Texture Analysis on the AZ31 Magnesium Alloy Using Neutron Diffraction Method

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Abstract. The nature of crystalline materials depends on the individual crystal properties and the features of the polycrystalline state. The direction of crystallite orientation (texture) can undergo evolution during casting, processing, deformation, welding, and also heat treatment. Because texture plays an important role in mechanical characteristics and physical behavior, initial characterization before mechanical treatment needs to be analyzed first. The neutron diffraction method for texture analysis has advantages compared to the x-ray diffraction method, because neutrons can penetrate the material up in the order of centimeters (bulk, texture) compared to x-rays which are only on the surface of the material (surface texture). This research uses magnesium alloy, because this alloy is very light, and is widely used in industries, such as the automotive, computers, communication systems and electronics. The magnesium alloy used is AZ31 type. The AZ31 magnesium alloy is selected due to the most ductile and the most popular amongst AZ wrought alloys (Mg-Al-Zn group). Initial characterization using the neutron diffraction method was held away before the welding procedure was taken out. In this study, a texture neutron diffractometer (DN2), BATAN, set at a wavelength of 1.2799 Ångstrom was used to characterize AZ31 material. The neutron source is produced by the GA Siwabessy reactor, which operates at a power of 15 MW. From the characterization of the neutron diffraction pattern, four pole figures {100}, (002}, {101} and (102) were taken. From the pole figure analysis, the crystallite orientation (texture) was obtained in the direction of {001} <110>. The highest intensity lies in the basal center (0002), also seen basal fiber {0001} and prismatic fiber {10-10}

Keywords: Magnesium, AZ31, texture, hexagonal structure, neutron diffraction

1. Introduction
Magnesium is the lightest of all light metal alloys and therefore is an excellent choice for engineering applications when weight is a critical design element. It is strong, has good heat dissipation, good damping and is readily available. The use of pure magnesium is rare due to its volatility at high temperatures and it is extremely corrosive in wet environments [1]. Magnesium is ductile and the most machinable of all the metals, it is among the lightest of all the metals, lightest metallic material used
for structural applications with a density of 1.738 g/cm³ in comparison with the densities of Al (2.70 g/cm³) and Fe (7.86 g/cm³), and Fe (7.86 g/cm³).

Magnesium alloys have an excellent combination of properties and also the sixth most abundant on earth. Magnesium alloy developments have traditionally been driven by requirements for lightweight materials to operate under increasingly demanding conditions. This has been a major factor in the extensive use of magnesium alloy castings, wrought products and also powder metallurgy components [2], to substitute some conventional structural materials for weight reduction in vehicles such as cars, trucks, trains and aircrafts. Nowadays magnesium alloys are used in automotive and mechanical (trains and wagons) manufacture, because of its lightness and other features. For automotive applications, Mg alloys of AM and AZ series are mainly used [3]. Cast alloys, widely used in interior and power-train components, account for more than 99% of magnesium alloys used today, while only a small number of wrought products are utilized. This is because magnesium alloys lack formability for wrought applications, and their high cost discourages the use of magnesium alloys for automotive applications. Magnesium and magnesium alloys are the easiest of all metals to machine, allowing machining operations at extremely high speed. All standard machining operations such as turning, drilling, milling, are commonly performed on magnesium parts [4].

Magnesium alloys have a hexagonal lattice structure, which affects the fundamental properties of these alloys. Plastic deformation of the hexagonal lattice is more complicated than in cubic latticed metals like aluminum, copper and steel. AZ31 magnesium alloy is the most ductile and the most popular amongst AZ wrought alloys (Mg-Al-Zn group). Soft as it is, this alloy offers good combination of strength and ductility for structural application after deformation with severe reductions [5]. At present, study of the AZ31 has been carried out, for example, investigation related to microstructure after extrusion at low speed [5], improving casting techniques to improve the quality of Mg alloys[2].

However, research progress on Mg alloys using neutron diffraction techniques is still very rare. Therefore characterization using neutron diffraction techniques becomes interesting, because of the nature of neutron interactions with matter. For example, characterizing the texture of materials, using a neutron diffraction technique can be observed textures at a depth of several millimeters, which cannot be obtained with other diffraction techniques, such as x-ray diffraction.

The aim of this study is to find the texture characteristics of AZ31 using neutron diffraction technique. The texture characteristics before welded is important, mainly to investigate characteristic of basal texture in hexagonal crystal structure.

2. Experiment and method

The AZ31 type Mg alloy material used in this experiment has dimensions of 100 mm x 60 mm x 6 mm. Before characterization using the neutron diffraction method, the element content in AZ31 was tested to determine the weight percent of the elements present in the Mg alloy. After the weight percent of AZ31 content is identified, characterization is carried out using the neutron diffraction method. Two neutron diffractometers are used to characterize AZ31. The diffractometer is DN2 texture neutron diffractometer and DN3 high resolution diffractometer.

Texture neutron diffractometer (DN2) was installed in the GA Siwabessy reactor experiment hall, and a high resolution neutron diffractometer (DN3) was installed inside the NGH building. The neutron source is passed through the beam tube S5. Comes from the GA Siwabessy reactor, which operates at 15MW of power. Monochromator is used to get monochromatic wavelength. Material characterization was carried out to obtain neutron diffraction data and pole figure data. Diffraction data are obtained with DN2 or DN3 using scans (θ, 2θ) at a certain angle range of 20. While the pole figure data is only
obtained using DN2 by setting the position \((\theta, 2\theta)\) at a certain Bragg peak, and scanning tilt \((\chi)\) in the range \(0^\circ \leq \chi \leq 90^\circ\), and scanning rotation \((\phi)\) at the range \(0^\circ \leq \phi \leq 355^\circ\). Neutron data are taken using the preset count mode by monitoring the neutron count at a specific count using a monitor detector. DN2 uses the BF3 monitor detector while DN3 uses the He monitor detector.

