

A REVIEW ON CERAMIC COATINGS FOR LOW CARBON STEEL SUBSTRATE AND ITS APPLICATIONS

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Abstract: Ever since the Second World War many Researcher have significantly contributed to the research in ceramics. The aesthetics of components, durability and wear resistance properties of components are increased by ceramic coatings. Surface coatings of ceramics to metals and to certain non-metals are the hot cake of research in ceramics now. Ceramic coatings are robust in structure and possess a higher level of lubricity the property of oxidation limit their use to temperatures under 1200⁰C making it much favorable for hot forging dies. Ceramic coatings on metals have proved to enhance the metal functional properties; they make the material free from corrosion, enable it to behave as a non-conductor under certain circumstances, give a better level of abrasion resistance and expose the capability of maintaining their integrity even at elevated temperatures of about 4500⁰ Fahrenheit. This property of ceramics has increased its popularity in the field of automotive industries and forging industries. Ceramic coating increases the working lifespan of the dies enabling them to produce a large number of components before they actually are worn out. In the current investigation various research works conducted by different researchers across the world in the field of ceramic coatings on metal surface is being investigated. The gap in the research findings is used for further experimental investigations.

Keywords: Ceramic coatings, low carbon steel, thermal barrier coatings,

1.Introduction

Ceramic coating on metals has emerged as one of the most adoptable methods of preparing metals to get prevented from rusting become wear resistant and to make it harder. However, the word surface coating on metals sounds very simple but in actual practice the process is not that simpler. The process of applying ceramic coating onto a substrate is a multi-stage process. It involves processes like surface preparation, abrasive blasting, cleaning, painting, curing and final equipment cleaning. Metal corrosion is a basic destructive process that brings down the life of components that are exposed to corrosive atmosphere resulting in greater economic losses. Thus, it does not lead one to any surprises, that the research on corrosion and protection of materials from corrosion is being concentrated [1]. The starting point of corrosion of any material is the material surface. Ceramic coatings help us to produce a material surface that is free from corrosion. The success of coating largely depends on mechanical, chemical and physical bonds that are responsible for the coating adherence and ultimate strength of ceramic layer.

2.Literature survey

Ever since 1970, there has been a significant improvement in the field of ceramic coating on metal surfaces. Different environments in the modern world demand different metal and their alloys that are capable of performing at elevated conditions. From the year 1980on wards ceramics has found its successful application in the automobile industry [2]. The first successful application in automobile industry was found in gas turbine wings later on the piston, piston crown, cylinder lining and valves have succeeded gas turbine wings [3]. Different metal ceramic combinations have shown different properties. When hardness and wear resistance are of consideration carbides like the silicon carbide and the tungsten carbide are used in the form of dispersoids. Whereas resistance towards oxidation even at high temperature is acquired by coating layers of oxides like TiO₂, SiO₂, Al₂O₃, etc., these coatings also impart hardness and wear resistance to the base material. These deposits are better than that of nickel deposits [4]. Owing to the extremely good quality and excellent properties in the past two decades, ceramic coatings find extensive applications in the surface modifications. Base alloys when have to be protected from corrosion, oxidation and minimization of damages due to wear ceramic coatings are the best suit. Another important function of ceramic coating is that they minimize the thermal barrier coatings [6]. Ceramic coatings in thin layers on the surface of metals have always

helped in enhancing mechanical performance of metallic substrates. By coating ceramics on the metal surfaces, heat resistance, wear resistance, corrosion resistance electrical insulation and many other properties can be improved. [7]. there are many ceramic coating methods for protective coatings on mild steel. The methods differ in terms of coating quality, complexity of process, investment costs and deposition efficiency

2.1. Ceramic Surface coating: its effects

Low Carbon Steel's Resistance towards corrosion:

Greater is the carbon content in steel, greater will be its corrosion rate this is an imperative factor that determines the corrosion resistance of steel [7]. Providing a protective coating on the surface is one of the most suitable ways to improve the anti-oxidation ability of carbon steels. A large number of experimental investigations have been made on the process of coating different materials on the base metal and the results were different from each other several such investigations include zinc composite coating, where in zinc metal along with ceramic, metal oxides and polymers is coated. Composite coatings provide different properties such as resistance to corrosion and sometimes superior electrochemical properties. Ghaziof Soroor [8] conducted an investigation to study the coating properties; he made a comparative analysis using cyclic voltammetry, Tafel test, XRD and ESEM. He arrived at the conclusion that corrosion resistance property of Zn-Ni coatings saw an impressive improvement due to the addition of alumina nano particles as compared to Zn-Ni-Al₂O₃. While coatings of Zn-Ni-Al₂O₃, displayed a uniform and compact deposits as compared against Zn-Ni. Popoola A. P. I [9] found that with Zn-ZnO- Yttria coatings on mild steel, an increase in the corrosion resistance, hardness and the wear resistance saw a significant improvement. He claims that Yttria can be added to increase the wear resistance surface hardness and corrosion resistance of mild steel. Also, by adding Yttria, finer microstructure can be obtained, and this is the root cause for increasing the hardness value, corrosion resistance value and wear resistance value of Mild steel. The ideal emerging materials that find suitability for wider engineering applications are the advanced ceramics. These materials because of their superior properties are being widely used in some biomedical applications, cutting tools, IC engines, gas turbine blades and spacecraft. Advanced ceramics differ from that of ceramics in their composition, processing techniques and its microstructure. In order to make them fit to be used in other engineering applications; extensive research has to be carried out in terms of mechanical, optical biomedical and electrical properties [10].

