

# Evaluation of Fracture Toughness of Thermal Sprayed and Hard Chrome Coated Aluminium-Zinc Alloy

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The determination of fracture toughness of aluminium alloy aviation parts, exposed to cyclic mechanical loading, is an important engineering issue. The service life and crack resistance of such unprotected metallic parts is limited under corrosive operating conditions. The resistance against fracture cracking and corrosion resistance can be increased by the surface coatings. The scientific research of fracture toughness of coated metallic parts is being carried out in a comprehensive way. In this research, fracture toughness behaviour of high velocity oxy-fuel (HVOF) spray coated and conventional hard chrome plated aluminium-zinc alloy parts were compared and the results are discussed. The fracture surfaces are investigated and fracture toughness values are calculated. Electron microscopy analysis revealed significant differences in crack growth morphology and toughness values. As a result, the fracture toughness value is higher in hard chrome plated parts.

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## 1. Introduction

High performance, heat treated aluminium-zinc alloys, such as 7075-T651, are widely used in a variety of aviation parts, due to their high specific strength and cost efficiency. Due to their chemical compositions, these aluminium series have insufficient corrosion resistance for aggressive operation conditions. Besides that, the fatigue cracking is the most common failure mechanism for these aviation parts.

The presence of surface defects and corrosion products, that act as crack initiation sites, considerably reduces the fatigue life and fracture toughness of the unprotected metallic parts. Particularly in aviation industry, fracture toughness and surface resistance are very important due to the high repetitive stresses on various pin, rod or profile holders, guiding systems in landing gear, body and wing systems.

In general, a wide variety of methods are used to improve the surface properties and crack resistance of aluminium alloys, particularly those involved in aviation applications. These are such methods, as electroplating, thermal spraying and anodizing. Electroplating process is a cost effective and a practical method.

By the hard chrome (HC) plating process, layers in a narrow range of thickness and with excellent surface properties can be obtained. The search for alternative surface technologies continues, because hard chrome electroplating is limited in terms of environment and health effects [1–7]. In recent years, tungsten carbide-cobalt (WC-Co) based high velocity thermal spray coatings have emerged as an alternative process to hard chrome plating, in the search for environmentally friendly coatings.

Among the thermal spray coating methods, the high velocity oxy-fuel (HVOF) spray process is particularly outstanding. With the HVOF process, it is possible to produce coatings with high hardness ( $> 1000$  HV), wear resistance and coating density (lower porosity  $< 1\%$ ). Literature surveys have also shown that HVOF spray carbide-based coatings on aluminium alloys increase the fatigue life and improve the corrosion resistance [5].

This investigation has been carried out in order to determine the fracture toughness of an aluminium alloy, coated with a HVOF spray WCCoCr coating, and to compare it with that of the uncoated and hard chrome electroplated aluminium alloy test samples, tested under the same conditions. The fracture surface and cross section of the coatings are investigated using scanning electron microscopy (SEM).

## 2. Experimental: materials and test method

Aluminium-zinc alloy (7075-T651) substrates (plate thickness of 70 mm) were used in this study. In the experimental studies, the plane stress fracture toughness  $K_{IC}$  was investigated using fatigue pre-cracked specimens. Fracture toughness measurement on compact test (CT) specimens have been carried out on MTS 810 machine with a load cell of 100 kN (Fig. 1a).

Some of samples were coated with WC10Co4Cr based thermal spray powders (Sulzer Metco 5847, particle size:  $53 \pm 11 \mu\text{m}$ , agglomerated and sintered), with layer thickness of approximately  $170 \pm 25 \mu\text{m}$ , by robot controlled HVOF spraying process. During spraying, JP5000 spray gun was used. Spray parameters: gas/fuel flow rate:  $\text{O}_2/\text{Kerosene}$ : 750–800/20–30 l/min., powder feed rate: 10–12 g/min, spray distance: 280–300 mm.

Another group of samples was electroplated with chrome. Surface preparation was done before coating process. Electroplating parameters were: voltage of 2.4–3.6 V, current density of 40–45 A/dm<sup>2</sup>, solution

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composition: chromic acid 250–300 g/l, sulphuric acid 2.55–3 g/l and catalyst, solution temperature  $50 \pm 5^\circ\text{C}$ .

