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Mechanical and Structural Comparison of AZ31 and AZ61 Magnesium Alloys Along with Deep Drawing Capabilities

Mechanical and Structural Comparison of AZ31 and AZ61 Magnesium Alloys Along with Deep Drawing Capabilities

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Abstract. In the world of advance development, rapid growth for any nation, country or individual is a must thing to have. There are several studies and researches that have put forward to us, not only revolutionized the human society but also helped us to live a better life in a better way. This study focusses on a similar track to analyze the characteristics of magnesium alloys; known for its high weight to strength ratio, so that it could replace; at time; extensively used materials i.e. steel and aluminum. The magnesium alloy has several advantages over steel and aluminum i.e. due to its low density, its weight is quite low, which is the reason that it is extensively used in aerospace and outer space application. Studies suggests that Low weight allows system to consume lesser fuel as compare to the normal ones. Along with it, inspite of having lesser density it doesn't compromises its mechanical strength and provide high weight to strength ratio; which makes it more suitable for structural and automotive applications. However, inspite of having such tremendous advantages, there are some drawbacks which leads to its minimum usage as compare to both the materials. Magnesium alloys have low ductility, however, it can be enhanced to certain level by several methods to make it cope with real world industrial, commercial and residential applications. This study focusses on analyzing the mechanical and structural characteristics of two grades of magnesium alloy i.e. AZ31 and AZ61. The conclusion has been made by carrying out different mechanical tests i.e. tensile testing, Brinell hardness testing, torsion testing and cupping testing. After conducting these tests this was concluded that AZ31 and AZ61 are a good replacement for aluminium as it has a poison's ration of 0.4 and 0.24 respectively.

1. Introduction

In present era, the primary goal of the nations are to make things sustainable while not compromising on its quality as well. Sustainability is the topic of prime interest nowadays, under which umbrella several work has been done in the field of energy, manufacturing, construction and metallurgy. The prime need of today's human society is to come up with a system that would consume minimum energy while giving out maximum work; without compromising its features.
A survey was conducted by American Society of Mechanical Engineers (ASME) in which a question was asked from 500 Europeans that: "To live life happily, what 3 resources do they need". Among various answers, according to the poll the most repeated ones are: good food, a car that gives good mileage and better house [1]. Another research states: that the amount of fuel consumption by automobiles or aeronautics applications depends largely on their own weight [2]. Moreover, as per manufacturing sector, currently huge budget is specifically allocated to remove the vibrations from the system; the reason of it is that currently used material (i.e. steel) for bulk production doesn't have

prominent damping capacity. Therefore; in previous studies certain measures were suggested to control the vibrating amplitude of process which unnecessarily adds up certain cost of product. For this reason, a solution is needed that would be able to address all of these deficiencies without increasing its cost.

For the ease of its manufacturing, number of magnesium alloy grades are available by altering the material composition so that the casting and forming parameters could be met easily. Among various, the highlighted features of magnesium alloys are: high damping capacity, high corrosion resistance and high specific strength. Moreover, due to its characteristic of having low density, thicker geometry can be formed relatively easily without applying any extra external stiffness. As mentioned earlier, in automobiles industry, most of the used grades of magnesium alloys are AM50, AM60, AS41 and AZ91. But however, very small research could be found on wrought magnesium alloys grades such as AZ31 and AZ61.

The magnesium alloys has been in debate since 1945 [3]. Several researches has been conducted in the usage of mg alloys for manufacturing of various products such as office equipment's, sports goods, agricultural machines and tools, electronics and telecommunication equipment etc. Some of these have been successfully commercialized while the rest showed steady use for quite long. Afterwards, this material began to be used for the manufacturing of cases for notebook, laptops and various electronic devices. Currently, number of researches is in progress that is working on the commercial use of Mg for vehicles and other transportation means [4–7]. The chemical compositions of both the grades have been shown in

.

