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Research Article

Effect of D-Gun sprayed Ceramic Coatings on Aluminum Material to Review Hardness and Corrosion Properties

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Abstract

Now a days, Aluminium is used in multiple applications such as Aerospace, Automotive, Marine and Rail etc., due its unique mechanical, thermal, chemical properties. Aluminium is light in weight, offers excellent resistance to corrosion. This high resistance extends the life of equipment, significantly reduces maintenance costs and preserves outward appearances. But the hardness of Aluminium is very less which can be improved using ceramic coatings. In this paper we discuss the change in hardness and how the corrosion weight loss is affected with the use of Al_2O_3 and Al_2O_3+40TiO_2 coatings.

Keywords: *Aluminum, Ceramic coatings, Al_2O_3, Al_2O_3+40TiO_2, Hardness, Corrosion test.*

1. Introduction

The detonation gun process is most effective for particular ceramic materials, such a tungsten carbide, that are required for producing highly dense coatings on a metal surface. It creates an explosion of oxygen and acetylene gas at around 6,000 degrees (F), melting the ceramic and firing it at high speed toward the target substrate (Venkataraman R, *et al* ,2006).

2. Detonation Gun

D-gun spray process is a thermal spray coating process, which gives extremely good bond strength, low porosity and coating surface with less oxide contents. Detonation gun uses oxygen and acetylene in a precisely measured quantity which is fed through a tubular barrel closed at one end(Lakhwinder Singh, *et al*, 2012). A nitrogen purge is used to clean the impurities present in the gun in order to prevent the possible back firing. Simultaneously, a predetermined quantity of the coating powder is fed into the combustion chamber. The gas mixture inside the chamber is ignited by a simple spark plug. The combustion of the gas mixture generates high pressure shock waves (detonation wave), which then propagate through the gas stream. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 4000^0 C and the velocity of the shock wave can reach 3500m/sec. The hot gases generated in the detonation chamber travel down the barrel at a high velocity and in the process heat the particles to a plasticizing stage (only skin melting of particle) and also accelerate the particles to a velocity of 1200m/sec. These particles then come out of the barrel and impact the component held by the manipulator to form a coating. The high kinetic energy of the hot powder particles on impact with the substrate result in a buildup of a very dense and strong coating. The coating thickness developed on the work piece per shot depends on the ratio of combustion gases, powder particle size, carrier gas flow rate, frequency and distance between the barrel end and the substrate. Depending on the required coating thickness and the type of coating material the detonation spraying cycle can be repeated at the rate of 1-10 shots per second. The chamber is finally flushed with nitrogen again to remove all the remaining hot powder particles from the chamber as these can otherwise detonate the explosive mixture in an irregular fashion and render the whole process uncontrollable.

Figure 1 Detonation gun used for Spraying

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With this, one detonation cycle is completed above procedure is repeated at a particular frequency until the required thickness of coating is deposited (Sumith Kumar, *et al*, 2017).

2.1. D-Gun Process parameters

Table1 Detail of D-Gun coating Process

Heat source	Acetylene and oxygen
Material	Carbide, Ceramic and Metallic powders
Gun length	100 cm
Flame temperature	Nearly 3,000^{0}C
Particle velocity	Up to 1000 m/s
Substrate temperature	20-140^{0}C

2.2. Salient Features

- Coatings are very hard, clean and dense.
- Coatings have low compressive stresses.
- Coatings have very high bond strength.
- Coatings have very less oxide contents.
- Coating characteristics are superior than Flame spray, Wire arc and Plasma spray coatings.

2.3. Typical Coatings and Materials used

Typical Coatings:

- Anti – Wear coatings
- Anti – corrosion coatings
- Metallic Coatings
  Materials:
- Aluminum alloy plates 50mm×50mm×50mm.
- Alumina (Al_2O_3) powder.
- Alumina+40%Titania (Al_2O_3+40TiO_2) powder.

2.4. Alumina (Al_2O_3) coating

Table 2 Chemical Composition of Alumina

Typical composition	Al_2O_3	SiO_2	other
Weight (%)	98.5	1	Balance

Table 3 Physical properties of Alumina

Melting point	2000^{0}C
Thickness of coating	100μm
Density	3.3
Porosity	Low
Bonding	Good
Emissivity	0.2-0.3
Thermal shock resistance	Very good

2.5. Alumina Titania (Al_2O_3+40TiO_2) coating

Table 4 Chemical Composition of Alumina Titania

Typical composition	TiO_2	Al_2O_3
Weight (%)	40	balance

Table 5 Physical properties of Alumina Titania

Melting point	1840^{0}C
Thickness of coating	100μm
Density(g/cc)	3.5
Porosity	Negligible
Dielectric strength(volts/Mil)	300
Emissivity	0.2-0.3
Thermal shock resistance	Very good

3. Results and Discussion

3.1. Hardness Measurement Scales

Hardness measurement can be on macro, micro and nano scale according to the forces applied and deformation obtained.

