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Corrosion effects of yttrium stabilized Zirconia coating on A105 medium carbon steel by Electrophoretic deposition process

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Abstract- Corrosion plays an important role in limiting the lifetime of systems used in petrochemical applications where corrosive medium is transported and the valve material is in direct contact with the corrosive medium. A105 steel is a common valve grade material which is used in high pressure petrochemical applications. Steel materials are often hardfaced with nickel alloys to withstand wear and corrosion for such applications but fabrication of the coating is more tedious and requires complex equipments. Zirconia has high resistance to chemical attacks, therefore it is chosen for this work to be coated on A105 medium carbon steel. The aim of this work is to study the corrosion behavior of the steel coated with yttrium stabilized zirconia using electrophoretic deposition coating process. Yttrium Stabilized zirconia is synthesized using zirconium oxychloride octa hydrate as precursor with 10 mole % yttrium nitrate heaxhydrate. The test results are compared with corrosion result of uncoated sample. The Yttria stabilized zirconia is synthesized and is characterized using XRD analysis. Ethanol is used as solvent, Polyvinyl butyral is used as the binder and citric acid is used as dispersant medium for the fabrication of coating using EPD process.

Keywords- Yittrium Stabilized Zirconia, corrosion, ceramic coating, Electrophoretic deposition

1. Introduction:

Nano crystalline zirconia has attracted attention as a coating material for its higher hardness, corrosion resistance and good thermal properties. These materials are used as thermal barrier coating for boiler applications and in nuclear reactors. Zirconia has a good thermal match with most metals, and so it is an apt material that can be chosen to be coated on steel. A105 medium carbon steel is most commonly used steel grade for valve applications; these materials are hardfaced with nickel alloy but commonly are subjected to pitting corrosion. Therefore it is necessary to form a suitable coating to increase its corrosion resistant properties further. Zirconia can be coated on steel through various processes namely sol gel dip coating process, plama spray process, chemical vapour deposition process, spray pyrolysis etc. Yttria stabilized zirconia have excellent chemical resistance, ionic conductivity, polymorphous nature. YSZ nano powders can be synthesized through several methods like hydrothermal, solvothermal, aqueous synthesis, organic precursor route, homogeneous precipitation, coprecipitation, spray drying, sol-gel, plasma spray, flame spray pyrolyosis, molecular decomposition and spray-ICP. Combustion synthesis is another route through which YSZ can be synthesized faster and simpler when compared to other synthesizing methods. This is faster and cheaper process where the starting temperature is low and is assisted by fuel added to the solution which on exothermic reaction gives the necessary heat energy to continue the reaction and synthesize the YSZ powder. The coating of materials through Electrophoretic Deposition(EPD) have started gaining more attention. It is a technique where the movement of charged particles(colloidal particles from suspended liquid) towards an oppositely charged electron takes place. The electrokinetic properties of a particle in suspension are governed by the electric charge distribution in the double layer that surrounds the particle. This double layer is formed when a surface-charge-carrying solid particle suspended in a liquid becomes surrounded by counter-ions of charge opposite to that of the particle surface. As the particle moves in the solution, the plane beyond which counter-ions do not migrate along with the particle is known as the slipping plane. The electrical potential at the slipping plane is known as the zeta potential It also has many advantages when compared with that of other coating techniques. Any complex shapes can be easily coated with much speed and desired accuracy. Coating of large components can also be done by this method. In this process, the forced movement of particles in a liquid medium takes place through applied electric field and the collection and deposition of particles on the conductive medium takes place. The method can be applied, in general, to any solids with particle sizes of less than 30 microns. Many researches have carried out on the kinetic electrophoretic deposition process and equations and formulae are being generated. Thus EPD plays an efficient role in cost effective coatings of various conductive materials.

2. Experimental Details:

A105 steel valve material is hardfaced with nickel alloy to increase the corrosion resistance of steel material. But since this process develops high residual stress in the material and non line of sight regions of the valve components cannot be hard faced, newer process are selected. Nano coating of zirconia is selected through EPD process which is highly efficient and is a low cost operation. Zirconia has a good thermal match with metals so it is selected as the coating material. Zirconia materials have low ionic conductivity so it is necessary that it should be doped with yttrium to promote ionic conductivity. Doping zirconia with yttrium replaces Zr^{4+} ions with Y^{3+} ions and adds oxygen vacancies with ionic conductivity.

A.Synthesis of Yttrium stabilized Zirconia:

Yttrium stabilized zirconia was synthesized using zirconium oxychloride octahydrate as precursor with 10 mole% yttrium nitrate hexahydrate (sigma Aldrich). 0.6g of Zirconium oxychloride octahydrate was reacted with excess amount of Concentrated nitric acid to from zirconium nitrate solution. 0.03g of yttrium nitrate hexahydrate was dissolved in 10ml of distilled water and heated at 60° Celsius and added to zirconium nitrate solution to form a composite nitrate solution. Urea is added as a fuel to assist in combustion process. The fuel-nitrate solution is then heated at 400° Celsius and white YSZ powder is obtained. The white YSZ powder thus obtained was hand ground using agate mortar and pestle for degglomeration.

