Effect of compression loading speeds on the room temperature mechanical properties of as-extruded AZ31 magnesium alloy

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Abstract: The room temperature compression experiments of as-extruded AZ31 magnesium alloy under different loading speeds were carried out on a universal tensile testing machine. The fracture failure characteristics and mechanism of the alloy under different compression loading speeds were analyzed by scanning electron microscope (SEM) and optical microscope (OM). The results show that during the compression test, the crushed AZ31 magnesium alloy sample has a certain pier coarseness, the macro fracture of the sample is located at one third of the sample, and the macro fracture mode is 45° shear fracture with the sample axis; With the increase of loading speed, the coincidence degree of macro fracture becomes worse, and its compressive strength changes in an undulating manner. When the loading speed is 2mm/min, the compressive strength reaches the peak value of 413MPa, and the fracture morphology of the sample shows a typical flat and flat rock like ductile brittle mixed fracture. With the increase of loading speed, the proportion of brittle fracture components increases, the shape of shrinkage fracture is rock like fracture, and the fracture fluctuation is relatively slow, the dimples distributed on the fracture surface are elongated and torn, and the compression speed has no obvious effect on the fracture morphology.

1. Introduction
Magnesium alloy is widely used in aerospace, automobile, military industry, transportation and other fields because of its advantages of low density, high specific strength and specific stiffness, good electromagnetic shielding performance and damping [1-3]. However, in practical application, aircraft and weapons need to bear certain compression and dynamic impact under special environmental conditions; In transportation, such as automobile collision accident, it will also receive high impact. Magnesium is a close packed hexagonal structure, during in room temperature, the CRSS (critical shear stress) of cylindrical and conical sliding is much higher than the base sliding and is not easy to start, there are only two independent sliding systems of the base and the three close packed directions \( \left( \frac{1}{3}[\overline{1}20], \frac{1}{3}[\overline{2}10], \frac{1}{3}[2\overline{1}0] \right) \) on the base, and there are few sliding systems, therefore, the plastic deformation of magnesium alloy at room temperature is difficult. The deformation and
fracture mechanism of magnesium alloy is complex due to the effects of heat treatment, forming process and added alloy elements. The common fracture mechanisms are ductile fracture, brittle fracture and ductile brittle mixed fracture. With the increase of deformation speed and the shortening of deformation time, the critical shear stress of various slip of magnesium alloy will change, so that the fracture mechanism of the alloy will also change. Under different compression deformation rate loading conditions, the fracture mechanism and the proportion of different fracture mechanisms will affect the compression, tensile and impact properties of magnesium alloys. With the rapid development of magnesium alloys, especially under the load conditions with high deformation speed, the technical requirements are higher and higher, and the fracture mechanism and failure form of magnesium alloys are an important embodiment of the compressive properties of magnesium alloys [5-12]. However, there are few studies on the influence of magnesium alloy on its properties under different compression deformation speeds [13-14]. Based on this, taking commercial as-extruded AZ31 magnesium alloy as the research object, the fracture mechanism and fracture morphology of as-extruded AZ31 magnesium alloy under different compression speeds are analyzed and discussed by using universal tensile testing machine, It provides some data reference for the application of magnesium alloy under certain compression and impact.

2. Experimental materials and methods
Commercial as-extruded AZ31 magnesium alloy is used, and its alloy composition is shown in Tab.1. According to the national standard GB7314-1987 metal compression test method, AZ31 magnesium alloy material is turned. The sample size and processing requirements are shown in Fig.1. The universal tensile specimen machine is used to carry out the compression experiments of the processed samples at different compression loading speeds, then the fracture is observed by SEM, and the influence of different compression rates on the fracture mechanism is analyzed. At the same time, the Metallographic Preparation of the fracture position is carried out. The samples are corroded by 1g oxalic acid +1ml acetic acid +100ml ethanol+5ml nitric acid, Then the microstructure near the fracture was observed and analyzed under the metallographic microscope.

| Alloy | Al   | Zn   | Mn   | Si   | Fe   | Ni   | Cu   | Ca   | others | Mg   |
|-------|------|------|------|------|------|------|------|------|--------|------|
| AZ31  | 2.5~3.5% | 0.7~1.3% | 0.2~1.0% | 0.05% | 0.003% | 0.001% | 0.01% | 0.04% | 0.3% | Bal.  |