Macro-hardness measurement is a simple method of obtaining mechanical property data from the bulk material from a small sample. When concerned with coatings and surface properties of importance to friction and wear processes for instance, the macro indentation depth would be too large relative to the surface scale features.

Micro hardness measurements are appropriate, where materials have a fine microstructure, are multi-phase, non-homogeneous or prone to cracking, whereas the macro hardness measurements are highly variable. Micro hardness is determined by forcing an indenter such as Vickers or Knoop indenter into the surface of the material under 15 to 1000gf load. Usually the indents are so small that they have to be measured with a microscope.

Nano indentation tests measure hardness by indenting using very small indentation forces, on the order of 1nano-Newton and measuring the depth of the indention made.

3.2. Vickers Hardness

The Vickers hardness is measured by means of FM-300e micro Vickers machine. In this method, a diamond indenter is applied perpendicular to the surface of the specimen which is to be tested. Four Vickers impressions have been made through in the surface of the each sample using different loads for different samples with a dwell time of 15 seconds. After indentation, the two diagonals of the rhombus-shaped Vickers indentation are immediately measured using optical microscope with a magnification of 500 and the boundaries are adjusted and fixed using knobs then values of the micro Vickers hardness were obtained (Lidija Ćurković, *et al*, 2007).

$HV=0.1891\times F/d^2$

Where:

HV = Vickers hardness,
F = applied load (N),
d = arithmetic mean of the two diagonal length (mm).

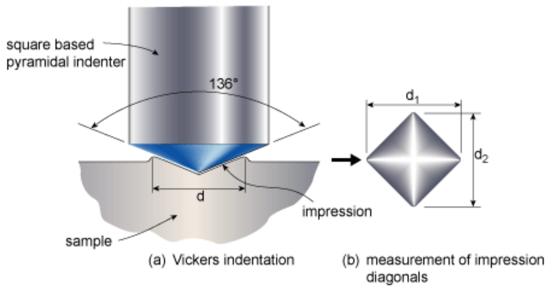

Figure 2 Diagram representing Vickers indentation and diagonal lengths

3.2.1. Microvickers used and it's Specifications

Table 6 Specifications of Micro Vickers used for testing

Serial no.	Part	Description
1	Turret	Turret has 3 positions over 360^0 for holding one indenter and two objective microscopes.
2	Indenter	Vickers indenter 1 no.
3	Load application	Standard test loads at 10 gf, 20 gf, 50 gf, 100 gf, 200 gf, 300 gf, 500 gf and 1000 gf.
4	Dwell time	15 seconds (adjustable between 10s to 60s)
5	Power supply	230V ±10% AC, 50 Hz, single phase.

Figure 3 Micro Vickers Used for Testing

3.3. Micro-Hardness Results

For Al plate, the load on the indenter was 0.2×9.81 N, the dwell time was 15 seconds, and length of the diagonals are observed as 66.39 and 69.13 respectively. The hardness is found to be 80.70 HV. For Al_2O_3 and Al_2O_3+40%TiO_2 plates, the load on the indenter was 0.5×9.81 N with the dwell time of 15 seconds. The length diagonals of Al_2O_3 coated Al are 44.82μm, 46.10μm and for Al_2O_3+40%TiO_2 coating it is 40.52μm, 39.96μm. The hardness values are found to be 448.74 and 572.81 respectively.

The micro-hardness values for uncoated Al, different coating powders are listed in Table and plotted as a graph. From the table it is clear that Alumina Titania is having the highest hardness value when compared to other combinations

Table 7 Hardness Test Details

S. no	Specimens	Micro hardness (HV)	Load (N)	Thickness (μm)
1	Al	80.7	0.2×9.81	-
2	Al_2O_3 Coated	448.46	0.5×9.81	100
3	Al_2O_3+40%TiO_2 Coated	572.81	0.5×9.81	100

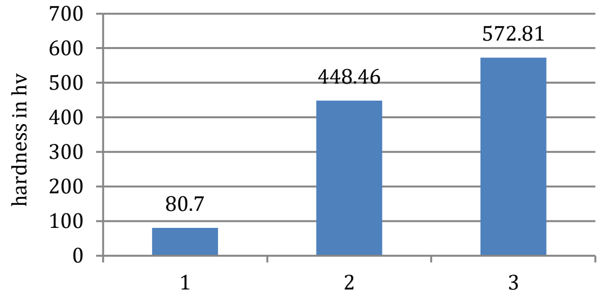

Figure 4 Comparison of micro hardness values

3.4. Corrosion Test

The tests were carried out in 98.4% HNO_3 and 35-38% HCl acids. The three different specimens are cut to required size of 25mm×25mm×10mm each. The samples were de-greased with acetone and then rinsed in distilled water before immersion in the 98.4% HNO_3 and 35-38% HCl acids; which were all exposed to atmospheric air.