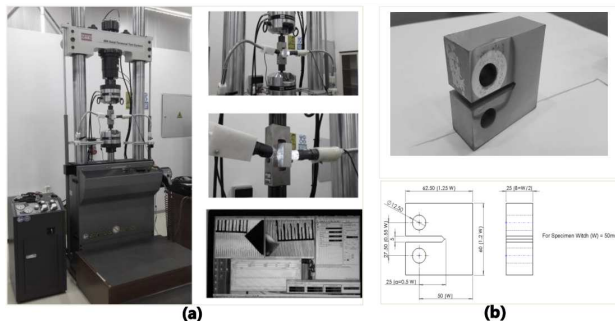


Fig. 1. Fracture toughness measurement (ASTM E399). (a) Fatigue crack test set-up, (b) V-notched sample and its geometry.

According to the standard testing procedures (ASTM E399) [8, 9] the coated samples are tested under mode I

fracture in TL orientation ((L) longitudinal, (T) transverse). All samples were pre-cracked (Fig. 1b) at 5 Hz, with load ratio of 0.1 (R). The influence of hard chrome coating (HC) and thermal spray (TS) coating on fracture toughness and fracture behaviour of Aluminum7XXX series alloy was measured and evaluated experimentally.

### 3. Results and discussion

### 3.1. Microstructural properties of coated samples

Table I illustrates and compares microstructures of the top surface and cross section and properties of the HVOF sprayed and electroplated samples. Cross-section microstructures show that HC coating layer has a homogeneous thickness of 15  $\mu\text{m}$ , where several typical micron sized crack webs are the only detectable features. Excellent surface quality and adhesion, with almost no interfacial defects, is detectable both on grit-blasted aluminium substrates.

TABLE I

### Microstructure and properties of the coatings.

Property	Coating thickness [ $\mu\text{m}$ ]	Roughness [ $\mu\text{m}$ ; Ra/Rz]	Micro hardness of coating [ $\text{HV}_{0.2}$ ]
Uncoated alloy	—	1.1/3.4	$200 \pm 20$
HVOF coated	$170 \pm 25$	3.2/14.2	$1150 \pm 25$
Hard chrome coated	$15 \pm 2$	1.4/6.8	$700 \pm 15$

HC

Top surface

HVOF

Top surface

Cross section

Electroplating process

Cross Section

Thermal spraying process

### 3.2. Test results of fracture toughness

For the fracture toughness experiments, the number of repetitions of the tests was three, and the average value

was calculated. As can be seen from the test results, the fracture toughness of the aluminum alloy can be increased by both coating processes. This is due to interface

properties of the coating structure and the top surface. The plane strain fracture toughness is  $32.5 \text{ MPa m}^{1/2}$  for electroplated part. This value is 50% higher than the one for uncoated samples. Increase of fracture toughness is lower for HVOF sprayed coatings (Table II).

TABLE II

Results of fracture toughness measurement.

Orien- tation	Code	<i>a</i> [m]	<i>w</i> [m]	<i>P</i> [kN]	<i>K</i> [MPa m <sup>1/2</sup> ]
TL	Uncoated	0.026	0.025	11.592	22.00
	HVOF sprayed	0.014	0.025	13.731	25.29
	Hard chrome plating	0.026	0.025	17.873	32.57

HVOF sprayed coating layer shows a typical lamellar thermal spray coating ( $170 \pm 25 \mu\text{m}$ ) structure with an irregular shaped micro sized porosity and micro cracks as

