Spark Plasma Sintered Carbon Nanotube Reinforced Ti6Al4V Composites with Improved Friction Coefficients

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Highlights

- Dense MWCNTs/Ti6Al4V composites consolidated by spark plasma sintering technique.
- The composites had improved friction coefficients over that of unreinforced Ti6Al4V.
- Retained MWCNTs acted as solid lubricants within the composites.

1. Introduction

The superior mechanical and thermal properties of carbon nanotubes (CNTs) have positioned them lately as ideal reinforcements for metal matrices. Recent studies have reported CNTs reinforced titanium (Ti) composites with enhanced mechanical and thermal characteristics, low wear rates and significantly reduced coefficients of friction (COFs). CNTs are known to be exceptional anti-frictional reinforcements for titanium matrix composites (TMCs) specifically. Nevertheless, there are only a few reported studies till date on TMCs being reinforced with CNTs owing to the attendant challenges of achieving the homogeneous dispersion of CNTs with Ti matrices (just like for metal matrices generally), damage to CNTs during processing, weak interfacial bonding and interfacial reactions between the metal matrix and damaged CNTs. This present study explored the synthesis of multi-walled carbon nanotubes (MWCNTS) reinforced Ti6Al4V composites via the spark plasma sintering (SPS) technique and investigated their COFs characteristics under dry sliding conditions.

2. Methods

MWCNTs/Ti6Al4V powders containing 0, 1, 2 and 3 wt % MWCNTs were prepared by high energy ball milling (HEBM) in dry condition and without the addition of any process control agent (PCA). The powders were milled for 6 hr at a speed of 50 rpm. Stainless steel balls were employed during the milling and a ball-to-powder ratio of 10:1 was used. The milled powders were consolidated by SPS at a sintering temperature of 1000 °C. The other sintering parameters used for consolidation of the powders were: applied pressure (50 MPa), holding time (5 min) and heating rate (100 ℃/min). Density and Vickers microhardness measurements were made on the consolidated bulk materials. Wear test samples were cut into 20 mm × 20 mm × 3 mm dimensions and prepared to mirror polished surfaces metallographically. These were subsequently subjected to dry sliding wear tests under 5, 15 and 25 N applied loads respectively at room temperature and humidity employing a UMT-2-CETR tribometer (Now Bruker Nano Inc., Campbell, CA). The ball-on-flat testing configuration was adopted with tungsten carbide (WC) as the counterface material. COF were monitored continuously for 1000 s as the WC counterface ball (Ø10 mm) slides against the test sample in a reciprocating motion at a frequency of 5 Hz and reciprocating speed of 10 mm/s. A stroke length of 2 mm was used during the tests. At least three triplicate tests were run at each test condition to ensure good repeatability in the friction results.

3. Results and discussion

The relative densities and microhardness properties of the as-received consolidated bulk composites are presented in Table 1. All the sintered samples had near full densifications. The composite samples had lower relative densities than the unreinforced Ti6Al4V, however they exhibited improved hardness values than the matrix alloy. The observed reduction in relative densities with increased weight fraction of the MWCNTs reinforcement in the alloy matrix was presumed to be due to the agglomeration and clustering of the MWCNTs which could have prevented adequate sintering during SPS processing of the samples.

Hence, the presence of pores within the composites. This was responsible for the deterioration in relative densities of the composites. The enhanced hardness in the composites was on the hand attributed to the presence of retained hard MWCNTs and TiC phases formed as a result of interfacial reactions between Ti6Al4V particles and defective MWCNTs.

Table 1. Properties of as-received MWCNTs/Ti6Al4V composites

MWCNTs content (wt %)	Relative density (%)	Microhardness $HV_{0.5}$
0	99.60 ± 0.03	362.19 ± 13.45
1	99.10 ± 0.02	378.00 ± 8.84
2	98.40 ± 0.04	395.73 ± 6.94
3	97.90 ± 0.02	397.58 ± 4.88

The variation in the COF profiles in the sintered Ti6Al4V and MWCNTs/Ti6Al4V composites (Figure 1) showed the unreinforced alloys had inferior COF performance compared to the composites under all the loads investigated. However, the composite with the 1 wt % MWCNTs content had the best comparative COF performance among the composites. This could be due to the better dispersion of MWCNTs within Ti6Al4V matrix, good interfacial bonding between the matrix and reinforcement and the self-lubricating effect of retained MWCNTs within the composite.

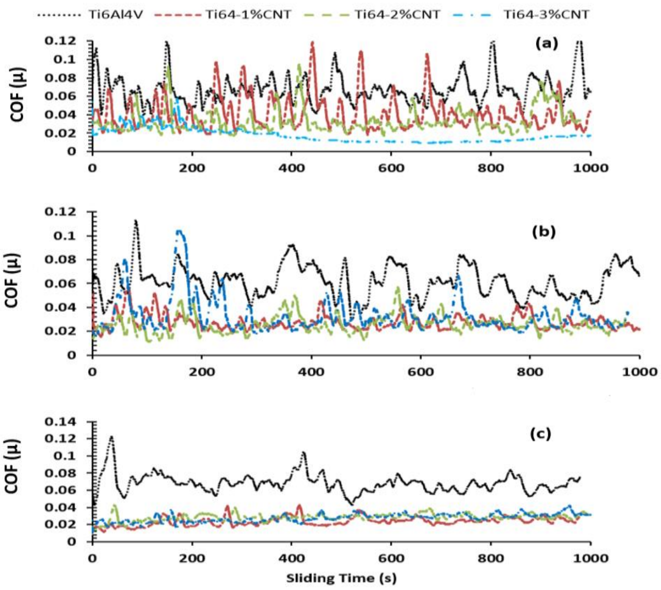

Figure 1. Coefficient of friction profiles in consolidated Ti6Al4V/MWCNTs composites under different applied loads (a) 5 N, (b) 15 N and (c) 25 N.

4. Conclusions

Addition of MWCNTs to Ti6Al4V metal matrices improved their friction coefficient performance during dry sliding. The anti-frictional characteristics of retained MWCNTs was a major contributor to the observed COF enhancement in the MWCNTs/Ti6Al4V composites.

References

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Keywords
Titanium alloy; Carbon nanotubes; Metal matrix composites; Coefficient of friction.