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# Corrosion resistance of Elektron 21 magnesium alloy

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**Materials**

## ABSTRACT

**Purpose:** Elektron 21 magnesium alloy containing neodymium, gadolinium and zinc has high strength, good corrosion resistance and excellent castability. It is designed mainly for aerospace applications. The purpose of the investigation was to study the corrosion resistance of Elektron 21 magnesium alloy in as cast condition and after heat treatment in 3.5% NaCl saturated with $Mg(OH)_2$ solution.
**Design/methodology/approach:** Solution treatment was performed at 525°C/8h/water, while ageing treatments at following conditions 250°C/4-96h/air. Immersion test was performed in 3.5% NaCl saturated with $Mg(OH)_2$ solution at room temperature. Specimens were placed in 3.5% NaCl solution for periods of time between one and 5 days. After immersion test, the microstructure and the appearances of the corroded structure were examined by optical microscopy (Olympus GX-70) and a scanning electron microscopy (Hitachi S3400).
**Findings:** The corrosion rates of Elektron 21 alloy increased with increasing the exposure time and finally (after 5 days) reached maximum value 0.092 $mg/cm^{-2}day^{-1}$. Solution treatment at 520°C for 8 h caused decrease in corrosion rate (0.072 mg $cm^{-2}$ $day^{-1}$) due to dissolving of intermetallic phase precipitates at matrix. Ageing at 200°C for 4h and 16h caused next decrease in corrosion rate to value 0.052 and 0,055 mg $cm^{-2}$ $day^{-1}$ respectively, while after ageing for 48h corrosion rate increase to value 0.067 mg $cm^{-2}$ $day^{-1}$, due to increase of volume fraction and size of β' phase and precipitations of equilibrium β phase. It was also noticed that the longer time of ageing the higher corrosion rates were observed.
**Research limitations/implications:** Future researches should include investigations of the influence of other environments on the corrosion resistance of Elektron 21 alloy.
**Practical implications:** The improvement of corrosion resistance of Elektron 21 alloy can cause increase in it application in aerospace industry.
**Originality/value:** The relationship between the ageing parameters, microstructure and corrosion resistance in Elektron 21 magnesium alloy was specified.
**Keywords:** Metallic alloys; Properties; Corrosion; Elektron 21 magnesium alloy

## 1. Introduction

Magnesium alloys with neodymium and gadolinium are characterised by high-strength and good creep-resistant alloys for automotive and aerospace applications [1-3]. The rare earth elements have beneficial effect of on the creep properties, corrosion and thermal stability of structure and mechanical properties of magnesium alloys [4, 5]. Elektron 21 is magnesium based casting alloy containing rare earth (Nd and Gd) for used to at 200°C in aerospace application. It has high strength, good corrosion resistance and excellent castability. Elektron 21 is being used in both civil and military aircraft and also in automotive (motorsport) industry [6, 7]. The strength of magnesium alloys with RE is achieved essentially via precipitation strengthening. These alloys precipitate from the solid solution according to the sequence of phases: $\alpha$-Mg→β"→β' →β. Sometimes between β' and β the $β_1$ phase has been observed [8-11]. The β” phase is metastable and fully coherent with the matrix. It has a $D0_{19}$ crystal structure. The intermediate β’ phase is also metastable and semi coherent with the matrix. The equilibrium β phase is face-centred cubic [5]. Data concerning corrosion of magnesium alloys containing aluminium are numerous [12, 13], but those concerning alloys with Nd and Gd are scarce [14]. There is not work on the effect of ageing on corrosion resistance of Elektron 21 alloy. However, the latter data seem to indicate that, in addition to favourable high temperature properties, certain Mg-Nd-Gd alloys present good corrosion resistance [15].

## 2. Description of the work methodology and material for research

### 2.1. Material for research

A cast magnesium alloy, Elektron 21, was examined. The alloy was purchased from Magnesium Elektron, Manchester, UK. The alloy’s chemical composition is given in Table 1.

Table 1.
Chemical composition of the Elektron 21 alloy

| Gd | Nd | Zr | Zn | Mn | Fe | Ag | Mg |
|---|---|---|---|---|---|---|---|
| 1,2 | 2,7 | 0,49 | 0,4 | 0,001 | 0,003 | 0,01 | balance |

### 2.2. Research methodology

Solution treatment was performed at 520°C/8h in air, following by water quenching. Ageing treatments were performed at 200°C. The duration of treatment varied between 4 and 48 hours. For the microstructural observation, an OLYMPUS GX71 metallographic microscope and a HITACHI S-3400N scanning electron microscope were used. TEM examination after ageing was carried out on a JEOL JEM 3010 microscope.

