International Journal of Fatigue 65 (2014) 51–57

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

# Fatigue strength of Al alloy cold sprayed with nanocrystalline powders

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ARTICLE INFO

*Article history:*
Received 26 January 2013
Received in revised form 4 September 2013
Accepted 5 September 2013
Available online 12 September 2013

*Keywords:*
Fatigue strength
Cold spray
Nanocrystalline
Residual stress

ABSTRACT

Nanocrystalline cryomilled and microcrystalline Al7075 powders have been deposited on Al5052 substrates using the low-pressure cold spray coating technique in order to study the effect of the powder micro/nano structure on fatigue behavior of coated samples. Microstructural characteristics and fatigue behavior of the coated structure have been surveyed through experimental tests. The powders' size and shape distribution have been studied using scanning electron microscopy. In order to obtain the *S–N* diagrams, grit blasted and coated samples with different treatment parameters have been tested for fatigue at load control condition. Grain size measurement has been performed by X-ray diffraction. X-ray diffraction has also been used to measure the residual stress distribution in both the deposited material and the substrate. Surface roughness measurements have been performed on all series. It has been observed that, although the coating porosity was not zero, the fatigue limit is slightly increased by using the cryomilled powders.



## 1. Introduction

Nanocrystalline (NC) metals are known for their significantly high strength. Surface coating of structural metals with NC materials is expected to improve their mechanical performance. Developing and understanding the damage tolerance of NC coatings are therefore essential for evaluating their overall functionality as structural materials in engineering components.

There are very few studies in the literature on fatigue strength of NC coatings. Hanlon et al. [1] studied the fatigue response of electro-deposited NC pure Ni and cryomilled ultrafine crystalline Al–Mg alloy. The fatigue crack growth experiments on NC and ultrafine crystalline (UFC) coatings were conducted using edge notched samples. It was reported that grain refinement generally led to an increase in resistance to failure under stress controlled fatigue, whereas a deleterious effect was observed on the resistance to fatigue crack growth. Ibrahim et al. [2] studied the fatigue behavior of nanostructured and conventional titania (TiO2) coatings thermally sprayed using air plasma spray (APS) and high velocity oxy-fuel (HVOF) processes onto low-carbon steel (AISI 1018) substrates. They showed that the nanostructured titania coated samples exhibited significantly higher fatigue strength compared to the conventionally sprayed titania partly due to the NC characteristics and partly due to the HVOF process [2].

Cold spray is an innovative coating technique in which metallic particles (10–50 μm) are deposited on metallic substrates [3]. The particle velocity, which results in high kinetic energy, plays an important role in bonding occurrence. The bonding happens in solid state when the particle velocity exceeds a critical velocity [4] and there is no melting; thus, compared to thermal spray coating methods no or negligible oxidation is reported in the coated material. Fig. 1 shows a schematic view of cold spray system and the coating process. In this figure, *P*, *d*, and *l* are pressure, diameter and length of the nozzle respectively; subscript *e*, *t*, and *i* are related to exit, throat, and input of the nozzle. The high velocity gas flow is obtained by passing a gas through a convergent–divergent (de Laval) nozzle. Cold spray coatings are becoming highly demanded in many different fields such as biomechanical and aeronautic industries. It is being used for many different surface improvement purposes such as corrosion resistance, wear resistance, or even dimensional restoration and repairing techniques. Direct use of nano size powders as feedstock powder in cold spray, due to the presence of the back flow, is not possible [3]. However, NC powders in micron size agglomerates are reported to be successfully used in cold spray coating by Ajdelsztajn et al. [5]. The hardness of coated NC–Ni is comparable with other NC coating

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0142-1123/$ - see front matter 
http://dx.doi.org/10.1016/j.ijfatigue.2013.09.001

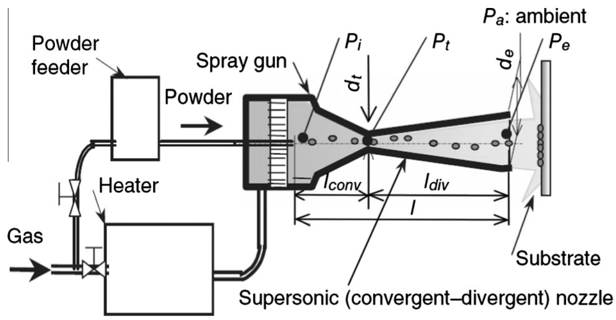


**Fig. 1.** Schematic view of the machine and bounding of material in cold spray coating [3].

producing techniques such as electro-deposition. Cold spraying has also been successfully used to obtain highly dense NC copper alumina metal matrix composite coatings [6].

