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Microstructure and wear characterization of AA2124/4wt.%B₄C nano-composite coating on Ti-6Al-4V alloy using friction surfacing

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Abstract: This work is focused on developing AA2124/4wt.%B₄C nano-composite coatings on Ti-6Al-4V using friction surfacing to improve the wear resistance. The composite was produced using conventional stir casting method and coatings were laid using an indigenously-developed friction surfacing machine. The rotational speed of the mechtrode was varied. The microstructure of the composite coating was observed using conventional and advanced microscopic techniques. The sliding wear behavior was evaluated using a pin-on-disc apparatus. The coating geometry (thickness and width) increased with increased rotational speed. The interface was straight without thick intermetallic layer. Homogenous distribution of nano B_4C particles and extremely fine grains was observed in the composite coating. The interfacial bonding between the aluminum matrix and B_4C particles was excellent. The composite coating improved the wear resistance of the titanium alloy substrate due to the reduction in effective contact area, lower coefficient of friction and excellent interfacial bonding.

Key words: aluminum matrix composite; titanium; friction surfacing; coating; wear

1 Introduction

Titanium and its alloys are characterized by a number of attractive properties such as high specific strength, excellent corrosion resistance, superior biocompatibility, high temperature resistance, erosion resistance, higher fatigue and cracking resistance. They are typically utilized in aerospace, marine, chemical, nuclear, power plant, medical, transport and sporting industries [1-4]. In spite of several advantages and applications, titanium and its alloys experience deprived resistance to sliding wear. Therefore, it is necessary to develop a coating on the surface to preserve the material from wear. Various physical and chemical deposition methods were applied to developing coatings on titanium surface to improve wear [5-9]. Thin coatings developed using those methods easily failed under the applied sliding load and detached from the substrate. Some investigators used laser cladding method to develop a thick composite coating on the titanium surface to improve wear [10-13]. Those coatings were characterized by the presence of pores, cracks, dilution into substrate, cast dendritic structure, uneven distribution and decomposition of reinforcement particles. A few investigators managed to develop wear resistant surface composite layers on titanium alloys using friction stir processing [14,15]. There are several advantages present in this method but the tool life is short and each tool is ultra expensive. Recently, CHEN et al [16] developed Al/B₄C composite coating on Ti-6Al-4V by mechanical alloying method and showed an improvement in wear resistance. Although this method is attractive, it is costly, time consuming and produces uneven coating thickness and poor surface finish.

Friction surfacing has gained lot of momentum and interest in the last decade as a viable technology to develop thick coatings on various metallic substrates to improve wear and corrosion resistance [17,18]. This process relies on frictional heating and severe plastic deformation to create the coating. The material to be deposited is required to be in cylindrical shape which is

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called mechtrode before the surfacing process. The mechtrode is mounted on the machine head and rotated at high speed. An axial load is also exerted along the mechtrode. The mechtrode is plunged against the substrate and pressed to generate frictional heat by rubbing action. The frictional heat developed at the tip of the mechtrode and the deformation caused by the rotating action create a viscoplastic region. After a preset dwelling period to allow sufficient deformation of the mechtrode, the substrate is then traversed. The traverse moment causes the deformed material to be deposited on the substrate and results in a coating. The entire process is accomplished in solid state without fusing either mechtrode or substrate. This feature enables to make coatings of different combinations of substrate and coating material. The major advantages are no pores, zero or lower dilution, absence or reduction in the formation of intermetallic compounds at the interface, low susceptibility to cracking and minimum residual stress [19-22].

Most of the works on friction surfacing were focused on developing coatings on various steels. Few works were devoted to create coatings on titanium alloys. RAO et al [23] reported that it is difficult to coat aluminum alloy AA6063 on Ti-6Al-4V due to the formation of excessive flash caused by quick softening of the aluminum rod. REDDY et al [24] successfully deposited AA2124/SiC composite rods on Ti-6Al-4V using friction surfacing and showed an improvement in wear resistance of titanium substrate. FITSEVA et al [25] created Ti-6Al-4V coatings on Ti-6Al-4V substrate using friction surfacing and analyzed the effect of rotational speed of the mechtrode on process capabilities and microstructure. FITSEVA et al [26] investigated the role of rotational speed on temperature profile, microstructure, grain size, microhardness and tensile strength of Ti-6Al-4V coatings on Ti-6Al-4V substrate. BELEI et al [27] formed Ti-6Al-4V/TiC composite coatings on Ti-6Al-4V substrate using a hole drilled in the mechtrode and filled with TiC particles. They assessed the role of hole dimension, number of holes and hole location in the process and the microstructure of the composite coatings.

