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The Effect of Casting Method on Fatigue Property Magnesium Alloy Used in Sports Apparatus

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The magnesium alloys AZ91-0.15Y used in sports apparatus were prepared through common casting and pressurized differential pressure casting respectively and the microstructure and fatigue property were investigated. It turns out that compared with common casting; pressurized differential pressure casting conspicuously refines the microstructure of the alloy, leading to a better fatigue property. In addition, the fatigue fracture transforms from brittle fracture resulted from common casting to the mixed trait of cleavage and ductile fracture resulted from pressurized differential pressure casting.

1. Introduction

Magnesium alloy has been widely applied in spaceflight, aviation, automobiles, motorcycles, shipping and other industries thanks to its low density, high specific strength, good performances of damping and recycling, and is expected a large-scale use in sports apparatus. However, the imperfect fatigue property of magnesium alloy severely hinders its application on sports apparatus. Not only the components of magnesium alloy, heat treatment, but the manufacturing techniques of the alloy, as well as many other factors have an influence on the fatigue performance of magnesium alloy. Currently, many researches focus on the effects of elements of magnesium alloy and heat treatment on fatigue performance, while few attach importance to the effect of manufacturing techniques. The author prepared magnesium alloy AZ91-0.15Y respectively through common casting and pressurized differential pressure casting, to explore the effect of casting method on the fatigue property of magnesium alloy AZ91-0.15Y from the aspect of manufacturing techniques. (Chen et al, 2012; Li et al, 2013).

Magnesium alloys are among the lightest metallic materials for structural applications. Due to high specific strength and rigidness, as well as good machinability and recyclability, magnesium alloy has been known as the 21st century ’green’ engineering material. In recent years, with the rapid progress of automotive and electronic industries, a number of magnesium alloy components have been manufactured to replace those made from plastics, aluminium alloy and steel ones. It can be expected that magnesium alloys will become the most important structural materials in commercial metal materials. Wrought magnesium alloys can exhibit the higher strength and better plasticity than cast magnesium alloys, and show the more significant potential in further applications of magnesium based materials. As structural materials in service, magnesium alloys are usually subjected to repeated reverse loading, and therefore the cyclic deformation behaviour of these materials needs to be studied in detail for safety reasons. However, many investigations were based on the macroscopic fatigue properties, neglecting the deformation characteristics of magnesium alloys. Due to hcp crystal lattice, twinning and slip are important to deformation of magnesium alloys. And in some cases, twinning may be the main deformation mechanism. As such, it is important to understand the role of twinning in fatigue process. So in this dissertation, the widely used AZ31 wrought magnesium alloy is chosen as model material to understand the role of twinning. In fact, some factors influence the behaviour of twinning, such as texture, strain rate, grain size and initial twins. According to the initial texture of the extruded AZ31 plate investigated by X-ray diffraction, samples were cut along different directions to discriminate the role of twinning and slip in fatigue process. Under different frequencies, the degree of twinning is different and its effect on fatigue properties was analysed. Magnesium alloy can be fined by equal channel angular pressing (ECAP), which suppress the activation of twinning. And the fatigue properties of untrained AZ31 can be

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understood. Initial twins can alter the deformation mechanism under fatigue process, and the influence of initial twins on fatigue properties can be acquired by pre-deformation. (Meng et al., 2013; Ma et al., 2013).

2. Testing materials and method

2.1 Testing materials

Mg, Al, Zn of industrial grade and master alloys Mg-5Mn, Mg-10Y were picked out and smelted in medium-frequency induction furnace, then cast into magnesium alloy ingots AZ91-0.15Y separately by common casting and pressurized differential pressure casting. For common casting, the materials was cast in an iron tool, and cooled in normal temperature. For pressurized differential pressure casting, the main technical parameters are as shown in table 1.

Magnesium alloy ingots made by two methods then were tested by X-ray spectrometer for chemical elements identification. The results are shown in table 2.

