An Eco Friendly Novel Metal Matrix Nano Composite Friction Surfacing Of Titanium Alloy

I. Esther\textsuperscript{a}, Dr.N.Murugan\textsuperscript{b}, Dr.J.Amos Robert Jayachandran\textsuperscript{c},
\textsuperscript{a}\textsuperscript{I. Esther (Research Scholar, MED, CIT, Coimbatore, India)}
\textsuperscript{b}\textsuperscript{Dr.N.Murugan (Professor, MED, CIT, Coimbatore, India)}
\textsuperscript{c}\textsuperscript{Dr.J.Amos Robert Jayachandran (Professor, MED, MIT, Namakkal, India.)}

\textbf{A B S T R A C T}

Friction surfacing process is a friction based solid state coating process, where no fusion of the materials occur. The process is eco-friendly in nature due to the absence of shielding gas as well as the formation of toxic gases during the melting of the coating materials thereby creating new avenues for minimizing environmental pollution. The process avoids melting of the coating material and it is free from most of the problems as encountered in the conventional surfacing processes. This produces coatings with no dilution combined with enhanced mechanical properties. Titanium alloy (Ti 6Al-4V) offers a combination of high strength, light weight, wear and corrosion resistance properties. The aluminium alloy based metal matrix nano composites (AMMNCs) are found to be suitable wear and corrosion resistant material especially for aircraft and space applications.

The present work pertains to production of friction surfaced coatings on titanium alloy by using aluminium metal matrix nano composites AA2124-B4C for improving the wear and corrosion resistance of the titanium alloy. The process parameters were then optimized for achieving the desired properties of surfaced coatings. The coating was characterized by metallography, dry sliding wear and potentiodynamic polarization testing. The coating exhibited excellent wear resistance, which is attributed to composite deposited on the surface. The coating was also found to have adequate corrosion resistance. Microstructures obtained from various zones of the surfaced layer were correlated to the enhanced properties.

\textbf{Keywords:} Eco friendly, Friction Surfacing, Metal Matrix, Nano composites, Wear, Corrosion, Microstructure.

\section{1.0 Introduction}

Though several combinations of metal surfacing was carried out by using Friction surfacing (FS) process, the FS of Titanium alloy (Ti 6Al-4V) with an Aluminium alloy (AA2124) reinforced with B4C nano Particles is hitherto not reported in the literature. The development of efficient friction surfacing process with optimal energy, economy, time and environmental concerns plays a vital role to obtain desired properties for widening its applications. The absence of melting in FS is a very promising factor for surfacing the materials at lower melting temperatures. Gandra et al, (2013). In this process, the Al-B4C Metal Matrix Composite (MMC) to be coated is fabricated in the form of a rod and rotated against the substrate with an axial load. Frictional heat generated by the forceful rubbing between rod and substrate, softens the rod at the interface thereby bringing it to a viscoplastic state. The material in the viscoplastic state gets coated over the substrate as the substrate moves against the rubbing portion of the rotating rod. Al2CuMg phase, Al3FeCu phase is present in the AA2124 MMC. This precipitate is used to strengthen several structure alloys used in aerospace industry, because they confer a desirable combination of strength, fracture toughness and resistance to the growth of fatigue cracks. Titanium and its alloys are widely used in the Aviation Industry because of their unique strength to weight ratio and excellent corrosion resistance properties. But they find minimal usage in general engineering applications due to their poor wear resistance. Depositing Aluminium MMC on titanium substrate could be an appropriate solution for improving their wear resistance and extending their applications.

\section{1.1 Literature Review}

Sakihama et al. (2003) reported reduction in both coating thickness and width for higher rotation speeds of the consumable rod in the FS process. Tokisue et al. (2006) observed the effects of
rotational speed on the circular patterns formed in the coating surface. The interval of circularity pattern became narrower for higher rotational speeds, thus resulting in a smoother surface finish. Rafi et al. (2010a) observed that higher rotation speeds paved its way for an effective forging effect which yielded flat coatings and consequently the coating width decreases with increase in rotational speeds.

Janaki Ram et al. (2012) investigated the metallurgical and microstructural properties of AISI 440C Martensitic Stainless steel FS coatings on low carbon steel substrates which was concluded with good microstructural, corrosion and wear resistance properties. Prasad Rao et al. (2012) investigated the copper coatings on steel by friction suracing and recorded the thermal profiles during friction suracing, which showed different stages of plastic deformation with respect to temperature and investigated the mechanism of bonding using the thermal profile data. This study demonstrated the feasibility of producing friction surfaced coatings on nonferrous substrates. Process parameter selection as a function of material properties is a key factor in getting successful coatings. Low carbon steel could be coated with ease over copper and Inconel 800 substrates. For steel coating over copper, defect free interface was noticed with physical mixing of steel and copper without any indications of formation of undesirable phases. No intermixing was noticed between low carbon steel coating and Inconel 800 substrate. Low carbon steel could not be coated over magnesium and titanium substrates. However, steel coatings could be produced over aluminum substrate using steel startup plate.