Literature survey revealed that there is large scope to develop coatings on titanium alloys using friction surfacing. Therefore, this work is focused on the development of AA2124/4wt.%B₄C nano-composite coating on titanium alloy Ti–6Al–4V using friction surfacing. The microstructure evolution was studied using conventional microscopy and advanced techniques. The sliding wear behavior was also evaluated. B₄C has several desirable properties including high melting point (about 2450 °C), low specific gravity (about 2.52 g/cm³), high hardness and strength, good thermal and chemical stability which is used as a ceramic reinforcement to enhance the mechanical properties of metal matrix composites [16,28,29].

2 Experimental

AA2124/4wt.%B4C nano-composite was produced using conventional stir casting method. The nominal composition of aluminum alloy AA2124 is presented in Table 1. Measured quantity of AA2124 was melted using an electrical resistance furnace. The temperature of the furnace was maintained at 800 °C. B₄C particles, preheated to 300 °C were gradually fed to the periphery of the vortex created by the mechanical stirrer rotating at 300 r/min. K₂TiF₆ flux was added to enhance the wettability with molten aluminum [28,29]. The average size of particles was 250 nm and the morphology is shown in Fig. 1. After intense mixing, the composite melt was poured into a cylindrical mould using bottom pouring arrangement. Short composite rods with diameter of 20 mm and length of 100 mm were machined from the castings. Those rods served as mechtrode during friction surfacing. The 8 mm-thick titanium alloy Ti-6Al-4V was used as substrate. The nano-composite coating on the substrate was achieved using an indigenously built friction surfacing machine (M/s RV Machine Tools, Coimbatore, India). Traverse speed of 15 mm/min was kept constant for all coatings. The rotating speed of the mechtrode was varied from 600 to 1000 r/min in steps of 100 r/min. The axial load and plunge rate of the mechtrode were respectively 30 kN and 10 mm/min. The process parameters were chosen based on trial experiments. Figure 2 shows a nanocomposite mechtrode after the coating process.

Table 1 Chemical composition of AA2124 aluminum alloy(wt.%)

Mg	Si	Fe	Mn	Cu	Cr
1.31	0.06	0.08	0.43	3.84	0.001
Zn	Ni	Ti		Pb	Al
0.04	0.004	0.03	;	0.006	Bal.



Fig. 1 FESEM micrograph of nano B4C particles

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Fig. 2 Photograph of mechtrode after friction surfacing

Specimens across the cross section of the coatings were machined for microstructural observation. They were mounted (STRUERS Citopress), polished (STRUERS Labopol) and etched with Kroll's reagent. The etched specimens were observed using an optical microscope (OLYMPUS BX51M), field emission scanning electron microscope (CARL ZEISS-SIGMAHV) and electron backscatter diffraction (EBSD). EBSD was carried out in a FEI Quanta FEG SEM equipped with TSL-OIM software. The cross-sectional macrographs were captured using a stereo microscope (OLYMPUS SZX16). The sliding wear behavior of the composite coating and the titanium alloy substrate was estimated using a pin-on-disc wear apparatus (DUCOM TR20-LE) at ambient temperature as per ASTM G99-04A standard. Pin specimens having a square cross section of 5 mm \times 5 mm were machined from the coating and the substrate using wire EDM. The wear test was carried out at a sliding velocity of 0.75 m/s, normal force of 20 N and sliding distance of 1000 m. The surface of the pins was flattened using emery sheets before wear test. The height reduction during wear test was recorded and translated into wear rate (Eq. (1)). The worn surfaces of the pin specimens were studied using FESEM.

$$R = \Delta H \cdot A/D \tag{1}$$

)

where *R* is wear rate, ΔH is height loss, *A* is cross section area of the specimen, and *D* is sliding distance.

