The Impact Compressive Properties of 7075-T651 Aluminium Alloy over a Wide Range of Strain Rates and Temperatures

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Abstract. The mechanical properties of 7075-T651 Aluminium Alloy was studied under dynamic compressive loading over a wide range of strain rates from 600s⁻¹ to 16000s⁻¹ and the temperature range from 25°C to 400°C. A classic split Hopkinson pressure bar (SHPB) and a radiant-heating furnace are used for the experiment and measurement. Some improved test and data processing technique are used to get more accurate test result. It is found that the compressive stress-strain response is insensitive to the applied strain rate but depends on experimental temperature. The experiment results provide a good basis to build a more valid and accurate material models for 7075-T651 Aluminium Alloy.

1. Introduction
7075-T651 aluminium alloy has been extensively used in commercial and military air carriers. Its mechanical properties over a wide range of strain rates and temperatures is of interest. A considerable amount of work has been done toward understanding and modelling its mechanical behaviour under low strain rates and various temperatures [1-4]. However, up to now, there has been less work concerning the effects of high strain rate and temperature and little work has been done related to its mechanical behaviour under a ultra-high strain rate and high temperature. The purpose of this paper is to experimentally study and characterize the behaviour of a 7075-T651 aluminium alloy during dynamic compression over a wide range of strain rates and temperatures.

2. Experimental
The material used in this study is the 7075-T666 aluminum alloy. Its chemical composition is shown in Table 1. The cylindrical specimens were prepared from the plates with the compression axis parallel to the rolling direction. For the test of strain rate below 6000s⁻¹, specimens were 6.0 mm in diameter and 4.0 mm in height and for higher strain rate experiments, a smaller specimen with a diameter of 3.0 mm and a height of 2.0 mm was used.

Table 1. Chemical composition of aluminum alloy 7075-T651 (WT. %)

|     | Ti   | Si  | Mn  | Mg   | Fe       | Cr      | Zn    | Cu   | Others |
|-----|------|-----|-----|------|----------|---------|-------|------|--------|
|     | 0.2  | 0.4 | 0.3 | 2.1-2.9 | 0.5      | 0.18-0.28 | 5.1-6.1 | 1.2-2.0 | 0.15   |

Dynamic compression tests were conducted using a split Hopkinson pressure bar (SHPB) [1] (Fig.1). The diameter of the striker, incident bar and transmission bar is 14.5 mm. The length of incident bar and transmission bar is 1000mm and the lengths of the strikers are 40mm, 30mm and 15mm. A geometrically optimized thin copper disc (pulse shaper) is used for ensuring the stress equilibrium within the specimen during the test [5] (Fig.2). A wide band strain amplifier (frequency...
response from DC to 2MHz) and a Tektronix 3014B Digital Oscilloscope are used and it guarantees almost no additional signal loss during the test. The tri-wave data processing method which calculates the stress, strain rate and strain using incident wave signal, reflect wave signal and transmission wave signal was used to obtain a more accurate stress–strain curve comparing to the classic two-wave method[6]. When using tri-wave method, the time shifts from gage I and gage II to the bar-specimen contact surfaces need to be calibrated carefully.

Figure 1. Schematic presentation of the compression split Hopkinson bar apparatus.

A chamber radiant-heating furnace is used to provide heating temperature from 25°C to 400°C. The specimen and part of the pressure bars in the furnace were heated together and it ensures the perfect contact between the specimen and the pressure bars. Since the highest temperature in the experiment is 400°C, the effect of temperature on the propagation of stress wave in the rods can still be ignored. The temperatures of the specimen were monitored using a thermocouple (TC-2) attached on the transmission bar near the contact end with the specimen and a carefully calibration is made (Fig.3). Though directly attaching the thermocouple (TC-3) on specimen is the best way to measure the temperature, it may introduce some interference to the mechanical response of the specimen especially when a small specimen is tested. The thermocouple (TC-1) can also be just put in the chamber, but it is found that a temperature gradient exists within the chamber and a maximum 50°C measurement error may be introduced.