Gandra et al. (2013) investigated the deposition of AA 6082-T6 over AA2024-T3 by friction suracing and studied the mechanical and wear properties. The thermo mechanical transformations experienced by the materials during processing were also investigated. Coatings were produced featuring a bonding with good mechanical and metallurgical properties.

### 1.2 Materials and Experimental Procedure

A FS machine was employed to deposit the Aluminium alloy (AA2124) reinforced with B4C nano particles on Titanium alloy (Ti-6Al-4V) plates of size 150X 200X 10 mm. Homogeneous AA 2124 - B4C Nano composites was produced initially by Stir casting and followed by Squeeze casting to the required size and shape without porosity in the castings. The consumable was prepared in the form of rod having 18 mm diameter. The chemical composition and microstructures of the substrate and consumable rod are shown in Tables 1 & 2 and Figures 1 & 2 respectively. The surface of the substrate was degreased with acetone and friction suracing was performed with an axial force of 600 kg and rotational speed of 800 rpm and traverse speed of 10 mm per minute. Partial development of Friction suracing procedures for surfacing of titanium alloy with aluminium metal matrix nano-composites was established.

The friction surfaced area was characterized for its metallurgical properties, using Optical microscopy, Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). Standard metallographic sample preparation technique and suitable etchants were used for identifying the microstructure in the Al-MMC coating, Titanium substrate and their Interface.

The surfaced area was further subjected to micro-hardness testing with a Vickers hardness machine at 300 gf load. Hardness profile was plotted for as cast aluminium substrate and surfaced area. Dry slide wear testing was carried out using pin-on-disc wear testing machine. The pin specimens of size 5 mm x 5mm x 30 mm were machined. The counterpart disc was made of hardened alloy steel with surface hardness of 65 HRC. The applied load was 19.63 N, sliding speed was kept constant at 179 rpm and the track diameter of 80 mm.

#### Table 1. Chemical Composition of the Substrate (Ti-6Al-4V)

| Material | Ti-6Al-4V |
|----------|-----------|
| C        | 0.1       |
| Al       | 5.5-6.75  |
| N        | 0.05      |
| O        | 0.02      |
| Fe       | 0.4       |
| H        | 0.015     |
| V        | 3.5-4.5   |
| Other    | 0.4       |
| Ti       | Balance   |

#### Table 2. Chemical Composition of the Consumable (AA 2124)

| Material | AA 2124 |
|----------|---------|
| Al       | Balance |
| Cu       | 3.8-4.9 |
| Mg       | 1.2-1.8 |
| Mn       | 0.3-0.9 |
| Si       | 0.2     |
| Fe       | 0.3     |
| Cr       | 0.1     |
| Zn       | 0.25    |
| Ti       | 0.15    |
| Other    | 0.05    |
| Other total | 0.15  |

![Fig.1 Pure Ti-6Al-4V](image-url)
1.3 Results and Discussion

Microstructure of titanium plate (Ti-6Al-4V) is shown in Fig.1. Titanium is an allotropic element, that is, it exists in more than one crystallographic form. At room temperature, titanium has a hexagonal close packed (HCP) crystal structure, which is referred to as “alpha” phase. This structure transforms to a body-centered cubic (BCC) crystal structure, called “beta” phase. Alpha stabilizers such as aluminium and oxygen, increase the temperature at which the alpha phase is stable. Beta stabilizer, such as vanadium and molybdenum, results in stability of the beta phase. In Fig.1 the microstructure shows the mixture of alpha and beta phases.

The microstructure of as cast AA2124 rod is shown in Fig.2 and the microstructure of 2% Al-MMC is shown in Fig.3. Presence of Al2CuMg phase is shown in Fig.2. AA2124 alloy is aluminium copper system. Alloys containing 4 to 6 % copper respond most strongly to thermal treatments. This aluminium copper alloy has high strength with good ductility. Depending on process parameter such as coating thickness, coating width varies shown in Fig.4 with the cross sections of specimens prepared from surfaced area. Fig. 5 shows the microstructure of interface between the substrate and consumable rod. Fig.6 shows the nano crystalline region between the aluminium side and titanium side and the Al3Ti layer and B4C nano region strengthen the interface. Fig.7 and Fig.8 shows the EDS script of titanium alloy and AA2124 alloy.
Mechanical testing such as Hardness, wear studies were carried out. Fig. 9 to 11 shows the wear rate and hardness of the surfaced area. Optimization of FS process parameters is partially done by using Design of Experiments for obtaining the desired properties and widening its industrial applications. FS having finer Microstructure and improved hardness by changing the appropriate process parameters. FS will enhance material compatibility and avoids distortion. FS will exhibit improved corrosion and wear resistance properties and also enhances the mechanical behavior of the material by forming the fine microstructure in the coating.

1.3.1 Axial force

Excessive loads result in non-uniform deposition with a depression at the middle of the deposit. In contrast, insufficient axial forces result in poorly consolidated interfaces. Some studies also showed that the mechanical strength of the deposits is enhanced by the rise of axial force. Axial load varies from 400-700 kg.