Considering the advantages of cold spray to other spray coating processes and the superior physical and mechanical characteristics of NC materials, it is expected that NC coatings can offer the potential for significant improvements in most engineering properties; especially fatigue strength. Furthermore, cold spray coating as an impact based process, induces compressive residual stresses in the substrate [7,8] which shall in turn result in additional fatigue strength improvement. However, to the best of the authors' knowledge, there are no reports yet of cold spray NC metals being used for fatigue experiments, as reported also by Padilla and Boyce [9].

There is even very limited published literature on fatigue strength of conventionally cold spray coated samples (with micron size powder). Price et al. [10] have reported a decrease in fatigue resistance of Ti6Al4 V alloy substrates cold sprayed with pure titanium. This fatigue strength decrease was reported to be due to the substrate-coating interface properties [10]. The effect of cold spray Al–13Co–26Ce coating on the fatigue strength of Al2024-T3 has been studied by Sansoucy et al. [11], who reported notable improvement in fatigue endurance of the coated samples. Ghelichi et al. [8] studied the fatigue behavior of Al5052 samples coated with pure Al and Al7075 feedstock powder. The results indicated good bonding between the coating and the substrate as well as significant fatigue strength improvement up to 30% in the case of Al7075 coatings. The fatigue test data showed a strong dependency of the fatigue strength on the deposited material and the spray parameters [8]. Al-Mangour et al. [12] studied the fatigue strength of annealed low-carbon stainless steel 316L cold sprayed coating. Their results showed the fatigue life of cold spray coatings was lower than bulk material. Compressive stresses found within the coating were reported to be too low to prevent fatigue crack formation and eventually the poor fatigue resistance was related to incomplete particle–particle bonding [12]. Mahmoudi et al. [13] have also reported fatigue life improvement of annealed magnesium AZ31B cold spray coated with aluminum powder.

This paper presents the results of a study on the effect of feedstock powders' structure on fatigue strength of cold spray coated samples. In this regard, Al5042 samples have been coated with Al7075 micron size powders with both micro and nanocrystalline structure. There is a general agreement that grit blasting can increase the deposition efficiency of the coating material by increasing the substrate roughness and thus enhancing mechanical anchoring [8,10,14,15]; thus grit blasting is frequently used as a preliminary treatment before cold spray coating, considering that it also induces compressive residual stresses in the substrate. In this study, all the substrates were grit blasted before coating process. The coated samples have been tested through pure bending fatigue test. Characterization tests such as X-ray diffraction (XRD) measurement for residual stress and grain size, surface roughness, microhardness measurements, and scanning electron microscopy (SEM) observation of fracture surfaces have been performed on the coated samples and reported herein.

## 2. Materials and experiments

### 2.1. Material and specifications

The materials considered in this study are Al5052, Al7075, and Al7075CM cryomilled powders. Al-5052, a high strength non-heat-treatable alloy with fatigue strength of about 110 MPa has been chosen as the substrate to be coated. This alloy is a good choice for structures subjected to dynamic vibration. Aluminum alloy 7075, chosen as the powders, is an alloy with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. Material specifications and chemical composition are given in Tables 1 and 2 respectively.

### 2.2. Coating procedure

Coating was performed at the University of Ottawa (ON, Canada), using a commercially available low pressure cold spray system [17] produced by SST Centerline Ltd, Winsdor (Canada). All samples have been grit blasted before coating to provide an increased surface area for mechanical bonding of the coating to the substrate. The samples are grit blasted by 18 oz. hopper gravity feed abrasive blaster gun until the surface appeared uniformly worked. The Al-7075 powders were cryomilled (180 RPM rotating velocity) with 820 g of spherical powders with ball to powder weight ratio (mass of milling media: mass of powder) of 32:1; 2.6 g steric Acid (0.35 wt% powder) has been used in order to prevent the welding of the powder to the canister and impeller. Table 3 shows the coating parameters for each set of samples.

**Table 1**
Nominal properties of the two aluminum alloys [16].

| | Hardness (Brinell) | Elastic modulus (GPa) | Elongation at rupture (%) | Poisson ratio | Yield strength (MPa) | Ultimate strength (MPa) |
|---|---|---|---|---|---|---|
| Al5052–O | 47 | 70.3 | 30 | 0.33 | 89.6 | 193 |
| Al7075–T73 | 135 | 72 | 13 | 0.33 | 435 | 505 |

**Table 2**
Chemical composition of the two aluminum alloys (wt%).

| | Cr | Cu | Fe | Mg | Mn | Si | Ti | Zn |
|---|---|---|---|---|---|---|---|---|
| Al5052–O | 0.18–0.28 | 1.2–2 | <0.5 | 2.1–2.9 | <0.3 | <0.4 | <0.2 | 5.1–6.1 |
| Al7075–T73 | 0.15–0.35 | <0.1 | <0.4 | 2.2–2.8 | <0.1 | <0.25 | – | <0.1 |