

Influence of HVOF Coating Thickness on Corrosion Behaviour of AZ31B Magnesium Alloy

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Abstract - The lightweight alloy feature of magnesium alloys is our primary concern in the field of numerous transportation-related applications and many more. The study reveals that recent years have seen the utilization of magnesium alloys, such as AZ31B, for a wide range of purposes. However, because of its weak resistance to corrosion, pure magnesium alloy cannot be employed directly in many such applications. This factor limits our ability to use this information effectively. For years, numerous investigations have been conducted to increase the corrosion resistance of magnesium alloys. According to researchers, covering magnesium alloy with another substance significantly enhances its corrosion resistance. Additionally, we discovered that the high-velocity oxygen fuel coating process meets our need to enhance the AZ31B magnesium alloys' corrosion resistance. Choose this coating technique, and we also discovered that coating ingredients aluminum oxide work well on magnesium alloys. Lastly, determine which magnesium alloy of the samples we looked at is the most corrosion-resistant.

Key Words: Mg Alloy AZ31B, HVOF, Al₂O₃, Zn, corrosion resistance.

1. INTRODUCTION

The natural phenomenon of corrosion causes the formation of chemically stable products such as sulfides, hydroxides, and oxides from pure metals. Corrosion is the phenomenon in which the materials, primarily metals, are deteriorated electrochemically and chemically in their environment. Corrosion is explained by electrochemical oxidation in which metals oxidize due to some oxidizers existing in the environment. The rusting process is an example of this phenomenon as it causes electrochemical corrosion of metals leading to the formation of iron oxides. There is the formation of oxides and salts of the metal because of electrochemical corrosion, which causes an orange tinge on the metal surface. Corrosion may be a phenomenon occurring to materials other than metals; however, the general term used to denote this is degradation.

1.1 TYPES OF CORROSION

1.1.1 Pitting Corrosion

Pitting Corrosion in the form of pitting is observed frequently in magnesium alloys such as AZ31B especially under chloride environments. Magnesium has an unstable oxide film that can break up, resulting in formation of small pits which act as active sites and cause corrosion to go deeper into the material. In the case of HVOF coatings, pores or imperfections in coating could result in corrosive liquid reaching the underlying material, thus increasing pitting effects.

1.1.2 Erosion-corrosion

Erosion-corrosion is caused due to mechanical wear along with corrosion. When the material comes in contact with moving fluid, its protective film is stripped away continuously. This leads to corrosion at the newly exposed material surface. HVOF coatings have high resistance against erosion-corrosion, but their efficacy decreases as thickness of coatings is less and porosity is high.

1.1.3 Galvanic Corrosion

Galvanic corrosion arises when there is potential difference between coating and magnesium alloy substrate. If the coating is of higher nobility than magnesium alloy, then exposed magnesium areas corrode fast. This type of corrosion is usually seen when coating is uneven or contains defects. Correct coating and proper application method are essential for avoiding galvanic corrosion.

1.2 SURFACE ENGINEERING APPROACHES FOR CORROSION PROTECTION

The magnesium alloy AZ31B belongs to highly reactive materials which can easily corrode when exposed to surroundings. Therefore, in order to increase durability and service life of this alloy, surface treatment plays a important role. Otherwise, this magnesium alloy cannot be practically applied in many cases due to the lack of protective measures. Surface treatment technologies that help reduce corrosion properties of alloys include anodizing, chemical conversion coatings, electroplating, and thermal spraying. However, coating procedures are usually more widespread since they form a barrier between the alloy surface and surrounding corrosive environment, slowing down the rate of interaction. Recently, thermal spraying techniques have been increasingly

applied to prevent metal from corrosion. HVOF coatings provide excellent quality by means of producing dense layer with high bonding and reduced porosity which prevent any corrosive substances from contacting metal. In addition, their efficiency mostly depends on coating thickness and adherence.

1.2 COATING

Surface coating is extensively used as one way of protecting the AZ31B magnesium alloy from corrosion by forming a protective film over the surface of the metal. Being highly reactive metal, the alloy is prone to easy corrosion when placed in an aggressive or moist environment. Thus, the use of a coating reduces the level of interaction of the metal with the environment and extends its life span. The coatings may have various modes of operation based on the composition of the coating material. Thus, for some coating materials, there is a sacrificial protection mode wherein the coating material corrodes before corrosion affects the base metal, while for other coatings the mode is purely protective. For the AZ31B alloy, barrier-type coatings are usually preferable due to their reduced environmental interaction.

1.3 HIGH VELOCITY OXYGEN FUEL COATING METHOD

High Velocity Oxy-Fuel (HVOF) coating process is one of the sophisticated thermal spray processes applied for improvement in surface properties of AZ31B magnesium alloys. In this process, the fuel gas and oxygen are injected in the combustion chamber where ignition occurs and results in extremely high-temperature flame. The flame further causes generation of high velocity gas flow which transports the coating particles to the substrate surface. During spraying, the powder particles become molten or semi-molten state and get impacted on the surface at a high velocity. Due to high impact, the particles become flattened resulting in formation of dense coating layer. This layer exhibits excellent bonding with the substrate and hence provides protection against corrosion. It is known that other coating processes result in relatively higher porosity coating layers than HVOF coating layer. Hence, there are minimum chances of entry of corrosive media through pores. One of the significant advantages associated with HVOF coating layer is its excellent adhesion property with substrate, which offers superior stability against corrosion under adverse conditions. Moreover, coating thickness can also be varied according to requirement.

