Optimization of wear and frictional parameters using IWO and PSO algorithms

Vajarala Venkata Reddy1, Ravi Kumar Mandava2, Deepak Kumar2, Vijay Pachore3, Vikas Kumar2 and V. Rama Koteswara Rao3

1School of Mechanical & Industrial Engineering, Diredawa University, Ethiopia.
2Department of Mechanical Engineering, MANIT Bhopal, India
3Department of Mechanical Engineering, R.V.R & J.C College of Engineering, Guntur, India

E-mail: ravikumar1013@gmail.com

Abstract. In the mechanical industries the tribological studies namely, wear rate (WR) and coefficient of friction (COF) are playing a significant role. Therefore, identifying the optimal parameters of wear and coefficient friction is a challenging task. To overcome this difficulty, in the present research work, the authors are using various non-traditional algorithms such as Invasive Weed Optimization (IWO) and Particle Swarm Optimization (PSO) algorithms. The non-linear equation has been developed for T6-heat treated Al 7075/SiC/FA MMC’s using response surface methodology. The three independent factors such as sliding velocity (SV), applying load (AL), and sliding distance (SD) are used to optimize the WR and COF. Finally, the performances of the established algorithms are verified in terms of their capability to develop the optimum solution.

Keywords: wear rate, coefficient of friction, heat-treated, IWO, PSO.

1. Introduction

Day-by-day the usage of aluminium metal matrix composite is increasing in all engineering applications, like aerospace, novel, automobile, etc. Till now most of the researchers have developed various metal matrix composites using several reinforcements namely, Al2O3, TiB2, TiC, and SiC, etc. [1] for increasing the performance of the material. The metal Al7075 is a matrix and zinc is the major component of the element. Because of the Zinc element, the alloy Al 7075 has good strength, strong, and good corrosion resistance material compared to the other alloys. Moreover, Al7075 has good fatigue strength and good machinability than other aluminum alloys. In general, there are two common approaches namely; powder metallurgy method and stir casting method researchers are following for fabricating the composites. In the current research work, the authors have used the stir casting method for making the Al7075/10%SiC/10%FA composite. Once the composites have been developed the developed composites were kept into T6-heat treated condition and identified the tribological properties based design of experiments. Further, the regression equation has been developed after response surface methodology (RSM). The researchers [2] discussed the influence of the particle size of the Al2O3 while conducting the tribological properties. They identified that the effect of the SiC improved the wear resistance of Al alloys. Later on, in [3] Sakip et al. proposed the Taguchi method for identifying influence parameters on dry sliding wear performance of AlB2/Al composites. The authors [4] used the Grey Taguchi method for optimizing the tribological parameters such as WR and
COF. Further, Rao et al. [5] developed an Al7075/TiC metal matrix composite for evaluating the mechanical and tribological properties using as casted and heat-treated conditions. The result shows that the specimens under heat-treated conditions are better improvement than the as-casted specimens. In [6] the authors are used the RSM to design the number of experiments for conducting the wear test of LM13/SiC aluminium composite. The authors considered the input factors namely, AL, SD, SV, and SiC. Gangadhara et al. [7] developed an Al6061/Gr metal matrix composite for determining the WR and COF. Based on the above literature review up to now very few researchers had reported the optimization of wear rate and coefficient friction using non-traditional optimization algorithms. Ali and Mohsen [8] used a genetic algorithm (GA) to optimize the mechanical properties such as tensile strength and hardness of aluminium nano-composites. In [9] the authors used GA to optimize the input factors such as percentage of SiC, AL, SD and SV of the wear rate, and coefficient of friction. Recently, Gangadhara et al. [10] used IWO and PSO algorithm to optimize the wear rate parameters. Therefore, in the current research work, an effort is made to optimize the parameters of WR and COF as T6-heat treated Al7075/10%SiC/10%FA using IWO and PSO algorithms. The non-linear regression equation of both WR and COF established from RSM is used in the current research work.

