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Experimental Investigation of Dynamic properties of AerMet 100 Steel

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Abstract

The dynamic properties characterization of AerMet 100 Steel at four different strain rates, namely 560/s、1200/s、2500/s and 4200/s were carried by a SHPB system. The stress-strain curves at these strain rates are obtained and they were compared with the quasi-static test results to analyze its strain effects. By comparing the stress-strain curves under different strain rates and quasi-static results, it can be found that the AerMet 100 shows strong strain rate sensitivity. For example, its yield stress under quasi-static compression is 1800MP while the yield stress is around 2300MP under strain rate 4200/s with an incensement of 24%. The hardening modulus under static compression is larger than that under dynamic compression due to the softening by the high temperature during high velocity impacting.

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Keywords: AerMet 100; dynamic properties characterization; strain rate hardening;

1. Introduction

AerMet100 is an ultrahigh strength steel alloy originally developed by Carpenter Technology Corporation to meet the demanding specifications of for landing gear of U. S. Navy carrier-based jet aircraft [1]. AerMet 100 has exhibited excellent performance with respect to ultrahigh tensile strength, fracture toughness and also offers exceptional resistance to stress-corrosion cracking and fatigue since 1990s.

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The unique combination of properties also makes AerMet 100 a natural candidate for aeronautic and aerospace applications such as landing gears, arresting hooks, catapult launch bars, jet engine shafts and other aircraft parts where 300M, AF1410 , AISI 4340 and other low-alloy steels have been used [2-4].

The current researches on AerMet100 mainly focus on: effects of heat treatment process (tempering time，tempering temperature, laser transformation hardening, etc.) on the mechanical properties [5-8]; effects of trace element on its fracture toughness [9-10]. Some researchers [2-3] elaborate on the overall performance of AerMet100 and conduct a comparison with several other ultrahigh strength steel alloys. Yang [11] conducted compression test under constant temperature or constant strain rate condition and characterized the stress-strain relationship under high temperature condition, and then investigate the effects of temperature and strain rate (0.01/s-10/s) on AerMet 100's flow stress. Cui [12] also studied the effects of temperature, strain, strain rate on flow stress, however, the strain rate they considered is relatively low and could not cover their application in high strain rate occasions. When considering AerMet 100's application in armor, landing gear and arresting hooks, they always experience high strain rate, making the investigation of dynamitic properties of AerMet 100 extremely necessary and important. This paper tested the mechanical properties of AerMet100 under different strain rate based on Split-Hopkinson pressure bar (SHPB) and studied the effects of strain rate on its mechanical properties by a comparison with quasi-static test results.

Nomenclature

E	Young's Modulus of the incident bar respectively
C_0	stress wave speed of the incident bar respectively
A_0	cross section area of the incident bar respectively
A	cross section area of the specimen
L	length of the specimen
A	cross section area of the specimen
σ	engineering stress
ε	engineering strain
$\dot{\varepsilon}$	strain rate

2. Experimental test facilities

The split-Hopkinson pressure bar (SHPB) technique is one of the primary experimental methods to characterize the dynamic property of material. The test material of SHPB has expand from traditional metal materials to soft materials such as bio-tissue, brittle material such as concretes, and the strain rate can be as high as 102-104/s[13, 14].

A typical SHPB setup is outlined in Fig.1 and Fig.2 shows the test facilities used in the experiment.

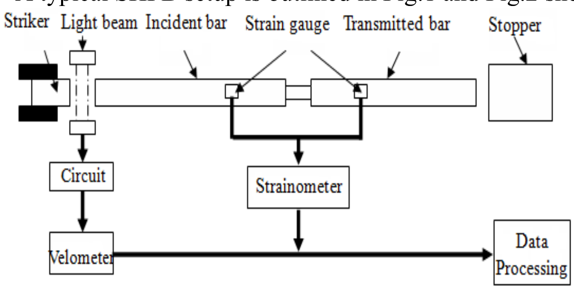


Fig. 1. Typical SHPB test setup

Fig.2.SHPB test facilities

SHPB measuring technique is based on one dimensional assumption and assumption of uniformity. When the striker bar impacts the incident bar, rectangular stress pulse is generated and travels along the incident bar until it hits the specimen. Part of the incident stress pulse reflects from the bar/specimen interface because of the material impedance mismatch, and part of it transmits through the specimen. The transmitted pulse emitted from the specimen travels along the transmitted bar until it hits the end of the bar. The stress, strain and strain rate in the specimen can be obtained in terms of the recorded strains of the two bars as follows:

$$\begin{cases} \sigma(t) = \dfrac{EA_0}{A}\varepsilon_t(t) \\ \varepsilon(t) = -\dfrac{2C_0}{L}\int_0^t \varepsilon_r(t)dt \\ \dot{\varepsilon}(t) = -\dfrac{2C_0}{L}\varepsilon_r(t) \end{cases} \quad (1)$$

