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Characteristics of PVD CrAlN thin film on Al-Si piston alloy

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ABSTRACT – CrAlN coatings are the foremost coating material used for automotive applications where mechanical properties such as hardness, roughness, adhesion are significant. In this research work thin film CrAlN coating is deposited by PVD magnetron sputtering technique and to evaluate the mechanical properties of CrAlN coating on Al-Si piston alloy. The microstructural, topographical analysis and composition of CrAlN coatings were examined by using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDX). Atomic force microscopy (AFM) images were taken from the substrate surface before and after the coating. The scratch adhesion of film-to-substrate was measured by using scratch machine.

1. INTRODUCTION

Aluminum and its alloys are now finding growing applications in the areas which primarily demand light weight and high strength characteristics in materials [1]. Indeed, there are excellent materials that are used to manufacture industrial, automotive, and aerospace components owing to their low density, fracture toughness, and corrosion resistance [2]. Accordingly, automotive manufacturers have been employing Al-Si alloy, especially in wear applications such as compressors, pistons, and cylinder blocks [1, 3]. Unfortunately, the use of this alloy has disadvantages due to microstructural defects such as coarse eutectic structure, massive amount of silicon contents, and porosity [1]. These significantly reduce the mechanical and wear properties. Wear is a mechanical process that results due to frictional force generated between two mating surfaces in sliding or rolling contact [4]. The poor wear resistance of Al-Si piston alloy limits their application [5-6].

For this purpose, the surface properties of aluminum alloys are enhanced by binary and ternary nitride coatings. These coatings are used to supplement the additional properties that are required in wear applications [7-8]. In order to yield optimum performance, the first and foremost requirement is that the deposited coating should be effectively bonded and adhered to the substrate.

2. METHODOLOGY

The CrAlN coatings were deposited on Al-Si piston alloy with very thin coating thickness using DC/RF Power magnetron sputtering system (TF450 Sputtering System, SG Control Engineering) shown in figure 1. The surface hardness, microstructure, chemical composition and roughness of CrAlN film is evaluated by Vickers hardness, field emission scanning electron microscopy (FESEM) integrated with energy dispersive X-Ray spectroscopy (EDX) along with atomic force microscopy (AFM). The scratch adhesion of film-to-substrate was measured by using scratch machine.

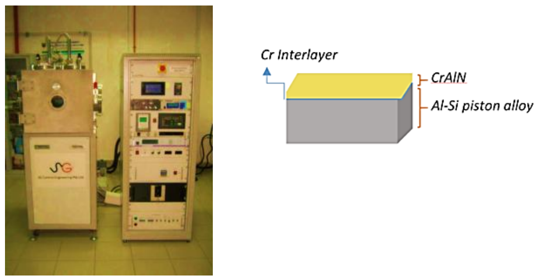

Figure 1 PVD magnetron sputtering machine.

3. RESULTS AND DISCUSSION

Figure 2 depicts the SEM cross sectional microscopy of CrAlN coating deposited on Al-Si alloy. The thickness as measured for CrAlN top layer and Cr Interlayer were 1.69μm and 1.1 μm respectively, contributing to an approximate total coating thickness of 3.1 μm. Under SEM the coating exhibits neither columnar nor granular structure. According to the EDX area mapping in Figure 2 an uniform atomic composition of 5% of N2, 26% of Al and 65% of Cr was obtained. Figure 2 is showing the diffusion rate of coating layers along with bulk substrate material and EDX cross sectional line scan, which implies adequate deposition of intended materials.

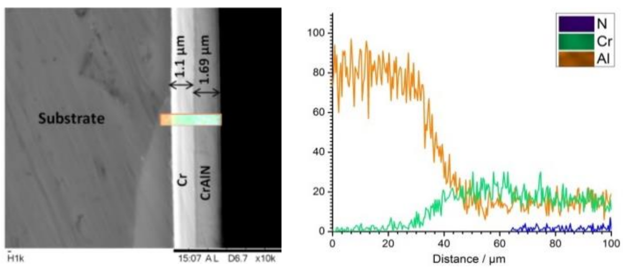

Figure 2 Cross-sectional SEM and EDX micrograph of CrAlN coating on Al-Si piston alloy.

AFM results of uncoated and coated samples shows surface roughness Ra value of 66 nm and 19 nm respectively, resulting in 3.47 times decrease the roughness of coated specimen shown in figure 3. Table 1 presents the micro hardness of uncoated and CrAlN coated substrates. The hardness of CrAlN coating contributed to an increase of approximately 7.2 times hardness of Al-Si alloy.

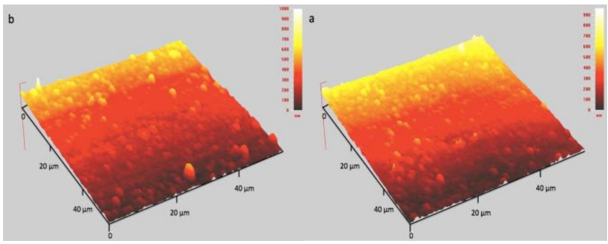

Figure 3 Three-dimensional AFM images of (a) uncoated (b) CrAlN coated samples.

Table 1 Comparison of mechanical properties of uncoated and CrAlN coated samples.

Material	Surface Roughness (nm)	Hardness (HV)	Adhesion Strength L_{c3} (mN)
Al-Si Piston alloy	66	90	-
CrAlN	19	654	2519

The adhesion of CrAlN coating on hypereutectic Al-Si alloy substrate was mainly promoted by mechanical interlocking. In scratch experiment, the adhesion strength of coating-to-substrate is commonly referred as critical load (Lc2). For coated sample, three scratch indentations were made at different areas. The average value of critical loads (Lc3) for adhesion strength is given in Table 1. Scratch response is evaluated in the form of abrupt changes in the slope of load versus depth profile and changes in surface morphology across the scratch track were investigated by optical microscopy as shown in Figure. 4.

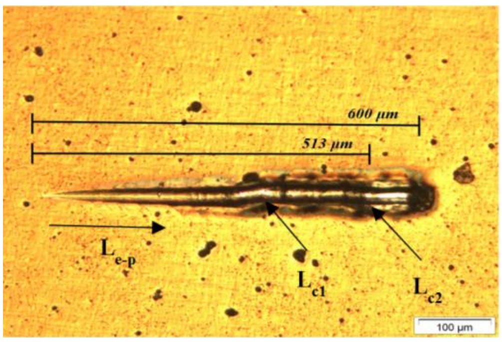

Figure 4 Evidence of failure mode of coating through scratch tracks.

4. CONCLUSIONS

In this research work, multilayered CrAlN coating was successfully developed on hypereutectic Al-Si alloy by magnetron sputtering PVD technique in an Ar+N2 gas atmosphere. The surface roughness of coated sample is (Ra=19 nm) as compared to uncoated sample (Ra=66 nm). The hardness for the coated sample was 654 HV indicating a significant improvement compared to the uncoated sample where the hardness was only 90 HV. The adhesion strength of coating was 2519 mN.

5. ACKNOWLEDGEMENT

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