

Mechanical properties investigation of the potential extruded MgAZ31B as a bone implant

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Abstract

Mg is a light metal that has superior properties, including low density, good ductility, medium strength, and good corrosion resistance, mg can also be combined to obtain better properties. Interest in the application of MgAZ31B for bone replacement has now become a major topic and continues to be intensified to improve results that are more compatible with bone constituents found in humans. In the human body, there are approximately 206 bones in an adult. Calcium, magnesium, and phosphorus are the main elements in the formation of human bones but there are many other elements in their formation, the real bone matrix is made of protein, collagen, calcium phosphate, calcium carbonate, magnesium salts, and other minerals. When viewed from the element of bone magnesium is an important part of bone formation and certainly not harmful to the main elements of human bones. However, before being used as bone implants, magnesium must pass the mechanical and clinical test stages.

Keywords: biomaterial, magnesium, AZ31B, mechanical properties.

Introduction

Magnesium is one type of material that can be used in biomedical, because basically, magnesium has superior properties, including low density, good ductility, medium strength, and good corrosion resistance, can be degraded and harmless to the human body, because of its properties – With these properties, the metal has a very wide use, not only biomedical, ranging from household goods to aircraft components. When viewed from the specific gravity of magnesium, this base metal belongs to the light group, namely 1.74 g/cm³ and 1.83 g/cm³, and when applied its morphological properties resemble bone [1].

Bone contains an abundant extracellular matrix network surrounding the separate cells. The extracellular matrix in human body tissues contains 15% water, 30% collagen fibers, and 55% crystalline mineral fibers. Mineral salts are stored in a skeleton formed by the extracellular matrix collagen fibers. Mg appears to have the

potential to serve as an ideal principal element for bone replacement applications due to its relatively excellent mechanical properties and degradability [2]. Previous studies have shown that Mg ion, a biodegradation product of eccentrically porous magnesium can induce new bone formation and stimulate angiogenesis. Porosity and pore size are important points to resemble the bone's morphological properties that are ready to regenerate. The porous scaffold should exhibit more than 50% porosity with a minimum recommended pore size of 100 m¹³⁻¹⁵. The average pore size greater than 300 m provides better conditions for bone formation and is full of blood vessels. However, on the one hand, magnesium having larger pores generally exhibits poorer mechanical properties which are significantly affected by their porous structure (pore size, porosity, and pore orientation)[3]–[5].

Materials and Methods

Mg AZ31B

Magnesium AZ31B (Mg AZ31B) is a type of magnesium alloy that contains the least percentage of aluminum, zinc, and iron. The use of this type of magnesium has been widely developed by researchers of modern materials or advanced materials because of its potential, namely the use of future materials in the medical field, especially human bones[6], [7]. Mg AZ31B is attracting significant attention in the biomedical field due to its excellent mechanical properties namely biodegradability and biocompatibility. Its density and modulus of elasticity are within the same range as natural human bone, making it an ideal bone substitute. Unlike other metallic biomaterials, Mg AZ31B can be adsorbed by the tissue and there is no need for a second surgery after the tissue has healed. In this case, the biodegradable implant dissolves in the physiological environment after fulfilling its function, especially in the cardiovascular field. The modulus of elasticity of magnesium is between 40 and 50 GPa. The stiffness of the material resembles that of human bone, which is between 10 to 40 GPa[8]. Since early 1878 Mg and its alloys have been investigated for the use of modern or advanced materials as biomaterials. Although Mg metal has a tensile strength unlike steel and has low stiffness, Mg has properties and abilities when used as a human bone implant material, not only safe but lowering the cost or cost far from the price of other implant materials. Mg metal has advantages that other metals do not have, namely biodegradable, non-toxic and mechanical properties like human bone in general. Biodegradable properties make Mg metal popular in the fields of materials, mechanical, science, and tissue engineering as the best candidate for bone implant materials. Ideally, a biodegradable implant material such as an Mg-based material is expected to have a corrosion barrier with a low initial corrosion rate in the body environment, allowing the implant to act as