Table 1: The technical parameters of pressurized differential pressure casting

Casting temperature	Lift velocity	Synchronized pressure	Crystallizing supercharge pressure	Resistance coefficient	Crusting supercharge velocity
720℃	38mm/s	740kPa	28kPa	1	2.8kPa/s
Mold-filling pressure	Crusting time	Mold-filling velocity	Crystallizing supercharge velocity	Lift pressure	Crusting time
48kPa	720s	40mm/s	3.6kPa/s	18kPa	6s

Table 2: The chemical components of the samples

Casting method	Al	Zn	Mn	Y	Other impurity elements	Mg
Common casting	8.997	0.803	0.317	0.148	＜0.025	The rest
Pressurized differential pressure casting	9.002	0.801	0.315	0.149	＜0.025	The rest

As it shows, both magnesium alloy ingots AZ91-0.15Y satisfy the requirements of components design.

2.2 Testing method

A X-ray diffractometer was used to apply a phase constitution test on Magnesium alloy ingots AZ91-0.15Y. A metalloscopy was used to observe the microstructures of two alloy ingots. A fatigue test is then applied by testing equipment. The testing parameters are as follows:

Load type-tension load
Stress ratio-zero
Loading frequency-100±2Hz
Testing temperature-normal temperature
Nominal stress range-30, 35, 40, 45, 50, 55, 60, 645MPa

We took the load cycles of the sample when it completely cracked as the fatigue life, and observed the fatigue fracture appearance by scanning electronic microscope (Meng, 2013).

3. Testing results and discussion

3.1 The phase constitution analysis results and discussion

The XRD patterns of magnesium alloy ingots AZ91-0.15Y made in different methods is shown in Figure1. Magnesium alloy ingot AZ91-0.15Y in common casting consists of four phases, including α-Mg, the basic phase, Mg17Al12, and Al8Mn5. While magnesium alloy ingot AZ91-0.15Y in pressurized differential pressure casting consists in α-Mg, as the basic phase, and little Mg17Al12, Mg3Y2Zn3.

3.2 The testing results and discussion of microstructures

The microstructures of magnesium alloy ingots AZ91-0.15Y made in different methods is shown in Figure2. The dendritic crystal in microstructure of magnesium alloy ingot AZ91-0.15Y in pressurized differential pressure casting is conspicuously restrained, hence the structure of alloy is refined (Frank C, 2011). It is mainly because in the process of pressurized differential pressure casting magnesium alloy AZ91-0.15Y, the high and low pressure field accelerates the flow of liquid metal, generating a shear force between liquid metal and crystal, which breaks down the existing dendritic crystal and produces more crystal nuclei, and that's why the grain of magnesium alloy AZ91-0.15Y is more refining compared with that of common casting.