The specimens were exposed for days to 3.5% NaCl saturated with $Mg(OH)_2$ solution maintained at room temperature, without stirring. Before the tests, the specimens were polished with SiC papers up to 1200 grit. After cleaning with acetone and drying, they were weighed to obtain their original weight ($m_o$) before corrosion. After immersion test, the corroded specimens were taken out of the solution, cleaned with distilled water and dried. They were then immersed in chromate acid (200g/dm$^3$ $CrO_3$ + 10g/dm$^3$ $AgNO_3$) to remove corrosion products. After that, the specimens were cleaned again with distilled water, rinsed with acetone and dried. The specimens were weighed on an analytical balance to an accuracy of ± 0.1 mg. The dried specimens were weighed ($m_1$) after immersion. The difference between $m_o$ and $m_1$ is the corrosion weight loss (Δm). According the test results, the corrosion rate was calculated.

## 3. Description of achieved results of own researches

### 3.1. Microstructure of the Elektron 21 alloy

A cast of the Elektron 21 alloy shows the presence of a lattice of precipitates at the solid-solution grain boundaries (Fig. 1), the lattice being composed of intermetallic phase contains magnesium neodymium and gadolinium.

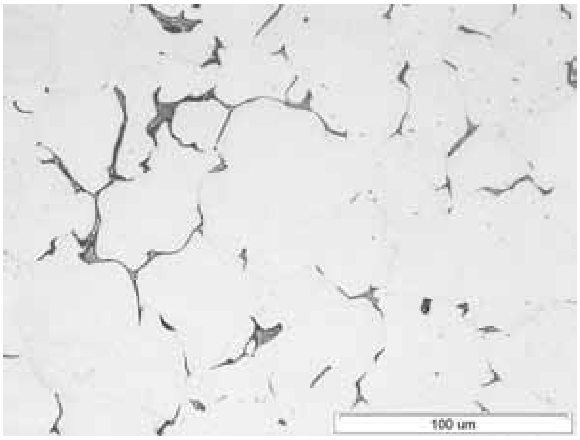


Fig. 1. The lattice of intermetallic phase at the solid-solution grain boundaries in Elektron 21 alloy in as cast condition

After solution treatment at a temperature of 520°C /8h with water cooling the precipitates of intermetallic phase dissolved in the matrix almost fully (Fig. 2).

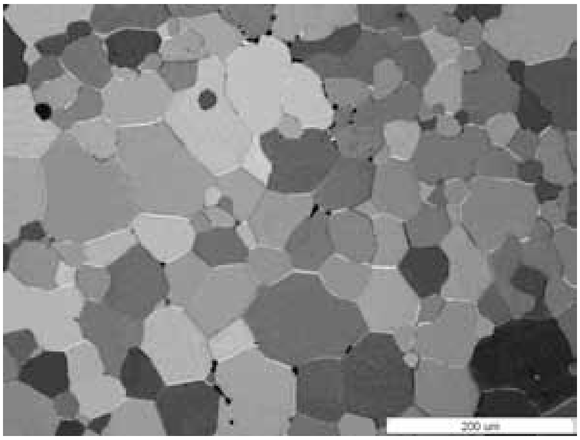


Fig. 2. Few precipitates of intermetallic phase on grain boundaries after solution treatment

After ageing for 4h and 16h at 200°C Elektron 21 is characterized by the fine dispersion of β’ precipitates in the matrix (Fig.3). The volume fraction and size of β’ precipitates increased with extension of ageing time. With continued ageing, the volume fraction and size of β’ phase still increased (Fig. 4).

Also there was a precipitation of coarse equilibrium β phase (face-centered cubic structure - isomorphous to $Mg_5Gd$) (Fig. 5). The microstructure now contained a small number of β' and few β precipitates inside solid solution grains.

