AN INVESTIGATION OF PUNCHING AND MECHANICAL PROPERTIES OF ROLLED AM60 AND AZ61 MAGNESIUM ALLOYS

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ABSTRACT

PhD. Thesis

AN INVESTIGATION OF PUNCHING AND MECHANICAL PROPERTIES OF ROLLED AM60 AND AZ61 MAGNESIUM ALLOYS

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In this study, the low pressure die casting method was used to produce AZ61 and AM60 Mg alloys following the hot rolling with two rolling speed and hot extrusion were applied at similar deformation rate. Light optical (LOM) and Scanning electron microscopy (SEM) was utilized to show the twins, dynamic recrystallization (DRXs) and secondary phases. The enhancement of mechanical properties obtained by micro-hardness and tensile tests were supported with the microstructural and pole figure analysis. In the industry, punching is required for the manufactured parts, and therefore the magnesium alloys that are manufactured (AM60 and AZ61) require strength to complete the punching process. an experimental study was carried out to examine the effect of different punch type on blanking force. The strength of mg alloys AM60 and AZ61 as casting and as two speed of rolling 2.5 rpm and 7.5 rpm treatment has been examined by using shearing force with same thickness 3mm. The effect of the perforated cutting type on forces required for cutting / punching has been realized on magnesium alloys used in the industry. Experiments were studied using three different cutting types, 0 °, R and 16 °. The results of the experiment showed that the AM60 alloy was stronger than AZ61, and the results also showed that the 16º hole type performs the breaking process at the lowest strength. necessary paste was used when using R type perforations for sheet production.

Key words: AZ61, AM60, Hot rolling, Microstructure, Mechanical Properties, Punching.

Science Code : 91421

ÖZET

Doktora Tezi

HADDELENMİŞ AM60 VE AZ61 MAGNEZYUM ALAŞIMLARININ ZIMBA İLE DELME VE MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

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Bu çalışmada, AZ61 ve AM60 magnezyum (Mg) alaşımları düşük basınçlı döküm yöntemi ile üretilmiştir. Üretilen Mg alaşımları iki farklı haddeleme hızında sıcak haddeleme ile %75 deformasyon sonucunda 3 mm kalınlığında levha haline getirilmiştir. Ayrıca döküm sonrasında Mg alaşımlarına yine %75 deformasyon oranında sıcak ekstrüzyon işlemi uygulanmıştır. Işık optik (LOM) ve Taramalı elektron mikroskobu (SEM), ikizleri, dinamik yeniden kristalleşmeyi (DRX'ler) göstermek için kullanılmıştır. Mikro sertlik ve çekme testleri ile elde edilen mekanik özelliklerin iyileştirilmesi, mikroyapısal ve pole figür analizleri ile desteklenmiştir. Endüstride imal edilen parçaların kullanılabilmesi için bir imal işlemine tabi tutulması gerekliliğinden yola çıkarak sıcak haddeleme sonrasında elde edilen 3 mm kalınlığındaki Mg levhalarına delme (zımbalama) işlemi uygulanmıştır. Deneyde düz uçlu, içbükey formlu ve 16 ° açılı olmak üzere 3 farklı zımba kullanılmıştır. Kullanılan zımba tipinin kesme kuvveti üzerindeki etkisi incelenmiştir. Deneyler sırasında kesme kuvvetlerini belirlemek için bir yük hücresi kullanılmıştır. Delme deney sonuçları AM60 alaşımının AZ61'e göre kesmeye karşı daha dirençli olduğunu göstermiştir. En düşük kesme kuvveti 16 ° açılı zımba ile elde edilmiştir. Ayrıca, delme işlemleri için düz uçlu zımbaların ve kesme işlemleri için içbükey formlu zımbaların kullanılmasının, parçaların kullanım amacına göre daha uygun olduğu bulunmuştur.

Anahtar kelimeler: AZ61, AM60, Sıcak haddeleme, Mikroyapı, Mekanik Özellikler, Delme.

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CHAPTER 1

INTRODUCTION

Magnesium alloys have strong durability; therefore, they play an important role in the transportation field, and also due to the properties of specific strength and light weight (strength / density) [1]. It is used in alloying. Magnesium also has high thermal conductivity, high dimensional stability, good electromagnetic protection, high damping, good workability and easy recycling [2]. These properties make Mg alloys attractive in many industries such as automotive, computer, aerospace, mobile phones, sports equipment. It is also used in light weight industries[3]. In addition, efforts have been accelerated in recent years to use energy resources more efficiently. In this context, the automotive industry is also working towards lighter vehicles in order to reduce fuel consumption [4] . Today, in parallel with the advancement of technology, the desired properties of materials also change. Corrosion resistance, resistance and adaptation to the environment can be changed positively by the materials being subjected to various processes. Although their mechanical properties are relatively low in pure form, these properties are particularly noticeable when alloyed with aluminum (Al), zinc (Zn) and manganese (Mn) [5]. The most common alloys are Al-Mn (AM50, Alloys such as AM60 and Al-Zn (AZ31, AZ61, AZ91) alloys. Other Mg alloys with good creep resistance at high temperatures are made up of rare elements [6]. For magnesium, especially Al, Zn and Mn, especially with earth metals and trace amounts of alloy elements Si, Y, Ca, Sr, Ba, Sb, Sn, Pb and Bi by increasing the mechanical properties of performance it is increasing [7]. Mg-Al-Zn (AZ91) alloys are mostly used for the casting of automobile parts and the castability of this alloy is quite good. Some studies have focused on increasing strength, hardness particularly by addition Zn, Mn, Al and rare earth elements to magnesium and its alloys [8]. Low-pressure die casting (LPDC) is the process whereby the metal rises into the mold cavity against gravity using pressurized gas, and high-pressure die casting (HPDC) is the process in which the metal is forced into the mold cavity at a high speed and pressure [9].

In this study, AZ61 and AM60 alloys have been produced by using an electric resistance furnace. The magnesium alloys manufactured were rolled by using two different speeds, 2.5 m/min and 7.5 m/min, respectively. The sheet thickness was decreased to 3mm thick. Effects of the material and rolling conditions on the blanking process were experimentally studied depending on the punch tip type and change of blanking forces. Three punches which have different tip forms were used. Force measurements were obtained by using a load cell during the experiments.

CHAPTER 2

LITERATURE REVIEW

To develop mg alloys and improve the properties of mg alloy must be adding different metals such as Aluminum, zinc, zirconium, Rare Earth elements etc. [10]. Scientists and researchers have a been interest in the possibility of use magnesium because of its high strength to weight ratio, but cannot be used directly as mentioned above , to overcome these drawbacks of magnesium must be add some materials to improve its properties[11]. Improve of magnesium properties to use in some applications have been studied by a lot of scientists and researchers and they got that, when aluminum is added to the magnesium alloy, it affects and gets better casting properties, develop corrosion resistance properties. An increase in yield strength of mg alloys[12]. Magnesium alloys such as Az91 has been made where main composition of 9% Aluminum 1% zinc and 0.3% manganese. And investigated that AZ91 has high strength to weight ratio[14]. Anther researchers have studied twin roll strip casting of AZ61 and the effect of casting conditions and rolling parameters on surface aspects and microstructure of the rolled[15].

Dr. Gürün and his collages studied the experimental examination of effects of punch angle and clearance on shearing force and estimation of shearing force using fuzzy logic comparing with this study where their result as following the effects of punch shear angle and clearance on the force required for blanking/piercing were examined on a grade of steel broadly used in the manufacturing industry, DC01. Experiments were carried out using five different punch shear angles, namely 0°, 2°, 4°, 8°, and 16°. Six matrices with varying clearance rates (0.4%t,0.5%t, 0.6%t, 0.7%t, 0.8%t, and 0.9%t) were used in this study, and these clearances were altered by modular matrices on the die. Which is related with this study as following:

Yu'an Chen and his collages (Effect of Zn on microstructure and mechanical property of Mg–3Sn–1Al alloys) The microstructure and mechanical properties of the Mg–3Sn–*x*Zn–1Al alloy were investigated. The microstructure of alloy consists of α-Mg and Mg_2Sn phases. The grain size decreased gradually with Zn content increases, and the amount of Mg_2Sn particles increased markedly. The as-extruded Mg–Sn–Zn–Al alloy exhibits excellent comprehensive mechanical properties, an ultimate tensile strength of 290 MPa, a yield strength of 184 MPa and an elongation of 12.2% at room temperature.

2.1. PHYSICAL & MECHANICAL PROPERTIES OF MAGNESIUM

Magnesium was first isolated by Sir Humphry Davy, an English chemist, through the electrolysis of a mixture of magnesium oxide (MgO) and mercuric oxide (HgO) in 1808. Now, magnesium can be extracted from the mineral's dolomite ($CaCO_3 \cdot MgCO_3$) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) but is most often obtained from seawater. Every cubic kilometer of seawater contains about 1.3 billion kilograms of magnesium. Magnesium is the lightest of used metals[16]. Table 1 shows physical properties of pure magnesium.

Table 2.1. Physical properties of pure magnesium.

Physical properties	Density (g/cm^3)	Melting Point (°C)	Specific Heat (Cal/g°C)	Electrical conductivity (%IACS)	Thermal Conductivity (W/mK)
Pure Magnesium	1.74	650	0.24	39	167

2.2 MAGNESIUM ALLOYS

Pure magnesium is usually used with the alloyed for engineering applications. Alloying is used to develop the formability of magnesium for both wrought and cast products. Zinc and aluminum are the most common alloying elements. Manganese, silicon and rare earth metals are other alloying elements that have significant influence on the properties of alloy [17]. Addition of alloy elements to mg to develop mechanical properties is common for instance Aluminum (Al) Increases tensile strength and hardness, Improves castability [18]. Zinc (Zn) Increases tensile strength and hardness Refine grain structure [19]. Manganese (Mn) Increases corrosion resistance with reducing the influence of iron and Increases yield strength [20], Silicon (Si) Increases molten metal viscosity Improves creep resistance forms Mg_2Si particles Reduces the corrosion resistance [21], Rare Earth Metals Reduces the freezing rang Increases hardness [22].

2.2.1. AZ61

AZ61 series magnesium alloys are among the most used alloys among magnesium alloys due to their good casting properties and good mechanical properties. It is frequently used in the aviation and aerospace industry and the automotive industry. Microstructure of AZ 61 alloys generally grain boundaries within a-mg main matrix
It consists of eutectic and intermetallic phases running along.

2.2.2. AM60

AM series alloys, one of the Mg alloys, are used especially in the production of steering wheel, wheel, automobile seat frame due to their high toughness and energy absorption properties. AM60 alloys have good elongation and impact resistance. These alloys; They have good castability, good mechanical properties and corrosion resistance. However, these alloys have low creep resistance at temperatures above 120 °C. The microstructure of the AM60 alloy generally consists of phases a-mg and $Mg_{17}Al_{12}$ [24-26].

2.3. MAGNESIUM CASTING

To obtain magnesium products with desired shapes beside casting can be use thermomechanical processes, to do Mg fabrication the technic that used are extrusion and rolling. Since at low temperature, magnesium shows low formability, these thermomechanical processing are usually implemented at high temperature (300 °C to 500 °C) [27].

2.3.1. Rolling

A conventional rolling device used in this study consists of two parallel rollers rotating at the same speed. In the normal direction (ND), where the length of the material increases in the rolling direction (RD), the material thickness has decreased [28]. Increasing width in the transverse direction (TD) was considered insignificant.

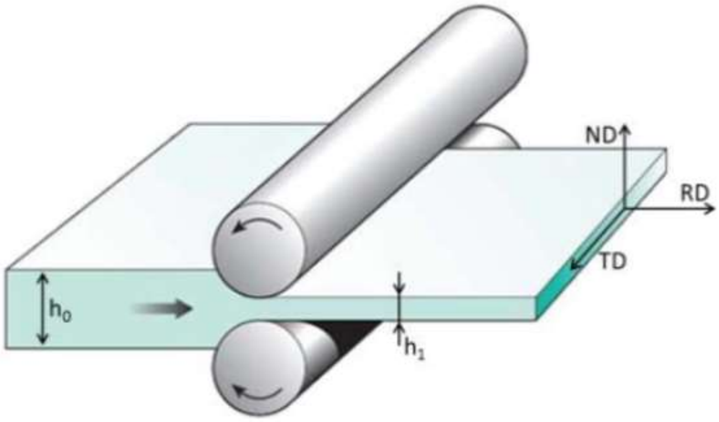
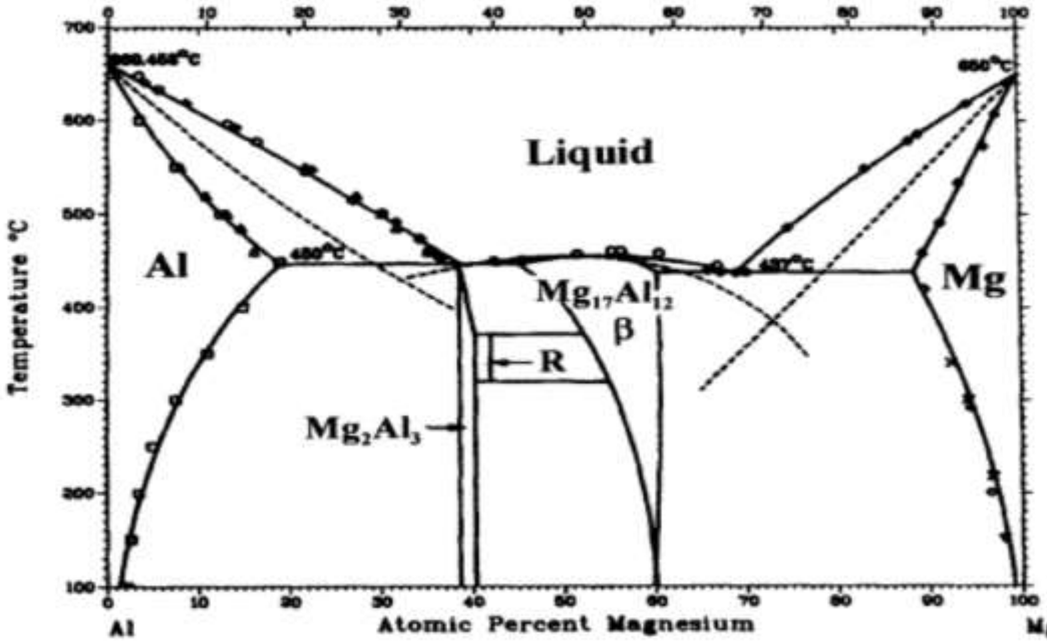


Figure 2.1. Schematic representation of a conventional rolling system [29].

