Study of Advanced Magnesium Alloys with Improved Bendability for Roll Forming

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Abstract: ***The growing demand for light weight products for automotive industries has been increased due to global trend of environmental preservation. In recent several years, although production of magnesium has risen dramatically, production of magnesium alloy sheet remains still at a very low level in practical use. The major barrier to greatly increased magnesium alloy use has been in still primarily high manufacturing cost as well as poor workability of wrought magnesium sheet alloys. finite element method (FEM) has been conducted to examine the shapes of cross section, springback characteristics, bending strains and longitudinal membrane strain of magnesium alloy sheet during forming. The aim of our study is to establish a guideline for roll design in the roll forming for wrought magnesium alloy sheet with improved bendability.***

Keywords: Magnesium alloy AZ31, bendebility, Flexible roll forming, ECASD

1. Introduction

As the lightest metal structural material, magnesium alloys have recently attracted a lot research interest because of their potential application for lightweight structural components particularly in electron, automobile industries. However, the manesium alloys always exhibit a poor ductility and formability at room temperature due to the hexagonal close-paked (HCP) crystal structure. [1]

Magnesium alloy widely used for automotive and electronics industries because of their advantage, such as high specific strength, high specific stiffness, and high electromagnetic shielding. But magnesium alloy have poor formability at room temperature due to their hexagonal closed-packed crystal structure [2]

Magnesium alloys have always been attractive to designers due to their low density, only two thirds that of aluminum alloys in the aerospace industry and therefore can be an innovation technology if used for low weight airframe structures. This has been a major factor in the widespread use of magnesium alloy castings and wrought products. New light materials are currently inserted in world strategies of transport vehicle industry since the environment necessities for pollution and reduction of fuel consumption. Therefore the industry takes part of the risk of development of such alloys but, in fact, some of this has been made at academic level. Some aspects of the necessities and characteristics concerning those alloys are: low costs, insulation (sound and thermal), impact safety, deformation strength, recyclability and guarantee (to aging as example). All those aspects are linked with the increasing of new vehicle models and reflect in production programs that are more and more complexes (Raynor, 1959; Roberts, 1960; Eliezer et al, 1998) [6].

Few slip systems and a strong basal plane texture. The formability is largely improved by heating between 200 and 300 C, therefore most products are press formed over 250 C with solid lubricants. However complex high temperature forming tool systems, poor surface quality and high cost limit the applications of wrought magnesium alloy sheet. Press formability of magnesium alloy sheets is strongly affected by the texture and it can be improved by reduction of basal texture intensity. [2] While the automotive industry can be considered a pioneer for many lightweight applications, the issue has spread to other industries as well. Possible mean to achieve weight reduction are to lower the material inventory e.g. by minimising the sheet metal thickness while increasing material strength or by substituting conventional steel or aluminum materials with even lighter material. Due to its low density combined with a good specific strength, magnesium offers an outstanding lightweight potential. Magnesium is the eight most common chemical element found in the earth’s crust what can be considered as an excellent raw material base for large-scale and mass production of consumer products. [3]

Reducing vehicle weight is an important approach for increasing fuel economy, addressing regulatory requirements, and meeting consumer needs. Magnesium alloys are among the lightest structural metals and offer tremendous weight saving potential; however, many technical and commercial barriers limit their use in today's cars and trucks [4]

Magnesium wrought alloys as structural materials

Structural applications include automotive, industrial, materials handling, commercial, and aerospace equipment. The automotive applications include clutch and brake pedal support brackets, steering column lock housings, and manual transmission housings. In industrial machinery, such as textile and printing machines, magnesium alloys are used for parts that operate at high speeds and must be lightweight to minimize inertial forces. Materials-handling equipment includes dock boards, grain shovels, and gravity conveyors. Commercial applications include handheld tools, luggage, computer housings, and ladders. Magnesium alloys are valuable for aerospace applications because they are lightweight and exhibit good strength and stiffness at both room and elevated temperatures.

Pyrotechnics: The first applications of magnesium powder were components of fireworks, flares, and other incendiary devices to produce brilliant white light. Fine magnesium wire was used for photographic flash bulbs. Magnesium is still used in fire starters for survival kits [5].