In summary, this research has been carried out in order to compare the mechanical properties of two different grades of magnesium alloys i.e. AZ31 and AZ61 and suggest the better one on account of its strength to weight ratio. Four different mechanical tests have been carried out on these two alloys and their parameters have been compared in the end. One new which haven't been done yet on magnesium alloys, is made part of this research namely; cupping test, in order to compare the behaviour of material when exposed to deep drawing process. The main objective of this study is to determine the poisons ratio of the selected two grade of Mg allow and then compare its compatibility with iron and aluminium.

2. Experiment description and outcomes

In this section, complete methodology and process that has been followed in order to address the above stated problem, is discussed in detail with their possible outcomes. For competitive and trustworthy results, the selection of standard procedures and process is quite useful. Therefore, ASM standards were used for tensile, cupping, torsion and hardness test. The equipment used for uniaxial tensile testing is GUNT universal material tester that uses DIN 50125 shape E standard specimen. In addition to that, torsion testing is carried out on TASK torsional tester.

Formability of a material is its ability to expand or undergo plastic deformation without getting failed or rupture. The cold forming of several elements having HCP crystal structure is quite limited in industry. The main hindrance in its limited formability is low ductility of alloys at room temperature, therefore, stamping magnesium alloy is a difficult task to carry out under room conditions [9]. Description of each test conducted along with the desired output with the specimen parameters can be seen below.

2.1 Tensile testing

2.1.1 WP300 Universal Material Tester

Material Tester, 20kN is a robust device specially designed for technical education and is one of the classic materials testing devices in the materials engineering field. The device's flexible design means that it is possible to carry out a variety of different experiments requiring tensile or compressive forces [10].

2.1.2 Outcomes of tensile test

i. Modulus of Elasticity

When a material is subjected to the tensile force it exhibits the linear behavior following hooks low. The slope of that linear line gives the modulus of elasticity or young's modulus. The young's modulus exhibits the stiffness of material under the influence of applied force.

ii. Yield Strength

When material exhibits elastic behavior, it yields proportional deformation with respect to applied force while obeying hook's law. In elastic region, when the force is applied continuously, a state is achieved when material tends to go in plastic region from elastic region i.e. now onwards all the deformation in the material will induce permanently.

iii. Ultimate Tensile Strength

As discussed previously, the maximum withstanding stress of material before it undergo a failure is known as ultimate tensile stress. This parameter is most important as it enable the designer who is designing any product to select the best possible material which could undergo and withstand in his application.

2.2 Hardness testing

Hardness is the valuable mechanical property that has intense importance in the designing of structures or modelling of material. Every material present on the earth crust showcased different amount of hardness when subjected to a force which certainly depends upon the composition of material it made off; most of the time the amount of carbon present. Its value and importance, sometimes, cannot be understated the information it provides, however, it can be utilized in conjunction with other material verification tests such as tensile or torsion to conclude the behavior of material.

2.2.1 Outcomes of hardness test

The test is performed while placing and holding the specimen while a specimen tends to press the specimen over the surface where hardness needs to be determines, afterwards a certain is given commonly known as dwelling time which allows the punch indentation to properly get embossed on material surface. The dwelling time differ to 10sec to 50sec depending upon the nature of material.

2.3 Cupping test

In sheet metal industry, the process of forming material into different shapes is extensively used. There are various mechanical parameters of the thin sheet metals that allow it to deform till various ranges in plasticity. Before commercialization, a material is tested under laboratory condition to find out the ideal behavior of material and later on to be compared with that of with onsite one. The cupping test is also one of the mechanically test especially conducted to determine the elongation a material will showcase under fixed amount of force i.e. in plasticity. The plasticity is the behavior of material in which material undergo permanent deformation without increasing the magnitude of force till the sample gets cracked. This test is usually performed on metal sheets having 0.2mm to 2mm thickness.

2.3.1 Outcomes of cupping test

The cupping machine is used to observe and perform deep drawing test. The test is conducted on a principle that punch creates a blank within the specimen blank. As the punch is of spherical shape it presses the clamped blank and deforms until the visible crack is observed. After the failure of specimen, it is unloaded and the depth of cup is measured.

2.4 Torsion testing

All of the forces above, address the effect of linear force on the property of material; whereas, when material is made a part of some structure, it has to undergo or withstand torsional loading also. Torsion testing address the issue of testing material and its behavior on the application of torsional test. On the application of torsional force, the material tends to twist and twisting angle can be observed.