Where E, C_0 and A_0 are Young's Modulus, stress wave speed, cross section area of the incident bar respectively. A and L are cross section area and length of the specimen. The stress and strain here are engineering stress and strain. True stress-strain relationship can be obtained by considering the relationship between true stress/strain and engineering stress/strain.

The test were conducted at five different strain rate, namely 560/s、1200/s、2500/s and 4200/s. Five repeated tests were conducted and then take average for each strain rate.

3. Test result

Fig.3 and Fig.4 show the stress-strain relationship at the strain rate of 560/s, the strain rate for specimen A26 is 640/s.

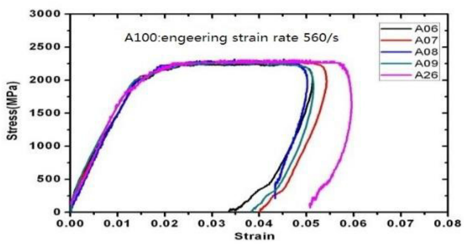


Fig.3.Engineering stress-strain curve at strain rate 560/s

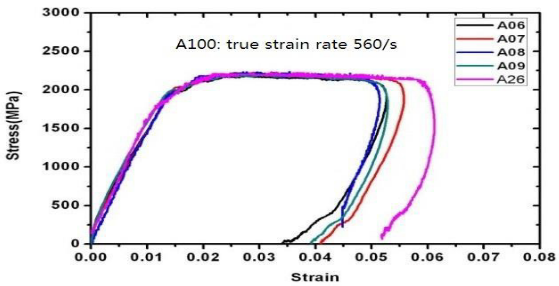


Fig.4.True stress-strain curve at strain rate 560/s

Fig.5 and Fig.6 show the stress-strain relationship at the strain rate of 1200/s, respectively.

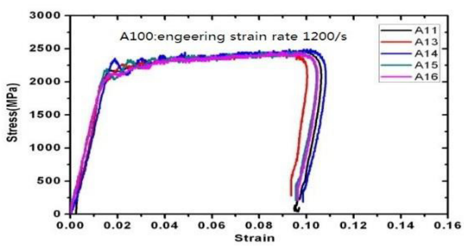


Fig.5.Engineering stress-strain curve at strain rate 1200/s

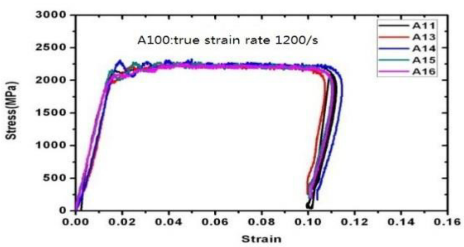


Fig.6. True stress-strain curve at strain rate 1200/s

Fig.7 and Fig.8 show the stress-strain relationship at the strain rate of 2500/s, specimen A18 and A20 failed during the test.

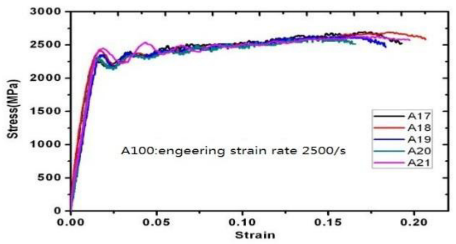


Fig.7.Engineering stress-strain curve at strain rate2500/s

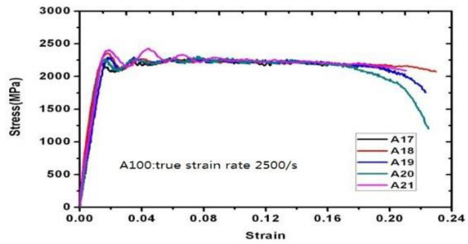


Fig.8.True stress-strain curve at strain rate 2500/s

Fig.9 and Fig.10 show the stress-strain relationship at the strain rate of 4200/s, all the specimens failed during the test.