Metallurgical: Magnesium is used as an alloying element in nonferrous alloys, such as aluminum, zinc, and lead. It is used as an oxygen scavenger in nickel and copper alloys and as a desulfurizer in iron and steel production. Magnesium improves the toughness and ductility of cast iron by making the graphite particles nodular. This is the greatest use of magnesium by weight [5].

Electrochemical Applications. Magnesium is highest on the electromotive series among metals in salt water, making it desirable as a sacrificial anode for cathodic protection. Constructive uses of this mechanism are employed in batteries [5].

Medical: Magnesium alloys are used in portable medical equipment where light weight is advantageous. It is also employed for wheelchairs used in sporting activities (where every ounce is critical). Because of magnesium's biocompatibility and bioabsorbability, alloys with other biocompatible elements (such as calcium) are being evaluated for cardiovascular stents and orthopedic devices for internal bone fixation. [5]

Magnesium alloys for transport applications

The automobile have more than a hundred years since its invention and the light alloys have been utilized since 1915. In the 30's the aluminum did substitute almost completely the casting iron as main component of pistons. In the same decade, in Germany, magnesium alloys were utilized in the production of camshaft and in the gear box, which leads, at that time, the total decrease of weight at least 7% of the total of the automobile. Magnesium alloy developments have traditionally been driven by aerospace industry requirements for lightweight materials to operate under increasingly demanding conditions. In the last decade several heavy magnesium parts have been assembled in passenger cars, such as gear box housings and crank cases (Aghion, 2003). Considerable research is still needed on magnesium processing, alloy development, joining, surface treatment, corrosion resistance, and mechanical properties improvement. Surface coatings produced for magnesium die-casting by hexavalent chromium baths have been used to provide stand-alone protection and as a pretreatment for painting. Teflon resin coating has been developed for Mg alloys; initially the coating is obtained with an aluminum vapor deposition and finish treatment with a Teflon resin coating. The Teflon resin coating is a low cost, chromium-free corrosion resistant coating for magnesium alloys. The coating not only has corrosion resistant properties, but also good lubricity, high frictional-resistance and non-wetting properties (Kulekci, 2008) [6].

Comparative and effective use of new Mg alloys

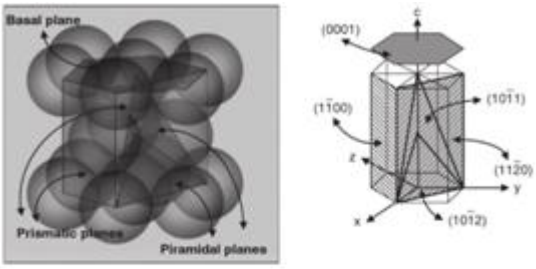
Another influence in research for new technologies of materials and light alloys relies on the shortening of models life. New materials and alloys are usually more expensive than commercial materials, so there is direct needs of investment in reduce the costs of production and development of such alloys allowing the utilization in large scale in the automobile production processes. The increase in the potential application of magnesium profiles is strongly dependent on the question of whether established forming processes for aluminum and steel can be changed to magnesium and its alloys. Broad-spectrum applications of magnesium alloys in the automotive industry are casting products. Several new magnesium alloys have been developed recently for high temperature applications to obtain an optimal combination of die castability, creep resistance, mechanical properties, corrosion performance, and affordability. Most of the new alloys can only partially meet the required performance and cost. The ZE41 alloy (gravity-casting applications) has moderate strength and creep resistance combined with good castability. Although this alloy exhibits poor corrosion resistance, it is still preferred for certain applications. Although the most commonly used magnesium die-casting alloys are of the AZ and AM series, improved elevated-temperature performance is required (gearbox housing, intake manifolds, oil pans, transfer cases, crankcases, oil pump housing). Insufficient creep strength of alloys can causes poor bearing-housing contact, leading to oil leaks and increased noise and vibration. The use of magnesium alloy casting in the automobile industry expands at an impressive rate in this decade, which can manage with the energy and environment problems. Alloy AZ91 (Mg-9Al-0.8Zn-0.2Mn) is the most favored magnesium alloy, being used in approximately 90% of all magnesium cast products (Guangyina et al., 2000). There are two patented magnesium alloys (Dead Sea Magnesium Ltd, 2012): Mg-Al-Ca-Sr based alloy (MRI 153M) and Mg-Al-Ca-Sr-Sn based alloy (MRI 230D). The MRI 153M is a beryllium-free, creep-resistant alloy capable of long operation at temperatures up to 150°C under high stresses (substantially superior to those of commercial alloys). The MRI 230D is a die-casting alloy developed for use in automotive engine blocks operating at temperatures up to 190°C. The alloy has excellent creep resistance combined with good castability, high strength, and superior corrosion behavior. The results obtained show that MRI 230D and A380 exhibit similar tensile creep behavior at 150–175°C under stress of 70 MPa (Aghion, 2003) [6].

