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Preparation of Wear-Resistant Coating onto Polymer Matrix Composites Via Arc Spray Process

Amine Rezzoug[1, 2], Saïd Abdi[2], Nacer Dilimi[3], Wahiba Djerir[1]

[1]Research Center in Industrial Technologies CRTI, BP64 Route de Dely Brahim, Chéraga, 16014 Algiers, Algeria, a.rezzoug@crti.dz
[2]Laboratoire des Sciences et Génie des Matériaux (LSGM), Université des Sciences et de la Technologie Houari Boumediene (USTHB), BP 32 El-Allia, 16111, Algiers, Algeria, Abdi81dz@yahoo.fr
[3]Laboratoire traitement de surface et matériaux, Université Saad Dahlab, Blida, Algeria, Nacer_dilmi@univ-blida.dz

ABSTRACT

This work aims to develop a wear-resistant coating ((FeCrNiBSi- (W-Ti) C)) onto a polymer matrix composite (Carbon/Epoxy), an aluminium mesh layer was used to avoid the degradation of the substrate and enhance the adhesion. The quality of the coatings was investigated in terms of microstructure, composition and wear behaviour. The tests were conducted using ball-on-disc tribometre. The results obtained revealed that the success of the coating is related to the choice of the bond layer. This coating improved the wear resistance of the composite by more than the double.

Key Words: *Polymer matrix composite, thermal spray coating, metal matrix coating, wear.*

NOMENCLATURE

Symbols :

Ws	wear rates, $mm^3.m^{-1}$
V_{disk}	disc volume loss, mm^3
D_s	sliding distance, m
F_N	normal load, N

Abbreviation:

PMC	Polymer Matrix Composite
MMC	Metal Matrix Composite
EDS	Energy Dispersive Spectroscopy
SEM	Scanning Electron Microscopy

1. INTRODUCTION

Among the innovate technologies for surface modification, thermal spraying processes are widely used to deposit coating to improve surface properties [1]. Recently, deposition of metal coatings on polymer matrix composite (PMC) is now possible with promising applications (wear and thermal resistance, electrical and thermal connectivity) [2, 3]. In the field of aerospace technology and energy, the need to protect the PCM components from wear and erosion conduit to development of metal matrix coating (MMC) reinforced whit ceramic such as WC and Al_2O_3 [4, 5]. However, to achieve such a innovate materials is extremely difficult (high chemical inertness of PMC, low melting temperature and surface tension, thermal and mechanical degradation of the substrate during the spray process, incompatibility and poor adhesion between metal and polymer) [6]. For this, the choice of the process and the feedstock material are the key challenges to obtain such a material.

In order to improve the surface properties of the polymer matrix (Carbon/Epoxy) composite materials, we have considered depositing an anti-wear metal matrix coating using a thermal spray process (Figure 1). This using bonds layers at interface made of compatible materials whit booth PMC and coating. The aim of this study is to reveal the benefit of the thermal spray process on the wear resistance improvement of PMC. So, the tribological behaviour of coated and uncoated PMC are investigated.

2. EXPERIMENTAL METHOD

The PMC substrates were elaborated using bag moulding process and cured via an integrated heating system. The composite consisted of an epoxy matrix (EPOCAST® 50, Huntsman, USA) reinforced by carbon fiber (BMS 9-8 TY1 CL2, Hexcel, USA). To promote the adhesion of coating an aluminium mesh (Hexcel, USA) was deposited at the top surface of the PMC before moulding.