Traditional rolling was implementation on a 12 mm thick plate. For the first trial, two passes were carried out at 300 °C with a 40% discount with preheating.

2.4.MG-AL BASED ALLOY

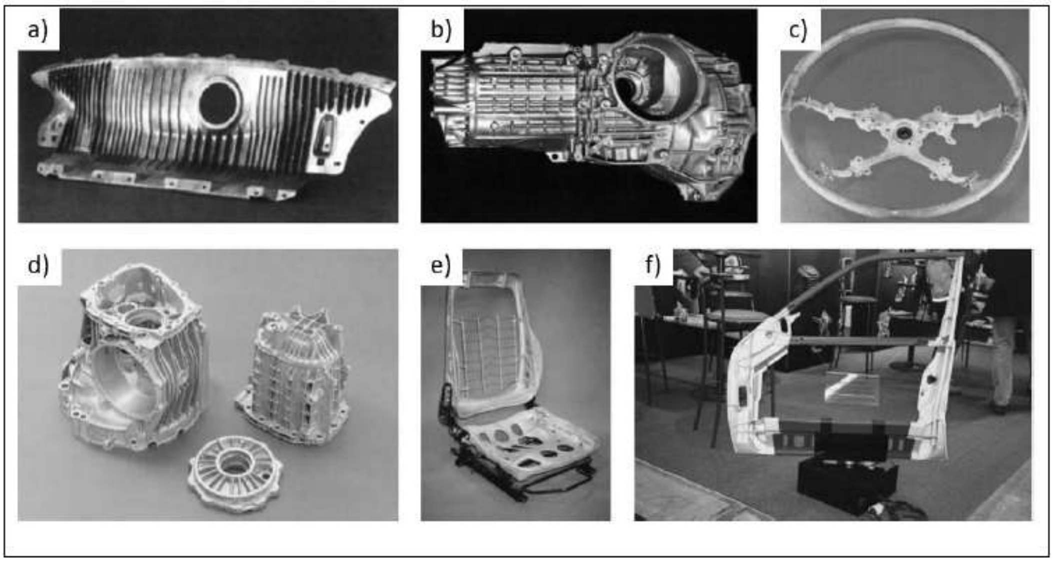
Using alloy aluminum with magnesium to improve mechanical and chemical properties such as strength and corrosion resistance. A maximum solid solubility of aluminum in magnesium is 12.6 wt% at (437 ^{o}C) (Figure 1) and then its solubility reduces to around 2% at room temperature. Hence, after a precipitation hardening treatment, an incoherent [30].



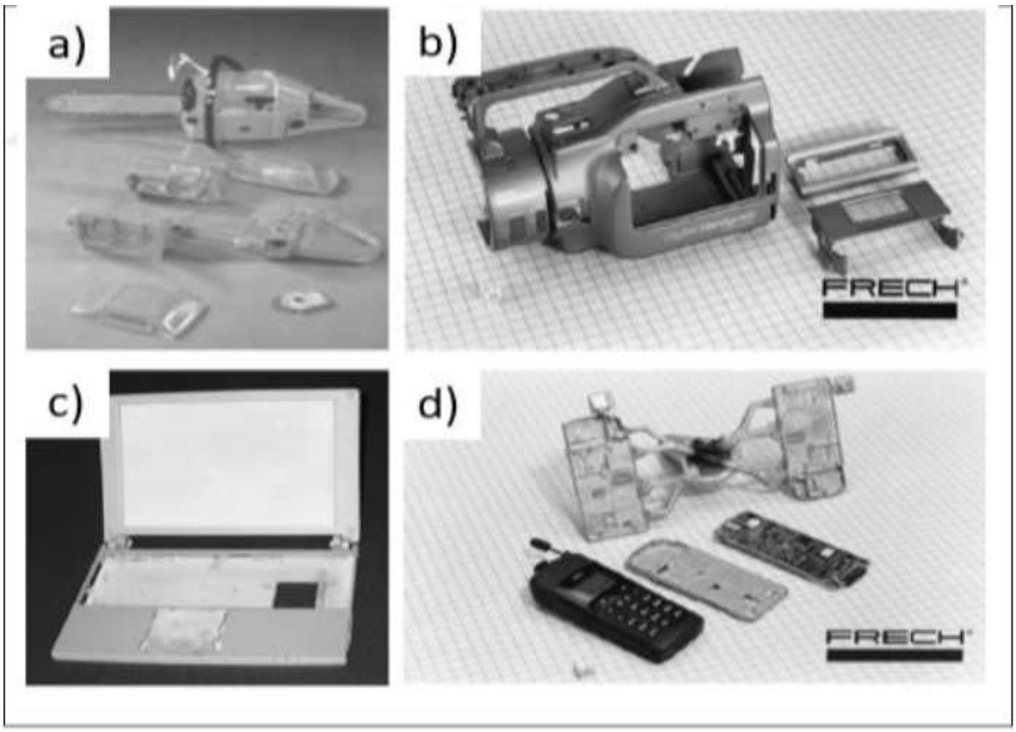
Figrue 2.2. Binary phase diagram of the Mg-Al [31].

2.5. MAGNESIUM AND ITS ALLOYS APPLICATIONS

Since it has low strength and toughness values, it is used by alloy. Magnesium also has high dimensional stability, good electromagnetic protection, and easy recycling [32]. The first use of magnesium alloys is considered in military applications. Nowadays, especially in the automotive sector, it is spreading in areas that require less energy consumption and lower gas emissions [32]. Magnesium alloys in the automotive sector date back to the 1920s. The first app is engine presses for Indy 500 race car in America. In Germany in 1937 magnesium presses produced about 4 million units. The other crankcase Mg was manufactured in 1931 by the general engine. Around 1970, applications of air-cooled gearboxes and engines were used in the automotive sector. Increased engine power and increased temperature led to the use of water-cooled engines instead of air-cooled engines, thereby reducing the use of Mg components. However, applications such as the Mg seat frame, passenger door and steering frame have been produced by brands such as Mercedes and BMW since 1990. It is also an ideal alloy for all portable electronic devices [33]. These properties are appreciated by Mg alloys in many industries such as automotive, computer, aerospace, mobile phones, sports equipment. It is also used as an implant material for low weight and adaptation to metabolism [33]. In addition, efforts have been accelerated in recent years to use energy resources more efficiently. In this context, the automotive industry is also working towards lighter vehicles in order to reduce fuel consumption [34].



Figrue 2.3. Magnesium auto parts, a) fuel tank protector, b) gearbox c) steering frame d) gearbox e) seat frame and f) passenger door frame[33].

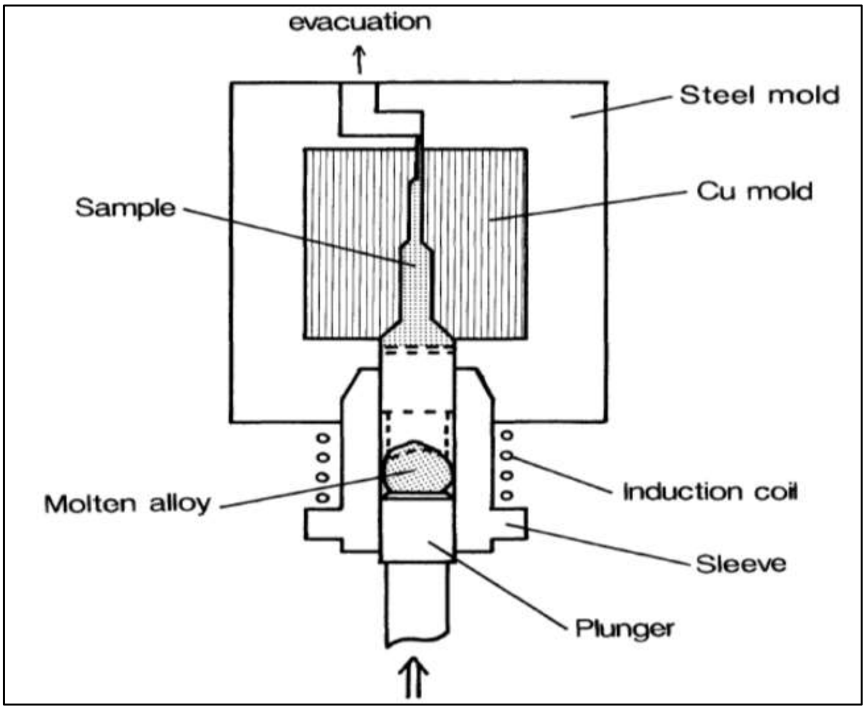


Figrue 2.4. Magnesium electronic parts a) saw b) camera c) laptop and d) mobile phone[34].

2.6. CASTING OF MAGNESIUM ALLOYS

2.6.1. High Pressure Die Casting

In recent years interest in magnesium alloys has increased as it has entered the automotive components industry such as steering wheel, dashboards, seat tires, door frames and powertrain components [35]. The important manufacturing process is high pressure casting for cast Mg alloy components used for a large number of applications. However, high-pressure casting (HPDC) Mg-alloys contain significant amounts of microporosity [36]. Microporosity and other casting defects appear to negatively affect the mechanical properties of cast Mg alloys and may result in significant variability in their mechanical properties [37]. Although microporosity amount appears to negatively affect the tensile ductility of HPDC Mg-alloys, attempts to establish quantitative correlations between the average porosity in bulk microstructure and fracture-sensitive properties such as strength or ductility have often failed [38].



Figrue 2.5. High pressure casting equipment.

2.6.2. Low Pressure Die Casting

Low pressure casting has been developed to eliminate hand ladders of hot metal. This process also uses metal molds to produce castings, but the molten metal is pressurized to obtain a faster or better controlled filling of the mold. The process uses pressures up to 7 MPa for special products such as automotive wheels, but the pressure typically used is below 0.5 MPa [39]. Low pressure casting is widely used for larger and non-critical parts. High quality castings of aluminum alloys are usually produced by this process, as well as magnesium and other low melting alloys [40].

2.6.2.1. Advantages of low pressure die casting

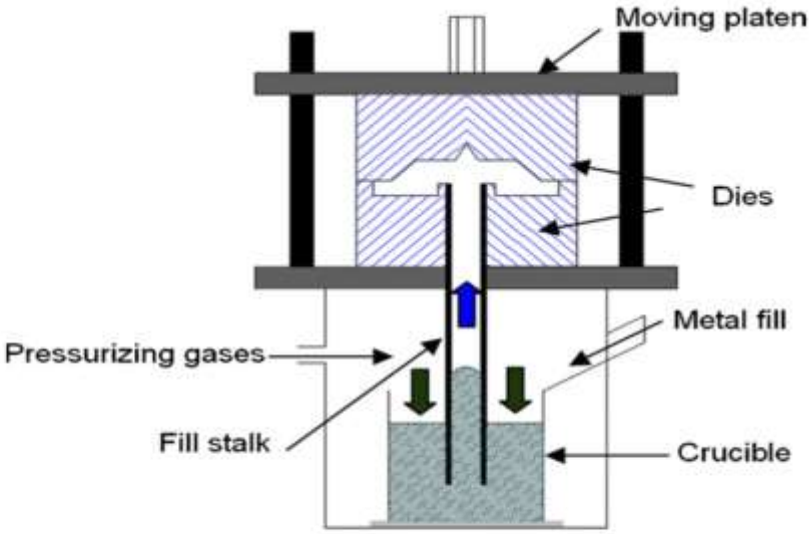
Below are shown the advantages of low pressure die casting.

- Very good strength values
- Greater use of material, without the need for feeders,
- Good dimensional precision,
- The whole process well adapted to automation,
- Less complicated machine and die technology.

2.6.2.2. Disadvantages of low pressure die casting

Below are shown the disadvantages of low pressure die casting.

- Slower launch cycles
- Minimum wall thickness
- Approx. 3 mm (in die)



Figrue 2.6. A schematic diagram of a typical low-pressure die [41].

CHAPTER 3

PUNCHING

3.1. PUNCHING APPLICATION FOR MG ALLOYS

Magnesium has an important role in engineering and industrial applications due to their light weight, where Density of the magnesium is (1.8 g/cm^3) Less than aluminum density (2.7g / cm^3) [44]. Several studies have shown that casting is still the main production method to produce Mg alloys where the dominant manufacturing process for magnesium components is casting, representing more than 95% of structural applications of magnesium, However, the low pressure die casting method still very limited [39]. The enhancing performance in engineering and industrial applications is criticale therefore, reducing the weight of construction materials is nessasery [45]. magnesium can be utilized as an application in aerospace industry. Magnesium alloys are made with a mixture of magnesium and other metals such as aluminum, manganese and copper [46]. In industrial and engineering applications, sheet metal forming using large-scale punching and cutting dies in manufacturing, the conditions under which punching and cutting dies are processed are influenced by the mechanical properties of sheet metal [47]. Previous studies have indicated that the most important factors that affect the shearing force and quality of parts are clearance and punch angle. The punch angle greatly decreased the required suppression/punch force. To improve the mechanical properties of sheet metal parts, surface quality, and dimensional precision, it is important to focus on the shapes and positions of the die and punch. [48]. In this study punching is required for the manufactured parts, and therefore the magnesium alloys that are manufactured (AM60 and AZ61) require strength to complete the punching process. an experimental study was carried out to examine the effect of different punch type on blanking force. The strength of mg alloys AM60 and AZ61 as casting and as two speed of rolling 2.5 rpm and 7.5 rpm treatment has been examined by using shearing force with same thickness 3mm. The influence of punch shear-type on the forces required for blanking/piercing were carried out on magnesium alloys used in the industry. Experiments were studied using

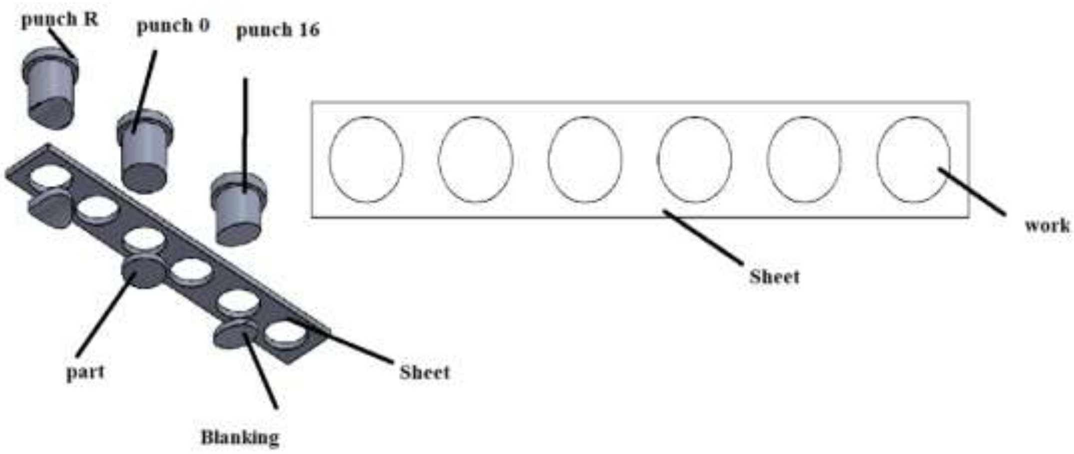


Figure 3.1. Different blank and scrap for blanking and piercing.

