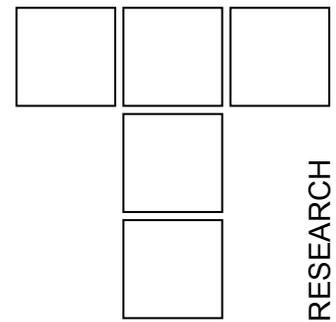


# Corrosion of Aluminium and Zinc-Aluminium Alloys Based Metal-Matrix Composites



*Corrosion behaviour of metal-matrix composites (MMCs) with aluminium and zinc-aluminium alloy substrate was discussed. MMCs corrosion forms and parameters affecting MMCs corrosion were described as well as corrosion testing methods. The corrosion characteristics of MMCs with zinc-aluminium alloy ZA-27 matrix reinforced by graphite particles, glass fibres and zircon particles were presented.*

**Keywords:** metal-matrix composites, corrosion, galvanic corrosion, pitting corrosion, corrosion testing, aluminium, zinc-aluminium alloys

## 1. INTRODUCTION

Metal-matrix composites (MMCs) are combinations of a metal or an alloy with a finite fraction (by volume or by weight) of second phase, generally ceramic, that is deliberately introduced into the metal in order to improve its properties /1/. MMCs are a class of materials with potential for a wide variety of structural and thermal applications. They can be tailored to give improved strength, stiffness, thermal conductivity, abrasion resistance, creep resistance, or dimensional stability. The successful application of MMCs requires adequate corrosion resistance as well.

In a MMC, the continuous, or matrix phase is a monolithic alloy, and the reinforcement consists of carbon, metallic or ceramic additions. Reinforcements, continuous or discontinuous, may constitute 10 to 60 vol % of the composite. Metal matrix imparts a metallic nature to the composite in terms of thermal and electrical conductivity, manufacturing operations and interaction with the environment /2/. The second phase may be in the form of fibers, monofilaments or particles. The fibers and particles can be metal (such as tungsten), non-metal (carbon or boron), or ceramic (SiC or Al<sub>2</sub>O<sub>3</sub>) /1/. For example, fibers and particles are

used in MMCs to increase stiffness, strength and thermal conductivity and to reduce weight, thermal expansion, friction and wear. Generally, the improvements that are achieved in the properties of the particulate reinforced metals (PRMs) are less extensive than with fibrous reinforcements. However, besides the lower cost, the PRMs possess the additional advantages of having generally isotropic properties, and of being mostly compatible with most metal working process (machining, deformation processing, welding), particularly when the ceramic volume fraction is below 30 % /1/.

PRMs can provide excellent resistance to both sliding wear and abrasion /1/. Good tribological performance is seen under conditions of mild sliding wear. PRMs can show significantly lower wear rates than unreinforced alloys over a substantially wider range of pressure and sliding speed. In general, factors such as increasing reinforcement size, hardness and fracture toughness, stronger matrix-reinforcement interface bonding and increasing reinforcement volume fraction lead to better tribological performance /1/. However, major enhancement of wear resistance in the severe sliding wear regime, or to high-stress abrasion, cannot be expected from these composites.

Zinc-based alloys with high amount of aluminium (designated as ZA alloys) comprise a family of die-casting alloys that have proven themselves in a wide variety of demanding applications /3/. The members of the ZA casting alloys are ZA-8, ZA-12 and ZA-27 alloy. These alloys combine high strength and hardness, good machinability with good bearing properties and wear resistance often

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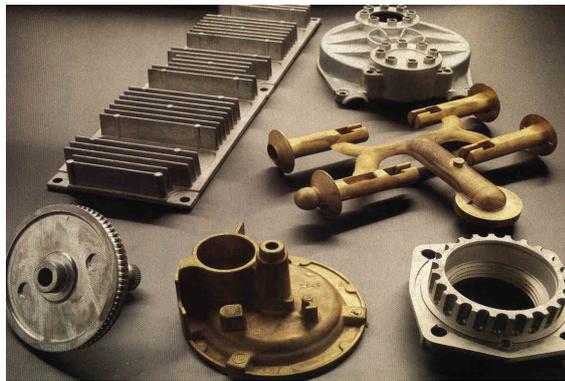
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superior to standard bronze alloys. Zinc-aluminium alloys are known to possess excellent bearing properties particularly at high load and low speed /4/. They have found increasing use for many applications and have competed effectively against copper, aluminium and iron-base foundry alloys. However, the elevated temperature ( $> 100^{\circ}\text{C}$ ) properties of zinc-aluminium alloys are unsatisfactory and restrict their use in some applications. One promising approach to improve the elevated temperature properties was reinforcing the alloys with SiC fibers or particles, alumina particles and fibers, glass fibers etc. /5/.