2. Mathematical Model of Al7075/SiC/FA
In this work, the T6-heat treated Al7075/10%SiC/10%FA MMC’s were produced by stir casting method was shown in Figure 1. The casted rounded specimens are used to measure the wear test on pin-on-disc equipment was given in Figure 2. Further, the factors such as AL, SD, and SV are the input process parameters [11] and the WR and COF are output responses [12]. Therefore, the ranges of input factors are used for conducting the present study are mentioned in Table 1.
### Table 1. Required Input levels for conducting the wear test.

| S.NO | Input Parameters       | Levels       |
|------|------------------------|--------------|
|      |                        | High (+1)    | Medium (0)  | Low (-1)   |
| 1    | Applying Load (N)      | 30           | 20          | 10         |
| 2    | Sliding Distance (m)   | 3000         | 2000        | 1000       |
| 3    | Sliding Velocity (m/s) | 4.5          | 3           | 1.5        |

### 3. Formulation of the Problem

The WR and COF of the T6-heat treated Al7075/10%SiC/10%FA is framed as an optimization problem. Moreover, the formulation of the WR and COF is given below.

- \( Z_1 = \text{Wear rate} \)
- \( Z_2 = \frac{1}{\text{Coefficient of Friction}} \)

Minimize \( f = Z_1 + Z_2 \) (1)

Subject to

- \( 10 \leq AL \leq 30 \)
- \( 1.5 \leq SV \leq 4.5 \)
- \( 1000 \leq SD \leq 3000 \)

where the variables AL, SV and SD are having their usual meaning.

After formulation of the problem, in the present paper, the authors used two different optimization algorithms such as PSO and IWO to enhance the wear parameters of Al7075/10%SiC/10%FA MMC’s. The explanation of the two non-traditional optimization algorithms is discussed in the next succeeding sections.

#### 3.1. PSO Algorithm

PSO is the most popular optimization algorithm using in many engineering problems for identifying the best suitable parameters. It is a stochastic optimization algorithm that was established in 1995 by Eberhart and Kennedy [13]. The working principle of the PSO algorithm is primarily inspired by the social behaviour of birds flocking and fish cooling. To regulate the sufficient food source for every particle has some individual velocity based on the information getting from the various particles of the swarm. Initially, the particles are randomly distributed in a solution space. Therefore, every particle acts as one solution to the problem and also it is moving on the multi-dimensional exploration space with exact speed and position for identifying the best solution. In this paper, the AL, SV and SD are considered as particles and the WR and COF are treated as the objective function. Therefore, the velocity of the particle \( V_{id}^{t+1} \) and position of the particle \( X_{id}^{t+1} \) are two important terms of the particle while searching in a multidimensional solution. The required velocity and position of the particle are calculated by using the below equations 4 and 5.

\[
V_{id}^{t+1} = W \ast V_{id}^t + C_1 \ast r_1 \ast (P_{id}^t - X_{id}^t) + C_2 \ast r_2 \ast (G_{id}^t - X_{id}^t)
\]

\[
X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1}
\]

Where \( t \) and \( W \) denotes the iteration number and inertia weight, \( r_1 \) and \( r_2 \) are the two random numbers, \( P_{id}^t \) and \( G_{id}^t \) are the local best and global best and \( C_1 \) and \( C_2 \) are the accelerations constants.
3.2. IWO Algorithm

It is a nature inspired optimization algorithm that mimics the natural behavior of weed ecology and biology established by Mehrabian and Lucas in 2006 [14]. Initially, the weeds are dispersed randomly in a cropping field (i.e. D-dimensional) and assign the minimum and maximum value of every weed. Secondly, in the reproduction phase based upon the fitness value, each weed crops no. of seeds. Therefore, the no. of seeds replicated from every weed is determined based upon the fitness. In this case, the fitness value increases linearly from a small to a higher value. The lower fitness weed will produce fewer seeds and the higher fitness weed crops more seeds. Therefore, the amount of seeds produced in each weed is calculated using the following mathematical equation only.

\[ S = \text{Floor}\left[ S_{\text{max}} + \frac{f-f_{\text{min}}}{f_{\text{max}}-f_{\text{min}}} \times S_{\text{max}} \right] \quad (4) \]

where \( f_{\text{max}} \) and \( f_{\text{min}} \) denotes the maximum and minimum fitness value, and \( S_{\text{max}} \) and \( S_{\text{min}} \) are the maximum and minimum no. of seeds produced by each plant separately.