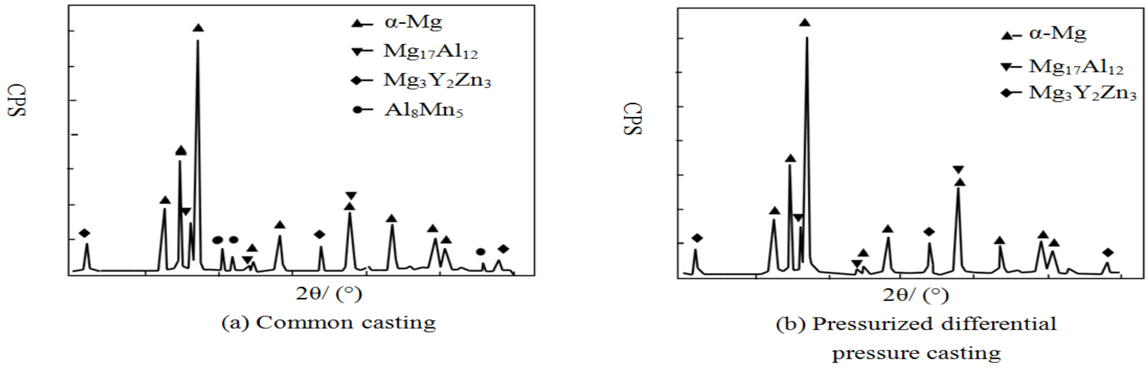


Figure1: The XRD patterns of the alloy ingots made in different casting methods

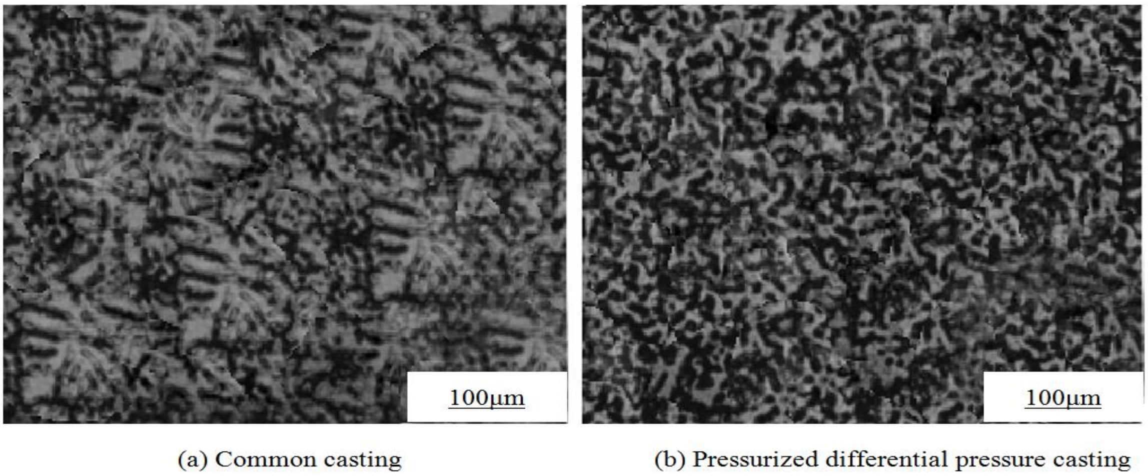


Figure2: The microstructures of the alloy samples obtained by different methods

3.3 The testing results and discussion of fatigue test

The testing results of fatigue test in normal temperature of magnesium alloy AZ91-0.15Y in different methods are as shown in Figure3.

Within the nominal stress range of 30 to 65MPa, magnesium alloy AZ91-0.15Y in pressurized differential pressure casting enjoys a longer fatigue life compared with the common casting one. When the nominal stress range reaches 30MPa, the fatigue life of magnesium alloy AZ91-0.15Y in pressurized differential pressure casting compared with the common casting rockets from 389, 558 to 898, 977 times, which rises by 130.77%. When the range reaches 45MPa, the alloy in pressurized differential pressure casting compared with the common casting one soars from 105, 324 to 784, 543 times, which increases by 644.89%(Zheng X, 2011).

When nominal stress range is 65MPa, the fatigue life of alloy in pressurized differential pressure casting compared with the common casting increases from 25, 456 to 512, 234 times, which rises by 1912.23%. To conclude, pressurized differential pressure casting enhances the fatigue performance of magnesium alloy AZ91-0.15Y. On the grounds that pressurized differential pressure casting refines the structure of magnesium alloy AZ91-0.15Y and strengthens anti-fatigue of magnesium alloy AZ91-0.15Y, hence efficiently promotes the fatigue performance of magnesium alloy AZ91-0.15Y.

