Study on strain rate dependence and energy absorption characteristics of two aluminum alloys 7A62 and 7085

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Abstract. The dynamic compression properties of two aluminum alloys 7A62 and 7085 were tested using Split Hopkinson Pressure Bar (SHPB) technique. The effects of strain rate on yield stress and dynamic energy absorption characteristics of the two materials were analyzed. The critical strain rate and the maximum energy absorbed before shear failure occurred of the two materials were given. The results showed that both the two materials show a strong strain rate dependence effect, and the yield stress increased with increasing strain rate. The aluminum alloy 7085 has a lower yield stress than 7A62 under the same strain rate level. But it has a better energy absorption characteristic than 7A62 for its good plasticity.

1. Introduction

Compared with traditional steel, aluminum alloy has a low density and is an ideal military lightweight metal material. The newly developed armored aluminum alloy is used as an important material for tanks and armored vehicle [1]. Its working scenes face extreme conditions such as detonation and high-speed impact. Therefore, studying its energy absorption characteristics under impact loads has guiding significance for its application in the field of armor protection.

In this study, Hopkinson rod dynamic compression loading experimental technology was used to study the strain rate dependence and energy absorption characteristics of armored aluminum alloy of 7A62 and 7085. The critical strain rate range of shear failure of the two materials is given, and the maximum energy absorbed before shear failure of the two materials were obtained. Based on the experiment result, comparative analysis was taken out on the two tested materials.

2. Experimental Procedure

2.1. Material

The raw materials are two kinds of armored aluminum alloy plates: aluminum alloy 7A62 (T6), 40 mm thick; aluminum alloy 7085 (32# Institution), 40 mm thick. The sample isφ8mm×4 mm
cylindrical sample, the thickness direction is consistent with the plate.

2.2. Tests

Dynamic compression tests were carried out on Split Hopkinson Pressure Bar (SHPB) equipment [2-4]. The schematic and physical map of SHPB equipment is shown in figure 1. It consists of gas gun, incident bar, transmitted bar, striker, buffer bar, shock absorber, and strain gage circuits to measure strain signal in the bars. In the tests, the gas gun launches the tubular striker to impact the incident bar. The elastic compressive stress wave travels through the incident bar toward the specimen. When the compressive stress wave propagates into the specimen, it reverberates within the specimen until a nominally homogeneous stress state is achieved. Thereafter, part of the wave is transmitted through the transmitted bar, and the rest is reflected back to the incident bar. The strain signals were transferred into electrical signals by high dynamic strain indicator; the electrical signals were recorded by the Multi-channel transient digital recorder.

In this experiment, steel rods with a diameter of 16mm were selected. The striker length is 300mm. Both the incident bar and transmitted bar are 1200mm in length. During the test, the loading speed is controlled by adjusting the air pressure to achieve different strain rate loading.

Figure 1. Schematic and physical map of SHPB.

3. Results and Discussion

3.1. The dynamic compression mechanical properties of 7A62 (T6)

The true stress-strain curve of 7A62 under different strain rate is obtained as shown in figure 2 after analysis of the experimental data. It showed that the yield stress is increased as the strain rate. When strain rate is higher than 1200s$^{-1}$, the yield stress of this material is greater than 800MPa. The failure strain is about 0.14, it can be inferred combined with the morphology of the test specimen, for shear failure occurred in 7A62-7 and 7A62-1.
Calculating the area enclosed by the curve and the x, y axis in the material's stress-strain curve is a fast method to estimate the energy absorption characteristics of a material[5]. In order to study the energy absorption characteristics of this material, W was used to represent the energy absorbed per unit volume of material, and the area under the stress-strain curve is the total energy absorbed per unit volume of material.

\[ W = \int_{0}^{\varepsilon_0} \sigma(\varepsilon) \, d\varepsilon \]

Where, \(\varepsilon_0\) is the maximum strain value reached during material compression. The estimation method is shown in figure 3.

The detailed test results of 7A62 are shown in table 1. It shows that the specimen was oblate and had no cracks after tested under the strain rate 1428 s\(^{-1}\). Shear failure occurred when the strain rate reached 2031 s\(^{-1}\). Therefore, it can be inferred that the critical strain rate of this material for dynamic shear failure is between 1428 s\(^{-1}\) and 2031 s\(^{-1}\). The maximum energy absorption is about 149MJ/m\(^3\) before shear failure occurred.

Table 1. Test results of 7A62 (T6).

| Test number | Initial length / diameter (mm) | Loading pressure (MPa) | Average strain rate (1/s) | Yield stress (MPa) | Maximum strain | Absorbed energy (MJ/m\(^3\)) | Remark       |
|-------------|-------------------------------|------------------------|--------------------------|-------------------|----------------|-------------------------------|--------------|
|             | \(l_0\) | \(d_0\) |                           |                     |                 |                               |              |
| 7A62-1      | 3.88  | 7.94   | 0.8                       | 3201               | 902            | 0.148             | 146.67       | Sheared into                |
| 7A62-2      | 4.02  | 7.88   | 0.8                       | 3455               | 876            | 0.12              | 107.25       | Sheared into                |
| 7A62-3      | 4.00  | 7.8    | 0.8                       | 3112               | 892            | 0.149             | 142.77       | Sheared into                |
3.2. The dynamic compression mechanical properties of 7085 (32 # Institution)

![Figure 4](image)

**Figure 4.** Typical true stress-strain curves of 7085 deformed under different strain rates.

The true stress-strain curve of 7085 under different strain rate is obtained as shown in figure 4. It showed that the strain rate effect of this material is also evident. Combined with the morphology of the test specimen, 7085-1 and 7085-16 were oblate and had no cracks, 7085-10 was sheared into three pieces, 7085-3 was smashed into pieces. It can be concluded that the yield stress and plastic strain of this material is increasing as the strain rate before it fracture. When the fracture occurred, there is a reduced of the highest value of stress and strain. Therefore, the fracture properties of this material are different under different strain rate ranges. This phenomenon is affected by the energy dissipation mechanism under the impact state.