Three different punch shear types, namely 0°, R, and 16°. The results of the experiment show that AM60 alloy stronger than AZ61, the result also obtained results of Experiments study show that punch type 16º carried out blanking with the lowest force, using of punch type 0º when blanking required while punch type R used for sheet production.

3.2. EFFECT OF PUNCH-DIE CLEARANCE

Several studies indicate that shear strength is not significantly affected by the value of clearance. However, it affects the quality of the product and therefore 1 to 3 mm thickness one clearance of 0.07 mm was used to give the best quality, for the sheet metal industry requires a range of different processes [49] in the manufacture of sheet metal parts are very commonly used of Sheet metal forming processes like blanking, stamping and bending, Metal shearing is used for Blanking and piercing in order to cut the incoming sheet material as necessary. The bleaching process means cutting a hole in a sheet metal and interested in the disc that is cut, while the drilling process means that when the sheet metal that now has a hole goes through the scrap if you are interested in a disc, the scrap is a sheet metal that has a hole through it [50]. as shown in the diagram in Fig. 3.2.

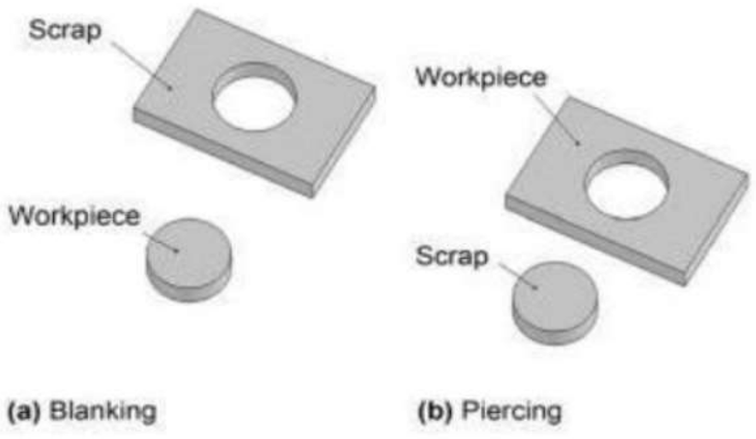


Figure 3.2. Blanking and piercing parts [50].

3.3. DIFFERENT AREAS OF THE PART EDGE

The shear edge of material influenced by different parameters such as the punch corner radius and therefore made several zones based on the method of material that has occurred,[50]. In general, it is preferred to have large shear zone and smaller burr the zones and deformation modes of the blanked part edge are given as follows and in fig (3.3). Rollover zone (zr): caused by plastic material deformation, Shear zone (zs): smooth and shiny area created during material shearing, Fracture zone rough surface, created after the material cracks, Burr zone (zb) is happened by plastic deformation, Depth of crack penetration (Dcp) is angle of fracture zone depends mainly on clearance [51].

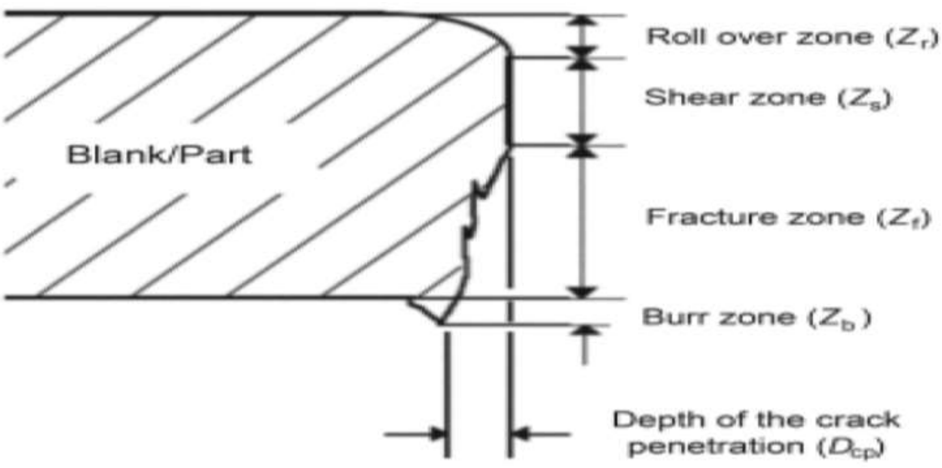


Figure 3.3. Zones of the edge[51].

3.4. THE EFFECT OF PUNCH TYPE

Recently some studies investigated the Experimental examination of the effects of punching angle and clearance on cutting force and estimation of cutting force. The test results indicate that shear forces can be reduced by 80% when using a 16 ° punch angle [52]. Punch clearance was found not to have as significant an effect as punch angle on cutting force. Although the reduction of cutting forces using angled punches is a practical and cost-effective method, it leads to deformations in the perforated part. As the punching angle increased, the amount of deformation increased. However, no deformation was observed on the strip. This leads to the conclusion that angled punches may be more suitable for drilling dies.

Experiments were carried out using Three type of separate punches 0°, R and 16°were used in the experiments with a diameter of 20 mm were prepared using wire EDM.

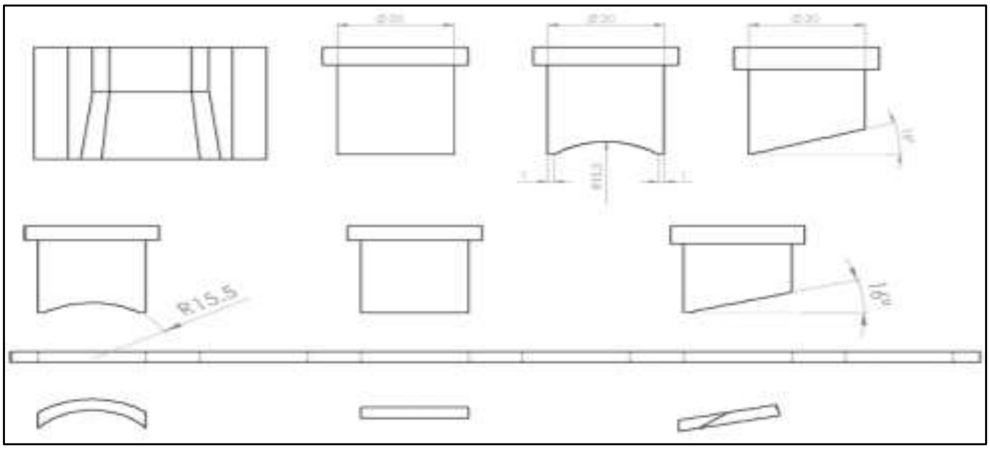


Figure 3.4. Type of punch.

3.5. THE BLANKING PROCESS

During blanking, the separating plate (which is also the blank support) holds the sheet material by applying a certain separating force. The sheet material between the punch and the die undergoes a very high deformation and cuts as the punch penetrates the sheet material with speed. The extraction plate removes the bullet from the punch during the upward movement of the punch as shown in (figure 3.4).

To obtain the best product and the minimum force required to blanking/piercing the magnesium alloys, three types of punching machine were used with the best type of clearance selected according to the previous studies [49]. Blanking force measurements were performed using a load cell. A 240 kN the load cell is attached to the die to measure the suppression / puncture forces in effect during the experiments.

The experimental results were transferred to the digital medium by the load cell, the data card, the amplifier and the data visualization software. To improve the precision of the measurements obtained, the signals generated by the load cell were strengthened by using an amplifier. An analog to digital converter used to transmit the amplified signal to a computer. The die set and load cell are presented in Fig. 3.5. Optical microscopy (OM) and scanning electron microscopy (SEM) were used to analyze the microstructures.

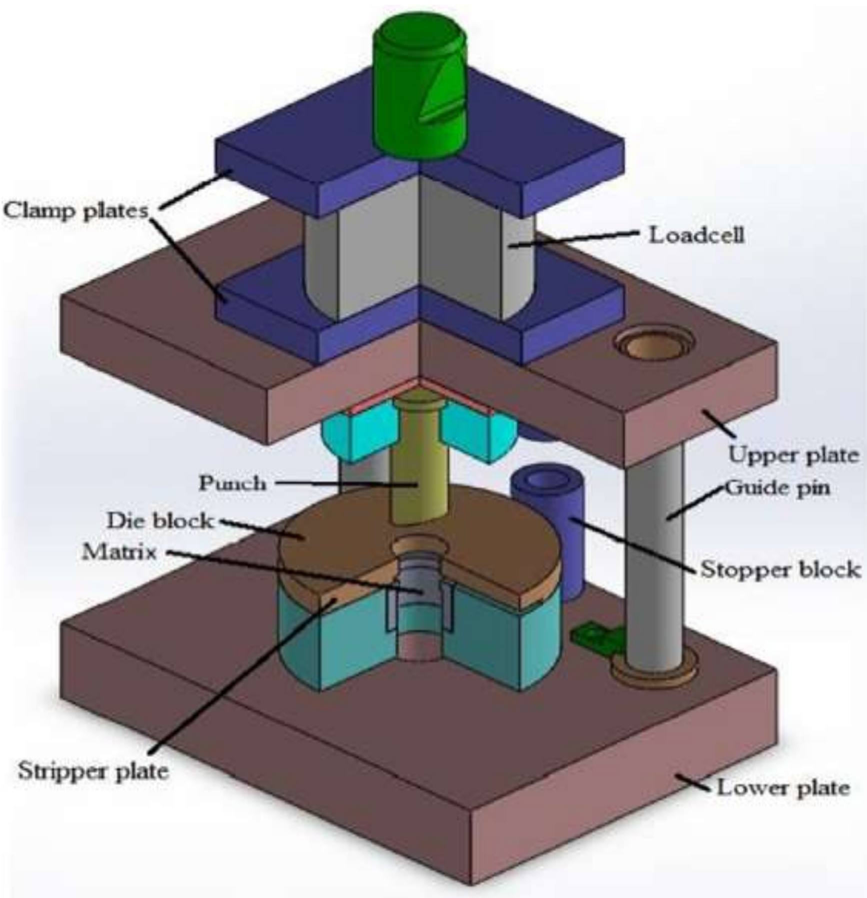


Figure 3.5. Schematic of the blanking tool setup.

CHAPTER 4

EXPERIMENTAL STUDIES

4.1. MATERIALS

In this study, microstructure, texture and mechanical properties of AM60 and AZ61 magnesium master alloys produced by casting were investigated after casting, rolling and extrusion processes. In addition, the cutting forces and cutting surfaces of the same master alloys with different punch geometries of the samples produced by casting and rolling at different speeds were examined.

AZ61 and AM60 Mg alloys is product with casting method. Low pressure die casting system (LPDC) as shown in Fig 4.1 is used in this study. After casting the casting samples put in furnace for homogenization heat treatment. Then rolling and extrusion manufacturing method is done for product this study samples.

4.1.1. Casting

The raw materials used for production are given in Table 4.1. Pure Mg, Al pure, pure Zn alloys from Turkey gauges are supplied from China. For the production, a special low-pressure gravity die casting method was used (Figure 4.1) and the casting conditions given in Table 5.2 were complied with. Pure Mg was first introduced into the stainless-steel crucible. After reaching a temperature of 775 ° C, after a waiting period of 1-hour, pure Al and gauge alloys were added to the ladle. Meanwhile, the molten metal in the crucible was continuously stirred. The final alloy was added to the pure Zn crucible and after 10 min stirring the molten metal was injected into stainless steel metal molds having a temperature of 350 ° C under 2-3 atm pressure.