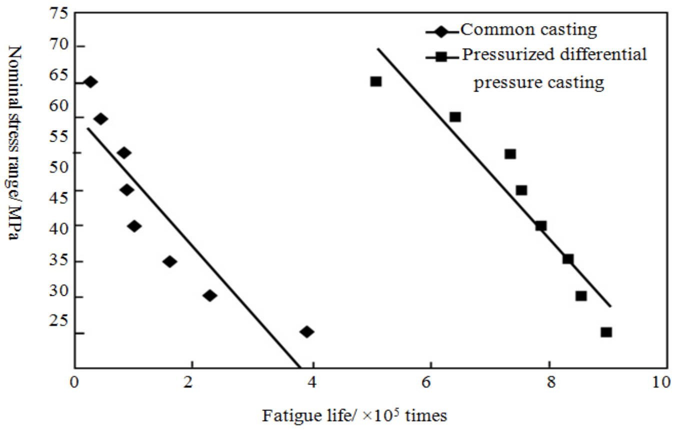
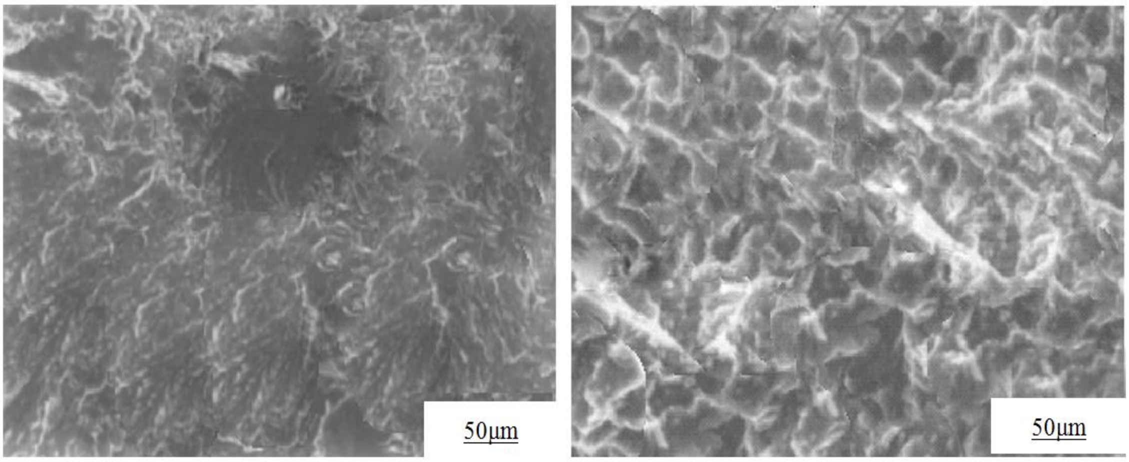


Figure3: The fatigue property of the samples

The appearances of fatigue fractures of different magnesium alloys AZ91-0.15Y is depicted in Figure 4. It is shown that an obvious brittle fracture occurs in magnesium alloy AZ91-0.15Y in common casting. Owing to reduplicate extrusions and frictions, the fatigue crack surface was polished. There are many tear ridges and a certain number of dimples in the fatigue fracture of magnesium alloy AZ91-0.15Y in pressurized differential pressure casting, presenting a mixed trait of cleavage and ductile fracture. It can be concluded that pressurized differential pressure casting is beneficial to promote the fatigue performance of magnesium alloy AZ91-0.15Y, which is consistent with the testing results of fatigue life test.



(a) Common casting

(b) Pressurized differential pressure casting

Figure 4: The appearances of the fatigue fractures of alloys made in different casting methods

4. Deformation mechanism

Anisotropic and temperature makes effects on mechanical properties of copper nanowires under tensile loading. Atomistic simulations are used to investigate the mechanical properties of copper nanowires along<100>,<110> and<111> crystallographic orientations under tensile loading at different temperatures. The inter-atomic interactions are represented by employing embedded-atom potential. To identify the defects evolution and deformation mechanism, Centro symmetry parameter is defined and implemented in the self-developed program. The simulations show that Cu NWs in different crystallographic orientations behave differently in elongation deformations. The stress strain responses are followed by a particular discussion on yield mechanism of NWs from the standpoint of dislocation moving. Generally, the study on the incipient plastic deformation will be helpful to further understanding of the mechanical properties of nanomaterial.

In addition, the Young's modulus decreased linearly with the increase of temperature. The crystal structure is less stable at elevated temperatures.