a scaffold until new tissue is formed, and then the remaining portion will corrode rapidly without any toxicity.[9]–[11]. Many alloying elements, including essential elements (Ca, Sr, Zn, Si) and low toxic elements (Sn, Zr), have been added to the magnesium matrix to obtain the desired corrosion resistance and maintain mechanical properties during the degradation process. Although the addition of alloying elements can increase the corrosion resistance of some test samples, so far the biocompatibility and corrosion behavior are still not satisfactory[12]–[14]. In table 1, in general, Mg AZ31B has a chemical composition of aluminum 2.5 - 3.5 %, Zinc 0.60 - 1.4%, and a low level of iron or Fe in the range ≤ 0.0050 %, this is to avoid excessive corrosion or rust.

Table 1. Komposisi Kimia Mg AZ31B

Unsur	% .wt
Aluminum, Al	2,71
Nickel, Ni	0,001
Calcium, Ca	0,001
Zinc, Zn	0.69
Copper, Cu	0,001
Iron, Fe	0,002
Silicon, Si	0,18
Magnesium, Mg	Bal
Manganese, Mn	0,32



Figure 1. Photo of Mg AZ31B cylindrical shape (without unit)

Magnesium AZ31B is purchased in the market in the form of a cylinder with dimensions of 130 mm long and 16 mm in diameter which is used in research and through an extrusion forming process with adjustable temperature variations. After that mg is made with a CNC machine.

Micro Vickers test

Before testing for tensile properties, magnesium that has not been machined will be tested for micro-Vickers hardness. The specimens were cut into two parts, the transverse section, and the surface section.



Figure 2. Vickers hardness tester

Tensile Test

The MgAZ31B is in the form of a shaft or cylinder with a diameter of 16 mm and a length of 130 mm. Tensile test specimens were shaped according to ASTM B557-02a standards (Figure 3).

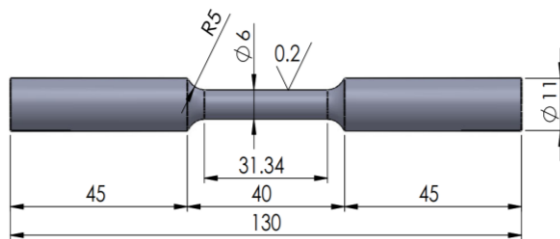


Figure 3. The shape and size of the tensile test specimen (ASTM B557-02a)



Figure 4. MTS Landmark 100 kN

Struktur mikro

Magnification using 500x, with etching solution used:

- Acetic-picral (1-5 s): 10 ml acetic acid
- 4.2 g picric acid
- 10 ml H₂O
- 70 mL ethanol (95%)

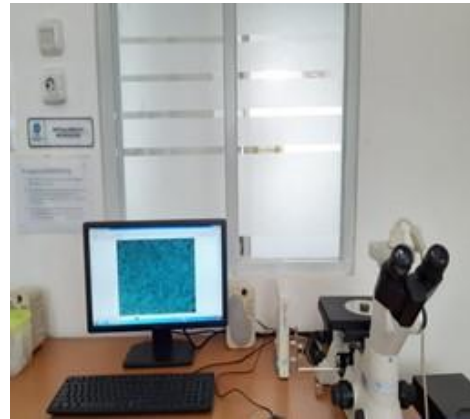


Figure 5. Metallurgical Microscope

Fractography

Fractographic observation aims to analyze failures related to crack growth and fracture properties of metals, components, and engineering structures.



Figure 5. Scanning Electron Microscope Zeiss EVO MA10

Results and Discussion

Micro Vickers hardness test results

Table 2. Micro Vickers Mg hardness test results AZ31B

Transverse Section	
(HV)	Avg HV
63,99	61,78
61,92	
59,32	
60,47	
63,13	

Surface Section	
(HV)	Avg HV
64,23	64,27
63,91	
63,41	
63,35	
64,31	

After testing with two different pieces, it turns out that on the surface magnesium has a higher hardness value by taking five indentation points, namely, 64.23 HV, 63.91 HV, 63.41 HV, 63.35 HV, and 64.31 HV with an average hardness of 64.27 HV. The difference in hardness is quite significant when compared to the hardness value in the transverse section area. The number of indentation points is also the same, namely five with a value of 63.99 HV, 61.92 HV, 59.32 HV, 60.47 HV, and 63.13 HV with an average hardness value of 61.78 HV. The difference in hardness values is about 3 HV and is plotted in Figure 6.