2.2. Ceramics in nuclear applications

Advanced Ceramics have found its application related to nuclear fission and fusion reactors. These are used in fission reaction in nuclear fuel cycles and in confinements of nuclear wastes. In case of fusion reaction these are used to sustain the fusion nuclear fuel cycle. In the nuclear reactors the material failure is due to swelling. These swellings on material surface are due to the knock of atoms by the neutrons atoms possessing high energy. the gaseous come together and form a bubble in crystals or along the boundary. In addition to these various defects such as the vacancies, dislocations voids, loops and introduction of interstitial spaces are created. Crystalline defects in materials affect various other properties such as the thermal diffusivity, electrical conductivity, and chemical stability [11]. The swellings of Al₂O₃ and the AlN ceramics is larger than that of Sic and Si₃N₄ ceramics. The degradation of base material is due to the micro crack or void formation on the material surface. This can be identified by the occurrence of linear swelling by more than 1% as compared to compounds with ionic bonding covalent bonded Sic and Si₃N₄ exhibit exceptional tolerance.

In rotary engine applications, advanced ceramic materials find a greater potential. Since it is not possible to manufacture a totally compact rotary engine, thus planning and production of metal ceramic bonds exhibit a greater demand. Couple in Constant of Thermal Enlargement (CTE) existing between the metals and ceramics becomes one of the major hindrances for the use of ceramic components in rotary engines. In practice the thermal application may produce excessive strain at the interface between metal and ceramics. The strain produced will be sufficient enough to create a catastrophic failure of ceramic material, thus it becomes a necessity to investigate different strategies for change in integrity of ceramic materials.

With the introduction of advanced ceramics to the production of gas turbine components, enhances the operational temperature of the turbine, which results in the higher turbine efficiency and reduces the impact on the environment. Sometimes the ceramic components used in the gas turbines are subjected to hot corrosion and recession due to the action of hot corrosive gases and vapours that are moving at greater velocities. The effect of these corrosive hot gases on ceramics makes it very much essential to use Environmental Barrier Coatings (EBC) which have a greater resistance to the destructive combustion atmosphere and possess the

capability to act as diffusion barriers which anticipate with the gaseous matter from reaching the ceramic coating. With the increased operational temperature, the use of Thermal Barrier Coatings (TBC) will become more essential. These TBC's are poor thermal conductors and allow a significant fall in temperature across the coatings, this enables the basic metal substrate to perform at temperatures lesser than that of combustion temperature. For the determination of CTE match, the deposition, and other properties of EBC's on ceramics with silicon as base and also EBC/TBC are considered for CTE match. While absence of harmful chemical interface interactions, actual TBC thermal conduction, hot corrosion resistance and EBC recession resistance are most essential for a CTE match [12].

2.3. Surface coating applications

Under this heading the applications of surface coatings in the fields like food industry, electronics industry, sports and technology, aeronautics and transportation departments, chemical and crude oil industries are explained. In the modern world, surface coatings have found its extensive use in some specialized areas such fields are sports equipment (e.g. horse hooves, swimming equipment, clothing, and golfing equipment), biomedical/ orthopedics art, and bronze industries [13]. By adopting surface coatings on a base material, a wide range of properties can be attained. The commonly use base materials are Diamond Like Carbon (DLC), nitrides, metals and alloys TBC and decorative coatings.