3 Results and discussion

3.1 Macrostructure of composite coating

The macroscopic cross-sectional appearance of the composite coating is depicted in Fig. 3. The composite coating was formed successfully on the titanium alloy surface. There are no major macroscopic defects such as pores or cracks observed inside the coatings. It is noticed that the side walls of the coatings are not smooth. This



Fig. 3 Optical macrographs of AA2124/4wt.% B_4C coatings on Ti-6Al-4V alloy at different rotational speeds: (a) 600 r/min; (b) 800 r/min; (c) 1000 r/min

can be attributed to the deformation behavior of the composite mechtrode. The cast mechtrode had poor ductility which did not provide a smooth material flow like a wrought aluminum rod. The rotational speed significantly influenced the coating geometry. The effect of rotational speed on the coating thickness and the width is graphically shown in Fig. 4. The coating width was found to be 17 mm at 600 r/min and 19.5 mm at



Fig. 4 Effect of rotational speed on coating geometry

1000 r/min. The coating thickness was measured to be 4.1 mm at 600 r/min and 11.5 mm at 1000 r/min. Both the width and the thickness increased with increased rotational speed. It is observed in Fig. 4 that the rate of change in thickness is higher compared to that of width. Both the intensity of rubbing action and the deformation rate of the mechtrode increase with an increase in rotational speed. The availability of frictional heat and deformed material is increased. Therefore, the coating geometry enlarged with rotational speed. The coating thickness in the present work appears to be larger than that of similar aluminum alloy coatings on various substrates [30-33]. SAKIHAMA et al [30] reported a maximum thickness of 7 mm of AA5052 coating on AA5052 substrate using friction surfacing. The larger coating thickness could be due to the following reasons. Very low traverse speed of 15 mm/min was used. A lower traverse speed accumulates frictional heat by longer residing time. Secondly, the thermal conductivity of the titanium alloy substrate is poor compared to that of aluminum coating rod. This allows the generated frictional heat to be transferred more along the mechtrode axis than through the thickness direction of the substrate. Thirdly, the plunging rate of the mechtrode is high. The net result of above factors is larger coating thickness.

3.2 XRD patterns and microstructure of composite coating

XRD patterns of the coated composite are plotted in Fig. 5. The peaks of the aluminum matrix and the reinforcement particles are clearly visible. The peaks of reinforcement particles are well pronounced as the rotational speed is increased due to better distribution. There are no peaks of any other compounds such as AlB_2 or Al_4C_3 , which suggests that there was no decomposition of B_4C during composite preparation.

Interface features are more important for a coating



Fig. 5 XRD patterns of AA2124/4wt.%B₄C nano-composite coatings at various rotational speeds

compared to its geometry. Figure 6 presents the microstructure of the titanium alloy substrate as well as the interface micrographs at various rotational speeds. The interface (Figs. 6(b-d)) is observed to be a continuous straight line. There is no considerable waviness of the interface. There is no penetration of the mechtrode into the substrate. There are no unbonded regions and pores at the interface, indicating a proper bonding with the substrate material. The nature of the interface appears constant over the range of rotational speeds applied. The micrograph of the substrate (Fig. 6(a)) shows fine grain structure. There appears no heat affected zone (HAZ) below the interface at the substrate. The microstructure beneath the interface looks similar to base microstructure. Temperature higher than 900 °C is required to bring a phase change in the substrate material. The temperature during surfacing is far below this temperature. Hence, there was no formation of HAZ at the substrate. An enlarged SEM micrograph of the interface at a rotational speed of 1000 r/min is shown in Fig. 7(a). It confirms the observations of the optical micrographs. Aluminum and titanium tend to react easily at elevated temperature to form intermetallic compounds at the interface [34,35]. The elemental distribution of Al and Ti across the interface is shown in Fig. 7(b). The rise and fall of the composition of each element lie within a narrow range. This observation confirms that there is no formation of thick intermetallic compound layer at the interface. On the other hand, there is no sharp change of composition of elements across a straight vertical line shown in Fig. 7(b). The narrow range indicates that there is diffusion across the interface at micron level. Such diffusion is beneficial to establishing a metallurgical bonding with the substrate.

SEM micrographs of stir cast AA2124/4wt.% B_4C nano-composite are presented in Fig. 8. The micrographs



Fig. 6 Optical micrographs of Ti–6Al–4V alloy (a) and interface of coatings (b–d) at different rotational speeds: (b) 600 r/min; (c) 800 r/min; (d) 1000 r/min



Fig. 7 FESEM micrograph of interface at 1000 r/min (yellow line indicates EDS position) (a) and EDS pattern across interface (b)