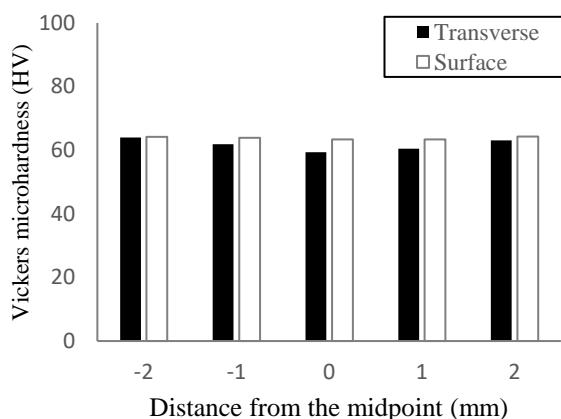


Figure 6. Hardness test curve

When viewed directly the difference is very visible in the results of the hardness test in the transverse section area, the closer to the midpoint area or the center point, the hardness value decreases or is smaller than the others. The hardness value at the center point is only around 59.32 HV, while the further the indentation point is from the center, the hardness value increases to 63.99 HV and 63.13 HV. This is because the deformation that occurs in the central point area is smaller than the surface and outer

areas. The extrusion process will result in higher deformation in the outer area.

Static tensile test results

The data will be obtained in the form of maximum stress (σ), yield stress (σ_y), modulus of elasticity (E), total elongation (%), and reduction of cross-section (%). Tensile testing was carried out on as many as four specimens, the three samples were carried out at a speed rate of 0.15 mm/minute.

Table 3. Tensile test results Mg AZ31B

Specimen	Stress (MPa)	
	Yield (0,2%)	Ultimate
Mg1T	185,15	270,45
Mg2T	188,44	269,29
Mg3T	184,45	269,13
Mg4T	186,44	269,51

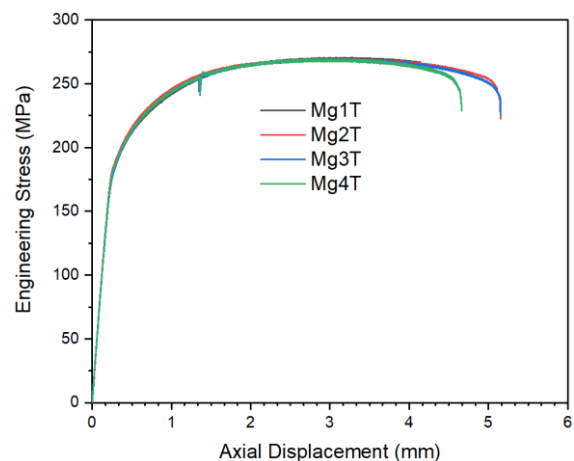


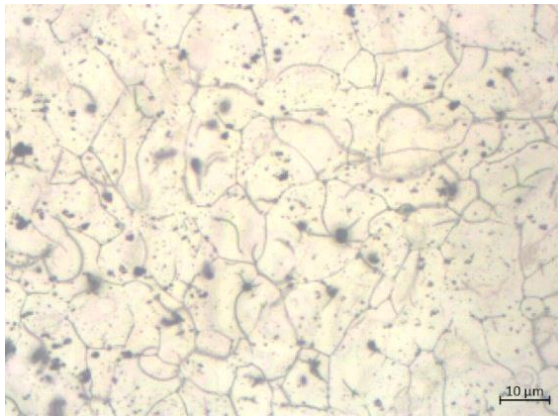
Figure 7. Relationship of stress incremental to specimen length change

