting the experiments as specified by the central composite design of experiments. The response equations that represent the weight loss for as cast and heat treated Al6061/Gr composites are given in Eqns (1) and (2), respectively.

$$WL_{as \text{ cast}} = 0.01815 + 0.00069*A + 0.000649*B - 0.000003*C - 0.01452*D - 0.000193*A*A + 0.000008*B*B + 0.00626*D*D + 0.000019*A*B - 0.000146*A*D + 0.000006*B*D + 0.000010*C*D \quad (1)$$

$$WL_{heat \text{ treated}} = 0.04900 + 0.00456*A + 0.002475*B - 0.000016*C - 0.00779*D - 0.000939*A*A + 0.000006*B*B + 0.00555*D*D + 0.000048*A*B + 0.000104*A*D - 0.000000*B*C + 0.000019*B*D \quad (2)$$

The statistical adequacy of the above models is tested and it was observed that the coefficient of correlation for weight loss of heat treated and as cast Al6061/Gr MMCs are found to be equal to 0.9978 and 0.9984, respectively.

3 Formulation as an Optimization Problem

The weight loss during wear test of as cast and heat-treated Al6061/Gr MMCs is formulated as an optimization problem. The as cast weight loss model that represent the formulation is given below.

$$\text{Minimize } (f) = WL \quad (3)$$

Subject to:

$$\begin{aligned} 3 &\leq A \leq 9 \\ 10 &\leq B \leq 30 \\ 500 &\leq C \leq 2500 \\ 1 &\leq D \leq 3 \end{aligned}$$

where the variables A , B , C and D are having their usual meaning. Similar approach is used to optimize the wear loss for heat-treated AMMCs also.

4 Optimization Methods Used

In the present study, two non-traditional optimization methods, namely PSO and IWO are used to optimize the wear process of Al6061/Gr MMCs. The explanation for the algorithms is given in the subsequent subsections.

4.1 Particle Swarm Optimization

PSO is a population based stochastic optimization algorithm developed by Eberhart and Kennedy in 1995 [12]. The operation of this algorithm is mainly inspired by the social behavior of organisms such as birds flocking or fish schooling. In order to determine the food source each particle has some velocity based on their personal experience as well as getting the information from the other members of the swarm. Initially, the particles are generated randomly in a D-dimensional solution search space. Each particle is a solution to the problem and it is moving in the multidimensional search space of the problem with a specific velocity and position for searching the optimal solution. In the present paper the variables of the problem, namely % reinforcement, load, sliding velocity and sliding distance are considered as the particles that explore the solution space and weight loss is treated as the objective function in the present problem. The particle velocity V_{id}^{t+1} and position X_{id}^{t+1} are two main characteristics of the particle while moving in a multidimensional solution space, and are determined by using the following two equations.

$$V_{id}^{t+1} = W * V_{id}^t + C_1 * rand_1 * (P_{id}^t - X_{id}^t) + C_2 * rand_2 * (G_{id}^t - X_{id}^t) \quad (4)$$

$$X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1} \quad i = 1, 2, \dots, n \quad (5)$$

where t is the iteration number, W is the inertia weight, V_{id}^t and V_{id}^{t+1} denotes the velocities and X_{id}^t and X_{id}^{t+1} represents the position of the particles i in t and $t+1$ generations, respectively, P_{id}^t and G_{id}^t are the local best (p -best) and global best (g -best), $rand_1$ and $rand_2$ are two random numbers varying in the range $[0, 1]$ and C_1 and C_2 are two positive acceleration constants, respectively.

4.2 Invasive Weed Optimization

IWO is a stochastic optimization algorithm that is constructed using the concept of weed biology and ecology developed by Mehrabian and Lucas in 2006 [13]. In a cropping field, weeds are dispersed randomly and they grow to become flowering weeds and produce new weeds by consuming unused resources. The fitness/qualification of the flowering weed is going to determine the no. of weeds generated by every flowering weed. The weeds with a good adaptation in the location will consume additional unexploited resources from the field and grows faster and harvest additional new seeds. Further, the newly formed seeds dispersed arbitrarily throughout the field and grows to a flowering weed. The above process will continue to reach the maximum no. of weeds in the field by using the limited resources. Finally, the weeds having better fitness/qualification could continue and harvest new weeds. The step by step procedure of the algorithm is explained below.

Initialization: Initially the number of weeds (i.e variables) is dispersed randomly in a D-dimensional solution space and assigns the maximum and minimum value of each weed.

Reproduction: In this stage each weed produces number of seeds based on the fitness/qualification value of the flowering weed in a cluster. The number of seeds reproduced from each weed is calculated based on the fitness value and it increases in linear manner from lower to higher fitness value. The higher fitness of the flowering weed produces more seeds and lower fitness of the flowering weed produces less seeds. The number of seeds (S) evaluated by each flowering weed is decided by using the resulting equation.

$$S = \text{Floor} \left[S_{\min} + \frac{f - f_{\min}}{f_{\max} - f_{\min}} \times S_{\max} \right] \quad (6)$$

Where f_{\min} and f_{\max} represents the minimum and maximum fitness value in the colony, respectively and S_{\max} and S_{\min} denotes the maximum and minimum production by each plant respectively.