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2.4.1 Outcomes of torsion testing

i. Shear modulus

The most important outcome of torsional test is shear modulus. Shear modulus is an elastic property of material that it exhibits on the application of torsional transverse internal force. For example, an example of rod can be taken that how much twist can be observed on application of specific force about its lengthwise axis. Due to application of this force, the material is distorted in such a way that its two opposite faces tends to slide parallel to each other. The shear modulus is also known as the modulus of rigidity.

3. Analysis

3.1 Mechanical test results, verification and analysis

3.1.1 Tensile Testing

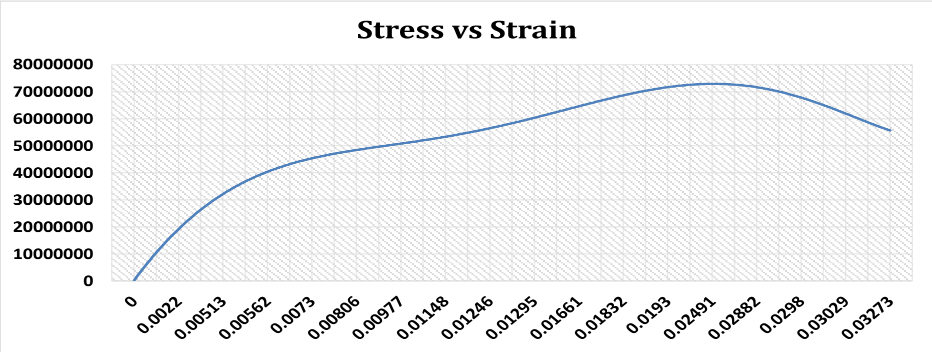

Figure 1. AZ31 observed stress and strain relationship (MPa vs m/m)

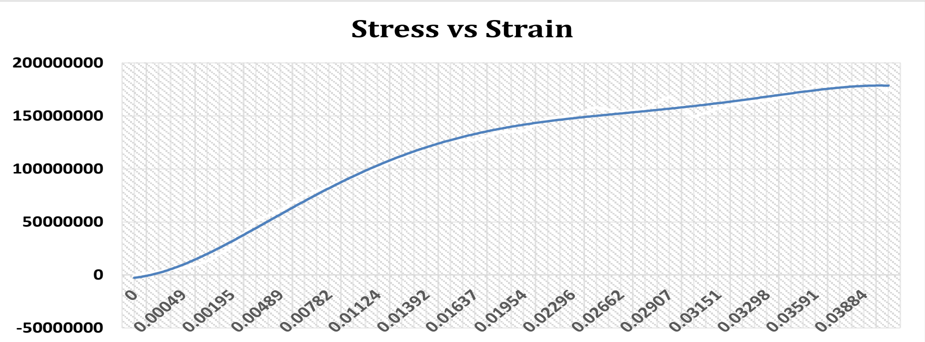

Figure 2. AZ61 observed stress and strain relationship (MPa vs m/m)

The extracted data from the Figure 1 and Figure 2 above can be seen in Table 1 below.

Table 1. Output of tensile testing

	Property	Observed Reading
AZ31	Young's Modulus	10.04 GPa
	Tensile Strength	35.3 MPa
AZ61	Young's Modulus	7.6 GPa
	Tensile Strength	233.1 MPa

3.1.2 Brinell Hardness Test

Table 2. Average indentation

	Sample #	d_1(mm)	d_2(mm)	D(mm)	Mean
AZ31	1	3.26	3.28	3.27	3.2675
	2	3.26	3.27	3.265	
AZ61	1	2.84	2.85	2.84	2.8350
	2	2.82	2.84	2.83	

After observing the mean indentation diameter, the HBS is calculated using **Error! Reference source not found.** and the results have been shown in Table 3 below. The observed hardness code for both the material can be written as:

1) AZ31 → 59 HBS 10/5/15
2) AZ61 → 79 HBS 10/5/15

Table 3. Hardness of AZ31 and AZ61

	Observed HBS
AZ31	59
AZ61	79

3.1.3 Cupping Test

On the basis of the depth achieved up to crack formation, the steel AZ61 more suited to cold forming processes such as cupping than the AZ31. The depth achieved per newton force of AZ61 came out to be $1.52\text{x}10^{-5}$m whereas that of AZ31 is $1.408\text{x}10^{-5}$ i.e. lesser than AZ61.