The test results obtained that the elongation value for the first specimen could not be calculated because the elongation of the specimen did not break. The elongation value of the second specimen is 16.48%, and the third specimen is 16.44%. The process of installing the extensometer with the installation position located right at the center gage length must be perpendicular to the specimen being tested. In the fourth specimen (Mg4T), the elongation of 18.95% means that the higher the tensile test speed, the higher the elongation of the specimen and the longer the gage length area. The reduction in cross-sectional area is around

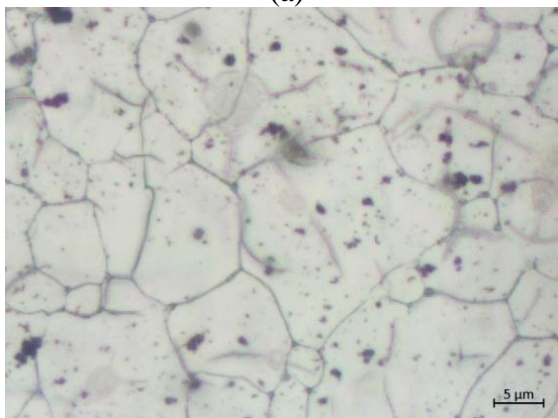
30%, this value is 5% higher than the three specimens with a speed rate of 0.15 mm/minute, when the necking area and gage length measurements are made it looks smaller and longer, the loading speed affects the plastic deformation of the specimen, the faster the load is applied, the faster the deformation occurs and the increase in length is higher. Then, when viewed from the fracture form, the three specimens tested for tensile have an unsymmetrical shape, in contrast to the fourth sample the fracture shape is 45°.

Microstructural observation

Cold working will induce a strain-hardening effect. The strain-hardening process is characterized by changes in its physical and mechanical properties, such as increased strength and significantly increased hardness. This proves that the greater the effect of deformation on the material or material, the greater the change in its mechanical properties.



(a)



(b)

Figure 8. Microstructure of Mg AZ31B Transverse section

Strain hardening is closely related to strength and ductility, if you expect the strength of the cold working forming process to be the solution, but behind the advantages, there must be drawbacks, the most prominent drawback is that the material will not be ductile and tend to be brittle. The extrusion process will change the microstructure of Mg AZ31B as shown in Figure 8 (A, B), the grain shape has an elongated and flat shape, The black spots are aluminum to increase the hardness of magnesium and fine to coarse lines are deformations caused by tensile forces during the metal forming process. The deformation that occurs is very large in the surface area because the cross-section is fixed and the metal is pulled. Mg AZ31B extrusion that has not been tested for fatigue shows inhomogeneous grain sizes ranging from 5-10 m. There are also several small grains distributed in the grain boundary region, this indicates that the recrystallization process occurs dynamically during the extrusion process. The metal formation process will cause large equiaxed grains.

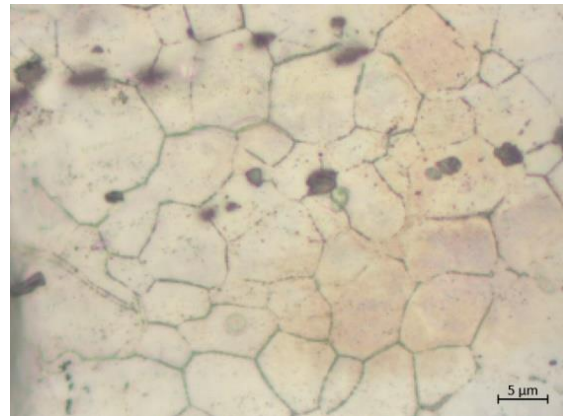


Figure 9. Microstructure of Mg AZ31B Longitudinal section

The grain size of Figure 9 ranges from 5-15 m and the grain orientation direction looks like a diagonal direction from bottom to top.

