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COMPARATIVE FAILURE OF AERONAUTICAL ALLOYS AA2024 AND AA7075 AT LOW AND HIGH STRAIN RATE

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ABSTRACT

This work compares the quasi static and dynamic failure of two types of aeronautical alloy, namely AA2024 and AA7175. Low strain rate tensile tests were carried out at a strain rate range close to 10^{-3} - 10^{-1} s^{-1} and high strain rate compression tests using a split Hopkinson pressure bar (SHPB) device at a strain rate range between 2000-4500 s^{-1}. The formation of shear localization bands, possibly adiabatic shear bands (ASB), can be seen on AA7175 as pre-failure mechanism during high strain rate compression.

Keywords: aluminum alloy, high strain rate, adiabatic shear band

INTRODUCTION

Aluminum alloys are important materials for primary aircraft structures due to their specific mechanical properties, established design and manufacturing methods, good fatigue and corrosion resistance. AA2XXX and AA7XXX aluminum alloys are two of the most common series used for airframes, with copper as main addition element for the former series and zinc for the latter one, see Starke et al. (1996) and Dursun and Soutis (2014). Aeronautical structures may be subjected to accidental overloads as notably encountered during impact loading, including e.g. hail storm or bird strike, see Y. Yang et al (2008). It is thus of major interest to know the response of the structural materials under high strain rate loading. As ductile material, aluminum alloys are subjected to void growth induced damage. Now, under high strain rate loading involving quasi adiabatic conditions, it has been shown that high strength metallic materials may fail under a specifically dynamic localization mechanism known as adiabatic shear banding (ASB) which makes premature the ultimate fracture, see e.g. Longère and Dragon (2015) and Roux et al (2015) for Ti-6Al-4V titanium alloy and high strength steel respectively. ASB has also been evidenced in 2519A, 2195 and 7075 aluminum alloys under high strain rate loading, see Zhang et al (2008), Yang et al (2012) and Yang et al (2009) respectively.

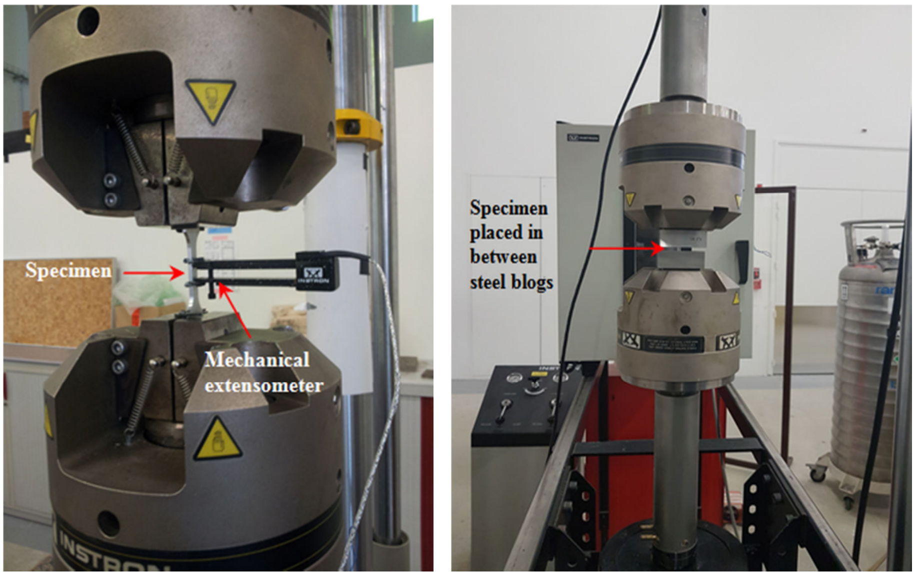
A comparative study of the low and high strain rate response of two types of lightweight aeronautical alloy, namely AA2024 and AA7175, is presented in the present work.

EXPERIMENTS

Two types of testing were done, compression and tension. Both tests were carried out using Institut Clément Ader laboratory testing facilities. Quasi static tension and compression tests were performed by using Instron electromechanical machine with load cell of 100 kN (see fig.