A majority of cutting applications are made proficient by spraying a thin layer of resistant coating. The coatings on the base materials vary in thickness in microns. This coating is responsible for improving the cutting-edge wear resistance and is responsible for reducing the friction and diffusion. This includes high speed cutting, machining of hard materials and other nonferrous material that cannot be cut otherwise. There is a significant contribution of surface engineering to the field of transport industry. Nearly to an approximate of 6% of the total cost involved in manufacturing an engine and the transmission system are involved in the coating technologies. The three major categories that find the application of surface coating are the Power units, fixed permanent structures and majorly the vehicle components. Coatings are used widely in the field of power generating units and power transmission systems. These surface coatings prevent the power units from excessive wear and corrosion. In order to improve the wear resistance property and increase the life of brakes and suspension of an automobile, they are treated with thermally sprayed coatings

The aerospace industry has been in practice of surface coatings over a period of 50 years from now. The surface coating on the gas turbine engines inhibits properties such as the high temperature strength, load bearing properties and the corrosion resistance. To protect the parts against corrosion they are thermally sprayed with polymer coatings. The gears and the bearings used in the aircrafts are coated with MOS₂ using PVD magnetron sputtering thus lowering the heat generation in the transmission system and prevents the meshing gear temperature rise. Surface modification can improve a components performance. The best example for this is the landing gear of the light combat aircraft. This was initially designed from maraging steel and thus requires a surface modification to enhance its wear resistance. The age-old practice of chromium plating exposes machining problems. Thus, by nitriding was developed and this process does not require any post machining operations also it does not reduce the fatigue life of the material unlike the hard chromium plating.

2.4. Methods used in surface coatings

In the current section we will be discussing entirely on the recent methods of surface coatings. Plasma spraying is the most popular technique used for the preparation of a large range of coatings. Plasma sprayed coatings find their applications in chemical industries, biomedical field, automobile and aerospace industries. In order to improvise certain properties like the wear and corrosion resistance along with bio-compatibility, plasma spraying is performed at an elevated temperature of 10000 K in consideration with higher specific energy densities and higher cooling rates. Oxidation problem is reduced due to the use of argon, hydrogen or nitrogen. Despite of its high cost involved in the production of plasma coatings this process is much preferred because of the advantage that even metals possessing higher melting points can also be plasma sprayed. Before plasma coating is applied one should ensure that the surface on which it will be coated is free from metal oxides, oil, and any other powders on the surface. The coating thickness obtained by plasma spraying ranges from 2.5-2500 μm .

Sol – gel method this method has become the most popular method of preparing the ceramic coating as this is much simpler, excellent adhesion of the coating to the substrate material, low processing temperature. For employing the Sol-Gel thin films on base metal surface, different techniques are being used such as the dip coating, spray coating and the spin coating. Surface modification works greatly depend on the laser process as compared to the age old heat treatment process as it is very economical and advantageous as compared to

other processes. Few of the advantages of the laser treatment process are it has a short processing time, faster heating and cooling rate, lesser energy consumption, fine coating properties, accurate process control local heating and is an environmental friendly process. Using the laser technology only the superficial layer of the metal substrate can be modified without altering the subsiding layers. Pulsed laser deposition which popularly known as the PLD is a much simpler technology that permits the growth of very thin films over a wider material range. This technique offers flexibility to produce various micro structured coatings, from dense and compact to columnar and a porous structure.

2.5. Developments in the field of ceramic coating

Earlier to 1990's, the application of ceramic coating was limited to protect certain metals components such as the Ni Super alloys, Ti –alloys and the Co-Cr alloy components. In the later years the applications were extended to a wider range of materials. The corresponding section highlights some of the newly emerged applications.

2.6. Heat resistant Ceramic Coatings used in Gas Turbines

The late 1990's, gave rise to power plants utilizing highly efficient turbines that ran on both the gas and steam. The operating temperature of these turbines was relatively high. To sustain such a high temperature, the turbine parts were manufactured from high heat resistant super alloy. The combined advances made in cooling technology and heat resistant coating technology have liberally contributed to the development of these high efficient turbines. Gas turbines that run at a temperature of 15000 C make use of blades made from a single crystal Ni-based super alloy. In such extreme conditions the use of TBC becomes very much essential in addition to this steam cooled technology also has to be employed.

2.7. High temperature Corrosion Resistant Ceramic Coatings used for Waste to Energy Boilers.

The modern day boilers promote the energy conservation and reduction of the harmful gases like CO₂ and oxides of various harmful gases. A higher performance is expected from these plants that are facilitating the demands of the society such as the economy globalization. The high efficiency waste to energy boilers runs utilizing the steam under a temperature of 4000C and a pressure of 3.9 MPa. The fluidized bed boilers which consume the industrial waste such as the biofuels, RPF, RDF, etc., are usually operated at temperature range of 4500C to 5400C and pressure varies from 5.9 to 9.8 MPa. The combusted gases of waste to energy boilers create a corrosive environment. The amount of HCL, SO₂, present in the flue gases coming from WTE is quite larger than that of flue gases coming from the fossil fuels boilers. There is a larger amount of deposition on high temperature boiler components. These deposits are of low melting point ashes that contain highly concentrated chlorides. To prevent these boilers from corrosive is becomes mandatory to use corrosion materials and corrosive resistant coatings to enhance the life and reduce the maintenance activity. In addition to this, it also becomes essential to make use of highly durable ceramics available at a lesser cost in combination with suitable metals in the production of boilers and its equipments.