Fig.1 Geometry of compression sample

3. Experimental results

3.1 Effect of different compression loading speeds on macro fracture of as-extruded AZ31 magnesium alloy
During compression at room temperature, the fracture mode of macro fracture of extruded AZ31 magnesium alloy under different compression speeds is basically 45° to the sample axis, as shown in
Fig. 2. The samples are all of the same batch, and their fracture positions are almost at about 1/3 of the upper end of the sample, forming cracks and expanding at 45° and shear crushing fracture, as shown in Fig. 3(a). The mechanism principle of the macro fracture mode is as follows: Fig. 3(b) shows the stress state of the compressed sample, the length diameter ratio of the sample is 2.5, Fig. 1 shows the compression direction of the sample, Fig. 2 shows the shear failure direction of the sample during compression, area “a” in Fig. 3(b) is the shear stress area during compression, and area “b” is the tensile stress area of the sample during compression, The stress shear direction is consistent with the stress failure direction indicated by the arrow in Fig. 2. The shear modulus of magnesium alloy is G=16GPa and the shear strength is 160MPa \[15\]. When it is subjected to axial compression load in direction “1” in Fig. 3(b), it is most prone to failure along the 45° direction due to its low shear modulus and shear strength. In the process of compression at room temperature, with the increase of compression loading speed, the fracture edge fissure increases, and the fracture position moves upward to a certain extent, but the fracture mode does not change. At the same time, the deformation of the sample has a certain directionality in the process of axial compression deformation. At the same time, regardless of the compression speed, the deformed fracture shape of the circular sample is basically oval. This is obviously different from that some metal samples will form waist drum or cylinder after compression deformation. The reason should be related to the dense hexagonal structure of magnesium alloy.

![Fig.2 Macorosopic fracture morphology of as-extruded AZ31 Mg alloy](image)

3.2 Effect of different compression rates on compressive properties of extruded AZ31 magnesium alloy

The variation curves of compressive stress and compression rate of as-extruded AZ31 magnesium alloy under different compression rates are shown in Fig. 4. With the increase of the compression deformation rate, the compressive strength of the sample changes in a wavy manner. When the deformation rate is 2mm/min, the compressive strength reaches the peak, about 413MPa; When the
compression rate is 100 mm/min, the deformation reaches 29%, and the average other deformation is about 10%~14%. The sample has a certain particle coarseness, indicating that the sample has a certain plasticity. This is also related to the dense hexagonal structure of magnesium alloy.

![Graph showing the influence curve of as-extruded AZ31 Mg alloy under different compression speeds.](image)

**Fig. 4** The influence curve of as-extruded AZ31 Mg alloy under different compression speeds

Through metallographic observation near the compression fracture, it is found that in the microstructure of Fig. 6, along the extrusion direction, obvious main cracks and secondary cracks can be seen near the fracture of the compression sample, and a certain amount of micro aggregate holes are distributed near the fracture, as shown by the arrow in Fig. 5. In the compression process of AZ31 magnesium alloy, the two fracture surfaces have poor connectivity, and there is obvious falling off at the crack edge, especially at the end edge of the sample fracture, which makes the length of the crack irregular, and the number of micro pores is obviously different. Micro-pore aggregation leads to the increase of local stress, which promotes the formation and propagation of cracks in the compression process, resulting in the falling off and fracture of local edges of cracks. With the increase of compression loading speed, it can be seen that the coincidence degree of the two sections of the sample becomes worse, and there are obvious slag dropping and embrittlement cracks. Secondary cracks can also be observed on the fracture surface, and some cracks can be observed near the main crack, indicating that the fracture of magnesium alloy is a process of multi-stage crack initiation and propagation.