Fig. 8 FESEM micrographs of stir cast AA2124/4wt.%B4C nano-composite

are characterized by a fine dendrite structure. This microstructure is known as rosebush-like dendrite structure [36]. The addition of nano ceramic particles

refines the coarse cast structure of the aluminum matrix to fine dendrite structure. It is observed in the micrographs that most of the particles are located in inter dendritic spacing. Fewer particles are observed inside the α (Al) grains. The solidification pattern dictates the nature of final dispersion of particles in the composite. The solidification front velocity is a crucial factor to either push or engulf the particles during solidification. The distribution in the micrographs suggests that the nano particles were pushed by the solidification front to inter dendritic spacing. This points out that the velocity of the solidification front was below the critical value to engulf the particles. The wetting action of nano particles might have increased the local viscosity of the molten aluminum, slowing down the solidification front. Clusters of nano-particles as well as some micro-pores are noticed in Fig. 8. Similar observation was reported by HARICHANDRAN and SELVAKUMAR [37] in stir cast Al/4wt.%B4C nano-composite. The nano-particles increase the surface area to be wetted by molten aluminum for several times compared to that of micron level particles. Hence, the tendency to form clusters is high in nano-particle reinforced aluminum composites.

SEM micrographs of the coatings at various rotational speeds are given in Fig. 9. There is no evidence for the existence of dendrite structure or segregation of particles along grain boundaries. The microstructure of the cast composite was completely changed into a new structure after friction surfacing. The white dots in the micrographs are the locations of nano B_4C particles. There is a homogeneous distribution of B_4C particles present in the coatings. The magnified view in Fig. 9(d) confirms this observation. The disappearance of the dendrite structure is related to the

intense plastic deformation of the mechtrode due to axial force and rotary movement. The rotating action of the mechtrode shattered the B_4C clusters into homogeneous distribution. A total rearrangement of B_4C particles took place during surfacing. It is possible that some large-size nano-particles might have encountered fracture. It is further inferred from Fig. 9 that the distribution was improved with increased rotational speed due to more mechanical action to scatter the particles throughout the coating.

Figure 10 shows representative EBSD images of the cast composite as well as the coating under various rotational speeds. The cast composite is characterized by coarse grain structure (Fig. 10(a)). It is the casting process that resulted in the formation of coarse grains. The average grain size was computed to be 45 µm. EBSD images reveal that there is considerable grain refinement in the coating after friction surfacing. Well-developed equiaxed grain structure is seen in the coating. The temperature rise during surfacing is likely above the recrystallization temperature of the aluminum matrix. Therefore, friction surfacing fits into a spectrum of hot working processes. The phenomenon that causes a reduction in grain refinement is known as dynamic recrystallization. Earlier studies on friction surfaced aluminum coatings pointed out that dvnamic recrystallization is the reason for grain refinement [31,33]. The frictional heat and severe plastic deformation are accountable for recrystallization. There are two possibilities of dynamic recrystallization. The total destruction and rearrangement of dislocations may lead



Fig. 9 FESEM micrographs of AA2124/4wt.%B₄C coatings on Ti-6Al-4V alloy at different rotational speeds: (a) 600 r/min; (b) 800 r/min; (c, d) 1000 r/min



Fig. 10 EBSD maps of AA2124/4wt.%B₄C nano-composite (a) and composite coatings at different rotational speeds: (b) 600 r/min; (c) 800 r/min; (d) 1000 r/min

to continuous extended recovery processes. Secondly, grains with little or no dislocations are generated in discontinuous passion [38]. The stain rate history of the mechtrode and the stacking fault energy influence the mode of dynamic recrystallization. Aluminum alloys are characterized by high stacking fault energy. So, it can undergo dynamic continuous recrystallization.

The effect of rotational speed on the grain size is quantitatively presented in Fig. 11. The average grain size is observed to be 1.71 μ m at 600 r/min and 1.24 μ m at 1000 r/min. The variation in grain size within the chosen parameter widow falls in a narrow range. Yet, the trend line appears to be decreasing with an increase in rotational speed. There are two key factors namely frictional heat and plastic deformation playing a crucial role in reaching the final grain size after surfacing. The frictional heat increases with increase in the rotational speed of the mechtrode and attempts to coarsen the newly born grains. The plastic deformation also increases with increased rotational speed and tends to reduce the grain size. The decreasing grain size suggests that the effect of plastic deformation is dominant over the effect of frictional heat.



