International Journal of Scientific & Engineering Research Volume 11, Issue 6, June-2020
ISSN 2229-5518

Study on Mechanical Properties of AZ91 Magnesium Alloy

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Abstract— Magnesium is the lightest structural metal present on Earth's surface. With a density of 1.74g/cc, it gives a high strength to weight ratio. This has made it very useful for many applications like automobile, aeronautical etc. Magnesium has many limitations and because of which it cannot be used directly as a replacement of steel and aluminium. Many alloys of magnesium have been developed to partially or completely overcome the limitations of magnesium without sacrificing other properties. One of the most used commercial alloys is magnesium alloy AZ91, which gives better properties than magnesium. The main aim of this project is to study the mechanical properties of magnesium based AZ91 alloy. The results were compared with the as-cast condition. The examined material has been obtained by die casting. The material is been subjected to T6 heat treatment.T6 heat treatment is a two stage process is combination of solution annealing at 413°c for 13 hours and subsequent aging at 200°c for 10 hours. Micro structural and mechanical properties (hardness) of the specimen were studied. The research has shown that hot working of AZ91 alloy provides high mechanical properties unattainable by cast material subjected to heat treatment. The investigated alloy subjected to hot working and subsequently heat treatment has doubled its strength and considerably improved the elongation compared with the as-cast material. The microstructure is observed under the optical microscope.

Keywords— Magnesium, AZ91, T6 heat treatment, Hardness and Optical microscope.

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1 Introduction

This project is based on the lightest structural metal present in abundance on the surface of earth, Magnesium. It is an element with atomic number 12 and mass 24. It belongs to the alkaline earth metals of the periodic table. It is the sixth most abundant element present on the surface of the earth and fourth most common element in the earth making almost 13% of the planets mass.

Magnesium has a density of 1.738gm/cc at 20 C which is almost one-fourth to that of steel and two-third of that of aluminium. This is the most important reason for the gaining importance of magnesium in structural applications. The parts which are formed with magnesium are light in weight which helps in increasing the fuel efficiency of a vehicle. Moreover the parts of the spacecrafts are also made of magnesium to decrease the weight of the shuttle. The alloys of this metal provide strength with reduction in weight without much increase in cost. Due to these limitations, magnesium cannot be directly used for any application. Therefore, many alloys of magnesium have been developed by adding different metals like Aluminium, Zinc, Zirconium, Manganese, Rare Earth elements, etc. These elements make different changes in the properties of magnesium alloy and hence make it usable in commercial scale.

One of the most commonly used magnesium alloy is AZ91. It has been used in many applications such as car seat frames, steering wheels, laptop frames, etc. and many others. The alloy's composition is 9% Al and 0.7% Zn in addition to these; some other elements are also present. Among the various magnesium alloys developed, AZ91, containing about 9 wt. % Al and 1wt% Zn, is the most popular commercial magnesium alloy. Statistically, more than 90% of magnesium cast products are made of this alloy.

A combination of solution annealing and subsequent aging, called the T6 HEAT TREATMENT. Heat treatment significantly changed the corrosion resistance of AZ91D alloy, compared with the as-cast condition; T6 treatment reduced the corrosion rate by 30–60%.

2 Literature Review

The high strength to weight ratio of magnesium has always made researchers keen about the usability of it. But due to many limitations it cannot be used directly, so research work is under progress to overcome the drawbacks of magnesium by alloy addition.

1. Effect of addition of Aluminium on magnesium alloy: Aluminium imparts better casting properties, improves corrosion resistance and imparts excellent ambient temperature strength properties.
2. Effect of addition of Zinc on magnesium alloy: The presence of zinc provides solid solution strengthing to magnesium matrix. It is found that there is an increase in yield strength of magnesium alloys.
3. Effect of addition of manganese on magnesium alloy: Manganese is added in a small amount (0.3%) to increase the corrosion resistance of the alloy. Further addition does not have an increasing effect.
4. Effect of addition of calcium on magnesium alloy: Addition of 0.4% Ca reduces the grain size of the alloy. Increased addition progressively decreases the grain size. Further, strengthening of B-phase takes place and high temperature strength is improved without affecting the ductility. 0.8% Ca forms Al_2Ca precipitate which drastically decreases the ductility. So its addition is controlled.
5. Effect of Bismuth addition on magnesium alloy: It forms Mg_3Bi_2 precipitates along the grain boundaries which is a thermally stable phase. This prevents the sliding of grains at elevated temperature.

