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Microstructure and fatigue behavior of cold spray coated Al5052

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Abstract

The effect of cold spray coating in inducing residual stresses in the substrate and its effect on delaying crack initiation under cyclic loading have been studied on Al5052 alloy specimens. Different sets of Al5052 specimens have been coated with pure Al and Al7075 feedstock powder, using a low-pressure cold spray coating technique. Some sets of specimens were grit blasted (GB) before coating. The microstructural evolution of the substrate after coating and the fatigue behavior of the coated structure have been studied. In order to obtain the fatigue *S–N* diagram for each set, as-received and coated specimens with and without preceding GB treatment have been tested in a load-controlled condition. X-ray diffraction has been used to measure the residual stresses both in the deposited materials and the substrates. The results are discussed to highlight the effect of this emerging surface treatment on the characteristics of the treated material. Compressive residual stresses, which led to appreciable increase in the fatigue life, have been observed in all the coated sets. The results indicate that the fatigue strength was significantly improved up to 30% in the case of Al7075 coatings. The results show a strong dependency of the fatigue strength on the deposited material and the spray parameters.

Keywords: Cold spray coating; Fatigue strength; Residual stress; Aluminum alloys

1. Introduction

Cold gas-dynamic spray (or simply cold spray) is a coating process that exposes the metallic or dielectric substrate to a high velocity (300–1200 m s^{-1}) jet of small (1–50 μm) particles accelerated by a supersonic jet of compressed gas at a temperature lower than the melting point of the material, resulting in coating formation of particles in the solid state [1–3].

The fact that the powders do not melt before impacting the substrate makes the cold spray process suitable for many different coating applications involving various materials including not only metals but also polymers and composites [4–6]. Bonding of the particles in this process occurs due to the high kinetic energy upon impact; therefore, the velocity of the particle plays the most important role in material deposition. The high-velocity impact of the particles causes compressive residual stresses in the substrate [5,7,8]; it leads also to high plastic deformation that results in surface nanocrystallization [9–11]. These two parameters are the most important factors and have the potential to increase the fatigue endurance of treated structures [12,13]. In fact, it is well known that the fatigue strength depends strongly on residual stress distribution, surface microstructure and grain size; however, the effect of cold spray coating on the fatigue strength is not still clear. It should be noted here that possible grain refinement and severe plastic deformation effects due to the cold spray process have not been considered in this study.

Price et al. [14] studied the effect of cold spray deposition of titanium coating on Ti6Al4V on the fatigue behavior of the samples. The fatigue life of the as-received and grit-blasted (GB) materials, both before and after coating, was studied experimentally [14]. A 15% reduction in fatigue endurance was observed after application of the coating to

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the as-received substrate; however, no significant reduction was observed on its application to the GB substrate. It should be noted that Price et al. [14] reported negligible compressive residual stresses on the deposited materials and the coated samples. The compressive residual stresses reported through cold spray titanium coatings were too low to prevent fatigue crack advancement. Scanning electron microscopy (SEM) observations were reported to show delamination in deposited material after fatigue test which represented no or little contribution of the deposited materials to the fatigue loading [14].

Sansoucy et al. [15] worked on the bending fatigue and bonding strength of Al–Co–Ce cold spray coatings. Their results show that Al–Co–Ce coatings improved the fatigue behavior of Al-2024-T3 specimens compared to as-received ones. To the best of the authors' knowledge, there is no other research currently available in the scientific literature on the effect of cold spray coating on fatigue strength.

The present paper studies the effect of Al alloy coatings on the fatigue strength of coated Al5052 substrates following the ASTM-B93 procedure [16]. Two different types of aluminum powders have been used to coat GB and as-received Al5052 substrates using a low-pressure cold spray technique [17,18] in order to study the effect of the treatments on the fatigue endurance of the substrate material. The specimens have been tested through pure bending fatigue tests performed at room temperature. The treated specimens have been characterized by residual stress measurement using X-ray diffraction (XRD), microhardness tests and SEM observations of the fracture surfaces.

2. Materials and methods

2.1. Materials

Al5052 is a high-strength, non-heat-treatable Al alloy, generally chosen for structures subjected to dynamic vibration [19]. Al7075, used as the feedstock powder in this study, is an Al alloy with Zn as the primary alloying element [19]. It is characterized by strength comparable to that of many steels, a high fatigue strength as well as good machinability; however, it has less resistance to corrosion than many other Al alloys. Table 1 presents the nominal material properties of Al5052 and Al7075.

In order to study the effect of different materials on the fatigue endurance of coated specimens, pure Al powder has also been coated on Al5052 substrates. Microscopic observations of the powders indicate that they all consist of almost spherical particles with a mean particle size of 15–20 μm. The coated specimens' microscopic observation also shows that the deposited material has a very dense structure with almost zero porosity (see Fig. 1).

2.2. Cold spray coatings

The spray parameters used for different sets of specimens are presented in Table 2. The coating was performed at the University of Ottawa Cold Spray Laboratory using a commercially available low-pressure cold spray system [17] produced by SST Centerline (Winsdor) Ltd. There is general agreement that GB can increase the deposition efficiency of the coating by increasing the roughness of the substrate and thus enhancing mechanical anchoring [14,20–23]. As such, coatings have been produced not only on as-received specimens but also on GB series. The GB specimens have been coated using the same spray parameters as the as-received ones. Fig. 1 shows the cross-section SEM observation of the coatings on both GB and as-received substrates. Although in the latter images of the specimen coated by Al7075, the difference in coating thickness is locally shown to be approximately 50%, it is observed that, on average, the thickness of the coating on the GB specimens is almost 15–20% more than that on the as-received ones.

Table 1
Nominal properties of Al5052 and Al7075 [19].

	Hardness (Brinell)	Elastic modulus (GPa)	Elongation at break (%)	Poisson's 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

As presented in Table 2, the spraying processes have been performed at quite different temperatures for Al7075 and pure Al series. This difference is caused by the fact that spraying pure Al at high temperature results in nozzle clogging, and thus a special nozzle made from polymer has been used for coating pure Al; however, the coating temperature is limited to 350 °C, since these polymers cannot withstand higher temperatures.

Surface roughness measurements have been also performed on all specimens in the longitudinal (L) and transverse (T) direction. The results are presented in Table 3.

2.3. Microstructural evaluation

To study the state of residual stresses, XRD analysis was performed using an AST X-Stress 3000 X-ray diffractometer (Cr Kα radiation, irradiated area of 1 mm diameter, $\sin^2(\psi)$ method, diffraction angle (2θ) of 139° corresponding to lattice plane (3 1 1) scanned between −45° and 45°). The effective penetration depth of the radiation is ~5 μm [25]. Measurements were carried out step by step by removing a very thin layer of material (0.01/0.02 mm) using an electropolishing device in order to obtain the in-depth profile of residual stresses. A solution of acetic acid (94%) and perchloric acid (6%) was used for electropolishing. The coating has been also characterized by microhardness measurements and SEM observations of the fracture surface. A diamond Vickers indenter was used, applying a maximum force of 50 gf. The load was applied gradually