Axial force strongly influences coating thickness and width, since it determines the rate at which material is deposited. As such, higher axial force result in a reduction in both thickness and width as shown in Fig. 4. The increase of axial force will increase the bonding strength. Thicker coatings produced with lower axial force, were observed to fail at the interface. High axial forces resulted in shorter heat exposure periods, resulting in less grain growth and limiting the substrate heat affection. Increasing the axial force results in thin deposits. This thin deposits cool faster. Yielding finer microstructures. This fine microstructure increases wear and hardness of the coating. Excessive axial force results in concave shape in the deposition.

1.3.2 Rotation Speed

Rotation speed influences the bonding quality, coating width and roughness. At lower the rotation speeds the bond strength increases. Excessive rotation speeds can also lead to a reduction of bonded width and substrate HAZ. High rotational speed resulted in smaller heat exposure periods, resulting in less grain growth and limiting the substrate heat affected zone. Fine microstructures form due to the rapid cooling of thinner deposition layer on the substrate. Rotation speed strongly influences coating thickness and width. Increasing the rotation speed result in a reduction in both thickness and width. The increase of Rotation speed, up to a certain extent, has also led to an increase on bonding strength. If the rotation speed is less thick coatings are produced. Failure in the interface were observed. To get the good joint optimized rotation speed is required.

1.3.3 Travel Speed

Travel speed strongly influences coating thickness and width. Higher travel speeds result in a reduction in both thickness and width. The increase of travel speed also led to an increase on bonding strength. Thicker coatings produced with lower travel speeds, were observed to fail at the interface. High travel speeds resulted in shorter heat exposure periods, resulting in less grain growth and limiting the substrate heat affection. Increasing the
travel speed results in thin coating. This coating cool faster, producing fine microstructure, results in less wear and increased hardness.

1.4 Conclusions

1. Surface of the Ti-6Al-4V alloy is improved with AA2124 B4C MMC coating using friction surfacing process.

2. Good bonding between the substrate Ti-6Al-4V alloy and The AA2124 B4CMMC composite coating were achieved.

3. Major improvement in the wear resistance of the composite coated titanium alloy. Due to the presence of hard carbide particles of Al alloy matrix due to reduced coefficient of friction.

4. Axial force enhance the bonding width. Higher the axial force results in reduction in both thickness and Width.

5. Increasing the rotation speed results in regular and flat

6. Al3Ti layer and B4C nano region near the interface increases the bond strength.

1.5 ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge Department of Science and Technology (DST-WOS-A) for funding the project. The author would like to thank Scientist Mentor for continuous encouragement and permission to publish this work.

1.6 REFERENCES

1. Sakihama et al. “Mechanical properties of friction surfaced 5052 aluminum alloy”. Materials Transactions vol.44, pp.2688–2694, 2003.

2. Tokisue, H, Katoh, K., Asahina, T., Usiyama, T., “Mechanical properties of 5052/2017 dissimilar aluminum alloys deposit by friction surfacing. Materials Transactions. Vol. 47, pp.874–882, 2006.

3. Reddy GM, Rao KS, Mohandas T, “Friction surfacing: A novel technique for metal matrix composite coating on aluminium–silicon alloy, Surfacing Engineering, Vol. 25, pp.25–30, 2009.

4. Kramer de Macedo, M.L., Pinheiro, G.A., dos Santos, J.F., Strohaecker, T.R., “Deposit by Friction surfacing and its applications”, Welding International, Vol. 24, pp. 422–43. 2010.

5. Madhusudhan Reddy, K.Satya Prasad, K.Rao and T.Mohandas, “Friction Surfacing of Titanium alloy with aluminium metal matrix composite”, Surface Engineering, Vol. 27, No2, pp. 92-98., 2011.

6. Rafi, H.K., Balasubramaniam, K., Phanikumar, G., Rao, K.P “Thermal profiling using infrared thermography in friction surfacing. Metallurgical and Materials Transactions A, Vol 42, pp. 3425–3429, 2011.

7. Gandra J., R.M.Miranda, P.Vilaca, “Performance analysis of friction surfacing”, Journal of Materials Processing Technology, Vol. 212, pp. 1676-1686, 2012.

8. Prasad Rao, A. Veerasreenu, H. Khalid Rafi, M.N.Libin, Krishnan Balasubramaniam, “Tool steel and copper coatings by friction surfacing – A thermography study, Journal of Materials Processing Technology, Vol. 212, pp. 402–407, 2012.

9. Prasad Rao, ArunSankar& H. Khalid Rafi, G. D. Janaki Ram, Madhusudhan Reddy “Friction surfacing on nonferrous substrates: a feasibility study”, International Journal Advance Manufacturing Technology, Vol. 65, pp.755–762, 2013.

10. J. Gandraa, D. Pereirab, R. M. Mirandab, P. Vilaçac, “Influence of process parameters in the friction surfacing of A A 6082-T6 over AA 2024-T3”, Procedia CIRP, Vol 7, PP 341 – 346, 2013.deposit.