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Study of Corrosion Behaviour of AZ91D Magnesium Alloy in Automobile Applications

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Abstract - ***Magnesium alloys in the field of various transport related applications and much more, the light weight alloy property of magnesium alloy comes in our main concern. From the study, identified that magnesium alloys like AZ91D were used most in the recent years for variety of applications. But pure magnesium alloy cannot be used directly in many such applications, as magnesium alloy has poor resistance to corrosion behavior. Thus, this factor restricts us to use this material. Lots of studies have been going on for years to improve the corrosion resistance of magnesium alloy. Researcher state that magnesium alloy with coating of another material, greatly helps to improve its resistance to corrosion behavior. Also, identified that High Velocity Oxygen Fuel coating method satisfy our need to improve the corrosion resistance property of magnesium alloys AZ91D. chose this coating method and we also identified that the coating materials like Aluminum oxide shows effective results with this coating method and on magnesium alloys. Finally, find the better corrosion resistive magnesium alloy among the samples we taken into consideration.***

Key Words*: Mg Alloy AZ91D, HVOF, Al_2O_3, Zn, *corrosion resistance.

1. INTRODUCTION

Corrosion is a natural process in which a refined metal is converted into a chemically stable compound, such as oxides, hydroxides, or sulfides. Corrosion is a process in which materials—particularly metals—are chemically or electrochemically degraded by the environment in which they exist. The most common explanation of corrosion is electrochemical oxidation, which occurs when metals react with an oxidizing agent present in their surrounding environment. An example of this process is rusting; this constitutes the electrochemical corrosion of metals that results in the formation of iron oxides. Electrochemical corrosion produces oxides or salts of the metal and causes an orange discoloration to appear on the metal's surface. Corrosion can affect materials other than metals as well, although the term often used to describe such an effect is degradation.

1.1 TYPES OF CORROSION

1.1.1 Galvanic corrosion is very widespread and is caused by two different metals with dissimilar electrochemical charges being joined together through an electrical connection. When the metal ions migrate from the anodic metal to the cathodic metal, corrosion takes place. In this situation, a corrosion protection layer must be applied to avoid either the ion migration or the process that causes it. Galvanic corrosion may also take place if only one type of impure metal is used. The process is initiated if there are various alloy compositions in one metal, which have dissimilar electrochemical charges. The anodic metal will be the weaker metal, and it will lose its metal ions to the cathodic metal. General corrosion takes place without any electrical charge, resulting in uniform corrosion.

1.1.2 Stress-corrosion cracking (SCC)

SCC can seriously damage a component beyond the point of repair. When a component experiences extreme tensile stress, SCC can occur along the grain boundary of the metal. Cracks form in the metal, and these areas become targets for further corrosion. The stresses that can cause SCC include those caused by cold work, welding, and thermal treatments. In addition to these potential causes of SCC, the environment in which the component is located can also cause the stresses to increase and intensify the potential for stress-corrosion. What may begin as minor stress-corrosion can quickly lead to failure or irreparable damage to the component. Localized corrosion is when there is corrosion within a small section of an element. This is because the element will have contacted something that triggers corrosion within a specific small area. Localized corrosion will be much faster in rate when compared to the corrosion rates for other sections of the same element. The effect of localized corrosion together with other factors like stress and fatigue will be much worse when compared to when those other factors act alone. Caustic agent corrosion occurs when impure gas, liquids, or solids wear a material down. Even though impure gases do not affect metals in their dry state, they tend to dissolve into highly corrosive substances when they come into contact with moisture. Hydrogen sulfide is one of such gases.

1.2 SURFACE PROTECTION

Now-a-days most of the research in design with magnesium alloy are focused towards the reduction of corrosion behavior on the surfaces so as to improve the components serviceability. In order to reduce the corrosion behaviour, various surface protections are done which is mostly usage of lubrication, application of surface coating, nitriding, carburizing, carbo-nitriding, anodizing, hardening

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and various other heat treatment procedures for the respective materials.

1.1.2 COATING TECHNOLOGY

Metal coatings serve as a protective layer between structural metal and alsothe environment causing corrosion. Metal coatings may be divided into two categories according to their position relative to the base metal on the activity series – more active coatings and more noble coatings. For the protection of steel, zinc, aluminum, and to a lesser degree cadmium may be used as more active coatings. As sacrificial anodes, these materials provide cathodic protection for the metal. The lifetime of the coating will depend on the coating thickness since it defines how much sacrificial material is present. More noble metals, such as chromium, nickel, and copper, belong to the second category. Protection provided by the use of such metal coatings relies solely on the integrity of the coating since enhanced corrosion will occur at holes. Even though there is danger involved, such coatings are widely used due to the additional properties that these metals possess. They make the surface shiny, hard and conductive. Metal coatings can withstand impact due to flexibility..