Physical metallurgy of magnesium

In magnesium, however, solutes are unable to create sufficient perturbation in the truly delocalized bonding among magnesium atoms. SFE, as a related property to free electron density distribution is thus given special attention below. Plastic deformation of magnesium invokes several puzzling questions. These anomalies are pointed out in this paper, and an attempt has made to gather from the existing literature the possible accounts of each phenomenon. The reader is also referred to the other chapter related to deformation, chapter forming of magnesium and its alloys, in this paper Topic like fatigue, creep and grain size related phenomena have hopefully been compressed into a comprehensible size, highlighting both more interesting as well as mainstream concepts without greatly compromising the meaning of these otherwise vast topics A.A. Kaya, Mugla University, Turkey chapter2 (33-35) [7].

Crystal Structure and its consequences

HCP crystala lattice and major planes of mangesiu are shown in Fig. 1.1 with lattice parameters a=3.18A and c=5.19A, slightly less than the ideal c./a ration of 1.62354 (at 25 C) of Mg crytal, appears important in explaining some fundamental characteristics of the metal. A comparison of c/a ratios as well as critical resolved shear stress (CRSS) for basal planes of different HCP metals is given in table 1.2. A.A. Kaya, Mugla University, Turkey chapter2 (33-35) [7].



1.1 Schematic description of hexagonal close-packed (HCP) crystal lattice and major planes of magnesium, source (Mihriban O. chapter2 (33-35) [7]).

Table 1.2: A comparison of CRSS levels for basal planes and c/a ratios of different HCP metals (25 C) source, (Mihriban O. chapter2 (33-35) [7]).

Metal	CRSS (psi)	c/a
Mg	63	1.624
Cd	82	1.886
Zn	26	1.856
Ti	16000	1.588
Be	5700	1.586

Advance magnesium alloy design

Solid solution alloying of magnesium -Pure metals are rarely used in structural applications. alloys, which are strengthened via mechanisms such as solid solution strengthening, precipitation hardening and dispersion strengthening, (that occur when a metal is combined with one or more elements), form the basis of structural metallic materials. Also, properties of an alloy can be altered and improved via microstructural design and modification.

A solid solution alloy is characterized by the complete dissolution of the alloying element (Solute) in the lattice of the base metal (solvent), either subsitutionally or in the inerstictial sites. Mg does not have any major interstitial alloys. According to the Hume – Rothery rules, extensive solid solutions cannot be formed if the atomic sizes of the solvent and solute differ by more than 15%. In the case of Mg, which has an atomic diameter of 3.2 A, the elements that fall in this favorable size range are LI, AL, W, Re, Os, Pt, Au, Hg, Tl, Pb and bi. M. Pekguleryuz, McGill University, Canda Chapter 5 (153-155) [8]

Additionally, a metal forms extensive solid solutions with metals of similar electronegativity and crystal structure. Valency also plays a role; a metal of low valency is more likely to dissolve one of higher valency than the reverse (relative valency effect) because the addition of extra electrons to a metal increases its bond-forming capacity and hence the stability of the metal structure. According to this rule, among the elements that have favorable size factors, divalent Mg would dissolve trivalent and higher valency elements in addition to divalent ones. However, as the solute valency increases so does the difference between the electrochemical characteristics of the solute and Mg, which is highly electropositive. In these cases, Mg forms second solutions. if these criteria are not satisfied, there are still possibilities for limited solid solutions. In this paper the alloy compositions are given in weight percent unless otherwise indicated. The highest solid solubility exists when size factors and relative valency are very favorable (up to 15% relative size, and valency of 2 or 3). In this region, solid solubility can be as high as 53% for in. However, the strengthening effect is not appreciable for these cases, due to extreme similarity of atom sizes. At around 12-15% size factor, where border line sizes are involved, alloy systems of Mg offer considerable solid solution strengthening (AI, Zn, REs, etc.) M. Pekguleryuz, McGill University, Canda Chapter 5 (153-155) [8].