The mechanical behaviours of silver nanowires are including point defects and 3D defects. Molecular dynamics simulations are used to study the deformation of the silver NWs containing defects under tensile loading. The embedded atom method (EAM) potential is employed to describe the atomic interactions. The investigation designs various kinds of defects inside NWs and studies the influences of the defects on the strength, and dislocation emission, deformation mechanism. This work contains two parts; one part is the point defects effect on deformation behaviours of the NWs. We mainly focus on the elastic behaviour of NWs at different loading rates and defect ratio. For the other part, the investigation designs ball-shaped closed cracks inside NWs. Analysis results demonstrate that if the leading dislocation are emitted from cracks, the strength of the defective NWs occur is lower than that of defect-free NWs. It also demonstrates that designed NWs with different orientations behaviour differently. We focus on the mechanical behaviours of twinned silver nanowires. The deformation of twinned silver NW is examined to reveal the strengthening mechanism of twinning boundary by using molecular dynamic simulation. In the first part, we study the mechanical responses of fivefold twinned silver NW for tensile and torsional deformations. Although the relaxed configuration of fivefold twinned NW possesses higher potential energy than<110> single crystalline NW, the internal stable of the unique structure provides a larger energetic barrier to defect formation. Under tensile loading condition, we find that the defect emission and propagation in fivefold twinned NW is prevented by the pre-existing twin boundaries. While the plastic deformation under torsion yield through the nucleation of coaxial dislocations, showing a quite uniformly distribution as observed in the end of the wire. In the other part, we study the mechanical responses of (111) twinned sliver NWs. Strong elastic deformation behaviour and fast stress releasing are observed under tension loading. Analysis results also demonstrate that smaller twin boundary space could make greater improvement of elasticity of silver NWs.

In this paper, we also recognize the importance of mechanical behaviours of Nano crystalline and the single crystal nanowire under torsional loading. For the first part of this section, the construction of silver Nano crystalline (NC) samples by molecular dynamics simulation is investigated. Firstly, the initial NC samples are assembled by Voronoi geometrical construction method, then the local minimized energy states of the samples are obtained. The Nano crystalline grain structure is analysed with radial distribution function (RDF), energy analysis and Centro symmetry parameter methods. Stress strain curves show the reverse Hall-Petch relation in the present simulations. The decrease of elastic modulus is dependent on the size of the nanostructure. In the second part, atomistic simulations are used to investigate the mechanical properties of<100> copper NWs under torsional loading. The loading rates, wire cross-sectional sizes and thermal effects on the critical angle of copper NWs are discussed. It may be predicted from our simulation that the NWs take different paths of deformation at different loading rates. For lower loading rates, the NW is showed clear periodic fluctuation characteristics in potential energy response, with dislocation and slippage occurring along the (111) plane. While in high loading rates, periodic fluctuation behaviour become less clearly defined, and atoms cluster into disorder arrays near the two ends of the NW.

Mg-6Zn-1Y-0.2Co-0.1Sc magnesium alloy gets be manufactured in one induction melting furnace, using industrial metals (Mg and Zn) and intermediate alloy (Mg-15Y, Mg-10Co and Mg-15Sc). In the processing of smelting and casting, the gas mixture of SF6 and CO2 plays a role as shielding gas, with by which volume ratio is 3:5. Aiming at the target of metal material Cu, speeding at 2°/min, piping pressure at 42Kv and piping flow at 32 mA, X-ray diffraction (XRD) takes phase analysis to describe the sample of, Mg-6Zn-1Y-0.2Co-0.1Sc magnesium alloy. At the same time, Metallographic microscope, as well as scanning electron microscope reviews and analyses its microstructure. Universal testing machine tests its low-temperature tensile and records the tensile fracture surface respectively, when the temperature is 0, -20, -40, -60, -100 and -150 ℃.