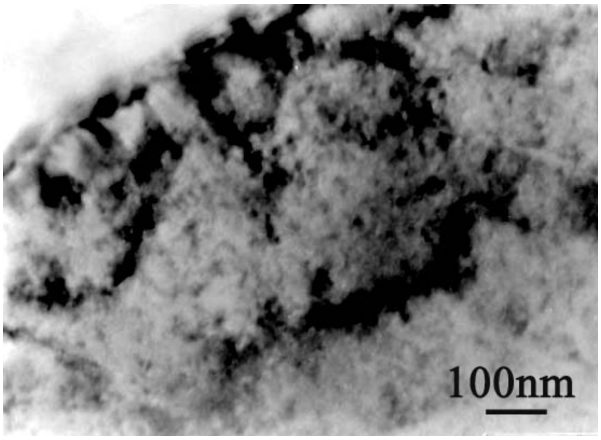


Fig. 3. β' precipitates in the matrix after ageing at 200°C for 16h

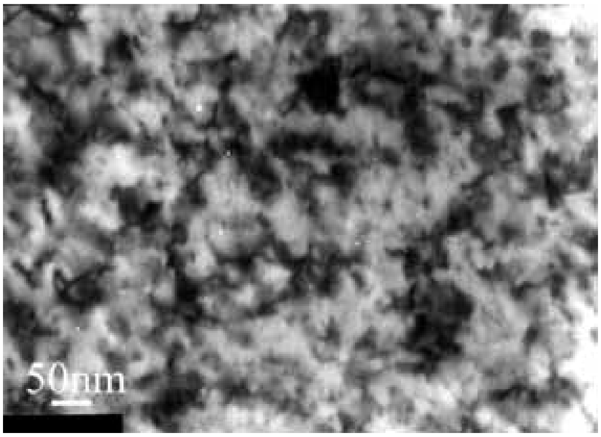


Fig. 4. β' precipitates in the matrix after ageing at 200°C for 48h

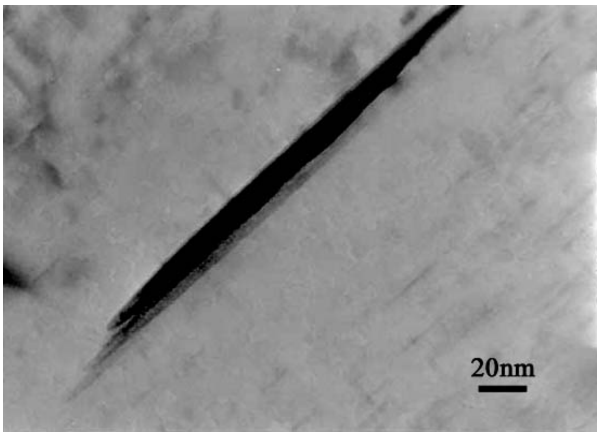


Fig. 5. TEM bright-field image taken from the alloy aged at 200°C for 96h. Precipitate of β phase

## 3.2. Immersion corrosion test

Fig. 6 shows typical surface features of the corroded specimens after 5 days of immersion test.

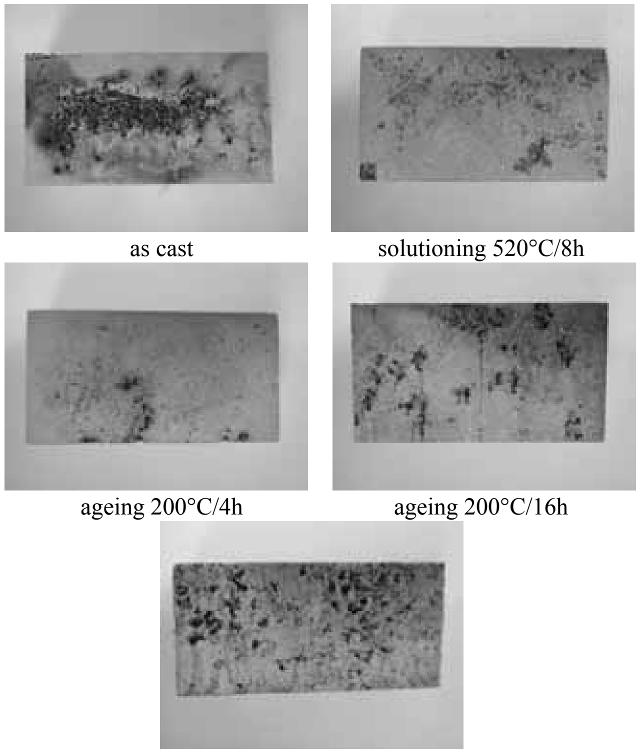


Fig. 6. Corrosion morphologies of Elektron 21 alloy in the as cast and after heat treatment conditions after 5 days of immersion test in 3.5% NaCl + $Mg(OH)_2$

From the appearance of the specimen surface Elektron 21 in as cast condition was more severely corroded than specimens after heat treatment. Only specimen after ageing 200°C/48 has similar morphology. The difference in macro-morphology of corroded specimens indicates different corrosion rates in dependence on the heat treatment parameters. After five days, serious corrosion damage occurred on the as cast alloy over its entire surface, whereas the corrosion of remaining specimens was only appeared on part of the specimen surface. The comparison of the corrosion rates results obtained from immersion test in 3.5% NaCl are given in Fig. 7.