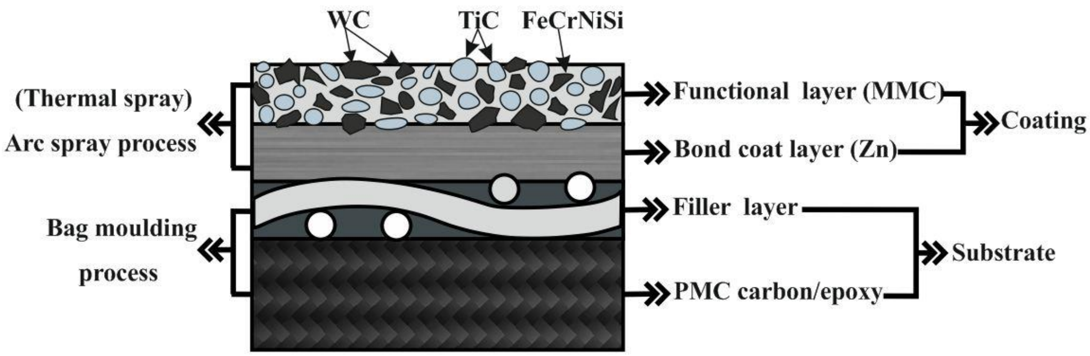


FIGURE 1. Concept of wear-resistant coating onto the PMC

Arc spray process was selected to deposit both of the bond coat and wear-resistant coating layers onto PMC (Figure 1); this was carried out by electric arc spray system (ValueArc®, Oerlikon Metco, USA). A zinc wire (Metco™ Zinc, Oerlikon Metco, USA) was used as feedstock material to produce the bond coating. This layer was essential to allow the deposition of the upcoming top coating (zinc low melting point and good wettability on non-metallic surfaces). The top coating was obtained using Metco™ 8297 cored wire; it is an iron-based wire filled with tungsten and titanium carbide powders (FeCrNiBSi- (W-Ti) C). The chemical composition of this wire feedstock material is given in Table 1; after spraying, the coating consisted of a metallic matrix composite. The projection concept and parameters were selected regarding our previous papers [7, 8] and for the top coating from the optimal results indicated by the work of Y.Fizi et al. [9] (Table 2).

FeCrNiBSi- (W-Ti) C (Metco™ 8297)	Fe	WC	Cr	TiC	B	Si
Mass fraction, %	Balance	26	13	6	2	1

TABLE 1. Chemical composition of cored wire FeCrNiBSi- (W-Ti) C (mass fraction, %)

Feedstock material	Zn	(FeCrNiBSi- (W-Ti) C)
Arc current	80 A	100 A
Arc voltage	38 V	36 V
Stand-off distance	130-140 mm	≈ 120 mm
Pressure of compressed air	0.37 MPa	0.38 MPa
Projection angle	90°	90°
Feeding rate	3 m/min	3 m/min

TABLE 2. Spray parameters for zinc bond coat and (FeCrNiBSi- (W-Ti) C) top coating

The tribological behavior of the samples was characterised using ball-on-disk tribometer CSM (CSM Instruments Inc, Switzerland). Wear tests were conducted at room temperature, at dray environment; the sliding distance and the angular velocity were fixed at 200 m and 400 revolutions/min, respectively. The tribological study consisted of the wear resistance comparison of the coated and the uncoated PMC under various normal load (F_N), from 2 N until 12 N. By determining the volume loss after testing, the wear rates (W_s) in $mm^3.m^{-1}$ can be calculated using the equation (1).

$$W_s = {}^{V_{disk}}/_{D_s} \qquad (1)$$

Where D_s is the sliding distance (m), and V_{disk} is the disc volume loss (mm^3). Wear morphologies and coating system micrographs were obtained using scanning electron microscope (JEOL 6360, Japan) and optical microscopy (Eclipse 3000, Nikon Instruments, USA).

3. RESULTS

Figure 2 shows a micrograph cross-section of the coating on the PMC with a bond coat layer of Zn. This coating was appliqued onto tow PMC (with and without filler layer). It is evident that the thermal spray of the top layer leads to a delamination between the PMC without filler layer and the zinc bond coat layer. This is due to the poor an adhesion between these two layers [8]. On the other hand, as it can be seen in figure 2 (right) the use of filler layer based on Al mesh allows depositing the top layer without significant damage. During the impact, the particles mechanically adhere to the surface of zinc, which is strongly adhered to the filer layer. The success of the coating elaboration can be attributed to the excellent interface between the zinc and the filler layer. Indeed, the filler layer increased the adhesion strength by about 50% compared to the PMC without filler layer [8]. In fact, to produce a wear-resistant coating onto a PMC surface, the modification of the top layer of the PMC using a filler (Al mesh) was an essential step. In our previous paper we have found that a uniform metal coating (zinc) could be successfully produced on PMC, and the zinc has been identified as a compatible coating for PMC. However, we notice that mechanical properties of the PMC composite decrease by about 15% after coating for the PMC without filler layer (fiber broken at the surface). In a new approach; this latter disadvantage was overcome via a filler layer.