ZA-27 alloy has the highest strength and the lowest density of the ZA alloys, as well as excellent bearing and wear resistance properties. Some examples of ZA-27 alloy application are presented in Fig. 1. This alloy also provides the highest design stress capability at elevated temperatures of all the commercially available zinc-based alloys.



**Figure 1.** Application of ZA-27 alloy

Notwithstanding this, the use of this alloy is rather limited because of drastic decrease of strength and creep resistance at temperatures above  $80^{\circ}\text{C}$ . Strengthening by ceramic particles or fibers is destined to improve strength to weight ratio and to increase tensile strength and creep resistance at higher working temperatures. The addition of 10 vol % SiC fibers to ZA-27 alloy does not improve tensile strength at room temperature, but does contribute considerably to improving strength at high temperatures /6/. The improvement in wear behavior has also been reported for Zn-Al alloys with aforementioned reinforcements. The results of tribological investigations of composites with ZA-27 alloy substrate reinforced by  $\text{Al}_2\text{O}_3$  particles of different size /7/ or by graphite particles /8/ has been presented most recently. The investigated composite materials have shown significantly higher wear resistance than the matrix ZA-27 alloy /7, 8/.

All the zinc-aluminium alloys have excellent resistance to corrosion in a variety of environments /3/. However, there has been a lack of specific

corrosion data of zinc-aluminium based MMCs and their corrosion resistance to date, because of very limited use of zinc-aluminium alloys as matrix material for MMCs.

Most of the commercial work on MMCs has focused on aluminium as the matrix metal. The combination of light weight, environmental resistance and favourable mechanical properties has made aluminium alloys very popular for use as a matrix metal. Aluminium and its alloys have been used as a matrix for a variety of reinforcements: continuous boron,  $\text{Al}_2\text{O}_3$ , SiC and graphite fibers, various particles, short fibers and whiskers. As a result, advanced metal matrix composites with improved mechanical, physical and tribological characteristics, were obtained.

The corrosion behaviour of a metal-matrix composite in various environments is one important consideration when choosing a suitable material for a particular purpose. The presence of the reinforcement fibers and particles and the processing associated with MMCs fabrication can cause accelerated corrosion of the metal matrix compared to corrosion of the unreinforced matrix alloy /9/. In general, corrosion behaviour of aluminium MMCs has been studied most extensively, while there has been hardly any information available on the corrosion behaviour of zinc-aluminium based composites.

## 2. CORROSION FORMS IN MMCS

Corrosion can affect the metal matrix composite in a variety of ways which depend on its nature and the environmental conditions prevailing. A broad classification of the various forms of corrosion is presented in /10/.

**Uniform (or general) corrosion** is characterized by corrosive attack proceeding evenly over the entire surface area or a large fraction of the total area /11/. General thinning takes place until failure. Uniform corrosion is relatively easily measured and predicted. In many cases it is objectionable only from an appearance standpoint. Zinc-aluminium alloys corrode in a uniform manner, unlike aluminium alloys which are prone to pitting corrosion.

**Pitting corrosion** is a localized form of corrosion by which cavities or “holes” are produced in the material /11/. Pitting is considered to be far more dangerous than uniform corrosion because a small, narrow pit, with minimal overall metal loss, can lead to the perforation i.e. to the failure of an entire engineering system. This form of corrosion is more difficult to predict than uniform or galvanic

corrosion. Pitting corrosion occurs when discrete areas of a material undergo rapid attack while most of the adjacent surface remains virtually unaffected. Apart from the localized loss of thickness, corrosion pits can also be harmful by acting as stress concentrators. Stress corrosion cracking and corrosion fatigue may initiate at the base of corrosion pits /11/.

