

Zinc Coating on Aluminum-Alloy Substrate by Cold Spray

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ABSTRACT: Metallic coatings that are generated by conventional techniques encounter many problems. These coatings are affected by oxidation and contamination as the coating is developed by spraying melted material. To achieve rapid, economical and phase pure metallic coatings, cold spray technique is applied. This work consists of similar technique used for development of Zinc coatings on aluminum-alloy as base material. Pure coatings were achieved by using convergent-divergent nozzle. Composition of the zinc powder and the aluminum-alloy substrate were investigated prior to coatings. The particle size distribution of coated powder was also found. Zinc coatings were generated with help of designed cold spray facility. It was then characterized using scanning electron microscopy. The effect of coatings on substrate hardness was determined by micro vickers hardness test apparatus. The study revealed that using cold spray zinc coating on Aluminum-alloy substrate can be achieved at room temperature. Since all the particles are of range 1-50 microns, very thin layer but continuous (no gaps/voids) can be achieved. Such fine coating would be impossible using conventional methods of metal coatings. Coatings cross-sections show that good bonding was established. The hardness test reveals that surface strength increases due to deposition of metal particles.

KEYWORDS: Cold spray; Zinc powder; Aluminium Alloy; Solid state coating.

I. INTRODUCTION

Presently the metallic coatings are developed by Thermal coating techniques. It has limited application due to melting the coating material, oxidation problems of coatings and non-applicability to the high temperature sensitive metals. Thermal coating techniques are also time consuming and uneconomical.

This study presents a new technique for development of metallic coatings, known as cold spray. In this process the metals, to be coated, are taken in powder form. Coating is made at room temperature by accelerating metallic powder to supersonic speed using a convergent-divergent nozzle. The velocity limit for various metals depends on its mechanical properties and is different for each one. These high speed particles when strike the base material, it undergoes plastic deformation due to abrupt change in particles-momentum. It lead to shear deformation of particles and results in a continuous coating on base material [1, 2].

The name cold spray is because of the fact that the powder particles temperature during coating is very low than its melting temperature. It is further distinguished into two different categories, which depends how powder particles are introduced into the nozzle. If the powder particles enter axially before the convergent section of the nozzle [3], then high pressure is required in powder chamber. This process called High pressure cold spray (HPCS).

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Contrary if the powder particles are injected in the diverging section of convergent-divergent nozzle, it is called Low pressure cold spray (LPCS). In this process because of low pressure expending gases the pressure in powder chamber is comparatively low than the HPCS [4]. Except from powder injection method both has same operating conditions. The HPCS results in high coating efficiency than LPCS while nozzle life is longer for LPCS. [5]

II. WHY ZINC IS COATED ON ALUMINIUM

The most plentiful element on the earth crust is Aluminum and it comprises almost 8.23 % of it. It is well known for its light weight and high ratio of strength to weight. Also in comparison to steel it has one-third of its stiffness. One major problem that aluminum undergoes is its surface oxidation when exposed to environment. It develops a layer of aluminum oxide (Al_2O_3) on its surface. This oxide layer decreases oxidation rate but it is electrical insulator and has brittle nature [6]. Aluminum alloys on other hand are more prone to surface oxidation process. There are three Existent techniques to prevent this surface oxidation. It consist of “alclading” [7], secondly the “chromate conversion coating” [8] and the third one is “anodizing” [9].

The metal zinc contrary to aluminum possesses corrosion resistance nature and has fair electrical conductivity [10]. It is, therefore, evident that coating aluminum with zinc can improve its corrosion resistance with minimum effect on its electrical properties.