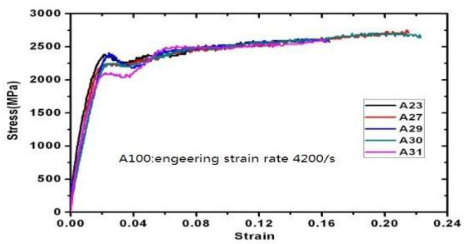


Fig.9.Engineering stress-strain curve at strain rate 4200/s

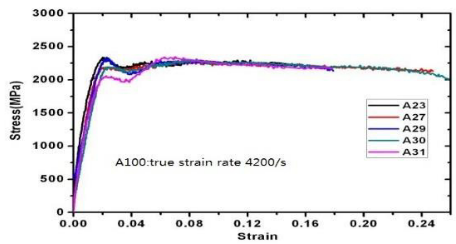
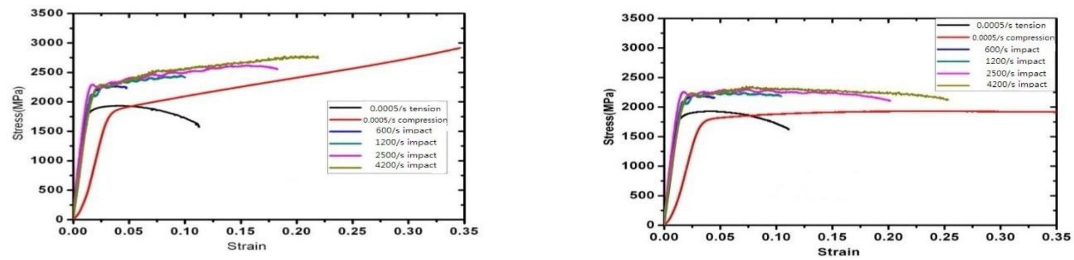


Fig.10.True stress-strain curve at strain rate 4200/s

Fig.11 (a) and Fig.11 (b) plots the stress-strain curves at different strain rates in the same coordinates in order to give an intuitive comparison.



(a) (b)

Fig.11. (a) Comparison of Engineering stress-strain curve under different strain rate; (b) Comparison of true stress-strain curve under different strain rate.

It is found that there are significant errors during the elastic static compression stage. Considering the symmetry between the elastic compressions and tension stage, we can take a correction by substituting the elastic static compression with the elastic static tension stage. The stress-strain curves after correction are shown in Fig.12 (a) and Fig.12 (b).

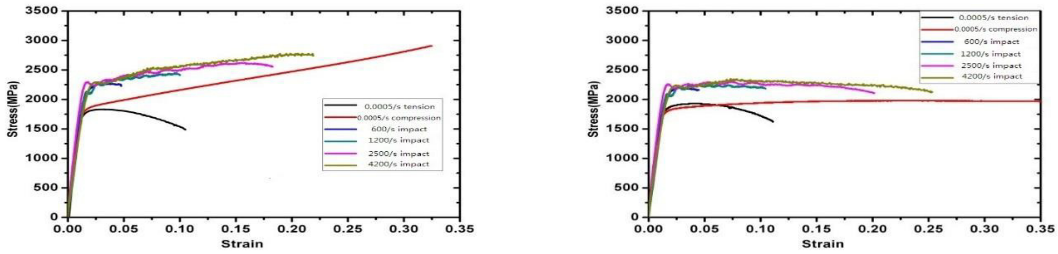


Fig.12. (a) Comparison of Engineering stress-strain curve under different strain rate (compression correction); (b) Comparison of true stress-strain curve under different strain rate(compression correction).

By comparing the stress-strain curves under different strain rate, it is found that the yield stress of AerMet 100 under quasi-static compression is 1800MP while the yield stress is around 2200MP under strain rate 560/s, with an incensement of 22.2%. However the hardening modulus under static compression is larger than that under dynamic compression. It is also found that the failure strain oversees 40% while all the specimen fails with strain less than 30% at the strain rate of 2500/s.

4. Conclusion

1. The comparison of yield stress between quasi-static and dynamic tests shows that there is a 20-30% increase of yield stress, presenting very sensitive strain rate effects in AerMet 100.

2. The comparison of hardening modulus between quasi-static and dynamitic tests shows that there is a decrease of hardening modulus under dynamic compression, indicating the softening effect caused by adiabatic temperature rise under dynamic deformation.

3.The comparison between failure strain under quasi-static and dynamic compress tests show that the failure strain is over 40% in static compression while shear failure occurred with strain less than 30% under strain rate 2500/s, it is estimated this is caused by Adiabatic shear failure. Future metallographic analysis can be carried out to locate the adiabatic shear band.

Acknowledgements

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