**Galvanic corrosion** occurs when dissimilar metallic materials are brought into contact in the presence of an electrolyte /11/. An electrochemical corrosion cell is set up due to differences in the corrosion potentials of the dissimilar materials. The material with the more noble corrosion potential then becomes the cathode of the corrosion cell, whereas the less noble material is consumed by anodic dissolution. Galvanic corrosion occurs at the anodic member of such a couple and is directly related to the galvanic current by Faraday's law. This corrosion form can also happen between metals and other conducting materials such as carbon and graphite /11/. Galvanic corrosion has been identified as a primary corrosion mechanism for graphite/aluminium composites in aerated solutions /12/.

**Crevice corrosion** is a localized form of corrosion usually associated with a stagnant solution on the microenvironmental level /11/. Such stagnant microenvironments tend to occur in crevices. Because oxygen diffusion into the crevice is restricted, a differential aeration cell tends to be set up between crevice (microenvironment) and the external surface (bulk environment). The cathodic oxygen reduction reaction cannot be sustained in the crevice area, giving it an anodic character in the concentration cell. This anodic imbalance can lead to the creation of highly corrosive microenvironmental conditions in the crevice, conducive to further metal dissolution.

**Stress corrosion cracking** is the cracking induced from the combined influence of tensile stress and a corrosive medium /11/. The required tensile stresses may be in the form of directly applied stresses or residual stresses. Cold deformation and forming, welding, heat treatment, machining and grinding can introduce residual stresses. SCC usually occurs in certain specific alloy-environment-stress combinations. Usually, most of the metal surface remains unattacked, but with fine cracks (intergranular or transgranular) penetrating into the material.

**Corrosion fatigue** is caused by crack development under the simultaneous action of corrosion and fluctuating, or cyclic stress /12/. The number of cycles to failure, the fatigue life, increases as the

maximum stress during cycling decreases until the endurance limit, or fatigue limit is reached. Both the fatigue life and the fatigue limit can be markedly reduced in the presence of a corrosive environment. The damage due to corrosion fatigue is almost always much greater than the sum of the damage by corrosion and fatigue acting separately. In general, a corrosive environment can decrease the fatigue properties of any engineering alloy, meaning that corrosion fatigue is not material-environment specific /12/.

**Microbial corrosion** of metals is closely associated with the formation of complex microbial biofilms on surfaces /12/. The microbial communities induce the formation of differential aeration cells under aerobic conditions because dissolved oxygen is consumed within microbial colonies. This decrease in oxygen levels provides an opportunity for anaerobic microorganisms to be established within biofilms. The attack of metal materials by microorganisms can take place either directly or indirectly, depending on a combination of factors such as metal composition, the nature of the surface, the extent of bacterial adhesion on surfaces, ionic strength of the solution, hydrodynamic conditions etc.

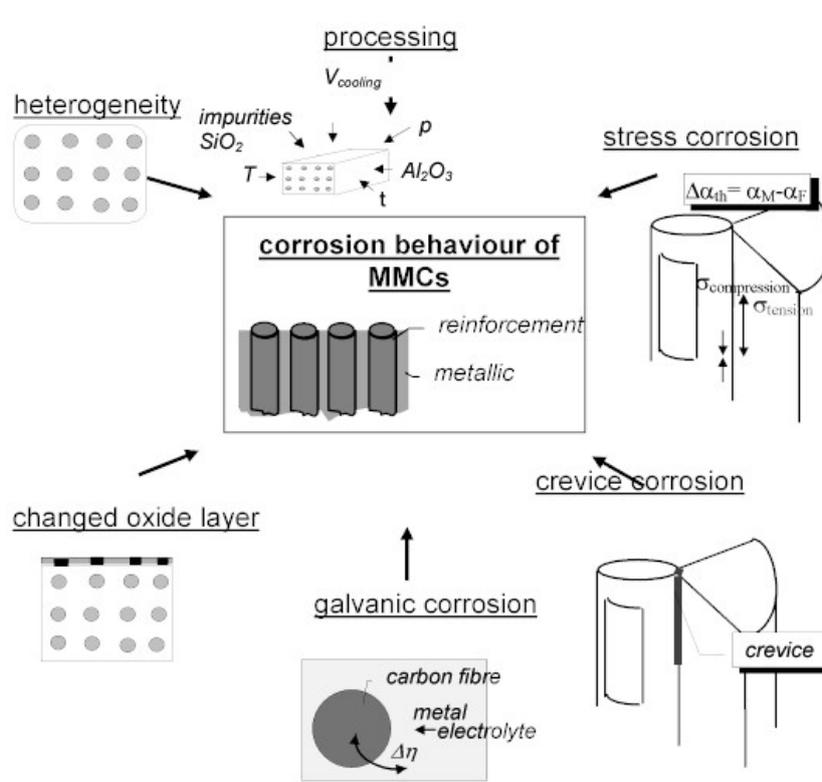
**Tribocorrosion** is an irreversible transformation of a metal resulting from mechanical and chemical/electrochemical interactions between surfaces in relative motion in the presence of a corrosive environment /13/. Tribocorrosion affects the friction, wear and lubrication behaviour of the tribological systems. Tribocorrosion phenomena are encountered in many technological areas where they cause damage to installations, machines and devices. Examples of tribocorrosion systems are pumps for corrosive liquids, orthopedic implants and food processing equipment. The chemo-mechanical mechanisms of tribocorrosion are still incompletely understood, because they involve the properties of contacting material surfaces, the mechanics of the contact and the corrosion conditions.