Fig. 8 shows the effect of heat treatment on the corrosion resistance of Electron 21 alloy after exposure in 3.5% NaCl + $Mg(OH)_2$ for 5 days. The corrosion rates of Elektron 21 alloy incresed with increasing the exposure time and finally (after 5 days) reached maximum value 0.092 mg/cm$^{-2}$day$^{-1}$. After solution treatment (520$^{o}$C/8h), the corrosion rate decrease due to dissolved of intermetallic phase precipitates and reached maximum value 0.072 mg cm$^{-2}$ day$^{-1}$. Ageing at 200$^{o}$C for 4h and 16h caused only slightly decrease in corrosion rate to value 0.052 and 0.055 mg cm$^{-2}$ day$^{-1}$, respectively, in a result of precipitation of β' phase. While after ageing for 48 h the corrosion rate increase to value

0.067 mg $cm^{-2}$ $day^{-1}$ due to increase of the volume fraction and size of β' phase and precipitation of equilibrium β phase.

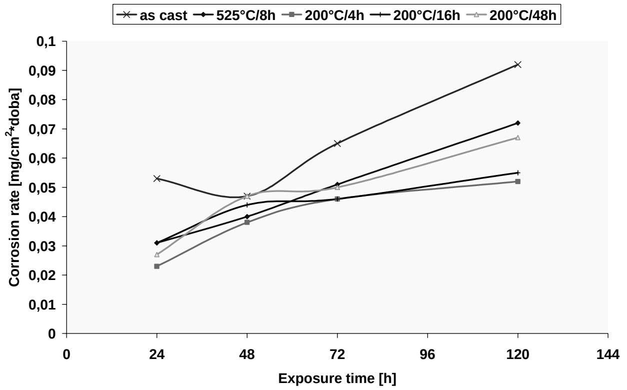


Fig. 7. Corrosion rates of Elektron 21 alloy before and after heat treatment during immersion test in 3.5% NaCl + $Mg(OH)_2$

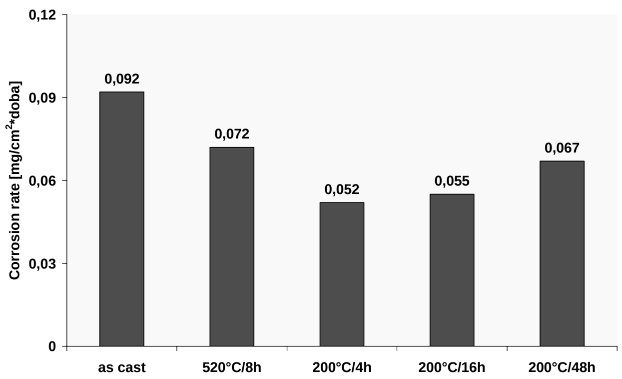


Fig. 8. Corrosion rates of Elektron 21 alloy after immersion test in 3.5% NaCl+$Mg(OH)_2$ for 5 days

The corrosion propagation was most uniform for the solution treatment condition. Corrosion rate decreases due to dissolution of intermetallic phase. Aged specimens (4h and 16h) were less corroded than as cast alloy, and the difference in corrosion damage depends on ageing time. With increased ageing time, the volume fraction of precipitates increased gradually and these particles behaved as the cathodic sites and thus matrix attack is favored by micro galvanic cell formation.

## 4. Conclusions

Based on the research results obtained, it has been found that:

(1) Corrosion behavior of Elektron 21 alloy strongly depends on heat treatment condition.

(2) Corrosion rate of solutioned specimen is lover than those for as cast due to disillusion of intermetallic phase precipitates and solution hardening.

(3) Lower corrosion rate of Elektron 21 alloy after short period of ageing (4h,16h) is caused by precipitation of metastable β' phase.

(4) Higher corrosion rate of Elektron 21 alloy after ageing treatment at 200°C for 48h is caused by increase of β' size and its volume fraction and also due precipitation of equilibrium β phases in microstructure.

## Acknowledgements

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