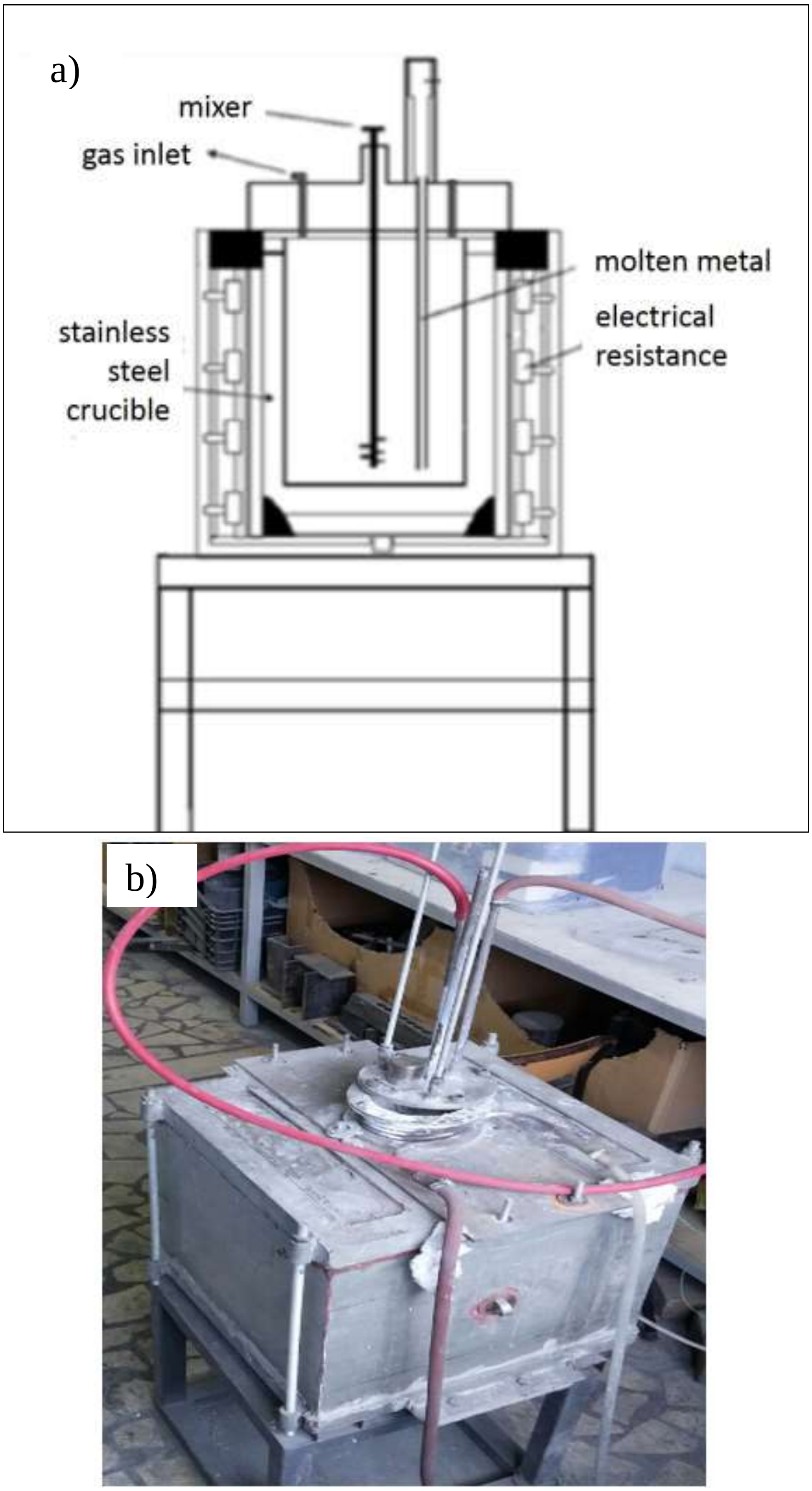


Figure 4.1. a) Diagram and b) Photo of a low pressure die casting furnace.

Table 4.1. Casting conditions.

Protective gas	Melting temperature (°C)	Mold temperature (°C)	travel allowance temperature (°C)	Casting gas pressure
Argon	775	350	350	2-3

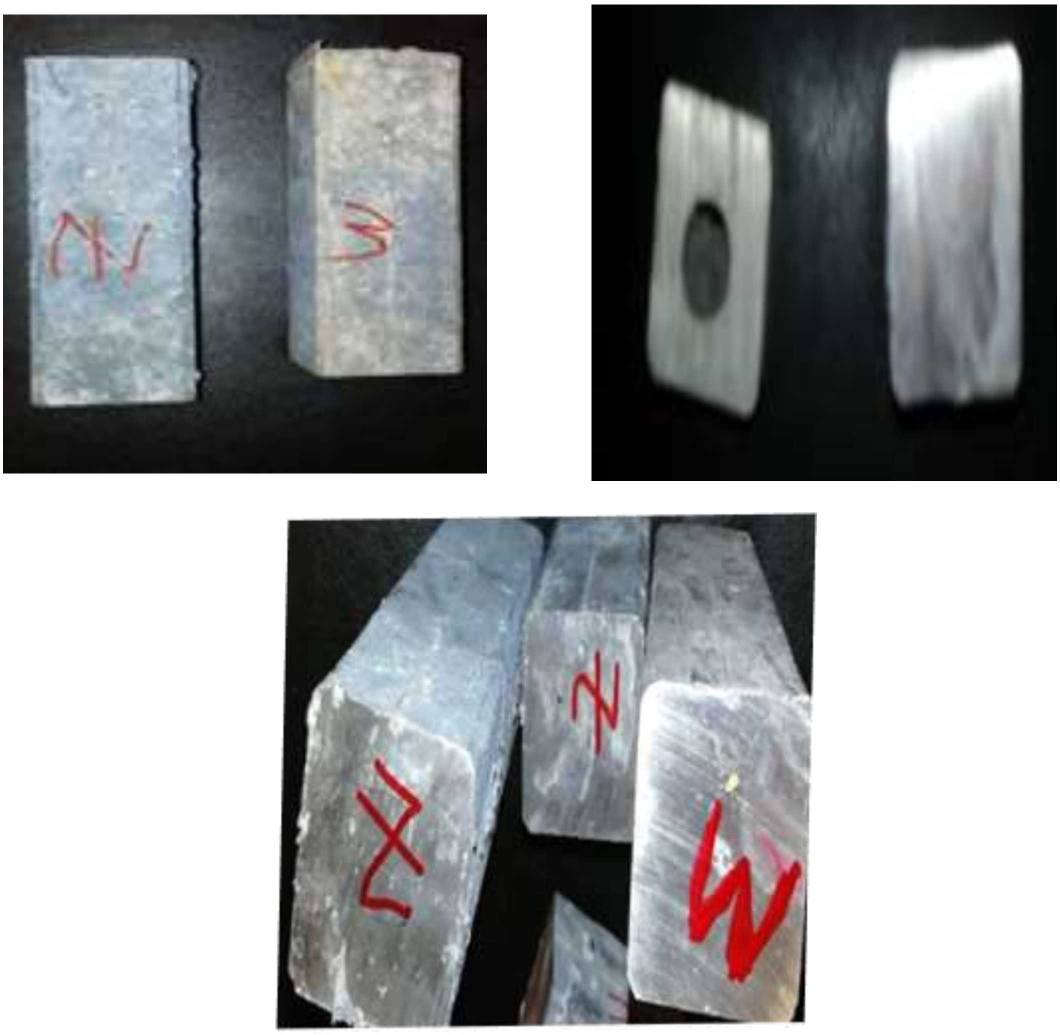
Table 4.2. Raw materials used for production (% by weight).

Raw material	Mg	Al	Zn	Mn
Pure Mg	99.9%	-	-	-
Pure Al	-	99.9%	-	-
Pure Zn	-	-	99.9%	-
Mg-Mn Master alloy	90%	-	-	10%

The chemical contents of the produced alloys are given in Table 4.3. Rigaku ZSX Primus II device belonging to XRF laboratory of Karabük University Iron and Steel Institute was used for chemical analysis.

Table 4.3. Produced alloy groups (wt%).

Alloys	Al	Zn	Mn	Mg
AZ61	5,95	1,05	0,0032	Bal.
AM60	6,11	0,0045	0,38	Bal.



Figrue 4.2. Casting samples.

4.1.2. Hot Rolling

After casting, billets with dimensions of 120x36x12 mm were heat treated for homogenization at 400 °C for 24 hours. In order to prevent metal oxidation during homogenization and homogeneous temperature distribution, the materials were embedded in sand. Homogenized materials with parameters in Table 4.4.'de hot rolling process was applied. Here, 15% (total 11 passes) and 30% (total 5 passes) section contraction was applied to each pass. Interpass materials were stored in an oven at 400 °C for 5 minutes. Billets with initial thickness of 12 mm total 75%

Table 4.4 Rolling parameters.

Rolling Temp.(°C)	Reduction per pass (% ±2)	Rolling speed (m/min)	Total number of passes	Total reduction (%)	First-Final thickness (mm)
400	15	2.5	9	75	12 - 3
400	15	7.5	9	75	12 - 3

Figrue 4.3. Rolling sample of magnesium alloys AZ61.

4.1.3 Extrusion

Casting sample is machining with rolling min stirring the molten metal was injected into stainless steel metal molds having a temperature of 350 °C under 2-3 atm pressure, then are sintered in a furnace (MAGMA THERM MT-137-B2) at 700 °C for 24 hours, after being sintered in 24 hours, using a specially designed extrusion die at 450 mm to concentrate 4 pieces of different samples. samples of the diameter were extrude to a diameter of 8 mm. Figure 4.4 shows the extrusion device used in the experiment.[68]

Figure 4. 4. Extrusion device used in the experiment.

In the first samples obtained after the extrusion process, as seen in Figure 4.5, deflection problem was observed [68].

Figure 4. 5. Extrusion device used in the experiment.

4.2. MICROSTRUCTURE INVESTIGATIONS

4.2.1. Sample preparation

The cast-iron, homogenized and post-extrusion microstructure of the produced alloys was prepared with an acetic-picral (70ml ethanol, 5ml acetic acid, 5g picric acid and 10ml pure water) etch. Sanding process with 600, 800, 1000, 1200, 2500 sanding sheets and polishing process with 1µm diamond suspension and 1µm felt were carried out before etching process.

4.2.2. Optical and Scanning Electron Microscope Images

The castings, homogenized and post-rolled microstructure examinations of the alloys produced were carried out on Nikon Eclipse MA200 optical microscope in Karabük University (KBU) Iron and Steel Institute metallurgy laboratory and Carl Zeiss Ultra Plus Gemini Fesem model scanning electron microscope in SEM laboratory. In addition, energy distribution spectrometer (EDS) studies were performed on the same SEM device.

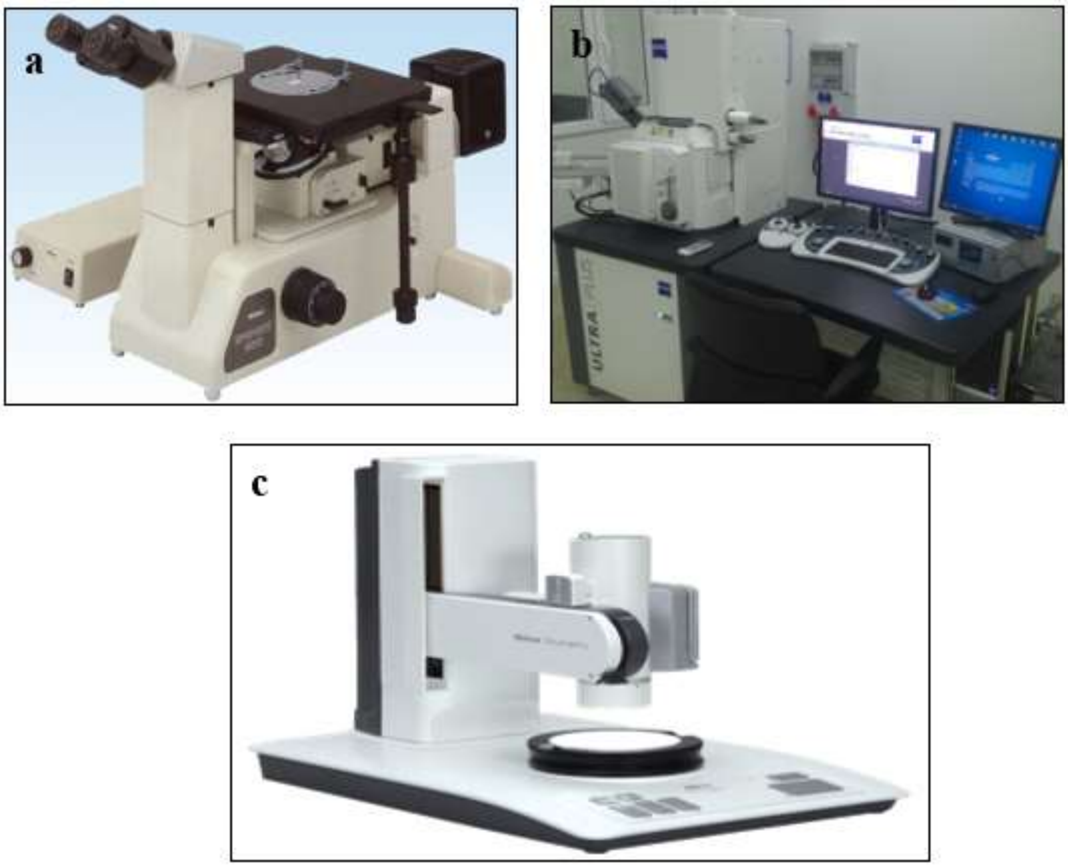


Figure 4.6. a) Nikon Epiphot 200 Model optical light microscope, b) Carl Zeiss Ultra Plus Gemini Fesem brand scanning electron microscope (SEM), c) Nikon Shuttle Pix P-400R Model stereo microscope.

4.2.3. X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) Analysis

Rigaku brand ZSX Primus II model XRF and Ultima IV model XRD devices were used in the XRD-XRF laboratory of KBU Iron and Steel Institute, respectively, to determine the chemical contents and phases-textures of the produced alloys. XRD graphs were taken in the range of 15-90 ° on a copper-targeted XRD device. Missing pole figure measurements were obtained from (0002), (10-10), (10-11) and (10-12) peaks and the maximum texture strength and distributions were determined using the MTEX toolbox.

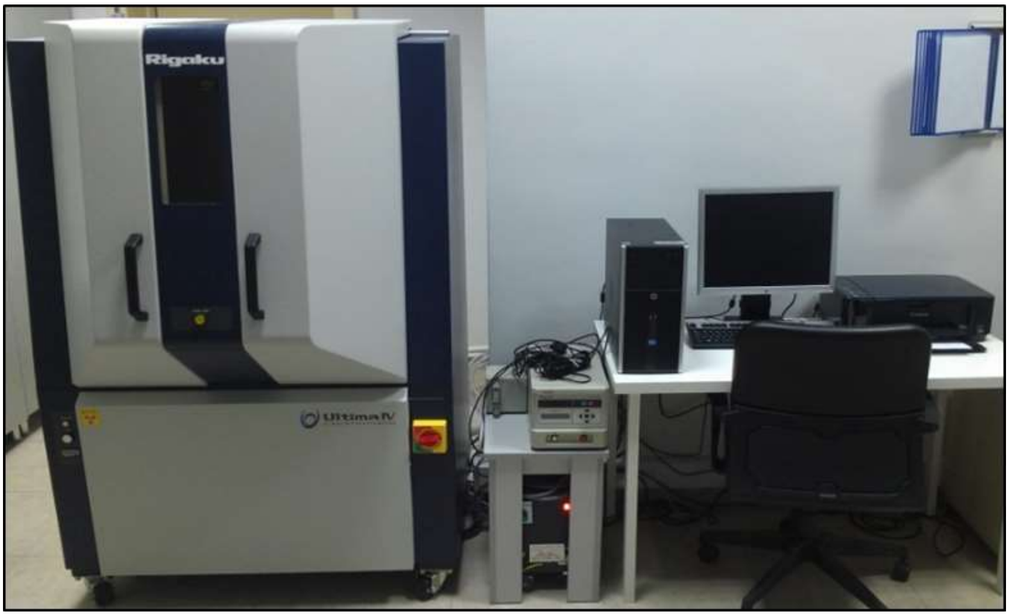


Figure 4.7. Rigaku Ultra IV model X-ray device (XRD).