ECASD process- A continuous severe plastic deformation (SPD) technique called equal-channel angular sheet drawing (ECASD) was used to mechanically deform an annealed magnesium AZ31B alloy, which has been recognized as simple and effective technique for improving metal's properties; among the most studied alloys using SPD techniques are magnesium alloy [12].

Repeated roll bending process- one of the author investigated the improvement of formability and bendebility of AZ31 magnesium alloy by repeated roll bending process, here the result has shown improvement in mechanical and microstructural properties [13].

Magnesium alloy design to enhance properties (Strength and ductility)

When the mechanical properties of Mg alloys are examined under comparable conditions, it is seen that alloying elements fall into three main categories

1) Those that increase both strength and ductility. These elements in order of effectiveness are: Al, Zn, Ca, Ag, Ce, Ga, Ni, Cu, Th (strength criteria) Th, Ga, Zn, Ag, Ce, Ca, Al, Ni, Cu (ductility criteria).
2) Those which provide little strengthening, but increase ductility: Cd, Tl and Li.
3) Those which may confer considerable strengthening but at the cost of ductility. These are: Sn, Pb, Bi and Sb. Based on the above information, it is not surprising that most common alloy systems have been developed in the Mg–Al, Mg–Zn and Mg − Al – Zn systems [8].

Bendability of AZ31B tube

One of the author has investigated in the bending operation is a plastic deformation process. At early stages of bending, low stress but higher plastic is developed in the bend inner radius compared to those in outer radius. this due to the lower compressive yield strength in compression than tension, leading to larger deformation at lower stress in compression condition. With the increasing bend angle, slightly larger plastic strains but significantly lower stress are developed in the outer radius compared with the inner radius, due to the considerably higher strain-hardening rate observed in the compression. It is noted that very high compressive stresses are calculated in the inner radius, higher than the compressive strength at bending temperature 150 degree [9].

Experimental History

the experimental setup was developed by Takayuki Hama, Yuhta Kariyazaki*, Keisuke Ochi*, Hitoshi Fujimoto and Hirohiko Takuda, here concluded a two-dimensional draw-bending test on an AZ31B Mg alloy sheet was carried out at various forming temperatures and BHFs, and the springback characteristics of the sheet were examined in detail. The following conclusions were drawn.

1) Flow stress decreases almost linearly with increasing temperature. Young's modulus is almost constant from RT to 100_C; however, it decreases when the temperature exceeds 100_C. The finite element simulation revealed that a decrease in flow stress has a greater effect on the variation in springback than a decrease in Young's modulus.
2) The amount of springback decreases with increases in temperature and BHF. The decrease in the amount of springback caused by the increase in temperature is much larger than that caused by the increase in BHF, which indicates that increasing the temperature is much more effective for reducing the amount of springback than increasing BHF.
3) The amount of springback becomes negligible at 200_C and above. This result is attributable to multiple factors: (a) flow stress decreases rapidly as temperature increases, (b) reverse bending on the sidewall arises at 150_C and above, and (c) fine grains due to dynamic recrystallization are formed at 200_C and above.
4) The occurrence and disappearance of twins are clearly observed near sheet surfaces during the draw-bending test at RT, and this microstructure evolution resembles that observed in the cyclic in-plane tension-compression test in the literature. The effects of twinning on the stress-strain curve should be investigated in greater detail to further understand the spring back characteristics of Mg alloy sheets at RT. Experimental result of Takayuki Hama, Yuhta Kariyazaki*, Keisuke Ochi*, Hitoshi Fujimoto and Hirohiko Takuda [11].

2. Conclusions

In this paper, we studied a different method to improve the bendebility of mg alloy for roll forming process and also discussed about the future mg alloys as under

1) The influence of forming temperature on the AZ31 Mg alloy is obvious. The bendebility can be improved with the increase in temperature. non-basal slip system started by heat increased is considered as the main reason why the plastic deformation of magnesium alloys can be improved with increasing of temperature, here the formability of AZ31 Mg alloy is on the decline with the increasing of forming speed.
2) Based on the above information, it is not surprising that most common alloy systems have been developed in the Mg–Al, Mg–Zn and Mg − Al – Zn systems.

