ABSTRACT

The aluminium matrix hybrid composites (AMHCs) with low coefficient of thermal expansion (CTE) and high strength are used in different engineering applications, such as aerospace, measuring instruments, electronic packaging, general optics, and antennas. To meet these demands, a new AMHC reinforced with negative thermal expansion material yttrium tungstate ($Y_2W_3O_{12}$) and high strength alumnium nitride (AlN) has been developed. Similarly, another AMHC has been reinforced with a combination of high strength and zero expansion carbon nanotube (CNT) along with AlN or $Y_2W_3O_{12}$ particles in order to obtain low CTE, high strength as well as adequate thermal conductivity. All the AMHCs were synthesized by a powder metallurgy route.

The AMHCs containing 30 wt. % $Y_2W_3O_{12}$ -(0, 5, 10 & 15 wt. %)AlN and 30 wt. % AlN–(0, 5, 10 & 15 wt. %) $Y_2W_3O_{12}$, defined as $Y_2W_3O_{12}$ and AlN rich composites, respectively, were prepared by using high energy ball milling. The powders were milled for various times, i.e., 0.5, 2, 4, 6, 8, 10, 12 &14 h and 10 h milled powder exhibited the desired microstructure. Subsequently, the 10 h milled powders were compacted followed by sintering at 550, 600 & 650 ^{o}C for 1 h. The 10 h milled powders were also compacted and sintered for various times, i.e., 1, 1.5 & 2 h at 600 ^{o}C temperature. X-ray diffraction (XRD) analysis reveals that the minimum crystallite size is obtained at 10 h of milling time. Scanning electron microscopy (SEM) results also show that uniform distributions of reinforcement particles form at 10 h of milling time. It is found that the maximum values of the relative density, hardness, and compressive strength of all the composites are obtained when the milling time, sintering temperature, and sintering time are fixed as 10 h, 600 ^{o}C, and 1 h, respectively. Response surface methodology (RSM) was also used to obtain an empirical relationship between the input parameters, i.e., sintering temperature, time and amount of AlN content, and the output response variables, i.e., relative density, hardness, and compressive strength. The results show that the developed mathematical models can predict the relative density, hardness, and compressive strength with a confidence level of more than 95%.

The composite samples prepared using the optimized milling and sintering parameters were subjected to heating at 400 ^{o}C temperature with 15 min soaking time followed by forging. It is found that the relative density, hardness and compressive

strength of all the forged composites is higher than those of the sintered composites. It is also found that the CTE value of the composites decreases with an increase in the amount of reinforcement ($AlN/Y_2W_3O_{12}$). A high compressive strength (500-520 MPa) along with a low CTE ($12\text{-}14\times10^{-6}\ K^{-1}$) is achievable in such hybrid composites by adjusting the amount of individual reinforcement. The thermal cycling experiments suggest that the composites are thermally stable.

The synergistic effect of the addition of $Y_2W_3O_{12}$ and AlN particles on the dry sliding wear behavior of Al-AlN-$Y_2W_3O_{12}$ hybrid composites has been investigated. The correlation between the input parameters (applied load, sliding speed, sliding distance, and volume fraction of reinforcement) and output responses (wear rate and coefficient of friction (COF) has also been studied by using the RSM technique. The wear resistance of the composites improves with the increasing amount of AlN and $Y_2W_3O_{12}$, and increasing sliding distance. The RSM results show that the load and amount of reinforcement significantly affect the wear rate and COF.

The effect of the addition of copper-coated carbon nanotubes (CuCNT) on the hardness, compressive strength, elastic modulus, thermal conductivity and coefficient of thermal expansion properties of two sets of aluminium matrix hybrid composites (AMHCs), i.e., Al-30 wt. % AlN-(1, 2 and 4 wt. % CuCNT) and Al-30 wt. % $Y_2W_3O_{12}$ - (1, 2, and 4 wt. % CuCNT) composites has been investigated. The TEM analysis reveals that the CNTs are effectively coated with copper. The SEM characterization reveals that the CuCNTs are uniformly dispersed in the aluminium matrix. Experimental results reveal that the addition of CuCNT into the AMHCs increases the hardness, compressive strength, elastic modulus, and thermal conductivity. Dilatometry studies reveal that the thermal stability of the AMHCs increases with an increase in the amount of CuCNT as well as the number of thermal cycles. The CTE value also decreases significantly with an increase in the amount of CuCNT in both sets of AMHCs.

Keywords: Aluminium matrix hybrid composites; Powder metallurgy route; Response surface methodology; Carbon nanotube