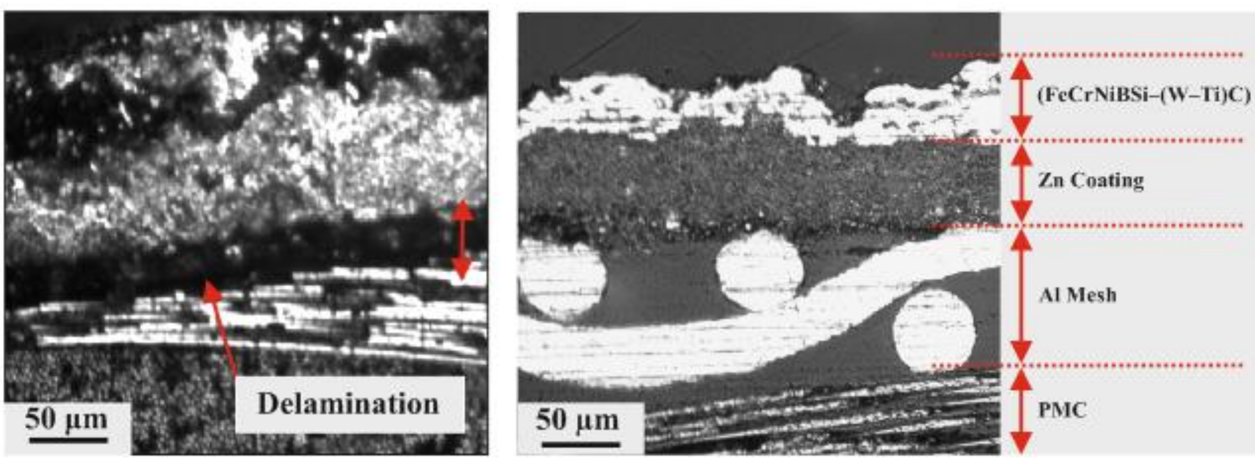
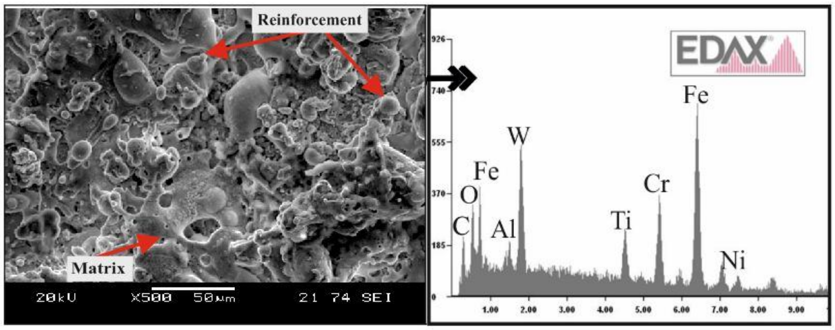


FIGURE 2. Optical image of the cross-section of arc sprayed zinc bond coat and (FeCrNiBSi- (W-Ti) C) functional deposited onto PMC (left) and PMC reinforced at the top surface whit filler layer of Al mesh (right)

Form the figure 3 it can be observed that the coating results from the superposition of splats of molten particles that form the matrix (FeCrNiBSi) and unmelted particles that form the reinforcement WC and TiC. The EDS analysis clearly reveals that the chemical composition of coating is nearly similar to the feedstock materials; nerveless, we notice the presence of oxidation (≈ 8%) occurring during the spraying. These results are very close to the results of Y.Fizi et al. [9] when they spray this MMC onto steel substrate, this indicates that in this condition the substrate doesn't affect the nature of coating, but It's essential for the adhesion.



Element	Wt%	At%
C K	12.13	36.73
O K	08.99	20.45
AlK	01.40	01.89
W M	23.01	04.55
TiK	04.70	03.57
CrK	10.72	07.50
FeK	35.04	22.82
NiK	04.01	02.49

FIGURE 3. SEM and EDS analysis of (FeCrNiBSi- (W-Ti) C) coating deposited on the substrate PMC using zinc bond coat

For the PMC used in conditions where they are subject to wear (automotive and aerospace as well as in structural engineering); the knowledge of their behavior is crucial to estimate their service life [10]. To highlight the contribution of coating to the wear resistance of PMC, the coated and the uncoated PMC were subject to wear tests (ball on disk).

The wear rate evolution of the coated and the uncoated PMC are illustrated in Figure 4. the wear rate of both coated and the uncoated PMC increase when increasing the applied load. The load has a significant influence on the contact stresses, which increase the friction at the interface and resulting therefore on the increase of the volume lose (wear rate). The uncoated PMC is less resistant to wear compared to the coated one for all the charges applied, this weakness is even more accentuated when applying an important load (12 N). It can be concluding that the severe wear mode is retched when applying 12 N. The metal matrix coating (MMC) has greatly contributed to the improvement of the PMC wear resistance, in fact, the coated PMC was about twice stronger than the uncoated one. This could be attributed to the nature of the reinforcements (WC and TiC), which are among the most used materials in the field of wear resistance (machining and drilling tools) [11].

