# Heat Treatment on Mechanical Characteristics of Cold-Sprayed Coatings

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***ABSTRACT: The Metal has been undergo heat at temperatures far below melting point, deposition of particles occurs in the cold spray phase by intense plastic deformation on contact in a solid state. In this phase spray particles therefore undergo no oxidation or decomposition. As something of a result, coatings which are scattered cold have outstanding mechanical, electrical in addition to thermal properties. In this job cold spray deposited pure Al, Ti ,Cu, and steel 326. Those coatings also assessed the tensile strength including elongation. The findings showed that there is low ductility and almost no elongation in the as-sprayed coatings of the four products. Heat treatment can however to some degree improve mechanical properties in case of cold-sprayed covering over the surface of metal. Here, it addresses consequences of treatment situations on both mechanical qualities of cold-sprayed products.***

***KEYWORDS: Brittle, Cold spray, Fracture, surface Heat treatment, Tensile strength***.

## INTRODUCTION

It is an growing technology for spray casing settled at some Institution for Applied Mechanics in mid-1980s. The distinctive feature of this spraying is processing is its lesser dispensation temperature as opposed to typical thermal spray processes; thus, lower current effects on administered materials. Cold spray is therefore especially suitable for the preparation of oxidation-sensitive layers or for applications in fields where oxidation and thermal effects must be avoided during the coating process. Cold sprig has so far been secondhand to sprig not only yielding materials counting copper, steel, aluminum, steel-based alloys, zinc, yet also cermet’s and ceramic materials from metal matrix composites [1].

A low oxidation is the most popular feature of cold-sprayed coatings. However, under optimal spray conditions, cold-sprayed coatings may be highly dense where the particles undergo severe plastic deformations. Low-oxidation thick coatings can also imply outstanding mechanical, thermal besides electrical properties. Hence coating dropped by spray is a good applicant to be applied as an industrial mechanical component. However, thermal effects, temperature background of subdivisions through deposition procedure produces approximately outstanding tensile stress. In addition, due to kinetic possessions, extreme bearing deformation engenders residual compressive stress. Particulate intensive plastic deformation often reduces ductility of cold squirted coatings attributable to acclimatization possessions of work. For cold-sprayed coating presence of residual stress and work hardening reduces the mechanical, thermal besides electrical properties [2].

The work has been published on improving cold-sprayed covering via heat treatment. Heat treatment will efficiently alter microstructure of Cu, Al, stainless steel coverings and Inconel 728 cold-sprayed. Owing to enhanced interaction of the particle interface, thermal besides electrical conductivity of cold-sprayed coverings increased, and micro-hardness reduced owing to elimination of work toughening during treatment. In addition, mechanical properties enhanced by treatment in addition to showed similar presentation as bulk materials.The preceding revisions have remunerated great consideration to improving mechanical possessions by heat treatment. Until now, however, determinants of mechanical possessions of coatings are still unidentified. Four standard Al, Cu, Ti besides stainless steel materials had all been dropped by cold spray in present sample, and their mechanical properties have been verified.In addition, effects of treatment on coating structures as well as mechanical possessions have been studied. It addressed connection between porosity of cold coverings counting the mechanical factor.

## METHODOLOGY

1. *Experimental Measures:*

*1.1.Feedstock powder for cold spray procedure:*

In the analysis, commercially obtainable powders Al (N98.7 percent), Cu (N98.7 percent), Ti (Grade 2), in addition to stainless steel 317 are recycled in addition to morphologies described in Figure 1(a)–(d). The unadulterated powders Al in addition to Ti possess ideal sphere-shaped shapes. The 316 Powders of pure Cu besides stainless steel exhibit near sphere-shaped forms.