6. The presence of antimony results in grain refinement of the compound. It also forms Mg3Sb2 precipitates at the grain boundary which improves the room and elevated temperature strength, creep properties and fluidity.

7. Effect of Zirconium addition on magnesium alloy: It acts as an excellent grain refiner in magnesium alloys. But there is a limitation to its use. It cannot be used in presence of elements with which it forms stable compounds such as aluminium, manganese iron, etc.

The magnesium alloy AZ91 has main composition of 9% Aluminum, 1% Zinc and 0.3% Manganese. This alloy has high strength to weight ratio, high specific modulus and exhibits very. This occurs due to the°good castability. But it loses its strength and other properties above 120 softening of the β-phase. Therefore, this material can only be used where the temperature does. Many alloy additions are done in order to increase the high temperature°not exceed 120 usability such as Ca, Sb, Pb, etc. But care has to be taken that other properties are not sacrificed.

Many forms of Magnesium alloy AZ91 have been made, namely: AZ91A, AZ91B, AZ91C, AZ91D and AZ91E. Here, the last alphabet denotes the number of specific composition registered with the same major composition.

3 EXPERIMENTAL PROCEDURE

3.1 Raw Material

The material used in this work was a die cast AZ91 alloy ingot with dimensions of 110mm × 100 mm × 30 mm. The actual chemical composition of the alloy is shown in the below table. The element contents are consistent with standards listed in the literature for this alloy. In experiments involving the as-cast alloy, specimens were cut from the ingot without any further treatment.The chemical composition of AZ91 used in this work is shown in Table 1.

3.2 Conduction of Heat Treatment

The as-cast alloy of 110mm × 100 mm × 30 mm is processed by T-6 heat treatment(T means Temper). The T6 heat treat is a 2 step process. It is the combination of annealing and subsequent aging.

Step 1: The alloy sample is heated at an elevated temperature at 413°c in muffler furnace for 13 hours followed by air cooling at room temperature. The material then moved to low temperature ovens for the second step of the process.

Step 2: The treated material was aged at 200°c in muffler furnace for 10 hours and followed by air cooling at room temperature.

Table 1- Chemical composition of AZ91

Element	Composition (wt.%)
Aluminium	9.12
Zinc	0.643
Silicon	0.001
Manganese	0.237
Copper	0.0008
Iron	0.0005
Nickel	0.0004
Magnesium	Balance

3.3 Cutting of material

The treated material cannot be used directly for further observations. It has to be cut to smaller sizes of 10mm x 10mm x 10mm(Fig 1) according to ASTM E16 standard to make samples of the material. The cutting operation of the material is done using water jet cutter.

3.4 Rockwell Hardness Testing

Rockwell hardness testing is a process of hardness measurement of a specimen. It measures the resistance of a specimen to indentation on application of constant load for small period of time.

The indenter used for Rockwell hardness test is ball indenter.

Procedure:

- The polished scratch free surface of the specimen is kept on the Rockwell hardness apparatus.
- Check the area where indentation is to be made.
- The load to be applied and the dwell time are specified.
- Loading is commenced.
- With the help of the measurement scales, the hardness value is noted and tabulated.

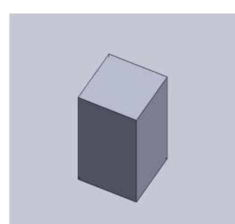

Fig 1- Testing sample 3D model

3.5 Optical microscopy

Principle- An optical microscope works on the principle of

conversion and diversion of light on passing through a lens. It creates a magnified image of an object specimen with an objective lens and magnifies the image further more with an eyepiece to allow the user to observe it by the naked eye. The optical microscope's magnification depends upon the combined magnification of the lens and the objective.
Optical Microscope was used for general microstructure observations and discontinuous precipitation area measurement because of its large field of view.