Figure 2. Stress equilibrium during a test.
3. Experimental Results
The experiments under the true strain rates from 600s\(^{-1}\) to 16000s\(^{-1}\) and temperature range from 25°C to 400°C was carried out. In order to eliminate signal noise, a 500 kHz digital low pass filter is used on the recorded data. The tri-wave method is used for measurement data processing. After the voltage-strain relation and time shift calibration are completed, no manual intervention is needed in the data processing process. Figure 4 shows a set of typical test signals and experimental results. Theoretically, based on the tested true-stress–true-strain curves, the material flow stress, work hardening rate and maximum stress at high strain rate conditions can be derived. However, the elastic response of a material cannot be measured reliably using a SHPB apparatus [1] and it is difficult to determine the exact yield stress as a quasi static experiment. For this reason, the material flow stress based on the 5% plastic strain is introduced [7].

![Figure 3. Temperature measurement (a) and calibration (b)](image)
3.1. Strain Rate and Temperature Dependence of Flow Stress

The flow true stress at 5% true strain as a function of strain rate and temperature is shown in Fig.5 (a) and (b). It can be seen (Fig.5 (a)) that the 7075-T651 aluminum alloy shows a weak strain rate sensitivity. The flow stress shows slightly positive strain rate dependence only at the room temperature. When the temperature is higher than 100°C and lower 350°C, the flow stress is almost independence of strain rate. The flow stress even shows a negative strain rate dependence when the temperature is higher than 350°C and It can be explained by strain rate thermal softening due to Adiabatic temperature rise when the strain rate is very high.

As shown in Fig.5 (b), the flow stress declines rapidly with increasing temperature and Drops sharply between 200°C and about 320°C. When the temperature is above 320°C, the drop rate of the flow stress becomes much slower. It seems that the temperature dependence of the flow stress is independent of strain rate.

Figure 4. Typical experiment signal (a) and test results (b).
Figure 5. The dependency of flow stress on (a) strain rate and (b) temperature for the 7075-T651 aluminum alloy.

3.2. Work Hardening Rate and Plastic Instability
The stress-strain curves are plotted in Fig.6 for different temperature and strain rate. It can be seen that the work hardening rates of the aluminum alloy only slightly changed with the temperature change (Fig.6(a)) and the work hardening rates have little change for different strain rates (Fig.6(b)).

The dependence of dynamic plastic instability point that the slope of the stress-strain curve becomes negative on specific strain rate and temperature is not mentioned in literatures because the maximum strain during this experiment usually was not enough to show this phenomenon. It is shown that this dynamic plastic destabilizing behavior clearly affected by temperature and strain rate. In Fig.6 (a), the instability strain decreases with increased temperature when temperature is below 300°C but when temperature is above 350°C, the plastic instability did not appear. In Fig.6 (b), the plastic instability strain decreases with strain rates are between 16000s⁻¹ and 6000s⁻¹. For lower strain rate,
since the experimental maximum strain is too small, no conclusion can be reached. In general, the plastic deformation of the alloy can be divided into three regions: the work hardening region, the platform region and the plastic instability region.

![Figure 6](image)

**Figure 6.** The true stress-strain curves for (a) different temperature and (b) different strain rate

4. Conclusions
The mechanical properties of 7075-T651 Aluminum Alloy were studied under dynamic compressive loading over a wide range of strain rates and temperature. Based on this study, following conclusions can be made:

- The flow stress of 7075-T651 aluminum alloy almost is constant with increasing strain rate at higher temperature. The flow stress only slightly increases with increasing strain rate at room temperature.
- The flow stress decreases with increasing temperature and the maximum flow stress decline rate appears in the temperature region between 200°C and 320°C. When temperatures are above 320°C,
the decrease of flow stress with increasing temperature significantly slowdown. The overall relation between flow stress and temperature cannot be simply represented with a power function.

- The work hardening rate is only slightly affected by temperature and strain rate. The dynamic plastic instability strain decreases with increased temperature and strain rate for the existing experimental data and more experiment is needed.

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