### 3. PARAMETERS AFFECTING MMCS CORROSION

One important advantage of the MMCs is the opportunity to tailor absolutely new properties due to the integration of reinforcements into the metallic matrix. The selection of matrix metal and reinforcing phase is generally based on the achieving of desired composite properties, while the interaction between produced MMC and its environment is usually of secondary importance /9/. Therefore, it is not uncommon for MMCs to have

lower corrosion resistance comparing to the monolithic matrix alloy. The presence of the reinforcement fibers and particles and the processing associated with MMC fabrication can cause accelerated corrosion of the metal matrix

compared to corrosion of the unreinforced matrix alloy /9/. As visible in Fig. 2, the corrosion behaviour of MMCs is determined by a variety of different influences.



**Figure 2.** The parameters influencing electrochemical corrosion of MMCs /14/

Accelerated corrosion may originate from electrochemical and chemical interaction between MMC constituents, microstructural effects and from problems related to processing /9/. The primary sources of MMCs corrosion include:

- galvanic corrosion between MMC constituents,
- chemical degradation of interphases and reinforcements,
- microstructure influenced corrosion and
- processing induced corrosion.

**Galvanic corrosion between MMC constituents**

The degree of galvanic corrosion in MMCs depends on the matrix alloy and on the reinforcement electrochemistry, as well as on the environment /9/. The reinforcements effect on corrosion appears to be also related to their geometry, volume fraction and electrical properties. Common reinforcements such as SiC, Al<sub>2</sub>O<sub>3</sub> and graphite are more noble than the metallic matrices, especially in the presence of air and chloride ions. Many reinforcement materials are either semiconductors (SiC) or insulators (Al<sub>2</sub>O<sub>3</sub> and mica). For reinforcements with very high resistivities, large ohmic losses through the reinforcement may limit galvanic corrosion significantly. If the

reinforcements that is used in a MMC is not of high purity, the electric resistivity may drop significantly, allowing galvanic corrosion to occur /9/. For example, SiC/Al MMCs are fabricated from both high-purity green SiC and lower purity black SiC, depending on the application. The resistivity of silicon carbide may vary by approximately 18 orders of magnitude, depending on its purity /9/. In fact, many reinforcement materials have electrical resistivities that are not high enough to prevent galvanic corrosion.

Galvanic corrosion in MMCs reinforced with conductive noble reinforcements is a concern in those environments in which the matrix metal corrodes actively. In cases where galvanic corrosion is under cathodic control, the composition of the reinforcement may affect the kinetic of hydrogen evolution and oxygen reduction, i.e. the rate of galvanic corrosion. During MMCs fabrication, reactions between the reinforcement and matrix may lead to the formation of an interphase or intermetallics at the reinforcement-matrix interface. If the interphase or intermetallic is better cathode than the reinforcement, then galvanic corrosion in MMC could be more severe than that predicted on the base of pure MMC constituents /9/.

**Chemical degradation of interphases and reinforcements** Reinforcement phases and interphases may undergo chemical degradation that cannot be predicted. A very important chemical degradation in aluminium MMCs is the hydrolysis of the  $Al_4C_3$  interphase /9/. Aluminium carbide degradation may affect both graphite-fiber and SiC reinforced aluminium MMCs. Reinforcement phases may also experience other forms of degradation. It has been reported /11/ that mica particles in mica/aluminium MMCs undergo exfoliation.