Fig. 11 Effect of rotational speed on grain size of composite coating

Figure 12 records a montage of TEM micrographs of the composite coating at a rotational speed of 1000 r/min. The distribution, bonding features and dislocations are obviously revealed. Fine distribution of nano-level B₄C particles is observed in Fig. 12(a). As discussed earlier, the plastic deformation coupled with the vigorous rotary action of the mechtrode causes good



Fig. 12 HRTEM micrographs of AA2124/4wt.% B_4C coating at rotational speed of 1000 r/min: (a) Fine distribution of B_4C particles; (b, c) Single B_4C particle; (d) Interface between aluminum matrix and B_4C particle; (e, f) Dislocations

distribution of B_4C particles in the coating. Single particles of various sizes are shown in Figs. 12(b) and (c). These particles appear to be glued properly with the aluminum matrix. The interface around the particle is continuous without interruptions such as pores or intermetallics. An enlarged view of an interface is shown in Fig. 12(d). It is confirmed that there is no reaction layer around the particle. The temperature prevailing

during friction surfacing is not high enough to trigger any undesirable interfacial reactions between the particles and the aluminum matrix. Figures 12(e) and (f) reveal large amount of dislocation density in the aluminum matrix and around the B₄C particles. The generation of dislocations can be attributed to two factors. Primarily, there is huge thermal disparity between B₄C particles and aluminum matrix. B₄C particles cannot expand and shrink at the same rate to that of aluminum matrix. Hence, dislocations are created to adjust the thermal strain during casting as well as surfacing. It is possible that some dislocations might have been carried from the casting process used to make the mechtrode. The dislocations around the particles in Fig. 12(e) might have originated from the casting process. Secondly, the cast composite is subjected to severe plastic deformation due to the rotating action and the applied axial force to make the coating. It is well known that the deformed material generates dislocations. Strain fields of dislocations are beneficial to improving the mechanical as well as the tribological behavior.

3.3 Microhardness of composite coating

The microhardness of the as-cast composite and the as-received titanium alloys was respectively HV 130 and HV 285. The microhardness of the composite coating as a function of rotational speed is presented in Fig. 13. The microhardness was estimated to be HV 170 at 600 r/min and HV 189 at 1000 r/min. The variation is within a range of 11.2%. The microhardness is improved (by 30.7%-45.3%) significantly subsequent to friction surfacing. The improvement in hardness of the coatings can be attributed to the microstructural changes which occurred during surfacing. The transformation of dendritic structure into fine-grained structure and the redistribution of segregated and clustered B₄C particles into a homogeneous distribution improved the hardness of the coating. The hardness is observed to increase with



Fig. 13 Effect of rotational speed on microhardness of composite coating

increased rotational speed. The increase in rotational speed refines the grains and improves the distribution of B_4C particles as discussed earlier. Hence, there is an increase in hardness.

3.4 Sliding wear behavior of composite coating

The wear rate and the frictional coefficient of the as-received titanium alloy were 280×10⁻⁴ mm³/m and 0.52, respectively, under the experimental conditions. Figure 14 shows the effect of rotational speed on wear rate and frictional coefficient of the composite coatings. The wear rate was calculated to be 250×10^{-4} mm³/m at 600 r/min and 221×10⁻⁴ mm³/m at 1000 r/min. The frictional coefficient was measured to be 0.42 at 600 r/min and 0.35 at 1000 r/min. The wear test results indicated that the wear rate of the coatings was reduced compared to that of the titanium alloy substrate. According to well known Archard's law of wear, the wear rate is inversely proportional to the hardness of the material. In the present study, the hardness of the composite coatings is lower than that of substrate material. However, there is an improvement in wear resistance of the coating. This contradiction is explained follows. The substrate titanium alloy is a as homogeneous material. On the other hand, the composite coating is a heterogenous material having a softer



Fig. 14 Effect of rotational speed on wear rate (a) and friction coefficient (b) of composite coating

aluminum phase and ultra harder B₄C phase. The wear mechanism under the applied normal load differs to each other. Full surface of the substrate specimen is pressed against the cutting action of the counterface asperities. The wear is higher due to increased frictional coefficient. Conversely, there is a homogenous distribution of nano B₄C particles in the composite specimen. The particles were characterized by excellent interfacial bonding as discussed in the previous section. The aluminum matrix may undergo wear initially which will expose a layer of B₄C particles. The particles subsequently bear the applied load and reduce the effective contact area. The frictional coefficient decreases which leads to reduced wear. The good interfacial bonding delays the detachment of particles from the aluminum matrix. As sliding proceeds, the frictional heat at the sliding interface increases. This causes a raise in misfit stress due to thermal disparity between aluminum matrix and B₄C particles. The increase in misfit stress enhances the interfacial stress. Several B₄C particles will be dislodged from the specimen surface when the interfacial stress exceeds the interfacial bonding strength. A fresh new layer of B₄C particles are exposed to the counterface. Previously dislodged particles are entrapped between the sliding specimen and the counterface disc. The wear mechanism is transferred from two-body wear to threebody wear. The net result is the reduction in frictional coefficient and enhancement of wear rate of coating. The improvement in the wear resistance is in the range of 10.7%-21.2%. A higher volume fraction of nano B₄C