3. Results and discussion

3.1. Elemental analysis of AZ31
Based on the American Society for Testing Materials developed a method for designating the alloys. The first two letters indicate the principal alloying elements according to the code listed in Table 1. The one or two letters are followed by numbers which represent the elements in weight % rounded to the nearest whole number. For example AZ31 indicates the alloy Mg-3Al-1Zn [1]. The material used for this experiment was AZ31 type magnesium alloy. This alloy was bought from China. The results of the characterization of elements using SPARK are shown in Table 1. When these results are compared with AZ31 used by Anna Dziubińska [6], and Pastorek [7], the Aluminum content is much higher, but still within the range given by M. Kang [8].

Table 1. Composition of AZ31 Magnesium alloys.

| Component | Al     | Be   | Cu   | Mn   | Zn   | Ag   |
|-----------|--------|------|------|------|------|------|
| % weight  | 3.15 ± | 0.0002 ± | <0.0020 ± | 0.163 ± | 0.916 ± | <0.001 ± |
|           | 0.04   | 0    | 0    | 0.003 | 0.031 | 0    |
| Component | Ca     | Cd   | Sn   | Sr   | Mg   |
| % weight  | 0.0009 ± | 0.001 ± | <0.004 ± | 0.0002 ± | 95.8 ± |
|           | 0.00001 | 0    | 0    | 0.0003 | 0.06 |

3.2. Crystal structure analysis
Mg alloys with type AZ31 have weight percent Mg as the majority element with aluminum as much as 3.15% and Zn as much as 0.916% as is shown in Table 1. The AZ31 was analyzed by neutron diffraction method. No other elements were detected, such as aluminum or other phases in the neutron diffraction pattern, so in the analysis only Mg was used as the refined element. Mg has a hexagonal structure with a P 6\(_3\) / mmc space group. From the results of the refinement obtained lattice parameter values \(a = 3.1986\) A, \(b = 3.1986\) A, \(c = 5.1969\) A, \(\alpha = 90^\circ\), \(\beta = 90^\circ\), and \(\gamma = 120^\circ\). The preferred orientation parameter \(G1 = 0.4013\) \(G2 = 0.0000\). There are 18 Bragg peaks identified for Mg in an angle range between 2\(\theta\) = 30° to 160°. The peaks are (100), (002), (101), (102), (110), (103), (200), (112), (201), (004), (202), (104), (210), (211), (104), (115), (212), (204). From the results of refinement with a value of goodness of fitting = 1.73 is shown in Figure 1. Analysis of diffraction patterns is done using FullProf software.
3.3. Texture analysis

Three components in hexagonal structure namely basal, prismatic and pyramidal play an important role in the analysis of hexagonal crystal structure [9]. These planes play a role in the orientation of crystallites. In the hexagonal materials, the \{0001\} basal texture is most frequent applied to identify the characteristic of hexagonal type from c/a ratio. The ideal pole figures of some important texture components, simulated rolling texture in HCP shows ideal basal texture, tend to form basal fiber texture, which is c/a = 1.633 [10]. These are perfectly suitable for Mg base alloys since their c/a ratios are ∼1.624 [10]. This is consistent with the results obtained from the analysis of AZ31 where c / a = 1.6247. Five pole figures (002), (100), (101), (102),(103) were analyzed by Labotex using a triclinic to monoclinic symmetry process. From the calculation of the pole figure using the sample symmetry process, it appears that the basal pole figure is in accordance with the texture analysis for hexagonal material. The highest intensity lies in the basal center (0002), its about 2.2 m.r.d (multiple random distribution) Also seen are basal fiber \{0001\}, prismatic fiber \{10-10\}, and orientation in the direction of \{001\} <110>. This is shown in Figure 3.

![Figure 1. Diffraction pattern of AZ31 obtained from high resolution powder diffractometer DN3](image)

![Figure 2. Basal, prismatic and pyramidal components of hexagonal crystal structure [9]](image)
Figure 3. Some pole figures of AZ31 obtained from texture diffractometer DN2, after the sample symmetrization process.

4. Conclusions
From the results of research using Mg metal alloys, the type of AZ31 can be concluded as follows, that Mg alloys meet the AZ31 criteria which is using the ASTM alphanumeric designation system encourages grouping magnesium alloys by principal alloy composition: magnesium-aluminum-zinc-manganese (AZ), AZ signifies that aluminum and zinc are the two principal alloying elements. The second part, 31, gives the rounded-off percentages of aluminum and zinc (3 and 1, respectively)[11]. From the AZ31 sample results that were characterized by the neutron diffraction method obtained the atomic lattice parameters $a = 3.1986$ A, $b = 3.1986$ A, $c = 5.1969$ A, $\alpha = 90^\circ$, $\beta = 90^\circ$, and $\gamma = 120^\circ$. From the calculation of the texture by the process of sample neutralization from triclinic to monoclinic the crystal has crystal orientation. The highest intensity lies in the basal center (0002), its about 2.2 m.r.d (multiple random distribution) Also seen are basal fiber {0001}, prismatic fiber {10-10}, and orientation in the direction of {001} <110>.

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