III. COLD SPRAY PARAMETERS AND BONDING MECHANISM

The cold spray parameters are particle size and shape; stagnation pressure and temperature; nozzle design its standoff distance and spray angle; and carrier gas. The carrier gas for particle is selected as Helium, Nitrogen, air or mixture of Helium and air. Helium gas causes highest particles velocity followed by nitrogen and the air [11, 12]. The gas pressure is maintained higher in powder chamber than in nozzle at point of ejection for smooth flow of powder. Velocity of particles at exit of nozzle depends on the gas velocity in nozzle and its expansion in divergent section of nozzle [13]. When particles at high speed, greater than a critical value, collide with the substrate, a high pressure field is generated at point of contact and it then proceeds in particle and substrate. The stress generated is greater than the yield stress and it leads to a phenomenon known as ‘adiabatic shear instability’. It causes plastic deformation of particles along the shear plane and the material accelerates laterally producing localized shear straining. The oxide layer is partially removed and pure metallic interaction occurs [14]. Flow stresses are, therefore, breakdown due to discontinuous leaps in strain and localize temperature [15-20].

In this study development of zinc coating on aluminum 6005-alloy as substrate will be discussed using HPCS technique. It is only possible if zinc particles are accelerated above its critical velocity that is 350 m s^{-1} [21]. Elemental composition of zinc powder and substrate was found by Energy dispersive X-ray spectroscopy (EDX). Particle size range was investigated by particles size analyzer (Multisizer-3). Coating was performed with self made cold spray facility using convergent-divergent nozzle. Operating pressure of 10 bars was achieved by water cooled two stage air compressors. The coatings were characterized by using scanning electron microscope (SEM). The micro-hardness test of coating was performed to find effect of coating on surface hardness of base material.

It was found that Zn powder can be coated in pure form on Aluminum-alloy substrate. Surface strength of substrate was also increased as a result of coating. Strong interface of Zn coating with substrate surface was found in SEM investigation.

IV. MATERIAL CHARACTERISTICS

Zn-particles size investigation

Fine powder of zinc of particle size of 1-20 microns was used as a coating material. The size distribution of powder was investigated by particle size analyzer (multisizer-3). Its works on the basis of electrical conductions and can measure particles in range of 1-100 microns.

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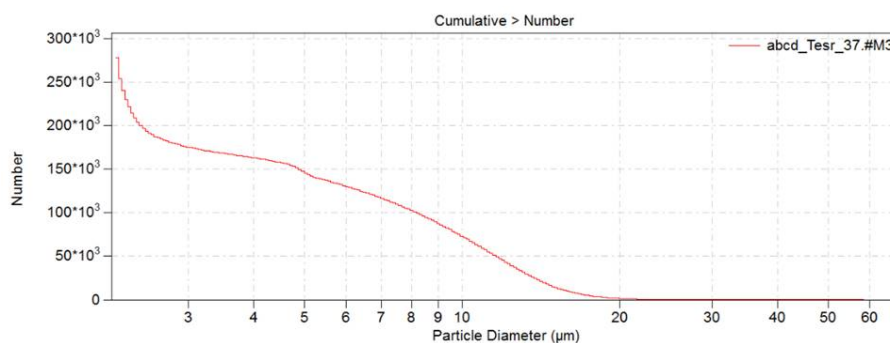


Fig. 1: Particle size study by Multisizer.3.

Particle size distribution curve of zinc is shown in above fig and particles ranges from 1 micron to 20 microns. On x-axis particle diameter is mentioned while on y-axis relative quantity in number is shown. Most of the particles was in range of 1-10 microns.

Aluminium substrate surface composition

Aluminum 6005-alloy with gauge thickness of “1 mm” was used as a substrate for coating. The elemental composition of as-received substrate was found out by EDX.

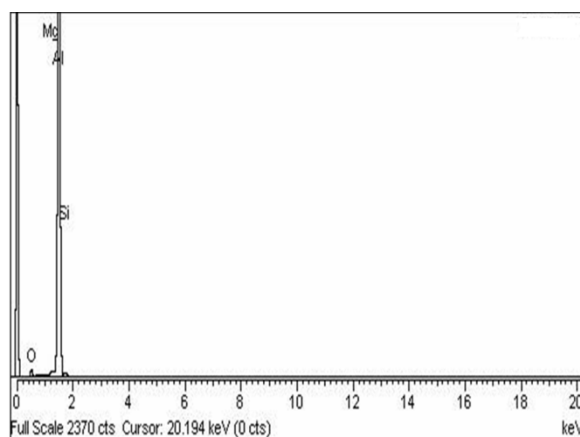


Fig. 2: EDX compositional peaks of Aluminum substrate.