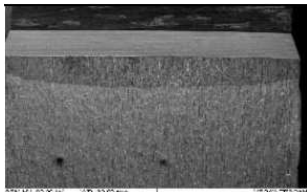


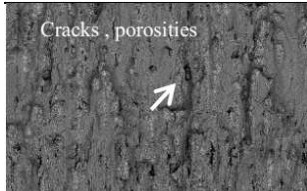
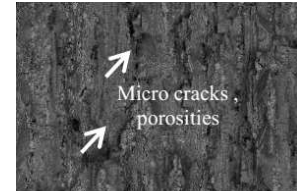
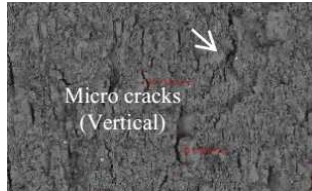
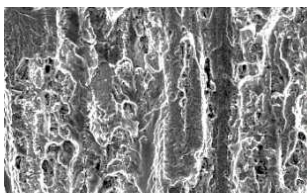
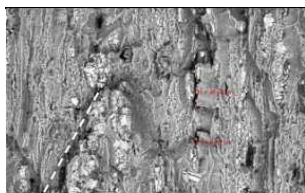
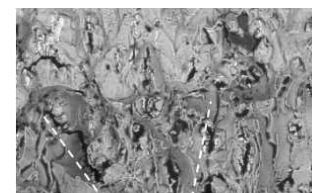
discontinuities. As-sprayed surface roughness condition and surface quality of HVOF coating is lower than those of HC plating. Sandblasting residues are observed at the interface. The micro hardness (Vicker Hardnes: HV) measurement results show that there is a significant difference between the coatings. Due to the WC reinforced Co matrix of the HVOF coating, its micro hardness is higher by approximately 300 HV. However, the discontinuity in the coating structure affects the crack resistance.


### 3.3. Microscopic investigations of fracture surface

When the pre-cracked samples are exposed to mechanical cycling stresses, the crack tip starts to open with the increasing tensile stress. After that, micro-cavities and micro cracks begin to move in front of the crack tip, while forming a tensile zone under the effect of plastic deformation stress.

TABLE III

SEM micrographs of fracture surface of coated and uncoated notched alloy samples after fatigue test.

Uncoated	HVOF sprayed	Hard chrome plated
		
		
<p>Crack size height: 1–2 mm width: 0.5 mm Many macrocracks, Macro discontinuous, Deformation</p>	<p>Crack size height: 100–150 <math>\mu\text{m}</math> width: 15 <math>\mu\text{m}</math> Many microcracks, porosities, Different direction (dashed lines)</p>	<p>Crack size height: 200 <math>\mu\text{m}</math> width: 25 <math>\mu\text{m}</math> Few microcracks, Different direction</p>
		


<p>Fracture surfaces</p> <ol style="list-style-type: none"><li>1. Unstable region</li><li>2. Pre-cracked region</li></ol>

Interactions and contact formation of discontinuities continue until they reach a critical dimension. The opening and spreading of the crack tip accelerates along with the critical length of microstructural cavities, irregular cavities, grain boundaries, micro cracks and other discontinuities. The mechanism of fracture varies depending on the presence and movement of direct micron-sized structural faults (Table III).

In the tests carried out, the coating structure is intense and the interface adhesion properties of coating play an active role in slowing the crack progression. Obviously, the fracture toughness values of the coated samples are increased. The hard chrome plated specimens are particularly more effective against crack propagation than thermal sprayed samples. Increasing the surface resistance of the substrate with the coatings provides resistance against cracking.

The fracture surfaces were examined under the electron microscope and different studied regions are presented in Table III. It was observed that the crack was unstable in certain regions and stable in other regions. The steady crack growth zone is partly smooth and does not show any deep groove. The unstable cracked growth zone shows rough, deep grooves and voids. The fractured surface of the coated specimens revealed a relatively more stable crack growth zone, as compared to the uncoated substrate.

#### 4. Conclusions

The effect of the coating on fracture toughness was investigated. When the aluminium alloy was coated with HVOF spraying or electroplating process, the fracture toughness values were increased. Significant rising in fracture toughness was measured with electro chrome plating process. Such increase in fracture toughness performance is correlated with microstructural and interfacial characteristics of the coatings.

Electron microscopy studies of the fracture surface showed that uncoated Al 7075-T651 specimen had unstable, larger crack growth region than the others. It has been observed that application of the coating slows down the crack growth. For this reason, it is absolutely recommended to apply a protective coating to the surfaces of aluminium alloys. It is thought that fracture toughness can be increased by extensive studies on thermal spray coatings. It has been found that micro crack size and direction on the fracture surfaces affect the fracture toughness level of the material.

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