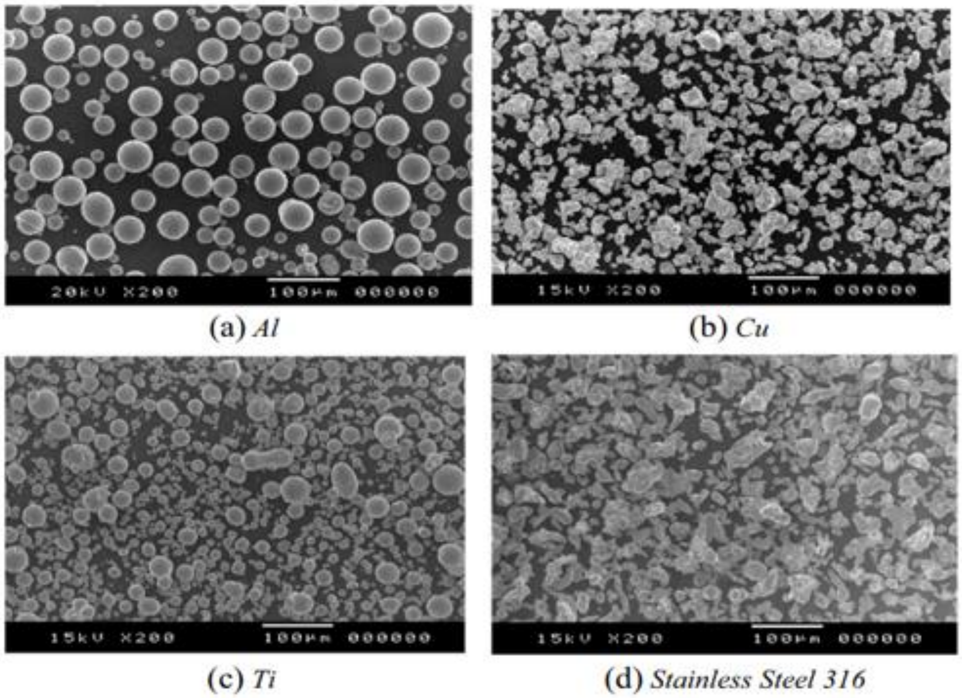



**Figure 1: (a) Morphology of Al, (b) Cu, (c) Ti, (d) Stainless Steel Powder**

Al powder has narrowest particle width range of four forms, with an average volume diameter of about 37 μm. The pure Ti powder diameter varies from 7 to 65 μm, as their average capacity is around 35 μm in both. The steel 317's powder width varies from 12 to 85 μm, besides particle diameter average is around 38 μm. The coatings were prepared using a profitable cold spray device, model PCS-1000 produced by PLASMA LTD. To accelerate working gas to supersonic level, a convergent – divergent nozzle has been designed. In this test nitrogen gas has been used as the propellant source. Table 1 indicates the spray conditions for cold spray.

**Table 1: Spray Condition**

| Materials | Al | Cu | Ti | SS316 |
|---|---|---|---|---|
| Gas Pressure (MPa) | 3 | - | - | - |
| Gas Temperature ( $^0$C) | 380 | 800 | 900 | 800 |
| Powder feed rate (g/mm) | 25 | 100 | 60 | 100 |
| Spray distance (mm) | 30 | - | - | - |

A 100 mm diameter in addition to length alloy cylinder were used as substratum, and more than 6 mm of coverings were put to fulfill the tensile specimen measurement. Figure 2(a) demonstrates the preparation procedure for coating. The cold-sprayed coverings were removed from substratum, and machined as shown in Figure 2 (b) to a tensile specimen.

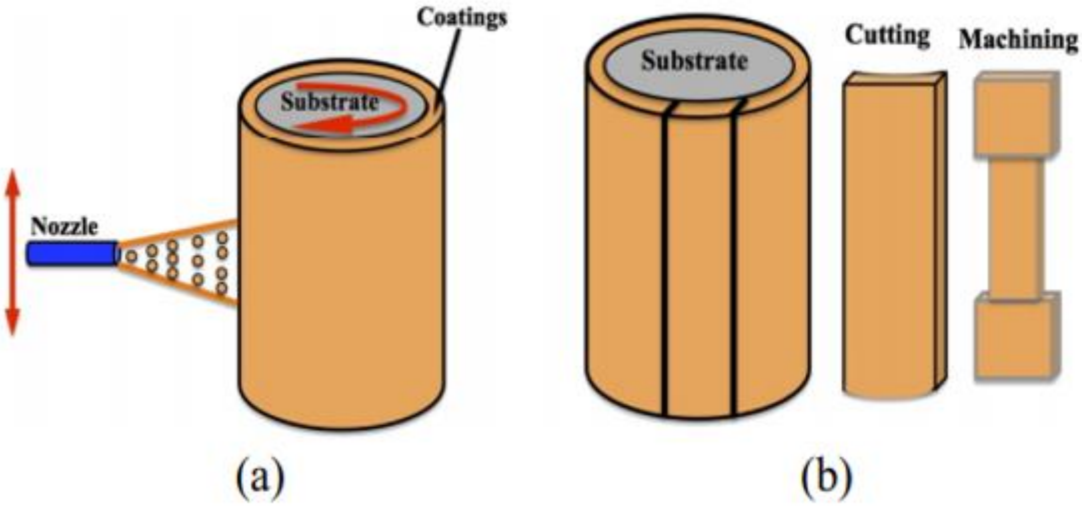



**Figure 2: Readiness of Tensile Specimen**

*1.2.Heat procedure in addition to tensile test:*

In an atmosphere of argon, heat treatment for tensile specimen were carried out. Table 2 indicates the conditions related to heat treatment. Tensile gauging equipment was used to measure the tensile examples of as-sprayed besides coatings: AG-X (110KN), manmade by Shimad Co. Ltd. During tensile test two camera fitted with tensile apparatus to quantity thickness of the specimen within length of gage.