The detailed test results of 7085 are shown in table 2. From it cracks appeared when the strain rate reached 3122 s\(^{-1}\). Therefore, it can be inferred that the critical strain rate of this material for dynamic shear failure is approximately 3000s\(^{-1}\). The maximum energy absorption is about 280MJ/m\(^3\) before shear failure occurred.
Table 2. Test results of 7085 (32# Institution).

| Test number | Initial length / diameter (mm) | Loading pressure (MPa) | Average strain rate (1/s) | Yield stress (MPa) | Maximum strain | Absorbed energy (MJ/m³) | Remark |
|-------------|-------------------------------|------------------------|---------------------------|--------------------|----------------|-------------------------|--------|
|             | l₀                             | d₀                     |                           |                    |                |                         |        |
| 7085-1      | 4.98                           | 8.98                   | 0.8                       | 2333               | 699            | 0.241                   | 212.71 | Oblate, No |
| 7085-2      | 4.98                           | 8.96                   | 1.75                      | 5482               | 808            | 0.344                   | 182.47 | Smashed into |
| 7085-3      | 4.96                           | 8.94                   | 1.75                      | 5532               | 794            | 0.208                   | 177.62 | Smashed into |
| 7085-4      | 4.96                           | 8.94                   | 1.5                       | 4708               | 771            | 0.235                   | 210.4  | Smashed into |
| 7085-5      | 4.98                           | 8.96                   | 1.5                       | 4474               | 686            | 0.326                   | 317.67 | Smashed into |
| 7085-6      | 4.96                           | 8.98                   | 1.75                      | 5216               | 889            | 0.194                   | 170.45 | Smashed into |
| 7085-7      | 4.04                           | 7.98                   | 0.95                      | 3597               | 758            | 0.361                   | 373.93 | one crack |
| 7085-8      | 3.98                           | 7.98                   | 1                         | 4485               | 776            | 0.154                   | 129.83 | sheared into three |
| 7085-9      | 4.08                           | 7.96                   | 0.8                       | 2558               | 708            | 0.2657                  | 240.44 | Oblate, No |
| 7085-10     | 4.06                           | 7.96                   | 1                         | 4369               | 788            | 0.182                   | 148.53 | sheared into three |
| 7085-11     | 4.24                           | 7.96                   | 0.8                       | 2369               | 712            | 0.246                   | 226.31 | Oblate, No |
| 7085-12     | 3.96                           | 7.98                   | 0.9                       | 3122               | 719            | 0.319                   | 303.72 | One crack |
| 7085-13     | 4.02                           | 7.94                   | 1                         | 4230               | 751            | 0.188                   | 161.86 | sheared into three |
| 7085-14     | 4.02                           | 7.98                   | 0.9                       | 2991               | 700            | 0.301                   | 280.19 | Oblate, No |
| 7085-15     | 4.08                           | 7.96                   | 0.9                       | 3226               | 704            | 0.322                   | 310.39 | Oblate, No |

3.3. Comparative analysis
The relationship between yield stress and strain rate was showed in figure 5. It is obvious that they are in line relationship. The yield stress of 7A62 is higher than 7085 in the same strain rate level. The strain rate hardening modulus for yield stress of the two materials is similar. But from figure 2 and figure 4, the maximum plastic strain of 7085 is higher than 7A62. It is indicate that 7085 aluminum alloy has a better plasticity and 7A62 aluminum alloy has a better strength.
Figure 5. The relationship between yield stress and strain rate.

The relationship between maximum energy absorption and strain rate of both materials was showed in figure 6. It showed that the value of energy absorption is increasing as strain rate before the fracture occurred. The dynamic energy absorption of 7085 is better than 7A62 obviously. This is due to the good plasticity of 7085.

Figure 6. The relationship between maximum energy absorption and strain rate.

4. Conclusion

(1) Both the two material 7A62 and 7085 had a strong strain rate dependence effect, and the strain rate hardening modulus for yield stress of both materials is similar.

(2) The critical strain rate of 7A62 (T6) for dynamic shear failure is between 1428 s\(^{-1}\) and 2031 s\(^{-1}\). The maximum energy absorption is about 149MJ/m\(^3\) before shear failure occurred.

(3) The critical strain rate of 7085 (32 # Institution) for dynamic shear failure is approximately 3000s\(^{-1}\). The maximum energy absorption is about 280MJ/m\(^3\) before shear failure occurred.

(4) 7085 aluminum alloy has a better plasticity than 7A62, and 7A62 aluminum alloy has a higher strength than 7085 under a same strain rate level. The dynamic energy absorption of 7085 is better than 7A62 obviously. This is due to the good plasticity of 7085.
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