1.1.3 HIGH VELOCITY OXYGEN FUEL COATING METHOD

High-velocity oxygen fuel (HVOF) is an advanced technology that uses a thermal spray coating method to improve or restore the surface properties including metals, alloys, and ceramics. The thickness of HVOF coating films can be up to 12 mm (1/2 inch). Typically, this technology is used to deposit coatings that are resistant to corrosion and wear; this includes films made of metals or ceramics. Some commonly used powder materials include WC-Co, chromium carbide, M-Cr-Al-Y, and alumina. The most successful HVOF coatings are those that are deposited with cermet materials (such as WC–Co) and other corrosion-resistant alloys.and dimensions of a part. This technology increases the useful life of the component by providing resistance against corrosion, wear, and rust. In this process, molten or partially molten materials are sprayed onto a surface using a stream of very hot and high-velocity gases. This results in the formation of a dense coating film; This layer can then be polished to achieve the finest surface finish. By using the HVOF coating process, it is possible to create a highly resistant coating film with excellent adhesion to the underlying surface.

2. LITERATURE SURVEY

You Sihang, et al explained the significance of wrought magnesium alloys that are considered a unique material used for structural due to its homogenous structure and improved mechanical properties. In this context, a brief overview of the recent advances made in the development of magnesium alloys is provided here with respect to the alloy design.

Song Guangling, et al reported the results of corrosion resistance tests conducted on casting AZ31Mg alloy in the presence of NaCl solution of concentration. Based on the polarization curves measured during the tests, some important characteristics related to the resistance of the alloy to Corrosion potential, corrosion current density, corrosion rate, and polarization resistance were all assessed in relation to electrochemical corrosion.

As mentioned by LiqunZhu et al., an aluminum-alloyed coating was deposited on AZ91D. The coating synthesized in the presence of aluminum powder at 420°C consists mostly of the 'β (Mg17Al12) phase'. Investigations concerning corrosion behavior using techniques such as polarization curves, impedance test, salt immersion test and salt spray test were conducted to evaluate the corrosion characteristics and corrosion performance of the magnesium alloy. As observed, the coated AZ91D sample exhibits a relatively higher resistance to corrosion compared to the uncoated sample.

P. Pradeep Kumar et al. state that magnesium (Mg) and its alloys are a promising option for creating light structures for energy-efficient applications. There is a unique class of magnesium alloys known as AZ. Aluminum (Al) and zinc (Zn) are the two main elements that make the AZ series the most significant series.

According to P.Fauchais, et al., Coatings were developed initially for protecting materials from corrosion and erosion; i.e., to prevent the chemical and physical reactions between the material and its surroundings. The issues related to corrosion and erosion remain highly relevant in numerous practical industrial applications and products, since they lead to the deterioration and failure of components and systems within manufacturing and processing industries, as well as during their service life.

3. MATERIALS AND METHODS

3.1 SELECTION OF MATERIALS

In the design and manufacturing of any component, the selection of materials is a very important part. The materials selected depending upon the application of the material where it is being used. The material with the equivalent strength value cannot be used for a different application else the component may fail during the service time. Our need of material suits the magnesium alloy varieties.

3.1.1. MAGNESIUM ALLOY- AZ91D

Magnesium alloys are among the lightest structural metals available. Magnesium AZ91D cast alloy is a very pure alloy. It exhibits high strength, very good corrosion resistance, and excellent castability. This alloy possesses outstanding mechanical qualities, as well as exceptional castability and corrosion resistance. By tightly regulating the concentrations of metallic contaminants like iron, copper, and nickel, corrosion resistance is attained. These contaminants are kept to the extremely low levels required to utilize primary magnesium.

Table -3.1 Chemical composition of magnesium AZ91D

Elements	Content (%)
Al	9.7
Mn	0.50
Zn	0.35
Si	0.1
Cu	0.03
Fe	0.005
Ni	0.002
Others, each max	0.02
Mg	Remainder

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3.2 MATERIAL PROCESSING

selected materials AZ91D were commonly manufactured for the industrial use. Materials produced for industrial purpose mostly comes to market in larger size and dimensions. So the materials were procured in larger dimensions than required. Here, safety in requirement of material were also considered. Two magnesium alloy AZ91D plates of 8mm x 200mm x 200mm were the materials procured for our study.

Figure - 3.1 a) AZ 91D plate b) AZ91D Specimen

The magnesium alloy plates are available in small cubic pieces of 10mm x 10mm dimensions after metal cutting process. Those small pieces of 8mm thick AZ91D are filed on their edges for attaining roundness. Sharp edges are not recommended to use and they do not fit with HVOF thermal spray machine's work piece holder.

3.3 HVOF coating

In the combustion chamber, gases or flammable liquids are combined with oxygen, ignited, and subjected to a continual burning process. Produced at a pressure of about 1 MPa, hot gases move in the direction of the front of a convergent-divergent nozzle. Hydrogen, methane, propane, propylene, acetylene, natural gas, etc. are examples of gases; kerosene, etc. is an example of a flammable liquid. The gas flow leaving the barrel is moving faster than sound, at a speed of more than 1000 m/s. Powdered feedstock is injected into this gas flow, causing the powder particles to reach speeds of up to 800 m/s. This stream, which is a mixture of hot gases and powder, is impinged on the surface (substrate) to be coated. These needles partially melt during the flow and settle on the surface.