**Table 2: Heat Treatment Conditions**

| Materials | Al | Cu | Ti | SS316 |
|---|---|---|---|---|
| Temperature($^0$ C) | 200,300,400, | 300,400,500 | 500,600,700 | 700,800,1000 |
| Time (h) | 4 | - | - | - |

*1.3.Coating Characterization:*

Using a traditional mechanical improving process to SiC besides equilateral interruptions, cross segments of as-sprayed besides heat-treated coatings have been equipped precipitously to their surfaces. A digital microscope (VHX-900, Keyence, Japan) was used to inspect the mirror-polished cross sections. The porosity of the coatings has been measured with the cross-section images using image analysis. Before examination, Cu in addition to Ti coatings stamped with 3% nitric acid, 2% fluoric acid, correspondingly. To clarify the cold-sprayed coatings failure process, a field emanation scanning electron light microscope was observed to fracture external of tensile specimens [3].

## RESULT AND DISCUSSION

1. *Mechanical possessions:*

Figure 3 shows tensile qualities of Al, Ti Cu and 316 steel coatings sprayed in air. It can be shown that all as-sprayed coverings have low ductility besides less than 0.5 percent of their tensile elongations. All the tensile strengths (particularly elongation) enhanced with treatment temperature increases.

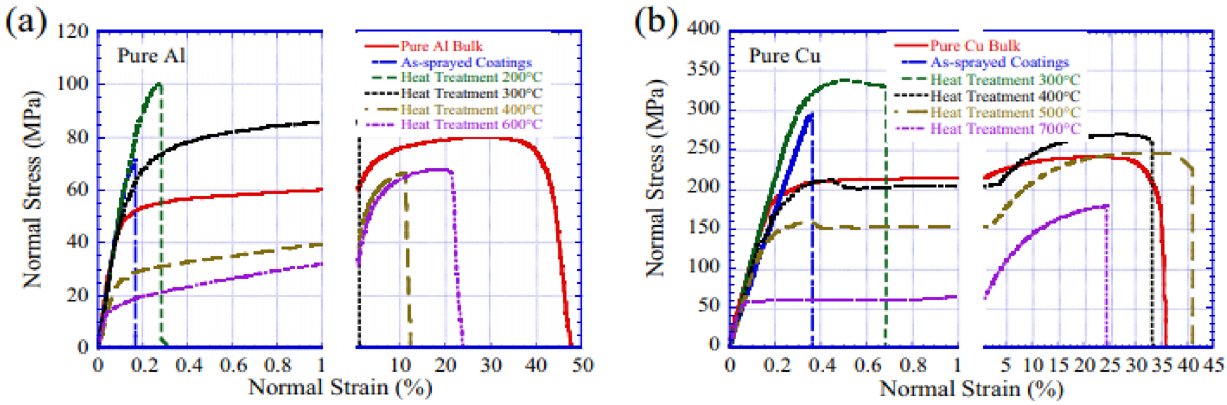



**Figure 3: Tensile Results for Cold-Sprayed (a) Al, (b) Cu**

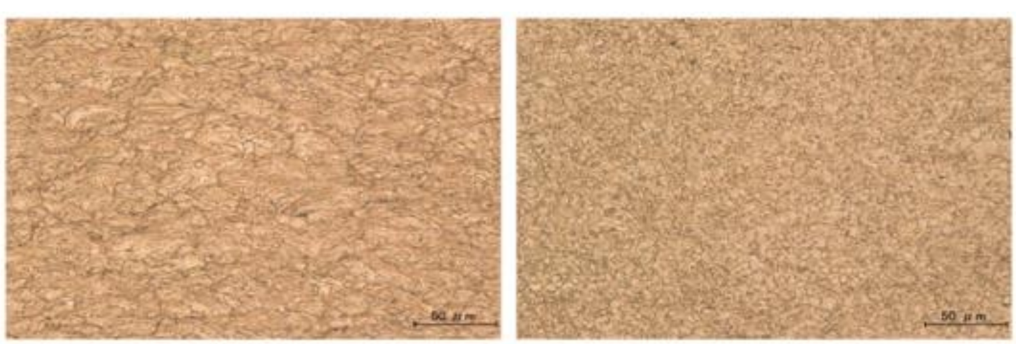
The sprayed surface has a strength similar to that of bulk for cold-sprayed for Al coatings, given low elongation. The sprayed Al covering gets even tougher afterward treatment at 200 °C but with low ductility. Further raising temperature of conduct to 330 °C, performance of coating diminutions at 200 °C linked with treated coating. However, it is developed than Al's. With an elongation of about 1.3 percent, the covering began to change ductility, as increase in temperature to over 400 °C, coating exhibited considerable ductility besides obtained somewhat 10 percent curvature. Though, after heat-treatment at 450 °C the strength of coating diminished.