**Microstructure influenced corrosion** MMCs corrosion may be influenced by microstructural features due to the presence of reinforcements. Intermetallic phases may form around reinforcements during composite solidification /15/. Intermetallics may have potentials and corrosion resistance different than the matrix. Noble and inert intermetallics may induce galvanic corrosion of the matrix, as discussed previously /9/. Active intermetallics may corrode and leave fissures or crevices in MMC (during dissolution).

High strength of particulate MMCs in comparison to their monolithic alloys is generated by high dislocation densities caused by a mismatch in the coefficients of thermal expansion between reinforcement and matrix /16/. Higher dislocation densities may affect the MMCs corrosion, i.e. they may increase corrosion rates in some MMCs /12/ It has been suggested that corrosion near the SiC-Al interface in SiC/Al MMCs could be caused by high dislocation density due to mismatch of the coefficients of thermal expansion between SiC and aluminium /17/.

The physical presence of the reinforcements may also have secondary effects on MMCs corrosion. For example, aluminium MMCs undergo significant corrosion in the open circuit conditions during immersion, even in chloride-free electrolytes. The formation of localized corroded regions in aluminium MMCs usually appears after several days of immersion /18/. The reinforcement particles (Si), which are inert in comparison to the matrix, are left in relief as the matrix corrodes, leaving behind a network of fissures that becomes either acidified or alkalinized, preventing matrix passivation /18/.

**Processing induced corrosion** Corrosion problems that do not directly arise from the reinforcement, matrix alloy, or their interaction, are usually induced by composite processing. Examples are corrosion of diffusion bonds and corrosion due to microstructural chlorides /9/. The boron/Al and graphite/Al MMCs have been fabricated using

techniques where aluminium foils and filaments are consolidated by diffusion bonding. If the diffusion bonds are of low integrity or contaminated, severe corrosion damage may result.

The microstructural chlorides, that were accidentally introduced by  $TiCl_4$  and  $BCl_3$  gases during processing some types of graphite/Al MMCs, has induced corrosion in the graphite/Al MMCs even in chloride-free environments and the occurrence of pitting has been noticed /19/.

The corrosion resistance of particulate reinforced metals (PRMs) is strongly influenced by the conditions of fabrication and processing, which may lead to the formation of an interphase between the matrix and reinforcement, interfacial stresses as well as high dislocation density in the matrix.

#### 4. CORROSION TESTING OF MMCs

The MMCs corrosion is the result of complex electrochemical interactions. An understanding of these interactions and the mechanisms of corrosion is essential to the continued development of corrosion resistant MMCs /20/. This understanding can only come from carefully planned and executed experiments. In order to apply a particular MMC, it is important to know the expected lifetime of the MMC.

MMCs corrosion test methods are specific and must be based on the conditions prevailing in certain environments and applications. A large number of factors affect corrosion behaviour of MMCs and therefore there is no universal corrosion test. Over time, laboratory tests have proven to be the most reliable and simple mean to generate information for the selection of materials /21/. Laboratory corrosion tests are subdivided into four categories: cabinet tests, immersion tests, high-pressure/high temperature tests and electrochemical tests. These four categories represent different sets of conditions accelerating corrosion processes.

**Cabinet tests** refer to tests conducted in closed cabinets where the conditions of exposure are controlled and mostly designed to accelerate specific corrosion situations. These tests are generally used to determine the corrosion performance of materials intended for use in natural atmospheres. In order to correlate test results with service performance, it is necessary to establish acceleration factors and to verify that the corrosion mechanisms are following the same paths. There are basically three types of cabinet tests: controlled humidity tests, corrosive gas tests and salt spray testing.

**Immersion tests** are the quickest and most economical means for providing a preliminary selection of best suited materials, but there is no simple way to extrapolate the results obtained from these simple tests to the prediction of a material lifetime. In these tests acceleration is achieved principally by intensifying the conditions (solution acidity, salt concentration, temperature) in order to increase MMCs corrosion rate. However, the degree of acceleration is unknown and no real consensus exists on the best solution concentration to use /20/.

Cabinet tests and immersion tests (exposure tests) are commonly used for ranking the performance of a group of related alloys and assessing quality control. Ideally, these tests should be conducted in actual service environments, but very few references in the literature cite service or environmental exposure results for MMCs. Most immersion test results found in the MMCs corrosion literature are for exposures in either acid or chloride environments. The concentration of the aggressive species (chloride or hydrogen ions) in these tests is typically greater than that expected during actual service /20/. Several investigators have used a 3,5 or 5 wt % NaCl solution for the chloride exposures of MMCs.