Table 4. Cupping test results without heat treatment

	Maximum Applied Force F_{max}(N)	Cup Length T (mm)	Ratio T/F_{max}
AZ31	1.205	16.97	$1.408\text{x}10^{-5}$
AZ61	1.037	15.85	$1.52\text{x}10^{-5}$

3.1.4 Torsion Test

The observations of material AZ31 is shown in the Table 5, whereas, AZ61 is shown in **Error! Reference source not found.**.

Table 5. Torsion testing result of AZ31 without heat treatment

Force (N)	Torque (Nm)	Angle of twist (rad)	G (Observed)	G (Mean)
10	0.1	$7.65x10^{-4}$	$1.69x10^{10}$	$1.62x10^{10}$
15	0.15	$1.21x10^{-3}$	$1.60x10^{10}$	
20	0.2	$1.57x10^{-3}$	$1.65x10^{10}$	
25	0.25	$1.92x10^{-3}$	$1.68x10^{10}$	
30	0.3	$2.47x10^{-3}$	$1.57x10^{10}$	

Table 6. Torsion testing result of AZ61 without heat treatment

Force (N)	Torque (Nm)	Angle of twist (rad)	G (Observed)	G (Mean)
10	0.1	$8.45x10^{-4}$	$1.53x10^{10}$	$1.54x10^{10}$
15	0.15	$1.30x10^{-3}$	$1.49x10^{10}$	
20	0.2	$1.61x10^{-3}$	$1.61x10^{10}$	
25	0.25	$2.13x10^{-3}$	$1.52x10^{10}$	
30	0.3	$2.45x10^{-3}$	$1.58x10^{10}$	

3.2 Derived quantities

Table 7. Poison's ratio of AZ31 and AZ61

	Observed Readings	Standard Readings	Poison's ratio
AZ31	Young's Modulus = 13.01 GPa Shear Modulus = 16.2 GPa	Young's Modulus = 14 GPa Shear Modulus = 17 GPa	0.40
AZ61	Young's Modulus = 7.6 GPa Shear Modulus = 15.4 GPa	Young's Modulus = 10 GPa Shear Modulus = 17.0 GPa	0.24

Table 8. Bulk modulus results of AZ31 and AZ61 without heat treatment

	Observed Readings	Standard Readings	Poison's ratio
AZ31	Young's Modulus = 13.01 GPa Poison's ratio = 0.40	Young's Modulus = 14 GPa Poison's ratio = 0.43	$21.6x10^{9}$
AZ61	Young's Modulus = 7.6 GPa Poison's ratio = 0.24	Young's Modulus = 10 GPa Poison's ratio = 0.29	$4.87x10^{9}$

4. Conclusion

In present era, the primary goal of the nations are to make things sustainable while also not compromising the quality. Sustainability is the topic of prime interest nowadays, under which umbrella several work has been done in the field of energy, manufacturing, construction and even metallurgy. The prime need of today's human society is to come up with a system that would consume minimum input while giving out maximum; and also doesn't compromises the strength.

In summary, this research has been carried out in order the compare the mechanical properties of two different grades of magnesium alloys i.e. AZ31 and AZ61 and suggest the better one on account of its strength to weight ratio. Four different mechanical tests have been carried out on these two alloys and their parameters have been compared in the end. One new test that not has been done on magnesium alloys yet have also made a part of this research namely cupping test in order to compare the behaviour of material when exposed to deep drawing process. The result of test shows that poison's ration of AZ31 and AZ61 came out to be 0.4 and 0.24 respectively; therefore, AZ31 could be used as a replacement of aluminium due to comparatively high shear strength whereas when it comes to ductility, AZ61 should be used in its place.

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