Primary Mg2Si became gradually smaller and spherical with the increasing ultrasonic vibration duration and power. With increasing vibration processing temperature, the size of primary Mg2Si decreases at first and then increases. The homogeneous dispersion of primary Mg2Si in the matrix resulted from capillarity effect and acoustic streaming shock wave enhanced by high intensity ultrasonic. The ultrasonic vibration altered the solidification conditions of Mg2Si and promoted melt flow impact on them, which changed morphology of Mg2Si from dendrite to particulate, and particularly restrained Mg2Si growth rate. The results of T6 and T4 heat treatment show that eutectic Mg2Si could be dissolved partially during solid-solution treatment. MgZn', MgZn2 and Mg2Sn were precipitated in aging process. The optimal T6 heat treatment parameters were determined as solution treating at 400℃for 20 h, chilled in water and then aging at 200℃for 10 h. The results of tensile tests at room temperature and high temperature indicated that the tensile strength and elongation of the composites could be improved due to alloying or ultrasonic vibration processing. With increasing alloying element content, the tensile properties of single and binary element alloying composites increased at first and then decreased. As Mg2Si modified to particles, the tensile fractures of the composites changed from quasi-cleavage fracture to mixed fracture with large amounts of dimples at room temperature. The tensile strength and elongation of ultrasonic vibrated composites increased with ultrasonic duration and power, and increased at first and then declined with rising vibration temperature. According to the microstructure and tensile properties of the composites, the combination of alloying component was optimized as 0.4%Ca+1.0%Ba+0.75%Sb+3.0%Sn, and the ultrasonic parameters were optimized as duration 60 s, temperature 680℃and power 0.6 kW. The microstructure and tensile properties of the composites, which were prepared by an alloying and vibration combination fabrication technique with optimal parameters of four element alloying and the ultrasonic, were further improved.

5. Conclusion

(1) The dendritic crystal in microstructure of magnesium alloy ingot AZ91-0.15Y in pressurized differential pressure casting is conspicuously restrained; hence the structure of alloy is refined, compared with the common casting one. Magnesium alloy ingot AZ91-0.15Y in common casting consists of four phases, including α-Mg, the basic phase, Mg17Al12, and Al8Mn5, while magnesium alloy ingot AZ91-0.15Y in pressurized differential pressure casting consists in α-Mg, as the basic phase, and little Mg17Al12, Mg3Y2Zn3.
(2) The fatigue property of magnesium alloy AZ91-0.15Y made in pressurized differential pressure casting achieves a remarkable promotion compared with that of magnesium alloy in common casting. Additionally, the fatigue fracture transforms from brittle fracture to a mixed trait of cleavage and ductile fracture.

References

Chen Q., Shua D.Y., Hua C.K., et al, 2012, Grain Refinement in an As-cast AZ61magnesium Alloy Processed by Multi-axial Forging under the Multi Temperature Processing Procedure [J], Materials Science and Engineering: A, 541(15): 98-104.

Frank C., 2011, Magnesium Alloys - Design, Processing and Properties. Intech: India, 56, 7, 78-98.

Li Q., Hao Q.T., Jie W.Q., et al, 2013, The Effect of Differential Pressure Casting on the Fatigue Property of Gypsum Molding A357Aluminum Alloy[J], Transactions of Nonferrous Metals Society of China, 34(5) : 1281-1285.

Ma X.Z., Xu C.X., Cheng W.L., et al, 2013, The Effect of Sr on the Precipitated Phase and Mechanical Property of AZ81magnesium alloy β-Mg17Al12[J], Casting, 62(3) : 230-234.

Meng X.B., Mao H.K., Xu H. et al, 2013, The Effect of the Content of Nd on the Mechanical Property of Magnesium Alloy ZM6[J], Heat Treatment, 42(6) : 8-9, 12.

Meng X., 2013, Nd’s influnce on the mechinal property of ZM6 magnesium alloy. Hot-working Technology, 42, 6, 8-9.

Sha G.Y., Han Y., Liu T., 2012, The Effect of Stress Ratio on Fatigue Behavior of Alloy Mg-3Al-2Sc [J], Processing Technology of Light Alloy, 40(9): 60-63, 69.

Zheng X., 2011, Microstructure and mechanical properties of NZ30K alloy by semi-continuous direct chill and sand moul casting processes. China Foundry, 8, 1, 41-46.