Wear experimentation on Tantalum carbide-based Niobium MMC

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Abstract. The niobium and its alloys have been used for automobile, marine, and aerospace due to its superior properties such as a lightweight ratio, strength, corrosion resistance, thermal and electrical conductivity. The present work was used to improve the substance properties such as hardness and wear. Tantalum Carbide (TaC) reinforced niobium metal matrix composite (MMC) was produced through the stir casting route. The specific wear rate was determined through a pin on disc tribometer with respect to the input actors such as sliding velocity, load, and temperature. Taguchi optimization was applied to found the optimal parameters. The variance analysis was used to found the influential factor in the wear rate.

Keywords. Wear, Pin on disc tribometer, Niobium MMC, Tantalum carbide, Optimal parameters.

1. Introduction
Niobium was malleable, ductile and it has a body-centered cubic structure. It has better physical and chemical properties. It has the best suitable for high-temperature-resistant applications. Niobium carbide was mostly used in cutting tools. Niobium becomes a superconductor at cryogenic temperatures. It has greater toughness, strength, formability, and weldability behaviors. The effect of microstructure and its wear characteristics were studied in titanium carbide-based cermets [1]. Tribological properties and wear prediction model were conducted in nickel alloys [2-3]. Wear resistance was investigated in tungsten carbide reinforced copper MMC [4]. Wear resistance has been increased when the addition of reinforcement particles in Al-Si alloy [5]. The effect of sliding distance on wear rate was analyzed in heat-treated Al–SiC composite [6]. Effect of heat treatment and wear
behaviors were studied in Al-Cu-Ni-Mg alloy [7]. The generated mathematical model was used to evaluate the wear rate [8]. The sliding wear behavior of copper-based composites were investigated [9-10]. Taguchi optimization of wear behavior was studied in magnesium alloy [11]. The Taguchi L9 orthogonal array was used to optimize the wear characteristics of Mg-SiC [12]. Several researchers based on the Taguchi approach of SN ratio and variance analysis to evaluate optimum conditions [13-30]. It is used to confirm and forecast higher performances such as mechanical, machining, wear, and corrosion behaviour of composites in different fields of application [31-42].

The present investigation was used to describe the wear behaviors of tantalum carbide-based niobium MMC. The wear parameters were optimized through the Taguchi method.

2. Experimental procedure
The niobium MMC was produced through stir casting technique. Niobium and nickel were the major composition of MMC. The raw materials of niobium and nickel have been placed in a graphite crucible furnace and it’s operated at 1900°C for 30 minutes. The reinforcement of tantalum carbide particles were preheated at 1650°C for 20 minutes. The preheated TaC (6 wt.%) particles and other particles such as aluminium, magnesium, chromium and silicon were added to the molten mixture. The stirrer was applied at 700 rpm for 20 minutes. The stirrer was stopped after achieving the uniform mixture of molten metal. It was transferred to the molding section and it’s converted into the required shape and size. The synthesized niobium MMC has a hardness of 534 BHN and a density of 9.26 g/cc.

3. Experimental details
The pin on disc tribometer was chosen for the wear test on niobium MMC. The specimen was prepared as per ASTM G99 standards. The pin was made with niobium MMC with 12mm diameter and 29 mm length. The disc material was EN 31 steel. The track diameter (100mm) was maintained at a constant parameter. The experimental setup was shown in Fig.1. The pin and disc have been cleaned with acetone for each experiment. The specific wear rate was calculated as below Equation 1;

\[
\text{Specific wear rate} = \frac{(m_1-m_2) \times 10^3}{\rho FL}
\]

Where,

\(m_1-m_2\) = Loss of mass of the pin during the experiment (g)
\(\rho\) = Density of the pin (g/cc)
F = Load (N)
L = Sliding distance (m)
4. Experimental results and discussion

For pin on disc wear experimentation, the different wear process factors, and its level were selected such as load (30-50N) sliding velocity (2-6m/s) and temperature (80-120°C). The specific wear rate was measured and it’s exposed in Table 1.

### Table 1. Experimental results for pin on disc wear test

| Exp.No. | Load (N) | Sliding velocity (m/s) | Temperature (°C) | Wear rate (mm³/N·m) |
|---------|----------|------------------------|------------------|---------------------|
| 1       | 30       | 2                      | 80               | 0.234               |
| 2       | 30       | 4                      | 100              | 0.324               |
| 3       | 30       | 6                      | 120              | 0.277               |
| 4       | 40       | 2                      | 100              | 0.534               |
| 5       | 40       | 4                      | 120              | 0.624               |
| 6       | 40       | 6                      | 80               | 0.598               |
| 7       | 50       | 2                      | 120              | 0.679               |
| 8       | 50       | 4                      | 80               | 0.786               |
| 9       | 50       | 6                      | 100              | 0.932               |

### 4.1. Taguchi method

Taguchi design with L9 orthogonal array was used to minimize the wear experiments. It provides all information and its effects on wear parameters. SN ratio was applied to normalize the experimental data in definite range. The aim of the experiment was to minimize the wear rate. Hence, the smaller the better criterion was chosen for this wear experiments. The SN ratio and means were calculated as per the smaller the better criterion and its shown in Table 2.

### Table 2. SN ratios and Means for wear test

| SN ratio | Means   |
|----------|---------|
| Level    | Load    | Sliding velocity | Temperature | Load | Sliding velocity | Temperature |
| 1        | 11.185  | 7.142          | 6.391        | 0.2783 | 0.4823           | 0.5393      |
| 2        | 4.670   | 5.326          | 5.283        | 0.5853 | 0.5780           | 0.5967      |
The SN ratio effect on the wear rate was shown in Fig. 2. The curves were drawn between data means and mean of SN ratio as per smaller the better criterion. The wear rate was minimum for all engineering applications. Based on the experimental aim, smaller peaks have been chosen from the plot. The optimal wear rate was attained at a load of 50N, sliding velocity of 4 m/s, and a temperature of 100°C.

The variance analysis for wear rate was shown in Table 3. The wear rate depended on load, sliding velocity, and temperature. Among all the input factors, the applied load (91.01%) was the most dominant factor which affects the wear rate. The next powerful factor was sliding velocity.

The regression developed model was shown in Equation (2) and it was used to analyze the response such as wear rate. Here, A, B and C were wear test input factors such as load, sliding velocity and temperature respectively.

Wear rate = 0.5542 - 0.2759 A - 30 + 0.0311 A - 40 + 0.2448 A - 50 - 0.0719 B - 2 + 0.0238 B - 4 + 0.0481 B - 6 - 0.0149 C - 80 + 0.0424 C - 100 - 0.0276 C – 120

--- Eqn. (2)
The Pareto chart effect on wear rate was shown in Fig. 3. The minimum wear rate of 0.234 mm$^3$/N-m was attained at the sliding velocity of 4 m/s. The maximum wear rate was attained at the sliding velocity of 6 m/s.

5. Conclusions

- Tantalum carbide reinforced niobium MMC was produced through a stir casting route.
- The stir casted niobium MMC has the hardness of 534 BHN and a density of 9.26 g/cc.
- The wear rate was measured through pin on disc apparatus with different levels of input factors.
- Taguchi optimization was applied to optimize the parameters. The optimal wear rate was attained at loads of 50N, sliding velocity of 4 m/s, and temperature of 100°C.
- The applied load (91.01%) was the most dominant factor which affects the wear rate and it was validated through variance analysis.

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