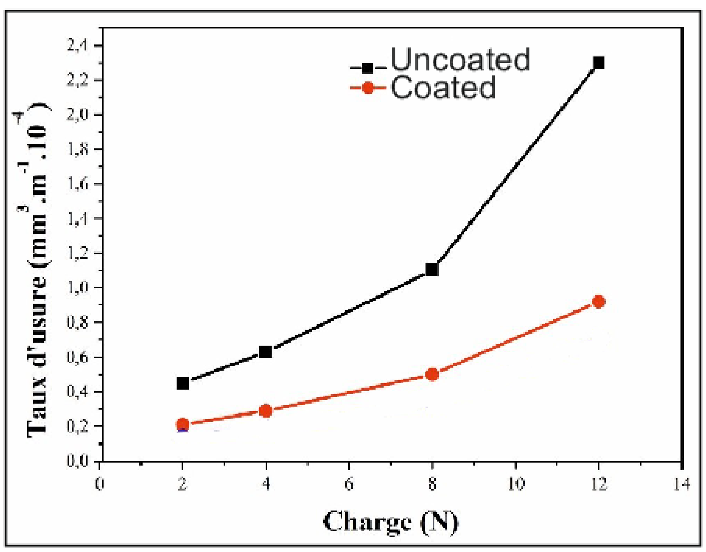


FIGURE 4. Evolution of the wear rate versus normal load of the coated and the uncoated PMC, obtained after a wear test of 200 m at a speed of 400 revolutions/min

SEM images of the worn surfaces of the coated and the uncoated PMC are exhibited in Figure 5. It can be seen that the surface of the uncoated PMC is more damaged. After 200 m of sliding wear under 12 N, the breakage of the fibers is facilitating due to the matrix degradation, and then the fibers are peeled from the surface by delamination. This contributed to the appearance of the microfissurations which lead to a brittle rupture [12]. On the other hand, grooves (micro-grooves) and scratches are observed on the worn surface of the coated PMC.

Reinforcing particles may be fragmented or detached from the matrix, subsequently trapped between the sample and the ball in the third body resulted in plastic deformation and removal of material of the coating. This phenomenon is generally observed during a wear test on MMC [11, 13]. Nevertheless, this surface degradation is not as important as the degradation of the uncoated PMC (low volume lose).

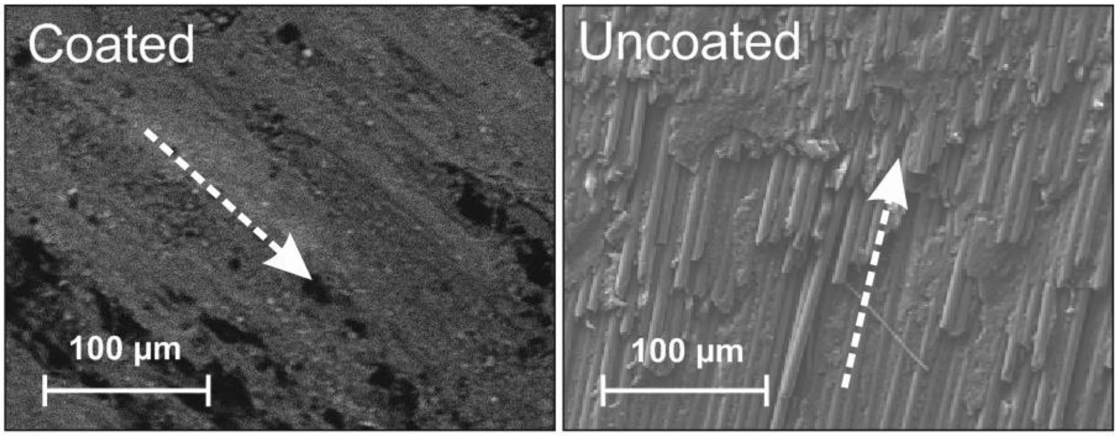


FIGURE 5. SEM micrographs showing the wear scar area of the coated and the uncoated PMC after wear test under 12 N for 200 m

4. CONCLUSIONS

This work has been devoted to investigate the tribological enhancement of polymeric matrix composites material using thermal spray coating. A promising solution consists of metal matrix coatings (FeCrNiBSi- (W-Ti) C). the adhesion and the functionality of the assembled material was by a filler layer of aluminum mesh and a bond coat of zinc which are compatible and with both of the metallic coating and the polymeric substrate.

The results of tribological wear tests have shown that MMC wear-resistant coatings have significantly improved the wear resistance of CMPs. In fact, at normal load of 12 N for 200 m sliding distance, the wear rate decries from 2.2 x 10^{-4} $mm^3.m^{-1}$ (uncoated PMC) to 0.88 x 10^{-4} $mm^3.m^{-1}$ (coated PMC) after coating. This method is very interesting for the modification of the surface properties of this kind of composites materials and provides them new functionality.

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