References

[1] Tingzhuang han, Guangsheng Huang, Yougen Wang, Guangang Wang, Yanchu Zhao, Fusheng Pan, **Enhanced mechanical properties of AZ31 magensium alloy sheets by continuous bending process after V-bending**., 26(2016)97-102,Elsevier

[2] Huang Guang-sheng, Zhang Hua, Gao Xiao-yun, Song Bo, Zhang Lei, **Forming limit of textured AZ31B magnesium alloy sheet at different temperatures**.Elsevier China 21(2011)836-843.

[3] K. Richter, R. Haase, F.Schieck, D.Landgrebe, **Tempered forming of mangnesium alloys using the example of roll forming**. Elsevier Germany 2S(2015) S60-S66.

[4] **William J. Jhoots, Paul E. Krajewski, "**Towards magnesium alloys for high-volume automotive applications" Elsevier Volume 128, February 2017, Pages 107-112.

[5] Charles Moosbrugger,editior **Engineering properties of Mangnesium alloy, Introduction to Magnesium alloy.** asm international 2017.

[6] W. A. Monteiro, S. J. Buso3 and L. V. da Silva, **application of magnesium alloy in transport** , Materials Science and Technology Center - IPEN, São Paulo,, Brazil

[7] A.A. Kaya, Mugla University, Turkey chapter2 (33-35), Mihriban O. Pekguleryuz,Karl U. kainer , A. Arslan Kaya, **Fundamentals of Magnesium alloy metallurgy** by wood hood publishing 2013.

[8] M. Pekguleryuz, McGill University, Canda Chapter 5 (153-155), Mihriban O. Pekguleryuz,Karl U. kainer , A. Arslan Kaya, **Fundamentals of Magnesium alloy metallurgy** by wood hood publishing 2013.

[9] Wenyum WU, Lv XIAO, Donghong wang, **Finite element simulation of magnesium alloy AZ31 tube bending.** MATEC web comferences 67, 05001(2016).

[10] Shunsuke Kanai, Shin-ichi Nishida and Hisaki Watari**, Manufacture of AZ31 magnesium alloy circular tubes by cold roll forming**, The 8th Pacific Rim International Congress on Advanced Materials and Processing,Japan(2013).

[11] Takayuki Hama, Yuhta Kariyazaki*, Keisuke Ochi*, Hitoshi Fujimoto and Hirohiko Takuda, **Springback Characteristics of Magnesium Alloy Sheet AZ31B in Draw-Bending**, Department of Energy Science and Technology, Kyoto University, Kyoto 606-8501, Japan.

[12] Daniel Pelaez, Cesar Isaza, Juan M. Meza, Patricia Fernandez-Morales, Wociech Z., Misiolek, Emigdio Mendoza, **Mechanical and microstructural evolution of Mg AZ31 alloy using ECASD process**. Elsevier-2015.

[13] Akira Yanagida, Yuma Hirai and Kenji Sekido, **Improvment of fromability of AZ31 Magesium alloy be repeated roll bending process**, Elsevier-2017 Japan

[14] Lei Wang, Qi Qiao, Yang Liu, Xiu Song, **Formability of AZ31 Mg alloy sheets within medium temperature, CCMG, Science Direct Journal of Magnesium and alloy** 1 (2013)312-317.

[15] Jian-quan TAO, Yan-ping Zhang, Fu you Fan, Qiang Chen, **Microstructural evolution and mechanical properties of AZ31 magnesium alloy prepared by casting solid extrusion forging during partial remelting**, Science Direct, Defence technology 9 (2013).

[16] Quingqing Zhang, Ding Tang, Dayong Li, Yinghong Peng, **Numerical and experimental study on in plane bending of microchannel aluminum flat tube**, Elsevier Journal of material processing technology 210(2010)1876-1884.

[17] Y Zhang, D H Kim, D W Jung, **Spring-back of flexible roll forming bending process**, IOP publishing conf. of material science and engineering 103 (2015) 012029.