The stable operation of the boiler for a longer period is made possible by the use of advanced refractory and many metallic materials such as the ceramic tiles, metal spray coatings and welded joining of Ni based alloys. Thus, the refractory materials are made of high purity silicon carbides and alumina finds its use. High temperature furnace damages and slugging f boiler walls are prevented by the use of silicon carbide refractories. Use of Silicon carbide tiles for water cooled furnace has portrayed better performance, lesser maintenance and greater durability. The boiler super heaters work under extreme environmental conditions of erosion and corrosion caused by the soot blowers at a temperature above 400^oC. To enhance the working life period of super heaters, cermet and ceramic spray coatings are applied. This application can even be extended to boilers that operate under 5000C temperature and 9.8 MPa steam conditions, Experimental investigations have shown that dual layer coatings of TiO₂ 625 alloy cermet coating using HVOF spray processes and Cr₃C₂-NiCr alloy cermet and ZrO₂(Yttria stabilized zirconia) or Ni based alloys using plasma jet spray process on exposing them in super heaters that were maintained at a temperature of around 5000C over a period of about 1.3 to 2 years. This pronounced a confirmation of its operating life span of more than three or more years. This life span could not have been obtained by any other metal spray coatings. A detailed investigation of the causes for deterioration was made. The investigations revealed that the deterioration of coatings was mainly due to the corrosive gas penetration. This penetration onto the metal coating interface has caused swelling of the coating layer. The swelling progresses further as the adhesive strength between the metal and the coating reduces and results in the breaking down of the layer. From this it is clear that, a dense coating is essential for increasing the lifetime. Some of the important material factors responsible for

governing the durability are the resistance towards corrosion, porosity exhibited by the coating material, adhesive strength of coating material with the base material and thermal properties of base material and the coating. In case of Ni based alloys or YSZ, the superficial layer forms the diffusion barrier for corrosive gas penetration.

2.8. Wear-Resistant Ceramic Coatings for Bio implants

There is an increasing demand for the improved performance and increased life of the joints. This is an urgent socioeconomic need that has to be fulfilled. This can be facilitated by the use of ceramics. By coating a ceramic films the wear resistance and the life of the joints are improved. Though the concept sounds simpler, establishing a coating on a joint that is successful clinically and also commercially successful has prone a challenge. The best found alternate to this is the adhesion of the coating to the substrate. The limitation of this technique is that if there is a failure the ceramic film forms a third body which increases the wear of the surfaces. In orthopedics application superficial films on joints formed by the vapour deposition or the chemical vapour deposition, zirconium oxide vapours and the DLC are extensively used

2.9. High temperature protective ceramic coatings for stainless steel

Perfect adherence of ceramic coatings to the substrate is a must for high temperature shielding coatings. It is seen that the oxide films over the alloy's free surface grow uncontrollably on heating during hot rolling or any other hot working conditions carried out at a temperature of 1200⁰C in the presence of oxygen for a period of certain couple of hours. The formation of multi-layered oxide layer on the surface of stainless steel causes a deterioration of metal layer varying from 1% to 2% this affects the quality of the stainless steel. Thus, greater care is taken to eliminate or minimize the process of high temperature oxidation. Thus, ceramic coatings have fascinated the protection of metal surface from high temperature oxidation.

2.10. Ceramic coatings extended opportunities Solid oxide fuel cell (SOFC)

In planar solid oxide fuel cells, the use of ceramic coatings is being investigated for extending the operational time of Stainless steel. SOFC 's is most attractive due to their higher efficiency cleaner emission as related to the combustion and have a higher potential for both stationary application and portable application. A fuel stack is formed by interconnecting the fuel cells. By interconnecting individual fuel cells mechanical strength and compartmentalized fuel flow and air to individual electrode is attained. The interconnections should exhibit electrical conduction along the stack at higher operating temperatures. Amongst SOFC's the ferritic stainless steel is considered the most promising as the stacks are operated at a temperature below 800⁰C.

3. Conclusion

From the current literature survey, it is seen that, the air plasma spraying technique is widely used for thermal barrier coatings owing to its increased thermal and surface properties. Due to its high wear resistance and low thermal conductivity surface modification techniques are in use. Advanced ceramic materials such as the yttria and the zirconia find its applications in gas turbines

4. References

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