4.2.4. Grain Size and Twinning Fraction Analysis

Grain size analyzes were calculated according to ASTM E112 standard from 200X magnification optical microscope images. SEM images with 500X magnification were used to calculate the twinning fraction and point calculation was performed according to ASTM E562-02 standard.

4.3. MECHANICAL TESTS

4.3.1. Hardness Tests

The hardness tests were carried out in the Micro and Macro Hardness Measurement Laboratory of KBU Iron and Steel Institute in accordance with TS-EN-ISO 6506-1 standard under a load of 187 mm kg. At least 3 measurements were taken from each material.

Figure 4.8. Shimadzu HMV2 microhardness tester for hardness measurements.

4.3.2. Tensile Tests

Tensile tests were carried out in the static laboratory of KBU Iron and Steel Institute using MTS branded 100kN Servo Hydraulic Dynamic Tester at room temperature with a speed of 1 mm / sec according to ASTM A370-12a standard. At least 3 tests were taken from each material.

Figure 4.9. Shimadzu AG-IS 50 kN tensile tester for tensile testing.

4.4. Punching Test

After preparing the samples used in this study, their length of 20 cm width and 30 mm thickness of 3 mm was introduced into the punching system as shown in figure 4.6 and the measurements of the suppression force were performed using a load cell that has a capacity of 120 kN and a data reading speed of 10,000 data / sec. The data reading speed was adjusted to 2000 data / sec. The experimental results were transferred to the digital medium by the load cell, the data card, the amplifier and the data visualization software. To improve the precision of the measurements obtained, the signals generated by the load cell were strengthened by using an amplifier. An analog to digital converter used to transmit the amplified signal to a computer. The experimental setup is presented in Fig. 4.10.

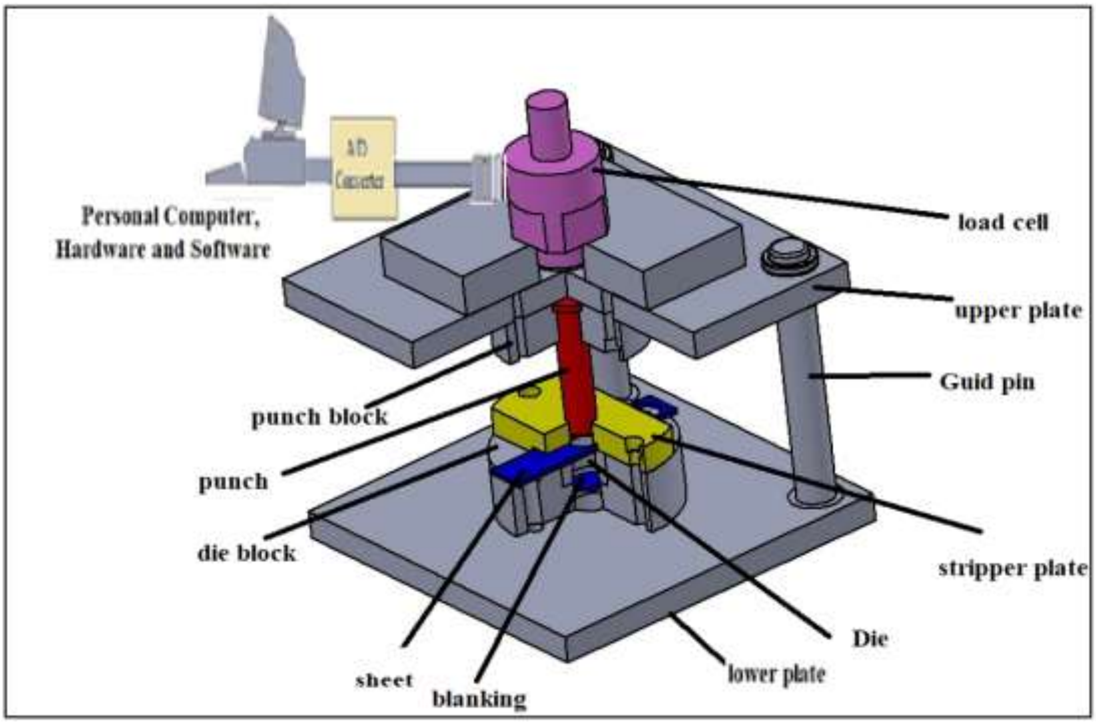


Figure 4.10. Schematic overview of the experimental set-up.

Three types of punches which have different tip forms were used in the experiments. Punches were machined with a diameter of 20 mm. Tip forms of the punches were assigned as flat ended (0°), concave formed (R), and angled (16°) and cut by using a wire EDM. Type of punches used in the experiments and form of the falling parts are given in Fig 4.11.

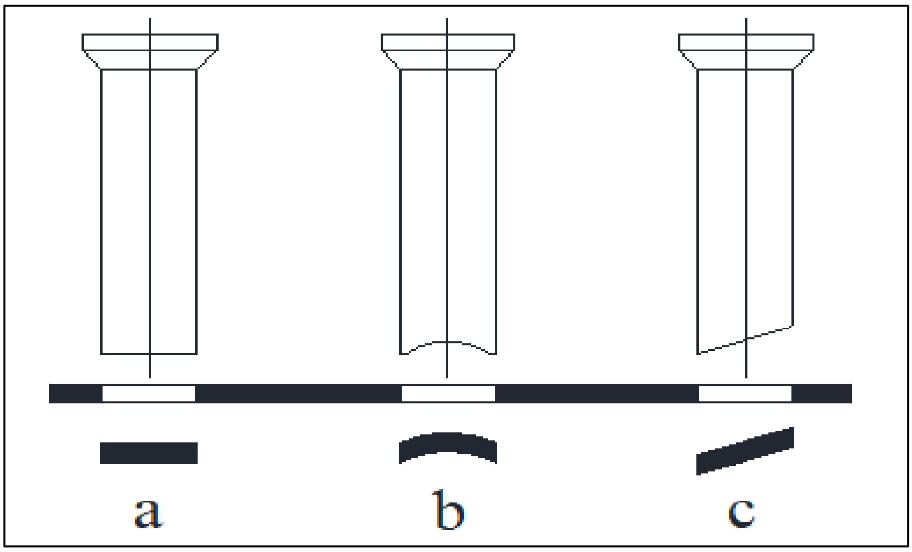


Figure 4.11. Type of punches used in the experiments and forms of the falling parts.

CHAPTER 5

RESULTS

5.1. MICROSTRUCTURE

The microstructure of the investigated alloys is shown in Fig.5.1 (SEM) and Fig 5.2 (LOM) as-cast and rolled - extruded, respectively. The as-cast images illustrate that AZ61 consists of globular shaped secondary phases which distributing at grain boundaries and in the matrix (see Fig5.1a). Moreover, the as-cast of AM60 alloy includes bigger sized and complex shaped secondary phases in the matrix and continuously distributed ones at grain boundaries (see Fig 5.2b). Hot rolling deformation initiates equiaxed grains, twins, and DRXs on the microstructure. As seen Fig 5.3(a-b), AZ61RS2.5 and AZ61 RS7.5 alloys have equiaxed grains however the twins more occupied on microstructure for AZ61 RS7.5 than AZ61 RS2.5. Further, AM60 RS2.5 and AM60 RS7.5 alloys include equiaxed grains which especially introduced as DRXs however the continuous DRXs more placed on AM60RS7.5 than AM60 RS2.5 (see Fig 5.3(c-d). In addition, the extruded AZ61 and AM60 alloys consist of equiaxed grains where the DRXs more presented at AZ61 than AM60 (see Fig 5.3e-f). The EDS results show that both AZ61 R2.5 and AZ61 RS7.5 Mg alloys include Mg-Al-Zn and $Mg_{17}Al_{12}$ secondary phases also AZ61 RS7.5 have Al8Mn5 type one (see Fig 5.3(a-b) and Table 5.1). Moreover, AM60 RS2.5 consist of $Mg_{17}Al_{12}$ and Al_8Mn_5 type secondary phases however AM60 RS7.5 have just Al_8Mn_5 (see Fig 5.3(c-d) and Table 5.1). Further, EDS results of extruded AZ61 don't illustrate any secondary phases on the other hand AM60 contain Al8Mn5 type (see Fig.5.3(f) and Table 5.1).

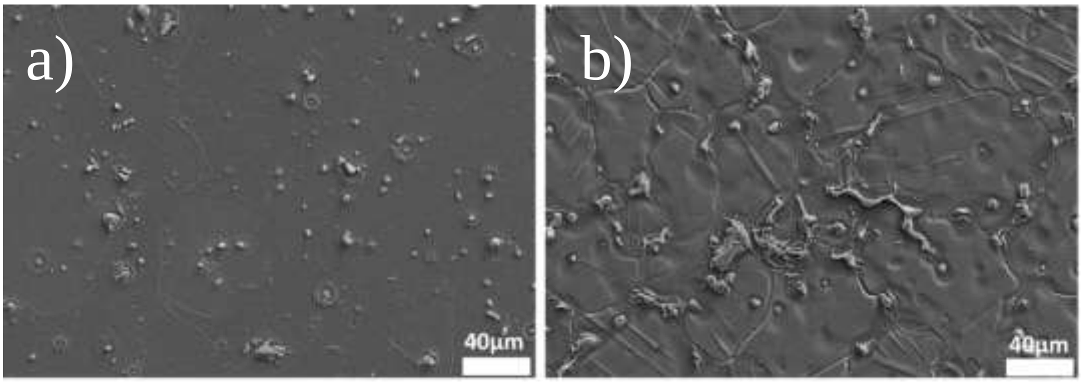


Figure 5.1. The SEM images of as-cast a) AZ61 and b)AM60 alloys.

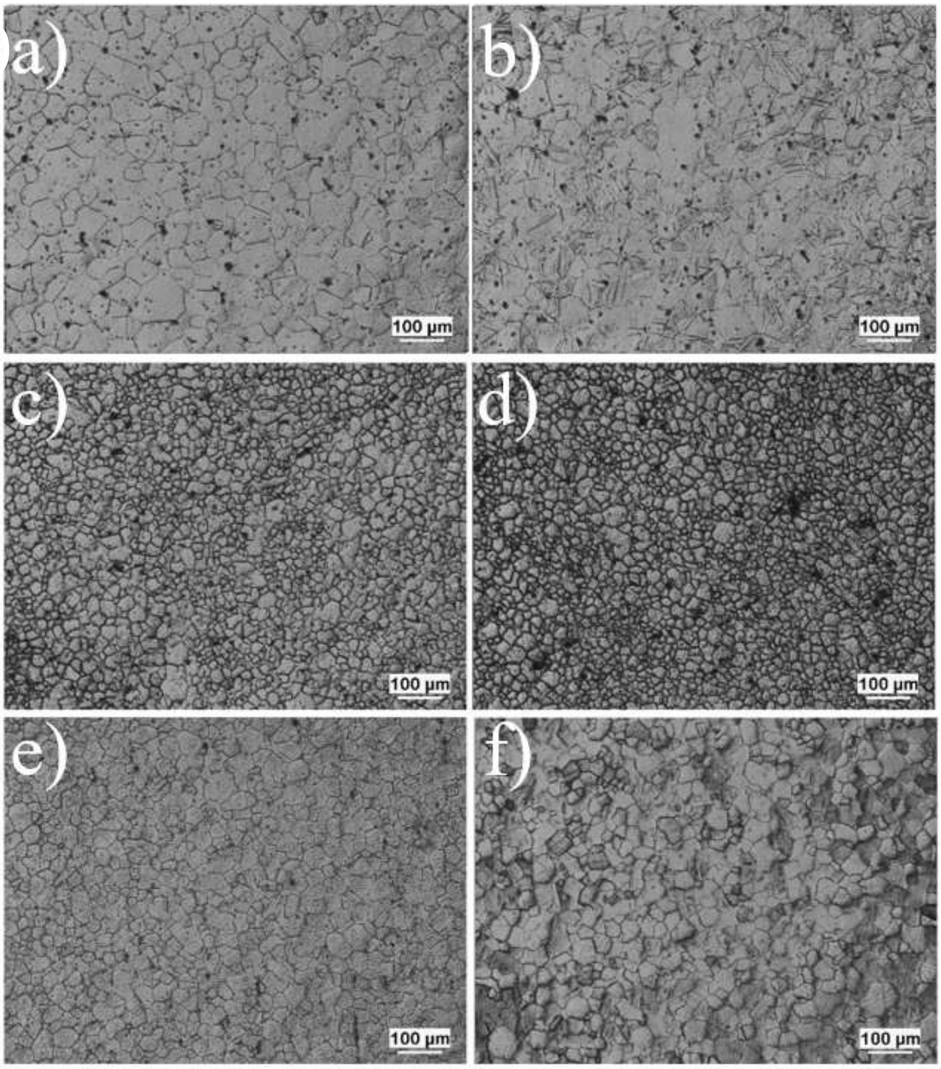


Figure 5.2. The LOM images of a-c) hot rolled AZ61 at b-d) hot rolled AM60 at e) extruded AZ and f)extruded AM.