The EDX result is shown in above fig. Elemental peaks show all elements of aluminum alloy-6005. It consists of magnesium(Mg), Silicon(Si), Oxygen(O) with aluminum peak(Al).

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Table 1: Percent weight composition.

Element	Weight (%)
O	9.68
Mg	0.50
Al	87.11
Si	2.71
Total	100.00

In above table relative weight percentages of various compositional elements are also presented. All elements add up to make a total of 100% weight percent.

Zn powder composition investigation

Elemental composition of Zinc powder was also investigated by EDX. The obtained result is presented in figure 3, which shows all the Elemental peaks for zinc carbon and oxygen.

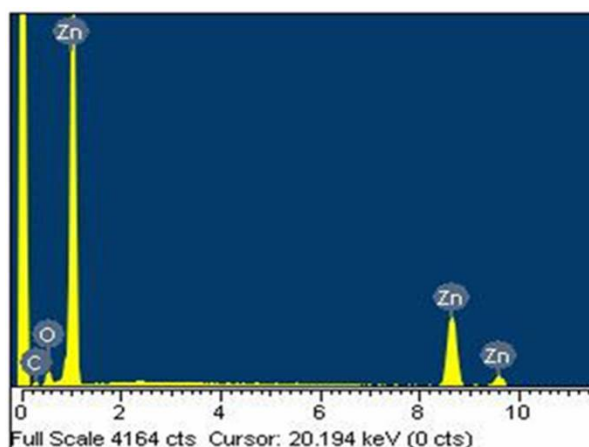


Fig. 3: EDX compositional peaks of Zn-powder.

On x-axis of above figure, is the intensity while on y-axis is amount of energy released due to electron transitions from high energy shell. Both high energy peaks with low intensity for high shell transition electrons and low energy with high intensity for low shell transition electron is shown.

Table 2: Percent Weight composition.

Element	Weight (%)
C	4.11
O	4.72
Zn	91.17
Total	100.00

Percent composition is given in above table 2. . it shows above 91 % of powder consists of pure Zinc powder with

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traces of Carbon and oxygen.

V. EXPERIMENTAL PROCEDURE OF COLD SPRAY

Cold spraying was performed on cold spray facility. A two stage Air-compressor was used to build the required pressure of 10 bars in a pressurize cylinder. A self made converging-diverging nozzle was used to generate Zn-coatings on aluminum substrate. The air-operated supersonic nozzle used for coating is shown in figure 4.



Fig. 4: Cold spray nozzle.

The above nozzle was having a converging part of length of 40 mm and diverging part of length of 100 mm with powder feeder attached to nozzle before the converging part. The powder chamber was pressurized a little above 10 bars to avoid back flow of powder and attached to the nozzle at an angle of 45° . The powder was having gravitational effect and was also pressed by high pressure air. This causes powder to pass through a 2 mm hole provided at the base and was injected radial into the nozzle before the converging part. The design parameters of nozzle are shown in table 3.

Table 3: Design parameters of Cold Spray nozzle.

S. No	Parameters	Values
1.	Inlet diameter (D_{in})	22.42 mm
2.	Throat diameter (D_{th})	5 mm
3.	Exit diameter (D_{ex})	6.92 mm
4.	Convergent length (L_c)	40 mm
5.	Divergent length (L_D)	100 mm
6.	Total length (L_T)	140 mm
7.	Exit Mach number	1.57
8.	Distance of powder injector from start of convergent region	22 mm
9.	Diameter of powder injector exit	2 mm

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Before coating the substrate was rough polished to get rid of all surface impurities. The coating was made by clamping the substrate in a cold spray chamber at 90° angle to the nozzle. During coating the nozzle was given movement in transverse direction at 50 mm s^{-1} and was kept 40 mm away from substrate. The nozzle was given several repetitions to get thick coating during spray process. After coating the samples were shear-cut from the substrate to carry the coating characterization. Surface hardness before coating and after coating was also checked.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

Coating surface characteristics

Coating characterization was done by sectioning proper size samples from coated surface. SEM was used to study coating surface. Coating Image at magnification of 500X, 1000X and at 20kv are shown in figure 5. It shows voids-free and continuous zinc-coatings. The white region on black background is because reflection of electrons from different deep and shallow coating surface.