Spatial dispersal: The seeds produced by each flowering weed are dispersed throughout the exploration space with mean equal to the position of the plants and varying standard deviation. Based on the value of variation of variance the new seeds are distributed around the parent weed. At the end of each generation the standard deviation of the present problem is calculated by using the following equation.

$$\sigma_{Gen} = \frac{(Gen_{\max} - Gen)^n}{(Gen_{\max})^n} (\sigma_{\text{initial}} - \sigma_{\text{final}}) + \sigma_{\text{final}} \quad (7)$$

Where Gen_{\max} represent the maximum number of generations, n indicates the modulation index, and σ_{initial} and σ_{final} denotes the initial and final standard deviation, respectively.

5 Results & Discussions

In the present research work, two optimization algorithms that is, PSO and IWO are used to optimize the wear phenomenon of Al6061/Gr MMCs. Initially, a parametric study has been conducted to identify the optimal parameters of the said algorithms. For conducting this study the parameters of PSO, namely number of generations, maximum population size, acceleration constants C_1 and C_2 , and Inertia weight are kept equal to 30, 50, 2.5, 2.5 and 0.99, respectively. Fig. 3 shows the results of parametric study conducted to PSO for both the as cast and heat treated Al6061/Gr MMCs. The optimal parameters for population size and maximum number of generations for as cast and heat treated AMMCs are found to be equal to {45, 90} and {50, 70}, respectively.

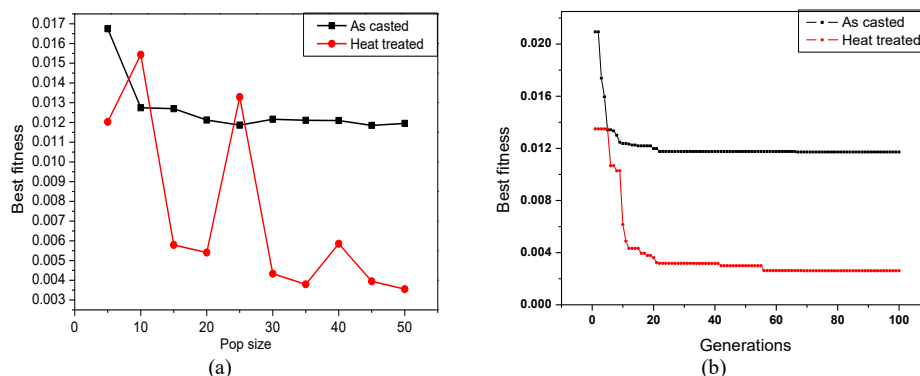


Fig. 3 Schematic diagram showing parametric study related to the PSO algorithm (a) Pop size vs Best fitness (b) Generations vs Best fitness

In the case of IWO algorithm also, a similar study has been conducted to evolve the optimal parameters that resulted in a reduced weight loss during the wear test of Al6061/Gr MMCs. During parametric study, the parameters related to the IWO algorithm are set at the following levels: sigma final = 0.001, exponent =5, minimum no. of seeds = 1, maximum no. of seeds = 3, initial population size = 10,

maximum population size = 20, no. of generations = 30, respectively. The results of parametric study related to IWO algorithm for as cast and heat treated AMMCs are given in Fig. 4. The optimal parameters, namely sigma initial, exponent, maximum number of seeds, maximum population size and maximum number of generations for as cast and heat treated AMMCs are found to be equal to {8%, 4, 8, 50, 60} and {8%, 8, 6, 30, 80}, respectively. Once the parameters related to the algorithm are optimized, the optimal values of the parameters that are responsible for the better performance of the response for Al6061/Gr MMCs are given below.