B. Fabrication of coating using Electrophoretic Deposition process:

A 0.1% wt of YSZ powder (0.001 gm/ml) was dissolved in 20 ml ethanol and stirred continuously using a magnetic stirrer and sonicated in an ultrasonic bath for achieving good dispersion of the particles in the dispersion. Size measurement of the dispersed particle was measured using nano zetasizer. Reagent grade 0.1 gms of citric acid was used as dispersant and 0.5 gms of polyvinyl butyral was used as binder and as a surfactant while nitric acid was used for ph adjustment. The ph of the solution was maintained at ph ~ 5.5-7. Using nitric acid for ph modification promotes cathodic deposition of YSZ onto the substrate. A105 steel specimen was used as the substrate to be coated. The specimen was cut to 20mm x 20mmx 2mm plate and was ground in an emery sheet of grit size 120 and was treated with nitric acid. The steel was connected to the cathode and a carbon electrode was connected to the anode. 30 V is applied in a room temperature of 25 ° Celsius, cathodic deposition takes place and YSZ is coated on the steel sample.

C. Poteniodynamic Polarization Test:

A three-electrode system unit with a platinum counter electrode of 1 cm^2 and an Ag/Agcl, 3M kcl electrode as the reference electrode were used to carry out the potentiodynamic polarization test in the electrochemical workstation to determine the corrosion rate. 5.0 wt.% nacl solution was used as the corrosive medium to conduct the test. The initial and final potential was -0.47501V and -0.47073V. The surface area of the area exposed to the corrosive medium was 0.1mm^2. The potentiodynamic polarization curve was plotted for uncoated sample and the sample coated with zirconia using electrophoretic deposition process.

3. Results and Discussion

D. XRD Characterization:

The XRD analysis was taken using Cukα radiation in the range of 2ϴ = 10° - 80°. XRD analysis was taken for the powder and the coated sample. The XRD diffractometry pattern of the synthesized powder from fig2. Confirms the presence of Yttrium stabilized Zirconia at peak angle formed at 30°, 32≤2ϴ≤ 37°, 50° and confirms the tetragonal symmetry at 72° ≤ 2ϴ ≤ 76°. From figure 3. The XRD data of the EPD coated sample confirms the deposition of zirconia coating on steel substrate using the EPD process. The peak for metal substrate is seen at an angle 45°≤2ϴ≤ 48°

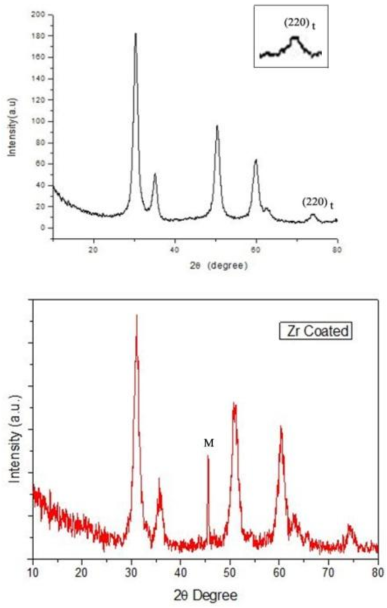

Fig 1 (A) XRD of synthesized powder, 2(B) XRD of the YSZ coated sample, substrate peak denoted by letter M

E. *Potentiodynamic Corrosion Test Result*:

Figure 3 and 4 shows the potentiodynamic polarization curve for uncoated and YSZ coated sample. The corrosion potential, corrosion current, polarization resistance and the corrosion rate is summarized in the table 1. From the results it is noted that the corrosion current density (Icorr) of the coated substrate (7.37 E-06 A) is much lower than that of uncoated substrate (1.23 E-05). The corrosion potential (Ecorr) of uncoated substrate is low, which is about -0.44851 whereas for coated sample the corrosion potential increases to -0.47324.

As the Ecorr value increases the corrosion resistance increases. After the corrosion test was conducted pitting corrosion was visible in naked eye for the uncoated substrate, whereas there was no visible corrosion marks for the coated sample. The corrosion rate was calculated to be 0.2046 mm/year for uncoated substrate and 0.08 mm/year for YSZ coated substrate.

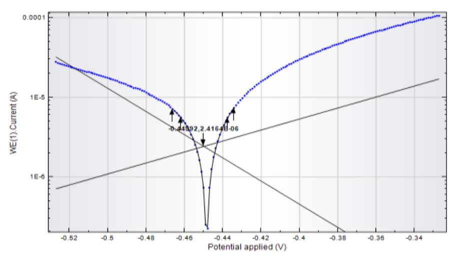

Fig 2 Taffel plot of uncoated substrate

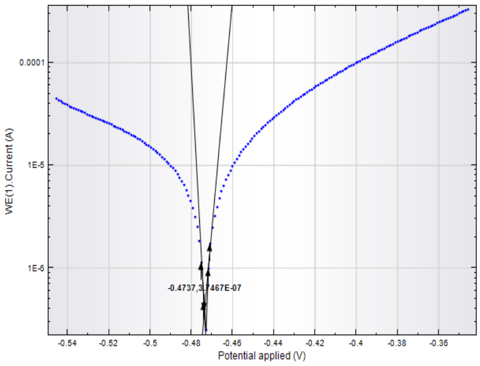

Fig 3 Taffel plot of coated substrate

Table 1. Potentiodynamic test result

	Uncoated substrate	Coated substrate
Ecorr (V)	-0.44851	-0.47324
Icorr (A)	1.23E-05	7.37E-06
Polarization resistance (Ω)	1503.8	2193.2
Corrosion rate (mm/year)	0.2046	0.085589

4. Conclusion

Yttrium stabilized Zirconia of particle size ranging from 250 to 600 nm was deposited on steel successfully using EPD process. The potentiodynamic test conducted on the uncoated and coated sample revealed that , specimen coated by yttrium stabilized zirconia had higher corrosion resistance than uncoated substrate. The corrosion potential increases for the coated substrate and thus increases the corrosion resistance.

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