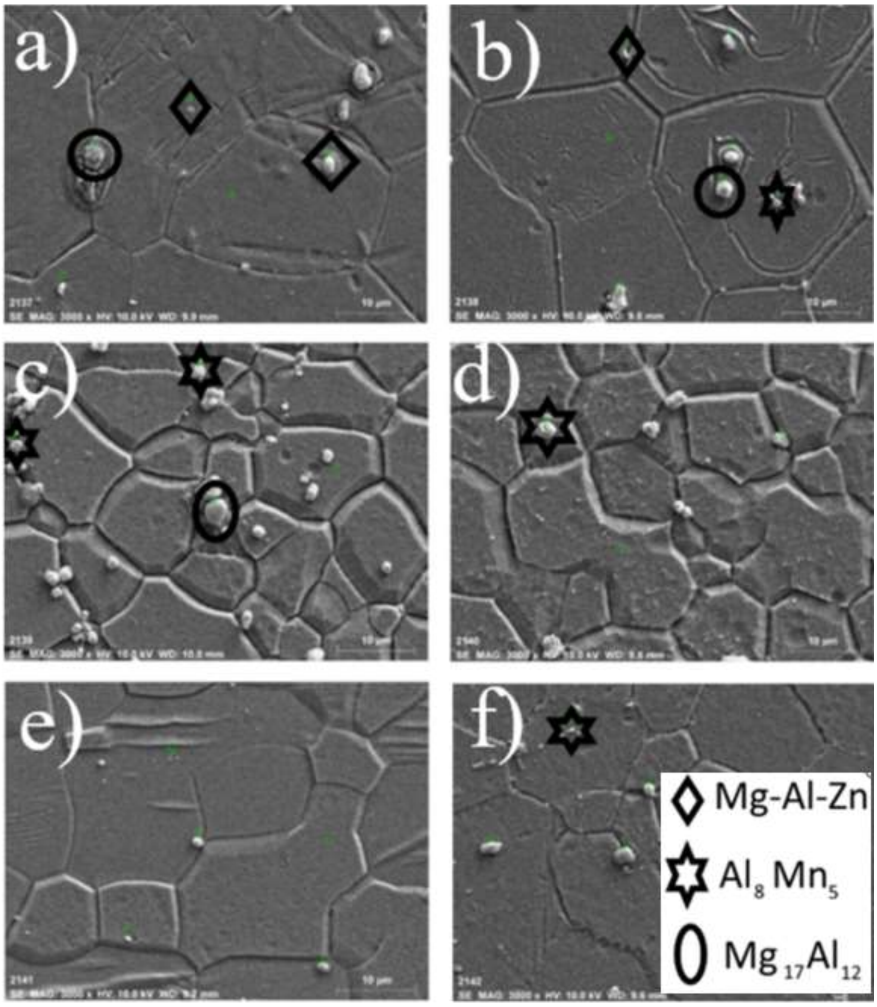


Figure 5. 3. The SEM-EDS results of a-c) hot rolled AZ61 at b-d) hot rolled AM60 at e) extruded AZ and f)extruded AM60.

Table 5. 1. EDS results of investigated alloys.

Method	Alloy	In Fig.	As Shaped	Mg	Al	Mn	Zn
Rolled	AZ61 RS 2.5	3a	○	60,31	35,68	0,00	4,01
	AZ61 RS 2.5	3a	◇	42,19	38,96	0,00	18,84
	AZ61 RS7.5	3b	○	81,35	14,37	1,17	3,12
	AZ61 RS7.5	3b	◇	51,23	26,69	2,83	16,25
	AZ61 RS7.5	3b	✡	4,64	53,65	41,65	0,05
	AM60 RS2.5	3c	✡	4,58	52,40	41,42	1,60
	AM60 RS2.5	3c	○	83,01	10,96	2,73	3,30
	AM75	3d	✡	2,94	53,18	42,63	1,24
Extruded	AM60	3f	✡	45,84	39,49	12,24	2,44

5.2. GRAIN SIZE

As seen Table (5.2), the average grain size of the samples is similar for rolled AM25 and AM75 and extruded AZ61 and AM60. However, the rolled AZ25 and AZ75 samples present different grain size wherein the AZ75 have highest one (see Table 4).

Table 5.2. Average grain size of investigated samples.

Method	Alloy	Average grain size (µm)
Rolled	AZ61 RS 2.5	46,8
	AZ61 RS7.5	62
	AM60 RS2.5	22,2
	AM60 RS7.5	21,1
Extruded	AZ61	32,5
	AM60	32,1

5.3. TEXTURE

The macro texture test results show that the texture intensity is lower at rolled samples rolled at higher rolling speed for AZ61 and AM60 alloys. Moreover, the extruded samples present lower texture intensity than rolled ones where the AZ61 shows lowest texture of 8,94 (see Fig 5.4).

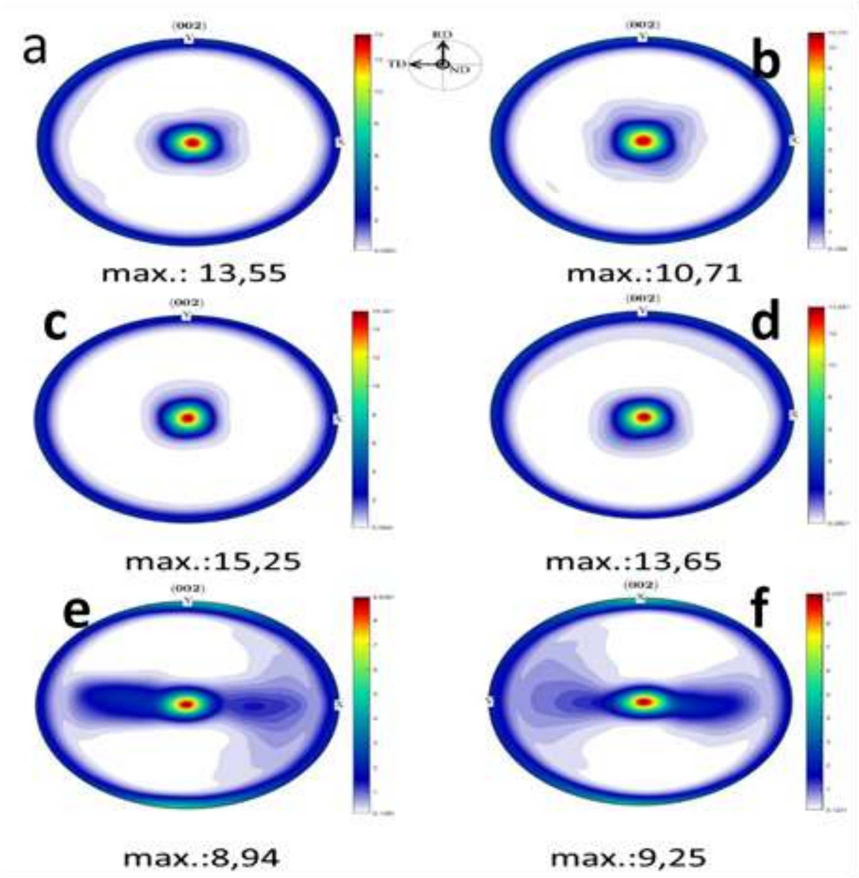


Figure 5.4. Macro texture evolution ,represented by (0002) pole figure, of the a-c) hot rolled AZ61 at b-d) hot rolled AM at e) extruded AZ61 and f) AM60

5.4. HARDNESS TEST

As shown at Table 5.3, the hardness results of all alloys groups after deformation is similar. However, as to rolled samples the lower hardness values was obtained by rolled at higher rolling speed ones. Furthermore, as for extruded samples the AZ61 have lower hardness value than AM60 (see Fig 5.5).

Table 5.3. Hardness Vickers results of investigated alloys.

Method	Alloy	HV
Rolled	AZ61 RS 2.5	68,63
	AZ61 RS7.5	67,63
	AM60 RS2.5	74,55
	AM60 RS7.5	72,87
Extruded	AZ61	55,37
	AM60	59,1

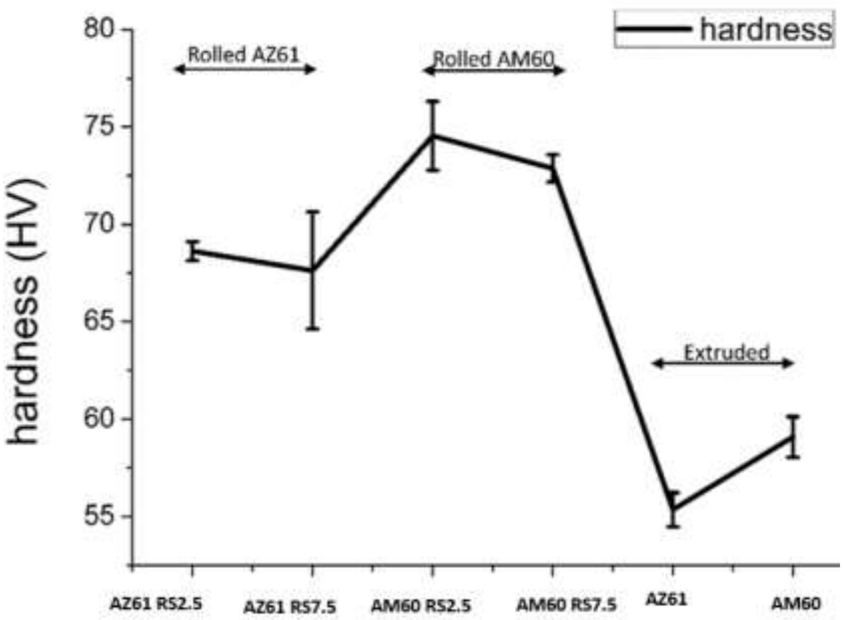


Figure 5.5. Hardness results of investigated alloys.

5.5. TENSILE TEST

Table 5.4. presents the tensile test result of investigated alloys. As seen Table 5.4. and Fig.5.6, the ultimate tensile strength (UTS) and elongation % values are higher for both. rolled AZ61 and AM60 alloys at higher rolling speed than lower ones. Further, yield strength (YS)of rolled AM60 showed similar result like AZ61. However, the yield strength is different for rolled AZ61 alloys which have highest one at lower

rolling speed sample. As to extruded alloys, AM60 consist of higher UTS, YS and elongation % than AZ61.

Figure 5.6. Tensile test specimens of hot rolled specimens.

Figure 5.7. Extruded tensile test sample.

Table 5.4. Tensile test results of investigated alloys.

	Alloy	$R_{p0.2}$ (MPa)	R_m (MPa)	A_{25} (%)
Rolled	AZ61 RS 2.5	143,87	191,46	2,66
	AZ61 RS7.5	133,09	218,45	5,59
	AM60 RS2.5	155,51	211,91	4,16
	AM60 RS7.5	158,15	226,59	6,11
Extruded	AZ61	184,07	242,54	15,39
	AM60	213,05	309,92	18,55

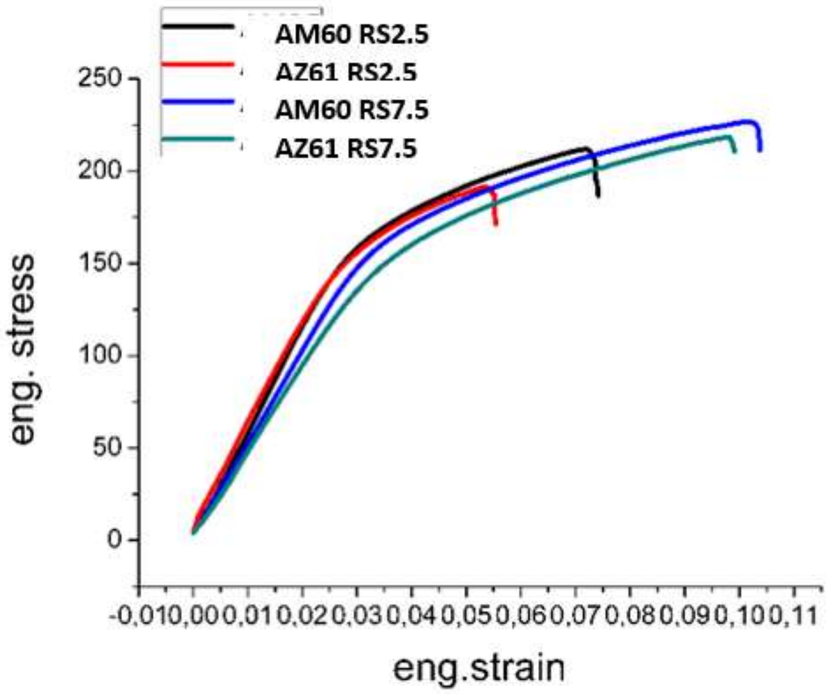


Figure 5.8. Tensile graph of investigated alloys as engineering stress (MPa).

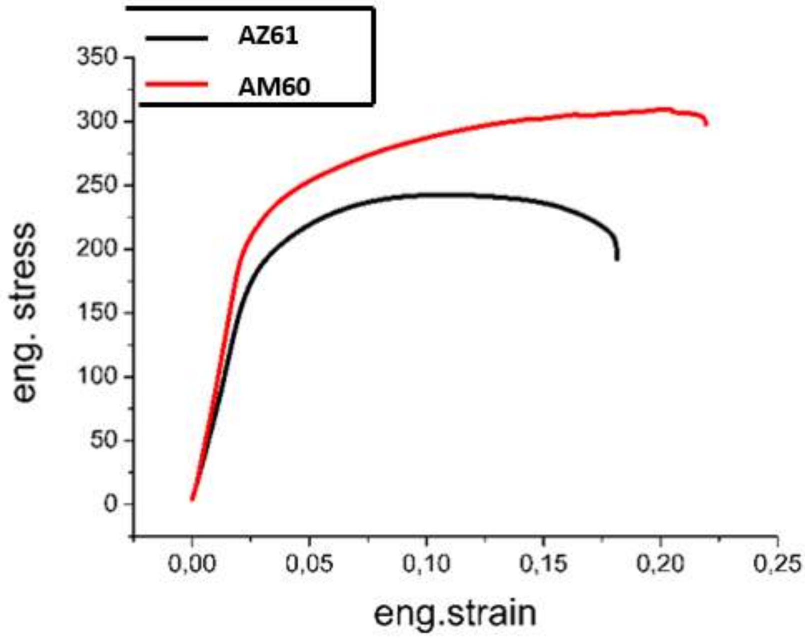


Figure 5.9. Tensile graph of investigated alloys as engineering strain (cm/cm).

5.6. FRACTURE

Fig 5.10 illustrates that the rolled samples include brittle type fracture wherein plate-like fracture results from main twins. However, the extruded samples show that ductile-brittle occurred as dimple or voids.