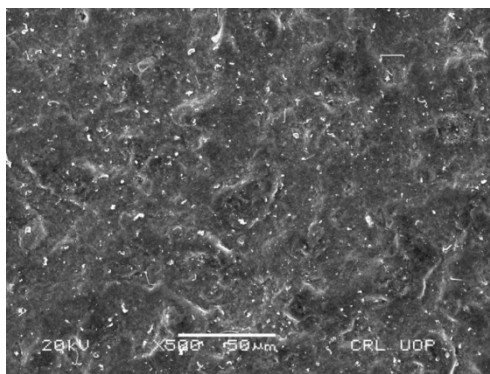


Fig. 5: Scanning Electron Microscope (SEM) images of coated surface at different magnification at 500X.

Coating Image at magnification of 1000X and at 20kv are shown in figure 6.

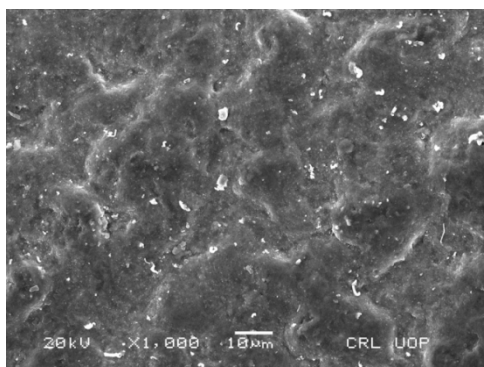


Fig. 6: Scanning Electron Microscope (SEM) images of coated surface at different magnification at 1000X.

In above figure continue continuous coating is visible. On impacting with surface of substrate, the particles undergo localized increase in temperature occurs which leads to bonding between them. The particles also deform along the shear plane and lateral flatter occurs resulting in fine coating.

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Coating cross-section characteristics

Cross-sections of the coating at magnification of 750 X as shown in figure 7.

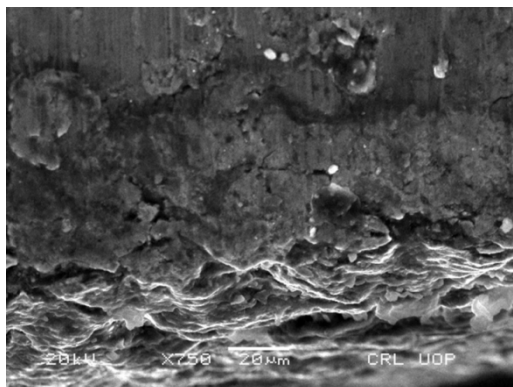


Fig. 7: Scanning electron microscope (SEM) image of coating cross-section at magnification of 750 X.

Above figure represents the continuous layers of coating of Zn on aluminium substrate. During coating different particles collide and hence deposit on each other forming continuous layers. It also illustrates that particles are well bonded with the substrate.

Hardness Test

Hardness test was performed by applying 100g load for 15sec on substrate before coating and then in-coated form. The micro-hardness of substrate was 50.5Hv0.1/15 and after coating it increased to 94.71Hv0.1/15. The increase in hardness is because of cold working of substrate by zinc particles. The resulted hardness is due to combined interaction of zinc-powder and aluminium substrate.

VII. CONCLUSION

In cold spray process, continuous coating was achieved and good bonding occurred between coating and interface. Bonding between various layers of coating was also good and hence thick coatings can be generated for different engineering applications. Also as a result of cold working process, hardness of substrate was increased. Critical velocity of Zinc is achieved with designed nozzle as deposition is only possible if velocity of micro-particles is greater than critical velocity.

VIII. FUTURE WORK AND MODIFICATIONS

Coating quality can be enhanced by controlling leakage problem from powder chamber and devising proper mechanism of powder injection. By installation of pressure gauge at inlet of the nozzle the pressure losses in pipe can be counteract. It facilitates to achieve higher velocity of particles. Cold spray chamber can also be manufactured for ensuring health and safety.

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