Further, in the spatial dispersal case, each flowering weeds are dispersed with a mean equivalent to the location of the plant and changing the standard deviation. Based on the variant the new seeds are scattered surrounding of the parental weed. Therefore, the generation of the standard deviation of the existing problem is determined by eqn. (7).

\[ \sigma_{\text{gen}} = \left( \frac{\text{Gen}_{\text{max}}-\text{Gen}}{\text{Gen}_{\text{max}}} \right)^{n} (\sigma_{\text{initial}} - \sigma_{\text{final}}) + \sigma_{\text{final}} \quad (5) \]

where \( \sigma_{\text{initial}} \) and \( \sigma_{\text{final}} \) represents the initial and final standard deviation, \( n \) denotes the modulation index and \( \text{Gen}_{\text{max}} \) indicates the max. no. of generations.

4. Results & Discussion

In this work, the authors used two optimization algorithms that are, PSO and IWO are used to enhance the wear and frictional parameters of Al7075/10%SiC/10%FA MMC’s. Firstly, a systematic study has been accompanied to categorize the best parameters of the aforementioned algorithms. To conduct this systematic study the important factors required for PSO such as no. of generations, maximization population size and the constants \( C_{1} \) and \( C_{2} \), and the weight and are kept equal to 40, 100, 1.5, 1.5, and 0.99, correspondingly. After conducting the systematic study the best optimal parameters of the PSO algorithm namely, maximum no. of generations and the population size of the T6-heat treated composites found to be equal to {50, 90}, respectively.

Moreover, the parameters required for IWO namely, sigma final, exponent, the minimum and maximum number of seeds, initial and final population size, and maximum no. of generations are equal to 0.001, 6, 2, 3, 10, 30, and 50, respectively. After conducting the systematic study the optimal parameters of the IWO algorithm namely, sigma initial, exponent, maximum no. of seeds, maximum population size, and maximum no. of generations of the T6-heat treated composites found to be equal to {6\%, 4, 10, 50, 70}, respectively. Further, the performances of the developed algorithms are shown in Figure 3 in terms of WR and COF.

![Figure 3. Result shows the best optimal parameters (a) WR and (b) COF.](image-url)
Table 2. Optimal input parameters and their corresponding output responses.

| Algorithms | Applying load | Sliding velocity | Sliding speed | Wear rate | Coefficient of friction |
|------------|---------------|-----------------|--------------|-----------|------------------------|
| IW0        | 14            | 2.5             | 1400         | 0.5490    | 0.7620                 |
| PSO        | 16            | 2               | 1800         | 0.5563    | 0.7474                 |

Table 2 shows the comparison results of the IWO and PSO algorithms. It can be observed that the IWO algorithm achieves superior than the PSO algorithm in terms of wear rate and coefficient of friction. It might be happened due to the advantage the IWO is a less sensitive, shorter calculation, derivative-free algorithm, and stable convergence compare to the PSO algorithm.

5. Conclusions

In this research paper, the effort is to recognize the best optimal parameters of the WR and COF of the T6-heat treated Al7075/10%SiC/10%FA MMC’s with the usage of PSO and IWO algorithms. The regression equations of the WR and COF are obtained by using response surface methodology. After conducting the simulations it was observed that the IWO algorithm performed better than the PSO algorithm in terms of WR and COF. Moreover, it has also been observed that the suitable parameters attained from the various algorithms have shown better results than the experimental values.

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