In addition, a small amount of twins can also be observed in the metallography near the fracture of the compressed sample. According to the research of M. H. Yoo [18], when twins meet grain boundaries during compression, high stress concentration will occur in the area near grain boundaries, which may cause twin nucleation or crack formation, and the direction of crack growth may also change. These cracks will gradually expand during compression and form undulating steps, which connect the cracks. Because the internal structure of the extruded sample is uneven, showing obvious extruded fibrous structure, there are some elongated original grains and a large number of fine dynamic recrystallization along the original grains. During compression at room temperature, once the sliding surface tends to be parallel to the stress direction, the sliding system in the magnesium alloy crystal stops moving under the action of compressive stress. However, the continuous increase of external force often leads to the occurrence of twinning. Twinning is first formed at the elongated original crystal boundary, while twinning is rarely generated in small dynamic recrystallization. Once twinning occurs, due to the change of crystal orientation, the sliding surface in the twin is no longer parallel to the stress direction, and the original sliding system starts again until fracture and the end of plastic deformation. When twins are encountered in the process of crack propagation at the edge of compression fracture, their propagation path will be forced to change, and the new propagation direction will be along the twin plane or symmetrical to the original propagation direction. Obviously, the blocking effect of twins on crack propagation is conducive to the improvement of material toughness [19]. When the crack propagation at the fracture meets fine recrystallization, it is hindered by the grain boundary and
propagates along the grain boundary. Therefore, the microstructure is uneven, twins are generated at the coarse microstructure and elongated original grain boundary, and cracks are easy to occur at the twins. Therefore, to improve the compressive plasticity of extruded magnesium alloy, it is necessary to improve the microstructure uniformity and grain size of the alloy.

3.3 Effect of different compression speeds on micro fracture of extruded AZ31 magnesium alloy

The micro fracture surface of extruded AZ31 magnesium alloy is formed under the action of compression load at different compression speeds, as shown in Fig. 6. It can be seen from the figure that in the process of compression at room temperature, the longitudinal compression fracture of AZ31 magnesium alloy is characterized by ductile brittle mixed fracture, and the fracture fluctuation is relatively slow. The dimple is elongated under the action of shear stress with obvious tear marks, forming flat and flat steps, and the fracture is characterized by rock and stone. Obvious marks of shear tear and extrusion friction during compression are distributed on the shear fracture. With the increase of compression loading speed, the deformation speed also increases. Therefore, the tearing edge similar to quasi cleavage fracture can be seen in the micro fracture SEM, which shows that with the increase of deformation speed, the brittle fracture composition of the modified material increases, so that the macro fracture surface is basically at an angle of 45° with the compressive stress. Some secondary cracks can be seen on the fracture surface in Fig. 6, which shows that during the compression process, the main crack propagation is accompanied by the initiation and propagation of some secondary cracks, which is basically consistent with the observation of fracture metallography.
Fig. 6 The evolution of fracture pattern of as-extruded AZ31 Mg alloy under the different compression rate. (high power SEM)

4. Conclusion

The above discussion and analysis show that different compression speeds have a greatly effects on the properties and fracture mechanism of as-extruded AZ31 magnesium alloy. The main conclusion are as follows:

(1) Under the compression load at room temperature, the fracture mode of as-extruded AZ31 magnesium alloy is shear fracture at 45° to the load direction, and the fracture position is about one-third of the upper end of the sample.

(2) With the increase of loading speed, the coincidence degree of macro fracture gradually becomes worse, and there are slag dropping and fracture edge breakage, indicating that the secondary crack propagates along the main crack and forms a closed loop during the fracture process of the sample.

(3) The extrusion direction and compression fracture morphology of the extruded AZ31 magnesium alloy are rock fracture, the fracture fluctuation is relatively slow, the dimples distributed on the fracture surface are elongated and torn, forming flat and flat steps, and its brittle composition...
increases with the increase of loading speed, belonging to the ductile brittle mixed fracture characterized by brittle fracture. The compression velocity has no obvious effect on the fracture morphology.

(4) During compression at room temperature, the sample of extruded AZ31 magnesium alloy shows a certain degree of coarse deformation. With the increase of compression loading speed, its compressive strength fluctuates. At the loading speed of 2mm/min, its compressive strength reaches the peak, about 413MPa.

This experiment is mainly aimed at the analysis of compression performance under the condition that the compression force is parallel to the extrusion direction. In the later research, the compression performance and fracture mechanism of magnesium alloy should be comprehensively analyzed under the condition that the compression force is perpendicular to the extrusion direction, so as to provide protective reference for the engineering application of magnesium alloy under compression and impact load.

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