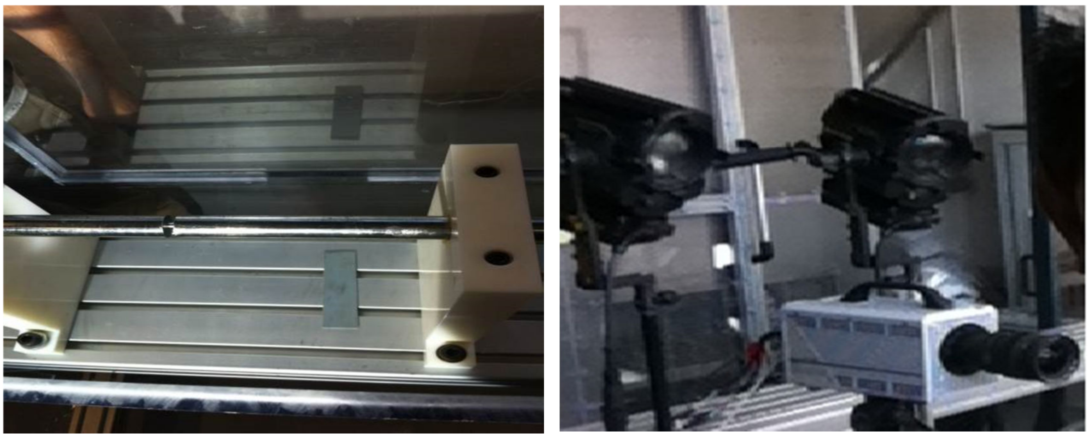
1a and 1b). Tension speed of 1.8 and 180 mm/min were applied. Quasi static tension tests were also carried out at temperatures of 100°C, 150°C and 200°C at a speed of 1.8 mm/min. The specimens were placed in a furnace at required temperature and heated during 30 minutes in order to allow temperature distribution for being homogenous in the specimen.

Dynamic compression tests were performed by using split Hopkinson pressure bar (see fig.2a). Photron high speed camera was used to record the specimen deformation during the test. The camera can capture 250,000 frames per second (28 X 16 pixel^2). Lighting system was provided by two Dedolight HMI with power of 400W each (see fig.1b).



(a) (b)

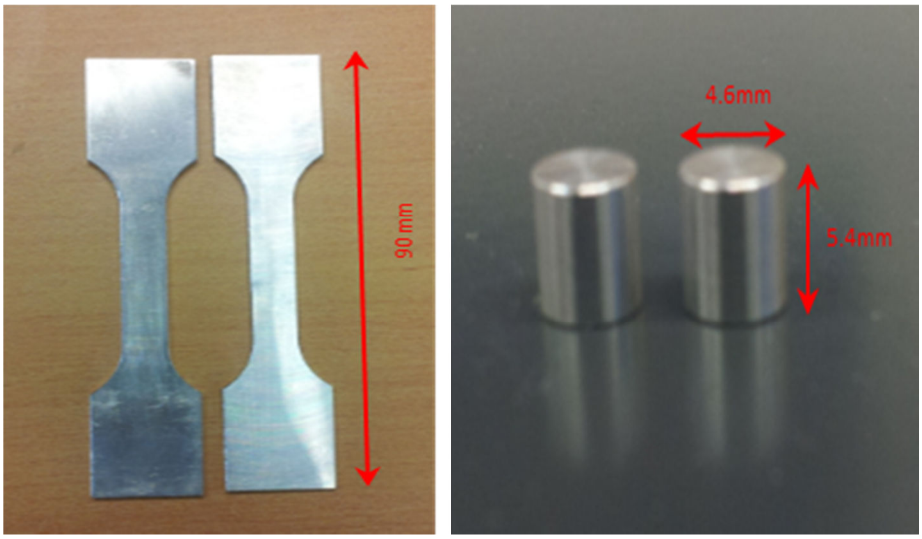
Fig. 1- (a) Quasi static tension test (b) Quasi static compression test



(a) (b)

Fig. 2 - (a) Dynamic compression test using SHPB (b) Photron high speed camera and lighting

Flat type tension specimens were used for quasi static tension tests and cylindrical shape specimens were used for quasi static and dynamic compression tests (see fig. 3a and 3b).



(a) (b)

Fig. 3 - (a) Tension specimen (b) Compression specimen

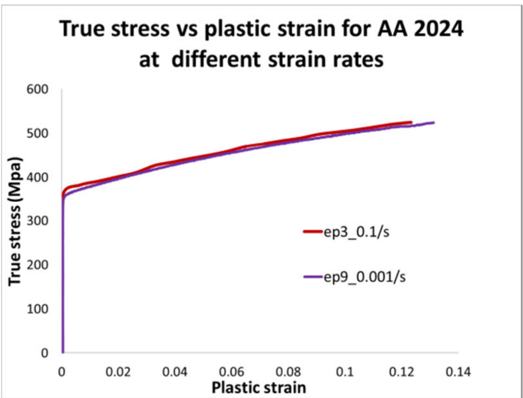
RESULTS AND DISCUSSION

Equivalent true stress versus plastic strain curves are plotted for each strain rate and for both materials in Figs. 4-6. According to Fig. 4, the initial yield stress of the 2024 aluminum alloy is close to 360 MPa (see Fig. 4a) and the one of the 7175 aluminum alloy is close to 470 MPa (see Fig. 4b).