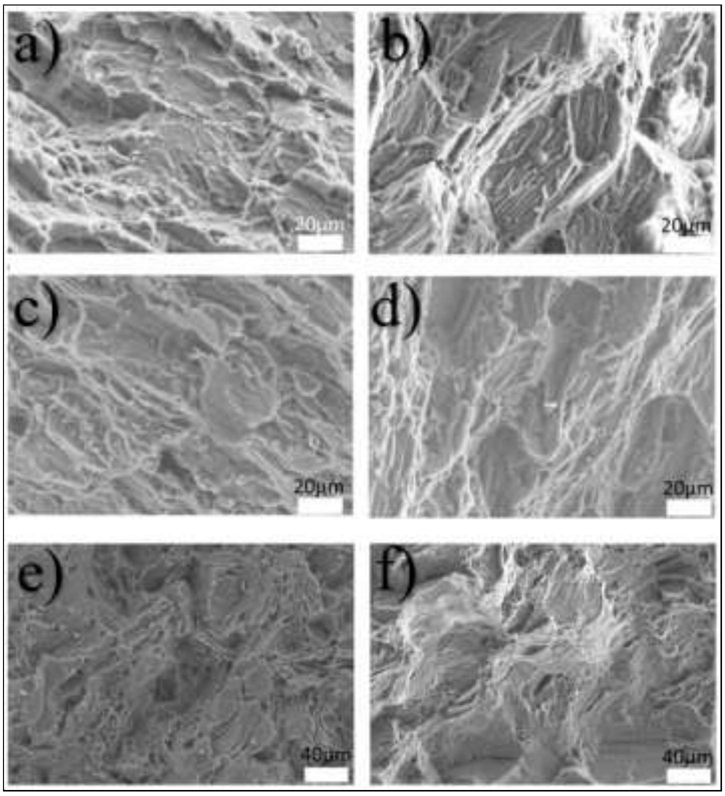


Figure 5.10. Fracture surface of rolled a)AZ61RS2. 5, b)AZ61 RS7.5, c)AM60 RS2.5, d)AM60 RS7.5, and extruded of e) AZ61 and f) AM60

5.7. EFFECTS OF PUNCH TYPE ON SHEARING FORCE OF MAGNESIUM ALLOYS

Three types of punches which have different tip forms were used in the experiments. Punches were machined with a diameter of 20 mm. Tip forms of the punches were assigned as flat ended (0°), concave formed (R), and angled (16°) and cut by using a wire EDM. Type of punches used in the experiments and form of the falling parts are given in Fig 5.11.

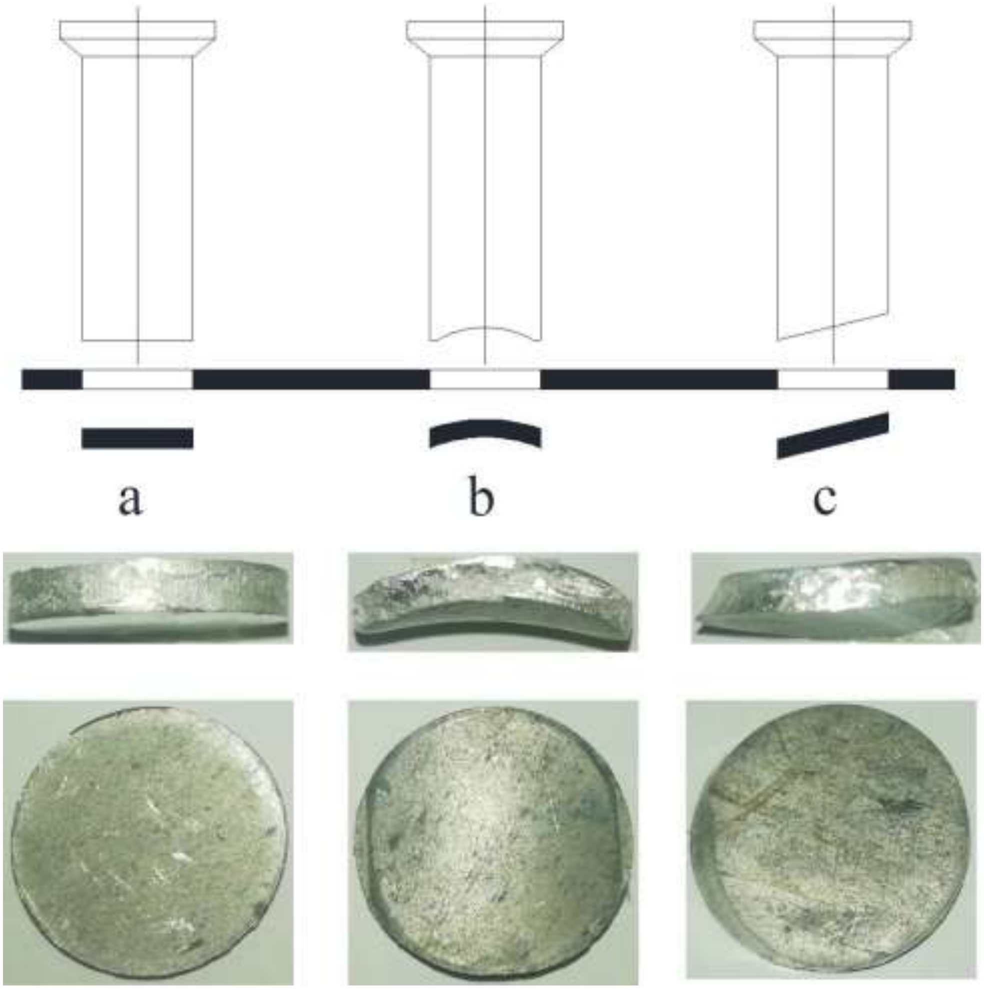


Figure 5.11. Effects of punch type on shearing force of magnesium alloys.

5.7.1. Effect Of Shear Forces

Through experiments conducted using three types of punching and one type of clearance applied to magnesium alloys AM60 and AZ61as casting and rolling speed of 2.5 rpm and 7.5 rpm have shown that the shearing force is significantly affected. The curve below shows the shear forces observed during the experiments were minimal when using punching (16°) and punching (R), while the highest value of this force was when using a punching (0°) with different magnesium alloys. From the results obtained it was also observed that the lowest blanking force was used with casting magnesium alloy with different punching types, while the blanking force of magnesium alloy AM60 was higher than blanking force of magnesium alloy AZ61, this indicates that the strength of alloy AM60 is higher than the strength of alloy AZ61.

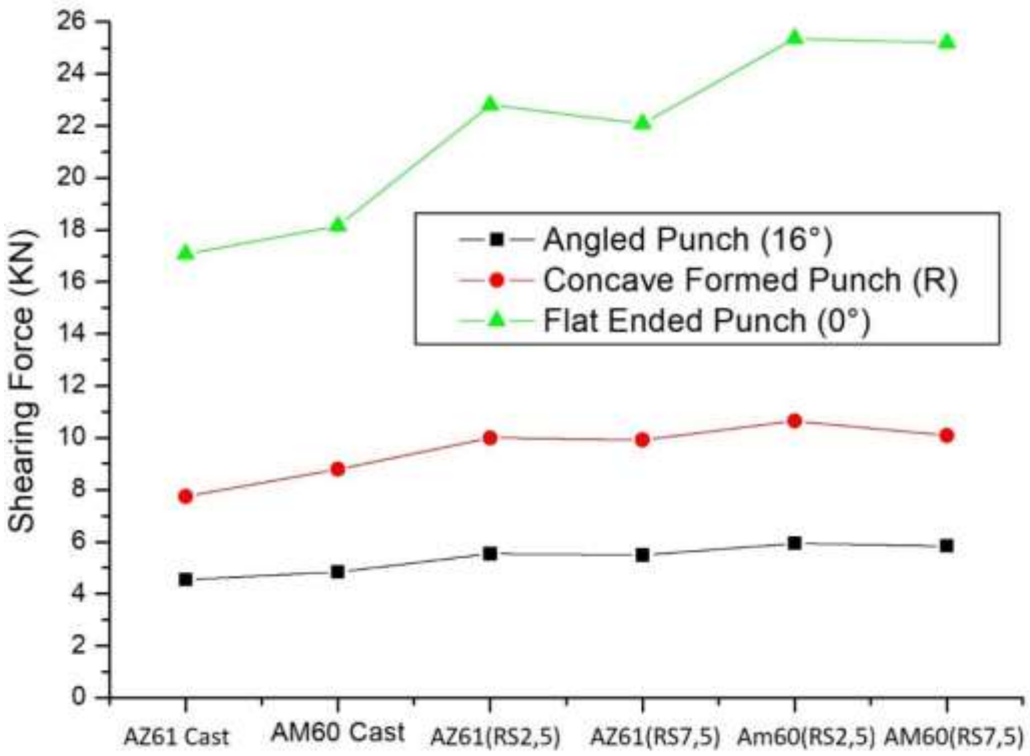


Figure 5.12. Blanking forces according to the punch type and material.

The results of punch (0°) were selected to compare the punching force in magnesium alloy, because the results in this type of punch were more obvious than other punch types due to the large alloy area exposed to Blanking/piercing operations in this type of punch.

Blanking force in magnesium casting alloys less than in mg rolling alloys, clearly that strength of rolling magnesium alloy higher than strength of casting magnesium alloys, simultaneously the rolled magnesium alloys had a higher punching force in type AM60 alloy than type AZ61 alloy that is mean strength of AM 60 higher than strength of AZ61 as shown in Fig 5.12.

Table 5.5. Rollover depth, smooth sheared depth, burr height, and fracture depth.

Alloys	**Punch Type**	**Rollover depth, mm**	**Smooth sheared depth, mm**	**Fracture depth, mm**	**Burr height, mm**
AM60 casting	0º	0.2	1.1	1.7	0.09
AM60 (RS 2,5)	0º	0.2	1.4	1.4	0.05
AM60 casting	R	0.3	1.35	1.35	0.1
AM60 (RS2,5)	R	0.3	1.3	1.4	0.05
AZ61 casting	0º	0.27	1.03	1.7	0.08
AZ61 (RS 2,5)	0º	0.17	1.43	1.4	0.05
AZ61 casting	R	0.22	1.1	1.68	0.07
AZ61 (RS 2,5)	R	0.35	1.25	1.4	0.05

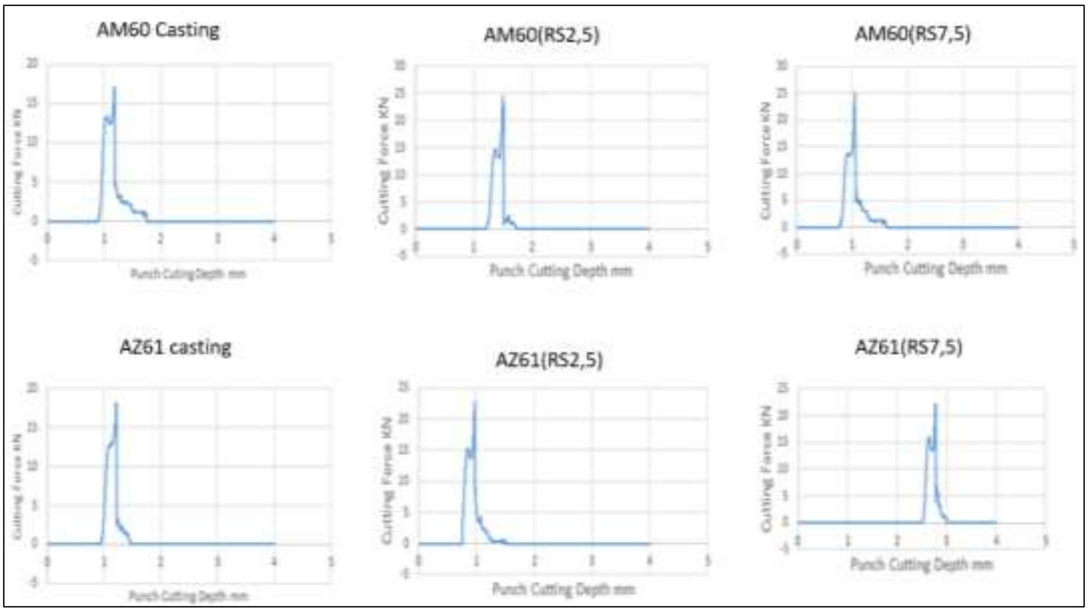


Figure 5.13. Punch penetration depth vs shearing force (displayed in separate graphs).

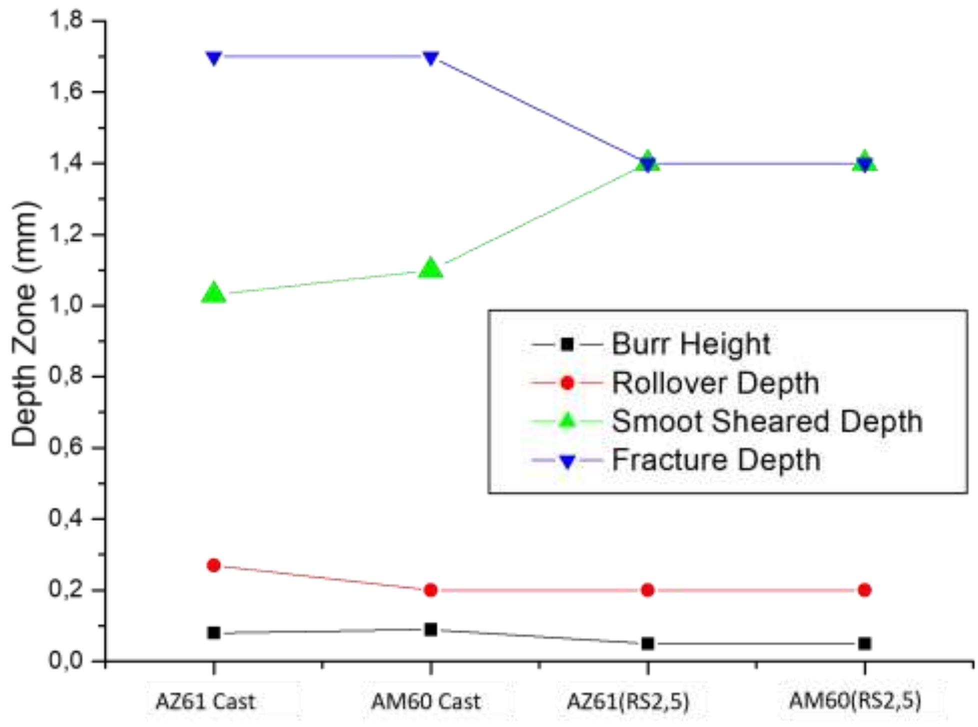


Figure 5.14. Depth zones for different Mg alloys gained from using of flat ended punch.