Al coating's most excellent properties were that which was treated at 650 °C, and coating had an invrement of approximately 28 percent and an overall strength of about 75 MPa. Moreover, after treatment hotness at 600 °C yield strength of Al coating decreased to well below the bulk content. The tensile strength and elongation for cold-sprayed Ti coatings was extremely weak compared to those of bulk Ti. Ti coatings typically have a tensile strength of fewer than 210 MPa and increment of less than 0.6%. It appears treatment has not greatly improved mechanical possessions of Ti coatings [4].

The tensile power as well as increment of stainless steel 316 coatings have improvement related to sprayed coating if temperature of treatment is fewer than 61 0 °C. As temperature of treatment is higher to 870 °C, tensile power grew to 350 MPa. It showed low ductility (less than 0.6 percent), however, because specimen deteriorated before stage of plastic deformation. Moreover, force and elongation are still lower than the average, as it collapsed throughout the tensile test at the preliminary stage of deformation [5].

2. *Microstructure:*

Whole process of the coating is also depends upon the micro structure of the material as the microstructure has been depending upon the temperature of the process and the variation of the temperature is a deciding factor in order to determine the structure of the material after the treatment . It has been found put that the temperature and microstructure has a relation by which one can easily predict the type of the micro structure at a particular temperature.The mechanical characteristics of cold-sprayed Ti, on the other hand, show essentially no impacts of heat treatment. Cu and Ti microstructures were studied to better understand the occurrence. Figure 4 demonstrations morphology of Cu coatings before as well as after treatment. Concurrently, Cu grain also distorted during much of impact process as displayed in Figure 4(a).



(a) (b)

**Figure 4: Microstructure for As-Sprayed Cu Coating, (a) Treated At 500ºC, (b) At 700ºC**

After 500 °C heat treatment particle interface vanished. Subsequently treatment at 500 °C grain of Cu coating looks extremely uniform and perfect. The particle of Cu undercoat is coarse relative to of 550 °C in order to further upsurge treatment temperature to 700 °C.

Micro structure of Ti coatings has been seen beforehand besides after treatment. It could said that Ti coating which is cold-sprayed looks very porous. Throughout the deposition process the as-sprayed covering reveals the Ti hardly deforms. Particulate Ti tends to be too hard to bend during impact. Some of interface amongst particles missing and had to be heat-treated at 600 °C but some remained [6].

Microstructure of Ti coatings has seen beforehand besides after treatment. It can said that Ti coating which is cold-sprayed appearances porous. Throughout deposition process scattered coating reveals the Ti subdivision scarcely deforms. Particulate Ti tends to be too hard to bend during impact. Many of the interface amongst particles disappeared and had to be heat-treated at 600 °C but few remained. It would appear as efficient diffusion among particle interfaces occurs individual at closer particle cohesion. Further raising the temperature of the heat treatment to 1000 °C, particle interface nearly missing but some pores persisted within coating. The fracture amongst the Ti-coating particle interfaces was shown to have occurred. According to the fractography, no dimple can be detected and this could seen as de-cohesive brittle separation arisen to sprayed coating. After heat treatment, stability of particles in coating seems to be very weak [7].

Defects can still be found on Ti heat-treated fracture surface at 1100 °C. The defects caused coating to fail initial on during tensile test (before reaching the plastic deformation stage). Thus the Ti coating fracture often belongs to brittle de-cohesive break at 1100 °C after heat treatment. It would appear that treatment can repair imperfections or holes within Ti covering when temperature of treatment is increased to 1100 °C. The breakage bypassed interface of diffused particles and thus made the surface of the fracture rougher. Some unimportant dimples could be found at fracture external, in addition to raising the temperature to 1100 °C.

It seems that coating fracturing belongs to the breakup of micro coalescence, as plastic deformation can be experiential. Various defects on fracture surface, however, can be observed and this reduces tensile strength of coating. It seems that 1000 °C heat treatment still isn't enough to repair all the flaws within the 316 stainless steel coating. In general, with the as-sprayed coatings, almost no ductility can be found, and heat treatment can to some degree boost their mechanical properties. to investigate the relationship involving densification besides mechanical properties, the openness of both as-sprayed coverings was computed in microstructures of Al and alloy steels coverings. Following that, the opacity of as-sprayed coating can be dignified, with findings displayed in Table 3.