Weight loss measurements following exposure or immersion in a corrosive media is a standard method used for assessing corrosion resistance /20/. Immersion testing can also be used in conjunction with other experimental methods, such as mechanical tests, to assess corrosion resistance.

Much of the corrosion literature for MMCs consists of simple immersion and salt spray test results. Data from these tests can provide useful information for some simple systems. However, the results of these tests are often not discriminating enough to separate similar types of alloys, and they do not provide information concerning the nature of corrosion mechanisms in MMCs /20/. In fact, the mechanism of degradation in an artificial environment, such as the salt-fog chamber, is often quite different than the operative mechanism in a natural environment. This difference in mechanism could lead to design decisions based on totally inappropriate data. Electrochemical test methods provide another means for evaluating corrosion resistance, and they can also be used to elucidate important mechanistic information.

MMCs susceptibility to pitting and crevice corrosion, as well as to other forms of corrosion, is typically evaluated by exposure testing or through the use of one or more electrochemical test methods /20/. Exposure tests provide information on the

weight loss, on the number of pit or crevice sites present on the specimen surface and the maximum pit or crevice depth. Electrochemical test methods indicate how the passive characteristics of one alloy compare to those of another and provide insight into the mechanisms responsible for corrosion.

**High-temperature/high-pressure tests** in an autoclave are a convenient means for laboratory simulation of many service environments. Four different variations of common HT/HP test method are described in detail in /21/.

**Electrochemical tests** yield information concerning corrosion mechanisms as well as information on corrosion rates. Electrochemical methods involve the determination of specific metal/solution interface properties. Prior to start an electrochemical test, it is customary to monitor the open circuit potential or corrosion potential for a period of time. Monitoring of the potential should be conducted for a long enough period of time to ensure that steady-state conditions exist between the MMC and its environment /20/. The length of time needed to establish a steady-state open circuit potential can vary from a few minutes to several weeks, depending on the particular MMC/environment combination. In some cases, the initial open circuit potential versus time behavior for MMCs reveals significant instabilities. The instabilities are the reason that the open circuit potentials are monitored prior initiating electrochemical experiments that rely on steady-state behavior, such as polarization tests.

Polarization experiments are the most commonly used electrochemical tests for assessing corrosion behavior of MMCs. Of specific interest are: anodic polarization, cyclic polarization and polarization resistance /20/. In general, polarization tests involve the potential changing of working electrode at a selected rate and monitoring the current which is produced as a function of time or potential. Anodic polarization curves provide useful information concerning the potential range over which a material is passive, the ease of achieving passivity, the amount of protection afforded by the passive film and the susceptibility to pitting /20/.

The potential is swept in a single cycle and the size of the hysteresis is examined along with the differences between the values of the starting corrosion potential and the return passivation potential. The existence of the hysteresis is usually indicative of pitting, while the size of the loop is often related to the amount of pitting /21/. The onset of pitting is marked by a sudden increase in the current density: the potential where this increase occurs is called the pitting potential. The higher the

pitting potential, the less susceptible the material is to pitting /2/. The cyclic polarization technique has been frequently used in investigations of corrosion behaviour of aluminium and aluminium alloys based MMCs

Another widely used polarization method is linear polarization resistance /20, 21/. This technique involves polarizing the specimen a few millivolts above and below the open circuit potential and measuring the current response. The polarization resistance determined can be used to calculate corrosion current density i.e. the MMC corrosion rate (uniform corrosion).

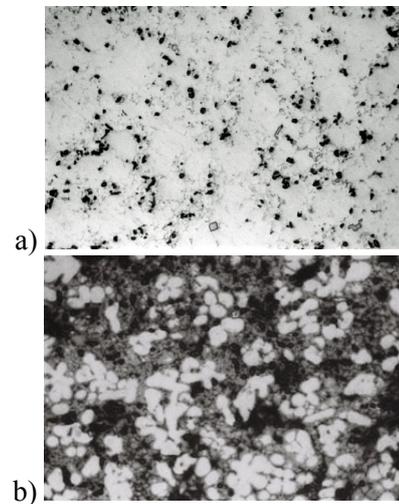
In general, polarization techniques can provide significant useful information regarding the corrosion mechanisms, corrosion rate and susceptibility to corrosion of specific materials (MMC) in designated environments /21/. Therefore, corrosion data under relevant conditions are necessary.