Fractographic observation

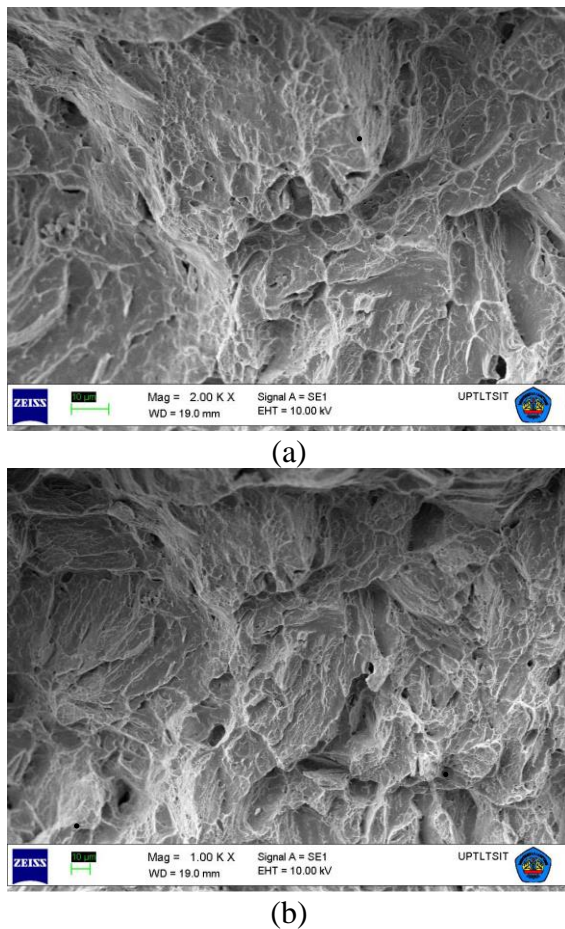


Figure 10. SEM of a fractured surface of the sample

In pure magnesium dimples, there is a close relationship between the constituent matrix and the second phase of the particles, the movement of dislocations during the low cycle fatigue test, and the number of dislocations at grain boundaries, greatly affects the formation of dimples. However, in mixed magnesium, for example, Mg AZ31B, it can cause nucleation of microvoids in the center of the magnesium sample. Then, the few microvoids coalesce to form larger voids. The presence of voids in the center of the sample will trigger magnesium failure caused by the unstable pressure that exists when the core area of the sample can no longer support the given load. As a result, the magnesium sample will fail and fracture on the surface due to shear forces which will form dimples.

Strengthening the mechanical properties of Mg Alloy

In general, the mechanical strength, including yielding strength and ultimate tensile strength, are influenced by chemical composition, grain size, and process technology. Alloying is the main route to enhance the mechanical properties. Solid solution strengthening of Mg is able to obtain after alloying with elements which possess hexagonal close-packed system, such as Al, Zn and Sr. Grain refinement is the other workable countermeasure to improve the strength and toughness of Mg alloy, since high grain boundary shows significant blocking effect on dislocation slip. Deformation process and rapid solidification technology have been proposed to refine the grains of Mg alloys. Deformation process is based on external force to achieve grain refinement, which also promotes the uniform distribution of the second phase. For instance, high-speed rolling process was applied to treat Mg-3Al-1Zn alloy, resulting in the grain size decreased from ~ 20 to $0.6-0.76$ μm . Equal channel angle extrusion was also applied to treat Mg alloy. Heat treatment is usually needed since the residual stress will be left in the Mg matrix after deformation treatment [15].

Conclusions

The micro-Vickers hardness test in the transverse section has an average of 61.78 HV and the surface section is 64.27 HV. The results of the hardness test are not much different from the results of the AZ31B Mg fabrication. Tensile test data that will be used for the low cycle fatigue test parameter is the yield strength value with an average of 186.01 MPa and an elastic modulus of 43.72 GPa. When the speed rate is doubled, it results in higher plastic and elastic energy with a 5% higher cross-sectional area reduction and a 2% increase in elongation. Has a round, elongated, and flat grain shape, and the grain size is not homogeneous between 5-15 μm . Grain size < 5 μm is distributed in the grain boundary

region. The fracture is intergranular. Dimples are found on the fracture surface of the plastic deformation zone. This stage of magnesium testing needs to be continued up to biocompatibility testing and clinical tests.

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