particles may be required to improve the wear resistance by several folds. It is observed in Fig. 14 that the increase in rotational speed reduces the wear rate as well as frictional coefficient. This could possibly be due to improved distribution, grain refinement and enhanced consolidation of plasticized material with increased rotational speed.

The worn surfaces of the titanium alloy substrate and the composite coatings at various rotational speeds are shown in Fig. 15. The worn surface appearance of the titanium alloy and the composite coatings is distinctly different. The worn surface (Fig. 15(a)) of titanium alloy is very smooth and clean with less debris. The groove pattern did not develop completely. The grooves were blended due to plastic deformation. The worn surface suggests that it experienced softening and plastic deformation due to accumulated frictional heat between the sliding pin and the counter disc. Adhesive wear mechanism seems to be in operation. On the other hand, distinct groove pattern is observed (Figs. 15(b-d)) on the worn surface of composite coatings. The worn surface is fully covered with numerous debris distributing evenly on the surface. That debris consists of pulled-out nano B₄C particles, iron-rich counterface debris mixed with aluminum matrix and B₄C debris, and newly-projected B₄C particles. The worn surface indicates that three-body abrasive wear occurred during sliding. This debris reduced the effective contact area of the specimen and lowered the frictional force, leading to an improvement in wear resistance of the composite coatings.



Fig. 15 FESEM micrographs of worn surface of Ti-6Al-4V alloy (a) and composite coatings at different rotational speeds (b-d): (b) 600 r/min; (c) 800 r/min; (d) 1000 r/min

4 Conclusions

(1) The coating geometry increased with an increase in rotational speed.

(2) The interface between the coating and the substrate was straight without any corrugations. There was no thick intermetallic compound layer at the interface.

(3) SEM micrographs revealed that the microstructure of the stir cast composite was totally transformed after friction surfacing. The dendrite structure disappeared and the segregation and clusters were turned into a homogenous distribution. The distribution was improved with increased rotational speed due to increased mechanical action.

(4) EBSD micrographs showed that the coarse grain structure in the stir cast composite was refined to extremely fine grains due to dynamic recrystallization.

(5) TEM micrographs displayed fine distribution of nano B_4C particles, excellent interfacial bonding without any reaction layer and dislocation-rich strain fields.

(6) The hardness of the composite coatings was improved compared to that of stir cast composite due to better microstructure and distribution of nano B_4C particles. The hardness was observed to increase with increased rotational speed due to finer grains and improved distribution.

(7) Wear rate of the composite coatings was lower than that of titanium alloy substrate. The improvement in wear resistance was attributed to reduction in effective contact area, lower coefficient of friction and excellent interfacial bonding.

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摩擦堆焊法在 Ti-6Al-4V 表面制备的 AA2124/4wt.%B₄C 纳米复合涂层的显微组织和磨损特性

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摘 要:为了提高 Ti-6Al-4V 的耐磨性,运用摩擦堆焊法在其表面制备 AA2124/4wt.%B₄C 纳米复合涂层。采用 传统搅拌铸造方法制备复合材料,然后用自主研发的摩擦堆焊机在不同的转速下进行涂覆。采用传统和先进显微 技术对复合镀层的显微组织进行观察,采用销-盘装置对制备材料的滑动磨损性能进行评价。复合涂层的厚度和 宽度均随转速的增加而增加。涂层与基体的界面呈直线,未观察到厚的金属间层。结果还表明,纳米 B₄C 粒子在 复合涂层中分布均匀,晶粒细小,铝基体与 B₄C 颗粒的界面结合良好。总之,该复合涂层由于其较小的有效接触 面积,较低的摩擦因数和良好的界面结合性能,使钛合金基体的耐磨性得到提高。 关键词: 铝基复合材料; 钛; 摩擦堆焊; 涂层; 磨损

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