Procedure- The specimens of 10mm x 10mm x 10mm for optical microscope were cold mounted and mechanically ground using water and silicon carbide paper with increasing fineness from P600 to P1200. The sample is held in perpendicular direction. The sample is moved along a single direction from one end of the paper to the other end and then lifted to bring back to the start position. The sample is rotated 90° in clockwise direction after each emery paper. After that, the samples were polished with ethanol and water-free cream containing diamond paste (1 µm) to the cloth and frequently spraying HIFIN fluid onto the surface of the cloth while polishing until a mirror-like surface finish was achieved. It should be noticed that water was avoided during the polishing, since it might oxidize the surface of the polished samples. Instead of water, ethanol was used to clean all polished samples. In order to reveal the microstructure of the samples, several etchants were used. A nitric acid solution (4 ml nitric acid and 100 ml ethanol) was used to etch the samples for 30s, followed by drying with cool air. Microscope observation was performed on a Kern optical microscope is a typical image showing how the area fraction of discontinuous precipitation was observed.

4 RESULTS AND DISCUSSION

Testing of the sample is carried out to find the advantage. Hardness test are conducted and the results are as follows:

4.1 Rockwell Hardness test Observation

Table 2-Hardness of the sample without heat treatment

Sl. No.	Hardness Value
1	12 HRB
2	14 HRB
3	19 HRB

Table 3- Hardness of the sample with heat treatment

Sl. No.	Hardness Value
1	35 HRB
2	40 HRB
3	45 HRB

The higher hardness value is observed for the sample with heat treatment. Moreover, the fine grain size achieved increases the resistance to dislocation movement which leads to strain hardening of the material increasing the hardness of the sample.

4.2 Optical Microscope Observation

The microstructure of heat treated sample:

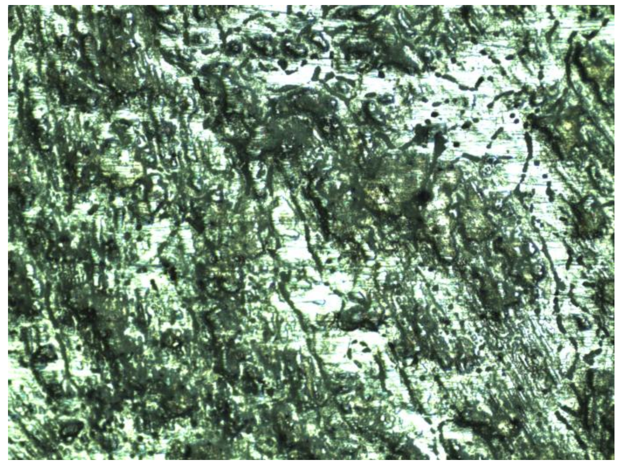

Fig 2 Microstructure of AZ91 alloy (50X magnification)

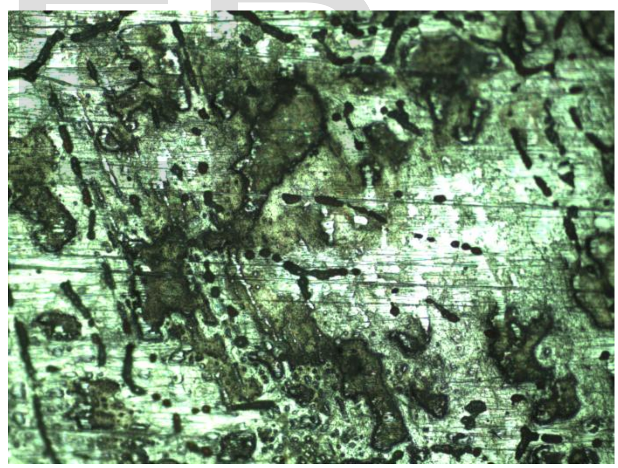

Fig 3 Microstructure of AZ91 alloy (100X magnification)

The microstructure observed after heat treatment contains a dark phase and a light phase. The light phase is the α-phase of magnesium. The dark phase is the β-phase precipitates of $Mg_{17}Al_{12}$ are formed due to the addition of alloying elements. Some dark black spots also observed. These spots can be inclusions or oxide precipitates formed due to reaction with air.

The observed microstructure shows finer grain structure of the sample after T6 heat treatment.

4 CONCLUSION

The conclusions of the project are as follows:-
[1] The hardness value for the AZ91 alloy sample is measured.

The observed values show the difference in hardness of treated and un-treated sample. The hardness value of the treated alloy is more than that of the un-treated alloy.

[2] The microstructure observations with the help of optical microscope are done which shows homogenization treatment of an AZ91 alloy at 420°C for 24 hours was found to be effective in dissolving the ß precipitates. Ageing at 200°C caused precipitates of ß phase mainly along the grain boundaries.

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