In our study, in order to maintain the friction, Aluminium Oxide coating is done using the HVOF method. The aluminium metal is heated to a higher temperature and is sprayed over the surface of the magnesium materials. During the spraying process, the aluminium mixes and reacts with the atmospheric oxygen and forms the aluminium oxide and deposits over the surface of the materials.

Table – 3.2 Coating Specifications

SI No	Base Metal Alloy	Coating Material	Coating Thickness (microns)	Time Taken (hours)
1	AZ91D	Al_2O_3	5	2.5
2			20	4
3		Zn	5	2.5
4			20	4

In AZ91D magnesium alloy, Al_2O_3 is coated with 5micron thickness in a specimen and with 20micron thickness in another specimen. Thus the variations in coating thickness were made to analyze their difference in corrosion behavior.

3.4 CORROSION TEST

Corrosion testing evaluates a material's corrosion resistance under various environmental conditions, such as salt water, temperature, and humidity. So to test the coated samples with non-coated ones to find the effective corrosion resisting one, we found Salt spray testing and Hot acid corrosion test would be effective. Based on our research with previously papers and articles, we found that Hot acid corrosion test is one of the advanced industrial test that is used among the industries to check on their material's corrosion resistance. It destroys the material completely on the acid medium used, to identify the corrosion rate in a material. This test takes comparatively lesser time than salt spray test and brings out the differences in corrosion resistance behaviour of the four coated samples and non-coated samples in much effective way.

3.4.1 HOT ACID CORROSION TEST

Hot acid corrosion test implementation differs based on the equipment used. To perform hot acid corrosion test, three specimens can be placed into it in one particular time. After the complete corrosion process completion for the first three specimens, the next three goes into the equipment.

Loading of the specimens into the machine is done by taking the three specimens in a glass rod and inserting deep into the machine where the corrosion process takes place. Each set of specimens were taken out at 4 hours, 8 hours and 16 hours to record its corrosion rate parameters. The corrosion rate parameter is mainly its weight loss (in grams) with time and it is plotted in a graph for three different time outputs 4 hours, 8 hours and 16 hours.

After this process, based on the result obtained, the corrosion rate determining calculations are performed and compared.

4. RESULTS AND DISCUSSIONS

After being properly cleaned with deionized water, the samples were dried in a hot oven for ten minutes. According to ASTM guidelines, a 3.5% NaCl solution was prepared for an immersion test to assess the rate of corrosion.

Table 4.1- Corrosion rate for time duration

Material	Weight Loss (g)	Time duration (hr)	Corrosion Rate (mm/year)
AZ91D	0.0011765	4	26.06
	0.0011765	8	13.03
	0.0011765	16	6.51
	0.0011765	24	4.5
	0.0011765	72	2.49

The corrosion rate of AZ91D is high at starting time and then it reduces when time increases. This happens because a thin protective layer forms on the surface during corrosion. As time goes, this layer slow down the further corrosion. So overall corrosion become less with more exposure time.

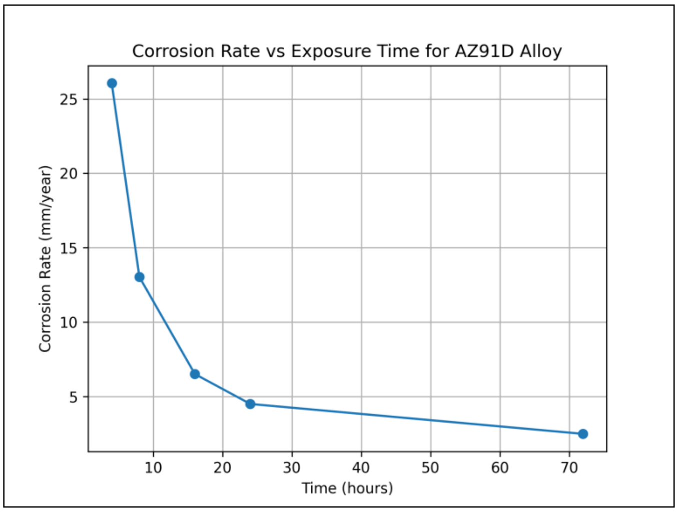

Fig -4.1: Corrosion rate Vs Exposure Time AZ91D alloy

The Figure 4.1 showed that corrosion rate is high in starting and then it decrease with increase in time. At 4 hours it is very high, but after that it drops quickly. This happens because protective layer forms on the surface. So corrosion become slower as time goes on.

5. CONCLUSIONS

In the present study, AZ91D Mg alloys were coated with aluminium oxide with two different coating thickness of 5 and 20 microns. AZ91D have show significant changes. Therefore, from the analytical data, it can be inferred that the anti-corrosion performance of AZ 91 D with a thickness of 20 microns had a significant impact on corrosion. Furthermore, it has also been observed that the corrosion rate decreased after coating, as a result of the zinc and aluminum oxide properties of the coating material. According to our research, a small increase in the hardness of coated materials can increase their corrosion rate. This makes magnesium alloys attractive choices for automotive applications where parts must operate in corrosive environments. To meet our need for reliable data on different acid concentrations, we may use the hot acid corrosion test in the future.

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