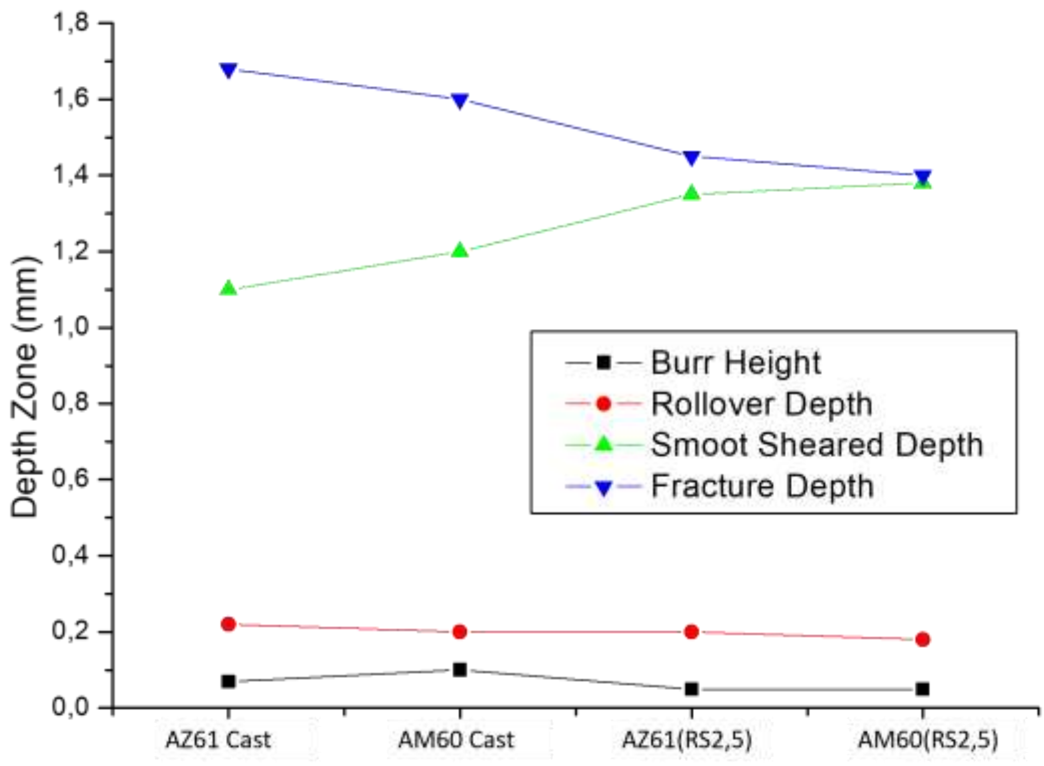


Figure 5.15. Depth zones for different Mg alloys gained from using of concave formed punch.

5.7.2. Smooth sheared, Burr depth and Fracture depth

On the every blanking, there is some amount of burr according to the material or type of alloys used, for instance Am60 casting burr increases according to the hard or soft material , Penetration increases as the flow of specialized soft materials increases, Therefore, burr was higher in casting alloys than rolling alloys because casting alloys (AM60 casting, AZ61 casting) were softer than rolling alloys (AZ61 rolled, AM60 rolled). Smooth increases as the material hardening increases, as shown in the figure below smooth depth in rolling alloys higher than in casting alloys. While the fracture depth increases in soft material more than hard material as shown in fig below.

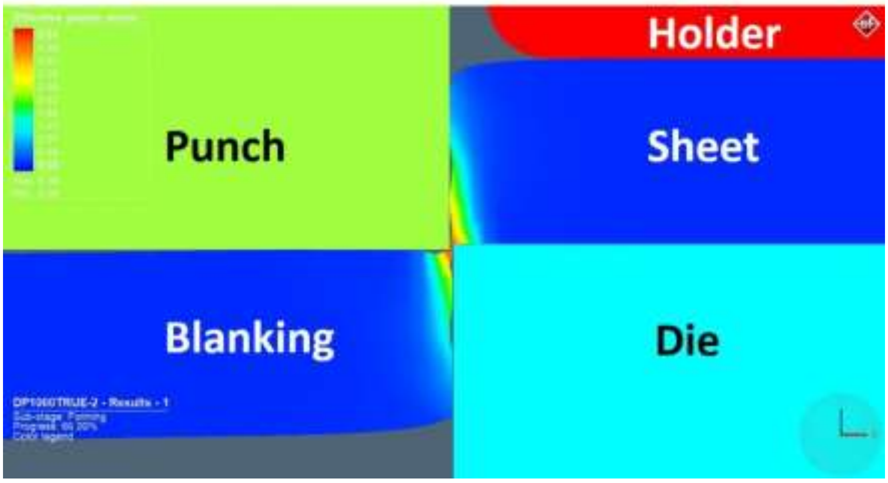


Figure 5.16. Punching simulation with Punch 0° (Flat) and name of parts (By SIMUFACT program).

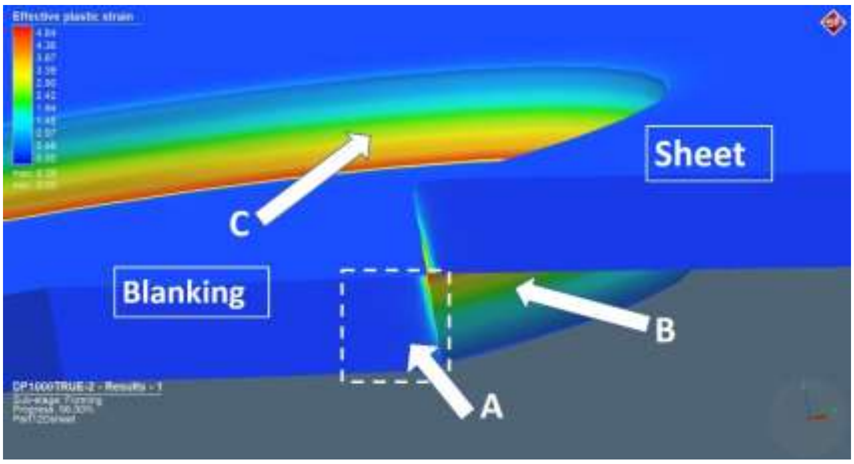


Figure 5.17. A) Blanking cross section, B) Blanking cutting surface and C) Sheet hole cutting surface.

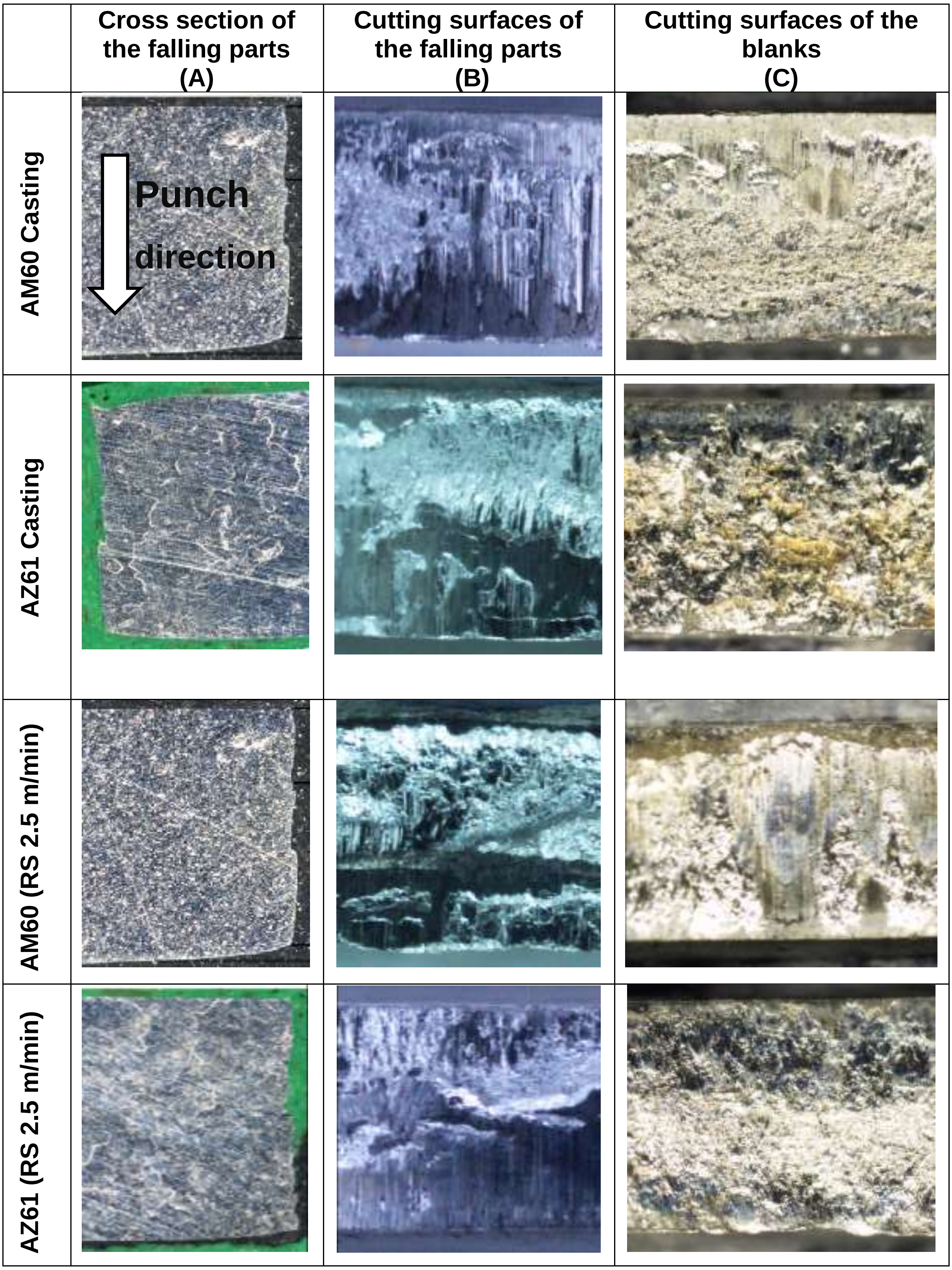


Figure 5.18. Stereo microscope images taken from cross section and cutting surface of samples after punching using flat ended punch (0°).

CHAPTER 6

DISCUSSION

6.1. TEXTURE AND MECHANICAL PROPERTIES OF PLASTICALLY DEFORMED AZ61 AND AM60

The equiaxed grains have typically occurred structures given by hot rolling to Mg alloys that are the main deformation mechanism giving rise to moderate tensile properties to them. However, the twins and DRXs also can be observed on microstructure based on the rolling conditions[55]. Some studies declare that the twins more dominant than DRXs to introduce on microstructure at low rolling speeds during plastic deformation. Twins boundaries can make a role as grain boundaries that enhancing the yield strength according to the hall-petch relationship[56, 57]. However, DRXs can be observed during hot rolling due to between pass applied for deformation energy show yourself as a new recrystallized grains and after the following pass, the DRXs shows more growth[58]. As shown in Fig. The rolled AZ61 alloys include bigger sized grains than rolled AM60 and the AZ61 RS7.5 one have smaller grains on microstructure. This is the reason for the YS and hardness Vickers of AZ61 RS2.5 more higher than AZ61 RS7.5 according to hall-petch. However, AZ61 RS7.5 alloy strong for UTS and more ductile than AZ61 RS2.5 due to the introduced Al_8Mn_5 type secondary phases. Further, rolled AM60 alloys present stronger YS than AZ61 that is convenient with hardness results wherein the effects on grain size on yield strength is seen as clearly. However, the hardness results for different rolling speeds are different both AZ61 and AM60 alloys wherein the nonhomogenous twins and continuous DRXs for AZ61 and AM60 could be the reason, respectively. When we discuss of elongation% of rolled samples it is clearly seen that the texture is the other factor also affecting the ductility as seen table AZ75 and AM75 have a weak texture which gives rise to more planes for slipping wherein these alloys showed more ductile than AZ61 RS2.5 and AM60 RS7.5. In addition, the extruded alloys both present highest elongation % values and lower texture intensity after the tensile test among test samples. On the other hand, the YS and UTS values of extruded samples higher than other alloys. When we examine the EDS results extruded samples include less amount secondary phases on microstructure. It is said that the solid solution hardening can be the main reason for the enhanced tensile results. Moreover, the fracture surface of extruded samples contains many cavitations and voids that are typical in ductile materials although the rolled samples demonstrated that brittle fracture surface contains flat like edges as like brittle materials [59, 60].

CHAPTER 7

CONCLUSIONS

As a result of this study, the average grain size of AZ61 and AM60 Mg alloys after plastically deformed by hot rolling and extrusion in the similar deformation amount is as following rolled AZ >extruded AZ and AM and >rolled AM alloys. However, the hardness of materials is following as rolled AM >rolled AZ and > extruded AZ and AM. As to tensile properties of materials, the highest YS, UTS, and elongation % was obtained by extruded AM60 wherein the values ~213, ~310 and ~19 respectively while the rolled samples consist of lower values. Contrary to the mechanical properties of extruded alloys, the texture of them also very lower than rolled ones.

The effects of various punch types on cutting force in the blanking/piercing process were examined experimentally. The ingot magnesium materials were produced by casting. The ingots were machined to the required dimensions and gradually rolled up to 3 mm thickness. The punches used in the experiments were machined by using a wire EDM as flat ended, concave formed, and 16° angled.

As a result of this study, the following conclusions can be drawn:

- The minimal cutting forces were observed during the experiments when using the angled punch (16°) and concave formed punch (R) while the highest value of this force was observed when using a flat ended punch (0°).
- The blanking force in casted magnesium alloys is less than in rolled magnesium alloys because of its lower hardness value, on the other hand, it led to a decline in the smooth shear fracture rate. This situation negatively affects the quality of the obtained product.

- When the rolled magnesium, alloys were examined according to punching force, AM60 alloy was required more force than AZ61 alloy. That means that resistance to cutting of AM 60 is higher than cutting of AZ61.
- As the hardness of the material increased, the smooth sheared depth increased too. Conversely, hardness of the material decreased the rollover depth, fracture depth, and burr height. Therefore, it can be said that increasing rolling rates and number of the applied passes positively affect the quality of the obtained product due to the increased hardness values.
- Depending on the side profile form of the falling part, it is suitable to use just flat ended punches for the blanking processes while all three type punches can be used for piercing processes.

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RESUME

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