**Table 3: Porosity as Prayed Coating**

| Materials | Porosity (%) |
|---|---|
| Al | 0.87 |
| Cu | 0.04 |
| Ti | 14.2 |
| SS 316 | 2.14 |

The asset of sprayed Cu covering is strongminded by interface strength of subdivisions, since nearly all failures. Few flaws can be found in the coating and 0.04 percent of extremely low porosity was measured. In comparison, intense strain hardening is shaped in particle impact development. This principals to outstanding Cu coating strength which is even higher than bulk and with as-sprayed Cu coating, almost no elastic deformation can be obtained, though it is tremendously thick. The stretchy capacity of Cu coating is practically strongminded by interface strength of subdivisions, since nearly all failures [8].

For dense coating the particle interface is mysterious and compactly associated interfaces can vanish for absorbent coating. That improves interaction asset of particles. However, hardening produced through cold spray procedure residues in coatings as subordinate temperature as grains do not alter. The thick coatings would therefore convert tougher but less ductility. The increased tensile stress of heat-treated Cu coating at 310 °C donate to dispersal in particle boundaries. The increase of heat-treated tensile strength at 800 °C indicates that substantial diffusion occurred at the particle interface. In comparison, there would be no major improvement in the mechanical properties for absorbent coatings associated to as-sprayed coatings because dissemination cannot happen while subdivisions are not forcefully attached.

## CONCLUSION

The mechanical belongings of Al, Ti, Cu, as well as 316 coatings of carbon steel had all been measured in this analysis, and it was also looked at how heat treatment affected their mechanical qualities. The elastic moduli of coatings appear to be primarily determined by their morphology, which was generated during the cold polymerization reaction and amended by later heat treatment procedure. The tensile strength is very strong for dense sprayed covering as Cu but elongation is low compared to the bulk content. Because of the diffusion among particles, the cohesive strength of the coating strengthened with lower heat treatment temperature, however, elongation was reduced because the ultimate strength produced during cold spray stage of development remained. The power vanished when the heat treatment temperature rose because the strengthening work was taken away. It was also possible to achieve excellent elongation because recrystallization has been able to restore deformation of the grain.

### REFERENCES


[1] R. Huang, M. Sone, W. Ma, and H. Fukanuma, "The effects of heat treatment on the mechanical properties of cold-sprayed coatings," *Surf. Coatings Technol.*, 2015, doi: 10.1016/j.surfcoat.2014.11.017.

[2] M. R. Rokni, C. A. Widener, V. K. Champagne, G. A. Crawford, and S. R. Nutt, "The effects of heat treatment on 7075 Al cold spray deposits," *Surf. Coatings Technol.*, 2017, doi: 10.1016/j.surfcoat.2016.10.064.

[3] M. R. Rokni, C. A. Widener, O. C. Ozdemir, and G. A. Crawford, "Microstructure and mechanical properties of cold sprayed 6061 Al in As-sprayed and heat treated condition," *Surf. Coatings Technol.*, 2017, doi: 10.1016/j.surfcoat.2016.12.035.

[4] S. Kumar, A. Jyothirmayi, N. Wasekar, and S. V. Joshi, "Influence of annealing on mechanical and electrochemical properties of cold sprayed niobium coatings," *Surf. Coatings Technol.*, 2016, doi: 10.1016/j.surfcoat.2016.04.027.

[5] S. Saeidi, "Microstructure, oxidation & mechanical properties of as-sprayed and annealed HVOF & VPS CoNiCrAIY coatings," *Thesis*, 2011.

[6] P. Coddet, C. Verdy, C. Coddet, F. Debray, and F. Lecouturier, "Mechanical properties of thick 304L stainless steel deposits processed by He cold spray," *Surf. Coatings Technol.*, 2015, doi: 10.1016/j.surfcoat.2015.07.001.

[7] C. M. Bleakley and J. T. Costello, "Do thermal agents affect range of movement and mechanical properties in soft tissues? A systematic review," *Archives of Physical Medicine and Rehabilitation*. 2013, doi: 10.1016/j.apmr.2012.07.023.

[8] S. Kumar, S. K. Reddy, and S. V. Joshi, "Microstructure and performance of cold sprayed Al-SiC composite coatings with high fraction of particulates," *Surf. Coatings Technol.*, 2017, doi: 10.1016/j.surfcoat.2016.11.047.