## 5. CORROSION BEHAVIOUR OF ZINC-ALUMINIUM ALLOY BASED METAL MATRIX COMPOSITES

As it was stated earlier, among the zinc-based foundry alloys used as matrix materials, the ZA family of alloys has been particularly popular. These alloys have some advantages over aluminium-based alloys, namely high strength and low casting temperatures, and have been used for lower cost replacements of bronze and brass castings /3, 4/. ZA-27 alloy, in particular, has been used in bearings and bushing applications as a replacement for bronze bearings because of the lower cost and equivalent or superior bearing performance.

All the zinc-aluminium alloys have excellent resistance to corrosion in a variety of environments /3/. In general terms, the presence of aluminium in the alloy enhances the well-known corrosion resistance of zinc, which is the main constituent of the alloys. Zinc-aluminium alloys corrode in a uniform manner. ZA alloys in the as-cast condition have adequate corrosion resistance for most atmospheric environments due to formation of a passive layer on the metal surface, which generally inhibits further corrosion attack /4/. Under more aggressive conditions such as marine environments, additional corrosion protection should be considered. As-cast ZA alloys can be anodized, painted, electroplated, chromated or polished. The type of finish selected will largely depend on service conditions, aesthetics and cost /4/.

Some of the widely accepted reinforcing materials in MMCs with zinc-aluminium alloys substrate include silicon carbide (particles, fibers), mica, zircon and graphite /5/. The microstructure of SiC<sub>p</sub>/ZA-27 composite (with 1 wt % SiC particles) is presented in Fig. 3.



**Figure 3.** Microstructure of SiC<sub>p</sub>/ZA-27 composite a) OM, polished, x 100, b) OM, etched in aqueous HNO<sub>3</sub> (9 wt %), x100

Due to its potential use as a solid lubricant, particulate graphite is a good choice as a reinforcing material for MMCs which are used for a wide range of applications including engine bearings, pistons, piston rings and cylinder liners. Such components need to have good wear resistance. It was shown /22/ that the addition of graphite particles into the matrix enhances ductility, ultimate tensile strength, compressive strength and Young's modulus of the composite, whilst causing the hardness to decrease significantly.

On the basis of recently performed tribological studies on the ZA-27 alloy composites with Al<sub>2</sub>O<sub>3</sub> particles /7/, as well as graphite particles /8/, the optimal content and size of reinforcing Al<sub>2</sub>O<sub>3</sub> and graphite particles have been defined /7, 8/.

Zinc and zinc-aluminium foundry alloys exhibit relatively good corrosion resistance in atmospheric exposure, immersion services, in soils and in a wide range of chemical environments /3/. However, there has been a lack of specific corrosion data of zinc-aluminium based MMCs and their corrosion resistance to date, because of very limited use of zinc-aluminium alloys as matrix material for MMCs /9/. The ZA-27 alloy as a matrix material was reinforced with ceramic particles or fibers (zircon, silicon carbide, alumina, graphite) /5,6/. The presence of the reinforcement fibers and particles and the processing associated with MMCs fabrication can influence corrosion resistance of the metal matrix /9/. During last century, several

authors have investigated the corrosion behaviour of MMCs with ZA-27 alloy substrate /23-25/.

The Seah and coworkers have investigated the corrosion characteristics of cast ZA-27 alloy reinforced with graphite particles (1, 3 and wt 5 %) in selected environments like HCl solution and used SAE 40 lubricating engine oil /23/. It was intended to explore the possible use of the composite in such acidic environments and to develop and evaluate this composite as a bearing material. The results have shown that the particulate graphite/ZA-27 composites corrode in HCl solution, but not in SAE 40 oil. The corrosion rate in HCl solution decreases with time, probably because of the presence of aluminium in ZA-27 alloy. As the graphite content is increased, the composite becomes more corrosion resistant. To observe the effect of heat treatment, composite specimens heat treated for 2, 3 and 4 hours were also tested for their corrosion behaviour. Heat treatment at 320°C for a few hours also enhances the corrosion resistance of the composite /23/.