However, the quality of the coating depends on a lot of factors, such as the spraying distance, fuel-air ratio, particle velocity, and temperature. Failure to control these factors could lead to the creation of faults like pores and cracks in the coating. Such faults could reduce the effectiveness of the coating as well as initiate the process of corrosion.

2. LITERATURE SURVEY

Hu et al., presented different types of corrosion occurring in magnesium alloys, along with the different influences on their corrosion behavior. From the above study, it becomes evident that corrosion in magnesium alloys is not only uniform but can also be localized according to the conditions present.

Furthermore, it was found that composition and microstructure are some of the important properties which have an impact on corrosion resistance of magnesium alloys. The study concludes that surface modifications play an important role in improving the performance of magnesium alloys.

Nguyen et al., studied the characteristics of AZ31B magnesium alloy and its composites having nanocrystals as the reinforcing material. The study was mostly based on the wear behavior and surface characteristics of the alloy. The study revealed that the addition of reinforcing material helps to increase the hardness and reduce surface wear. It has indirect implications for improved corrosion resistance.

According to Jonda et al., WC-based coatings were applied on AZ31 magnesium alloy by HVOF coating process. Microstructure analysis revealed that the applied coating is uniform and strongly bonded with substrate material. It was concluded that this coating protects the magnesium alloy from the attack of corrosion environment directly. The dense structure of applied coating prevents corrosion attack. Thus, it is clear from the study that HVOF coatings are useful for improving the surface properties of magnesium alloys.

In another study, Sun et al. applied Fe-based amorphous coatings on magnesium alloys through HVOF coating process. In this study, effect of different environmental conditions on corrosion behavior of magnesium alloys were investigated. It was concluded that dense structure of applied coating minimizes the penetration of corrosive materials. Consequently, corrosion rate was lower than the rate exhibited by uncoated samples.

In their study, Thirumalaikumarasamy et al., investigated the corrosion behavior of AZ31B magnesium alloy coated with alumina and deposited by plasma spray technique in the presence of chloride. From the results of their investigation, it can be concluded that coating of the metal with alumina provides corrosion protection of the metal surface through minimizing the effects of corrosive elements on the metal surface. Coated samples were found to corrode slower compared to uncoated samples. It is clear that the performance of the metal in terms of corrosion depends significantly on the thickness and porosity of the coating.

3. MATERIALS AND METHODS

3.1 SELECTION OF MATERIALS

Selection of materials is very important for designing and manufacturing any part. Selection of materials depends on the use of materials in a particular application. There are possibilities that the part fails during its operational lifetime if the material of the same strength value is used for other applications. Different types of magnesium alloys meet our requirements.

3.1.1. MAGNESIUM ALLOY- AZ31B

Magnesium alloys are among the lightest structural metals available. Magnesium AZ31B 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 AZ31B

Elements	Content (%)
Magnesium	97
Aluminum	2.50 - 3.50
Zinc	0.60 - 1.40
Manganese	0.20
Silicon	0.10
Copper	0.050
Calcium	0.040
Iron	0.0050
Nickel	0.0050

3.2 MATERIAL PROCESSING

selected materials AZ31B 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 AZ31B plates of 8mm x 200mm x 200mm and two magnesium alloy AZ31B plates of 6mm x 200mm x 200mm were the materials procured for our study.



Figure - 3.1 a) AZ 31B plate b) AZ31B Specimen

The magnesium alloy plates are available in small cubic pieces of 10mm x 10mm dimensions after metal cutting process. Those small pieces of 6mm thick AZ31B and 8mm thick AZ31B 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 impinging 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	AZ31B	Al ₂ O ₃	5	2.5
2			20	4

In AZ31B magnesium alloy, Al₂O₃ is coated with 5micron thickness in a specimen and with 20micron thickness in another specimen. In the same alloy AZ31B, 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. 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	Time duration (hr)	Corrosion Rate

	(g)		(mm/year)
AZ31B	0.000628	4	17.65
	0.000628	8	8.82
	0.000628	16	4.414
	0.000628	24	2.94
	0.000628	72	1.08

The corrosion rate of AZ31B 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.

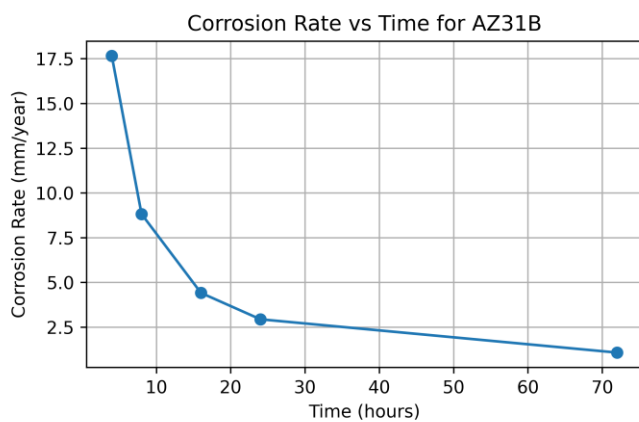


Fig -4.1: Corrosion rate Vs Exposure Time AZ31B alloy

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, AZ31B Mg alloys were coated with aluminium oxide with two different coating thickness of 5 and 20 microns. AZ31B have show significant changes. Therefore, from the analytical data, it can be inferred that the anti-corrosion performance of AZ31B 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 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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