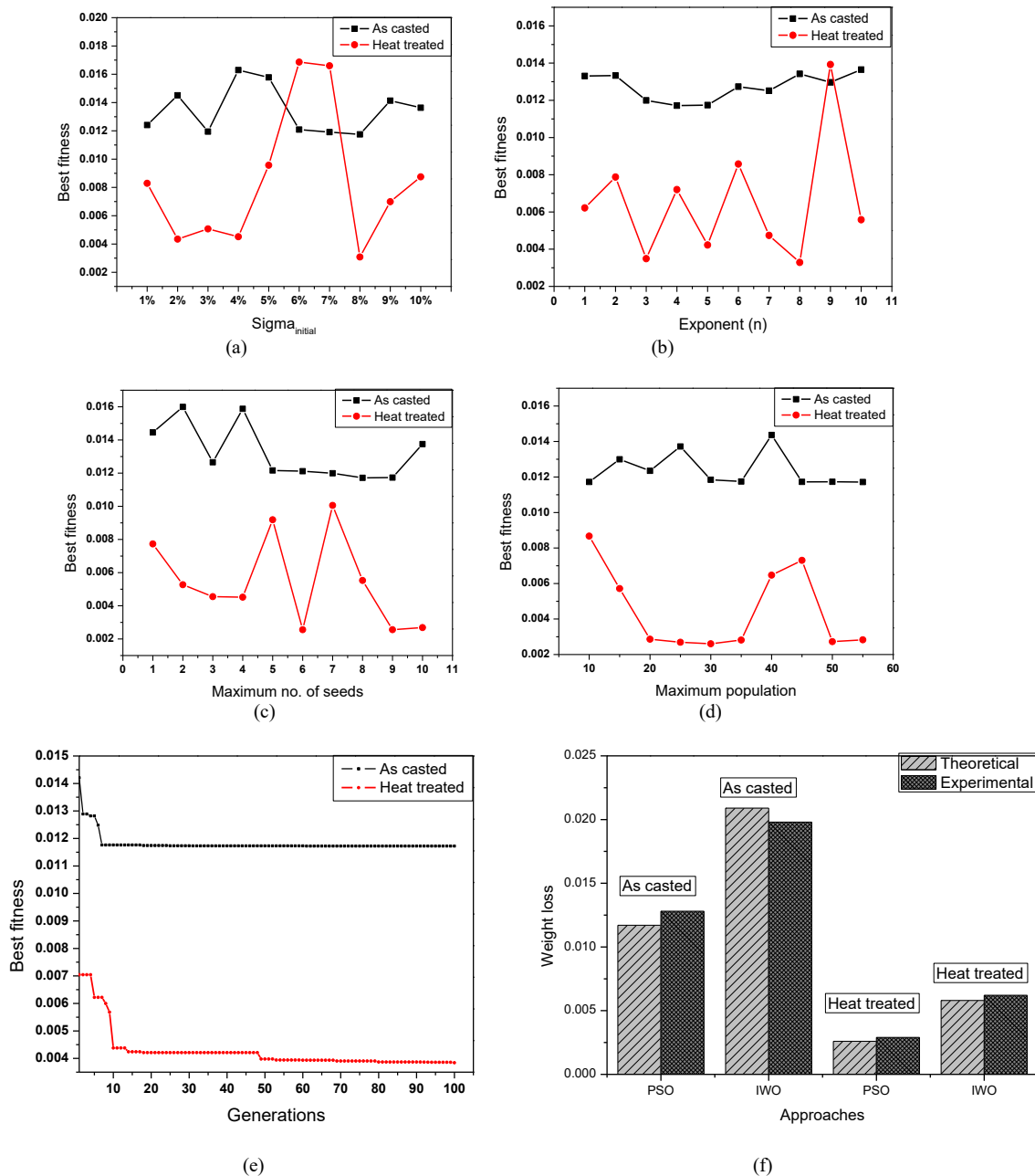


Fig. 4 Schematic diagram showing parametric study related to the IWO algorithm (a) Sigma_{initial} vs Best fitness, (b) Exponent vs Best fitness, (c) Maximum no. of seeds vs Best fitness, (d) Maximum population vs Best fitness (e) Generations vs Best fitness, (f) showing the comparison of experimental and theoretical weight loss during wear test.

Table 2: Comparison of optimal parameters and their corresponding response values.

As casted					
	%reinforcement	load	sliding distance	sliding velocity	wear loss
PSO	8.9995	10.0024	500.0024	1.0024	0.0117
IWO	9.0000	16.0000	927.0000	1.0000	0.0209
Heat treated					
PSO	8.9955	10.0025	2500.0000	1.0025	0.0026
IWO	9.0000	10.0000	2297.5000	1.0000	0.0058

From Table 2, it has been observed that PSO algorithm is found to perform better than simple IWO algorithm. It may be due to the reason PSO is a less sensitive, limited parameters, derivative free technique, stable convergence and shorter calculation time and stable convergence characteristics compared to other heuristic optimization algorithms. It is also important to note that the confirmation experiments are conducted for the optimal sets of parameters obtained with PSO and IWO algorithms for both the as cast and heat treated AMMCs. The results of comparison for the wear test are shown in Fig. 4 (f). From Fig. 4(f), it has been observed that the experimental results obtained for wear test are very close to the optimal values obtained from various algorithms. The percentage error between the experimental values and optimal values for PSO and IWO algorithms for as cast and heat treated AMMCs are seen to be equal to {8.59%, -5.55%} and {10.34%, 6.45%}, respectively.

6 Conclusions

In the present research an attempt is made to optimize the wear phenomenon of as cast and heat treated Al6061/Gr MMCs with the help of two non-traditional optimization algorithms, namely PSO and IWO. The weight loss equation obtained using the response surface methodology is utilized as the objective/cost function to optimize the said process. It has been observed that PSO algorithm is found to perform better than IWO algorithm in terms of weight loss during wear test. It has also been observed that the experimental verification of optimal parameters obtained using different algorithms have shown good agreement with the experimental results.

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