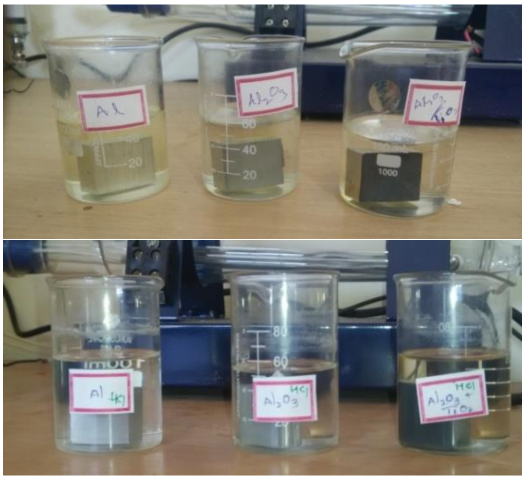

Figure 5 Samples under corrosion test

The results of the corrosion tests were evaluated by mass loss and corrosion rate measurements on one hour intervals. The samples were exposed in the acidic environments for 7 hours. Mass loss (mg/cm^2) for each sample was evaluated by dividing the weight loss (measured using a three decimal digit electronic weighing balance) by its total surface area. Corrosion rate for each sample was evaluated from the weight loss measurements following standard procedures (K. K. Alaneme, *et al,* 2001).

3.5. Corrosion Results

The comparisons of corrosion properties of uncoated Aluminum plate, Al_2O_3 coating and Al_2O_3+40TiO_2 coated Aluminum plates at room temperatures in HNO_3 and HCl were illustrated in Fig 5. The mass change of $Al2O_3$ coating was larger than all those Al and Al_2O_3+40TiO_2 coating in both the acids.

Average corrosion rate is given by:

CR= $(m_0-m)/(S_a \times T)$

Where CR is corrosion mass rate, m_0 and m indicate the mass of sample before and after corrosion, S_a is the surface area of the coating and T is the corrosion time.

In 35-38% HCl, Al_2O_3 coating displayed the poorest corrosion resistance of 0.14602 $mg/cm^2/h$. Al_2O_3+40TiO_2 had the best anticorrosion property of 0.05714 $mg/cm^2/h$, which was nearly 2/3 of Al_2O_3. The corrosion rate of the coatings increased considerably when tested in 98.4% HNO_3 acid. Al_2O_3 exhibited the highest corrosion rate of 0.2539 $mg/cm^2/h$, while Al_2O_3+40TiO_2 showed the lowest value of 0.07301 $mg/cm^2/h$ which was less than 1/3 of Al_2O_3. The corrosion rate of Al plate remained at 0.10475 $mg/cm^2/h$ (Hongwei Yang, *et al,* 2006).

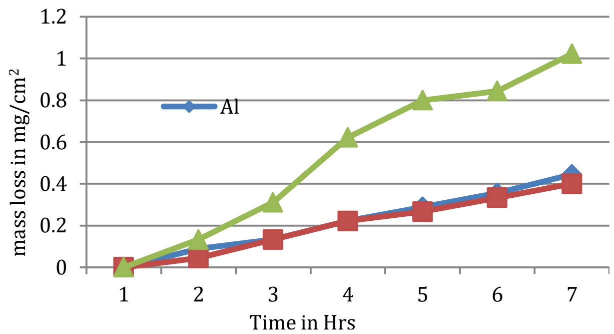

Figure 6 Variation in Mass Loss of Al, Al_2O_3 and Al_2O_3+TiO_2 in 35-38% HCl

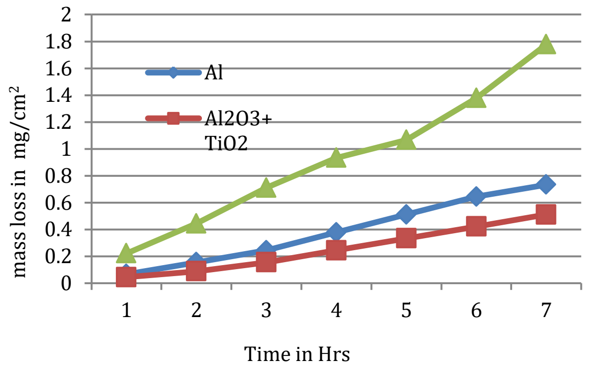

Figure 7 Variation in Mass Loss of Al, Al_2O_3 and Al_2O_3+TiO_2 in 35-38% HCl

Conclusion

It is observed that the Mechanical properties were enhanced by coating aluminum alloy with ceramic powders.

- The surface hardness of the aluminum is increased in both cases.
- In the work, the corrosion behavior of Aluminum, Alumina coating and Alumina Titania coating in HCl and HNO_3 was investigated.
- From the results, it is observed that Alumina Titania exhibited excellent corrosion resistance both in HCl and HNO_3 media than the Aluminum and Alumina Samples.

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