Sharma et al. /24/ have been investigated the effect of zircon particles on the corrosion behaviour of zircon particulate/ZA-27 alloy composites in acidic medium (HCl solution). The compocasting technique was used to produce composite specimens containing 1 to 5 wt % of zircon particles. Corrosion tests were conducted at room temperature using conventional weight loss method in accordance with the ASTM G-69-80 standard. The material loss was predominantly due to the formation of pits on the surface. In the base ZA-27 alloy, the pit formation was crack-induced, while in the composites, the pits developed at the matrix/particle interface. The corrosion resistance of composite materials increased with the zircon content in the material. The corrosion rate was found to decrease with time.

The glass fibers/ZA-27 alloy composites have been found to possess excellent wear resistance. However, it is important that other properties of the material are not impaired, one of which is the corrosion resistance. An attempt /25/ was made to evaluate the corrosion behaviour of ZA-27 alloy reinforced with glass fibers in HCl solution. This corrosion environment has been commonly used for corrosion testing since it provides high concentration of chloride ions which act as a passive film destabilizers. The glass fiber/ZA-27 alloy composites were fabricated by compocasting technique. Corrosion tests were conducted at room temperature using conventional weight loss method. In order to observe the difference in corrosion behaviour between heat-treated and non heat-treated (i.e. as cast) specimens, some

composite specimens were heat treated for 2, 3 and 4 h at 320°C. The specimens were all air-cooled after heat treatment. The results obtained show that corrosion rate seems to decrease with the duration of corrosion test. This is probably due to the presence of aluminium in the matrix ZA-27 alloy. The percentage weight loss due to corrosion decreases monotonically with glass fibers content. In other words, the more glass fibers is added, the greater is the corrosion resistance of the composite. The glass fibers are inert and are not expected to affect the corrosion mechanism of the composite. However, when the glass fibers content is increased, there is less matrix material to corrode and this results in an expected reduction in the weight loss observed. Heat treatment, whether for 2, 3 or 4 hours, significantly improves the corrosion resistance of the composites, no matter what the glass fibers content. Heat treatment affects only the matrix zinc-aluminium alloy and not the glass fibers in this composite. One possibility is that heat treatment at 320°C has improved corrosion resistance of the metal matrix, thereby resulting in greater overall corrosion resistance of the glass fiber/ZA-27 composite. The glass fibers do not react with the matrix material and hence do not affect its chemical properties, even at high temperatures.

According to the results obtained /23-25/, the corrosion resistance of MMCs with zinc-aluminium alloy ZA-27 substrate increases with the enhancement of reinforcing phase content in composite material. The MMCs corrosion rate was found /23-25/ to decrease with time.

## 6. CONCLUSION

Aluminium and zinc-aluminium based metal matrix composites can provide excellent resistance to both sliding wear and abrasion. The selection of matrix metal and reinforcing phase is generally based on the achieving of desired composite properties, while the interaction between produced MMC and its environment is usually of secondary importance. The presence of the reinforcement fibers and particles and the processing associated with MMCs fabrication can cause accelerated corrosion of the metal matrix compared to corrosion of the unreinforced matrix alloy. It is necessary, therefore, to tolerate a rate and a form of corrosion that will be no significantly detrimental to the properties of the MMC during its anticipated life. Generally, for providing the MMCs high corrosion resistance, the microstructure of the composite and the interface between the reinforcement and the matrix need to be controlled.

Corrosion can affect the metal matrix composite in a variety of ways (galvanic, pitting, stress corrosion cracking, tribocorrosion) which depend on its nature and the environmental conditions. Test methods for determining corrosion resistance of MMCs are specific and must be based on the conditions prevailing in certain environments. MMCs susceptibility to pitting and crevice corrosion, as well as to other forms of corrosion, is typically evaluated by exposure testing or through the use of one or more electrochemical test methods. Exposure tests provide information on the weight loss, on the number of pit or crevice sites present on the specimen surface and the maximum pit or crevice depth. Electrochemical test methods indicate how the passive characteristics of one MMC compare to those of another and provide insight into the mechanisms responsible for corrosion.

In general, corrosion behaviour of aluminium MMCs has been studied most extensively, while there has been hardly any information available on the corrosion behaviour of zinc-aluminium based composites. It was shown that corrosion resistance of MMCs with zinc-aluminium alloy ZA-27 substrate increased with the enhancement of reinforcing phase content in composite material. The corrosion rate was found to decrease with time.

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