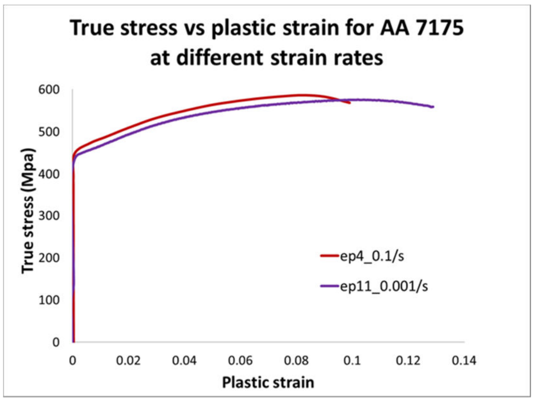
According to Fig. 6(a) the flow stress is increasing with increasing strain rate for AA2024 for every strain value from 0.02 to 0.1. Fig 6(b) shows the flow stress increasing with increasing strain rate from strain of 0.02 to 0.04 for AA7175. After this amount of strain there is no significance increase in AA7175 flow stress with increasing strain. AA7175 shows no strain rate sensitivity at larger strain value.

Both AA2024 and AA7175 thus exhibits only slight strain rate dependence - in the range considered, see Fig.6. Under quasi static tension loading, both alloys exhibit strain hardening until necking. Under dynamic compression loading, AA2024 exhibits strain hardening all along the deformation process, i.e. up to a plastic strain value close to 0.3 for the tests carried out here (see Fig. 5a).

The critical plastic strain value (marking the passage from strain hardening to strain softening) is close to 0.1 for the AA7175, i.e. much lower than the one of the AA2024 (see fig 5b), and the strain softening is also more significant leading to a sudden drop in stress at a plastic strain close to 0.2 - this drop in stress is not observed on the AA2024. It must be noted that the strain softening is notably a consequence of the competition between strain hardening and (plastic dissipation induced) thermal softening under (quasi) adiabatic conditions. Quasi static compression for AA2024 shows strain hardening all along the deformation process, as for tension tests, (see Fig. 5a), whereas AA7175 shows strain hardening only up to 0.1 (see Fig.5b) then a plateau beyond this value.

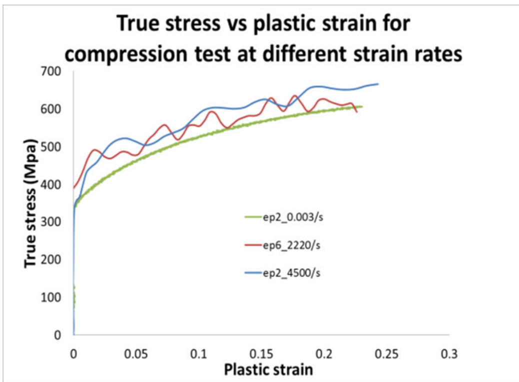


(a) AA2024

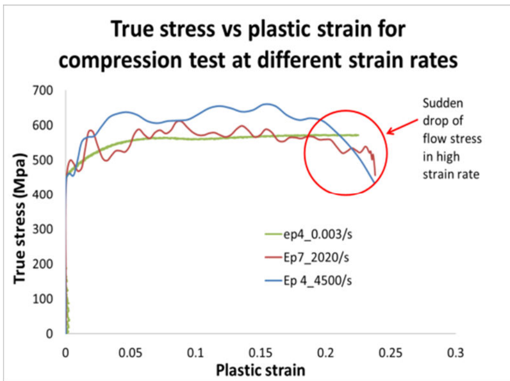


(b) AA7175

Fig. 4 - Stress-strain curves for quasi static tension test at various strain rates. a) AA2024 and b) AA7175

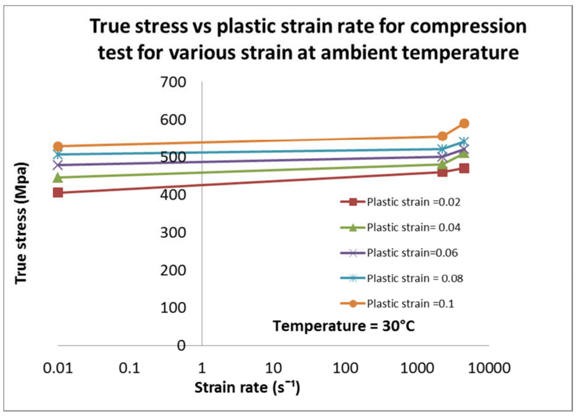


(a) AA2024

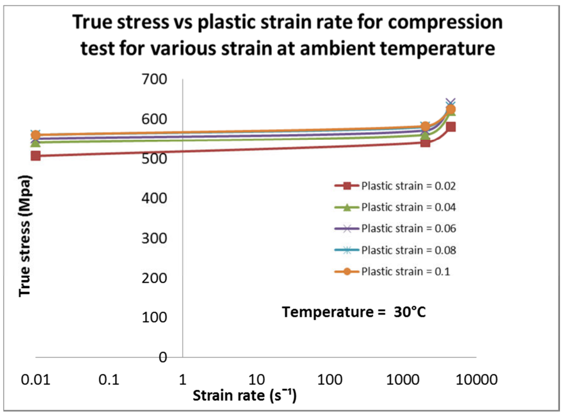


(b) AA7175

Fig. 5 - Stress-strain curves for quasi static and dynamic compression tests. a) AA2024 and b) AA7175



(a) 2024

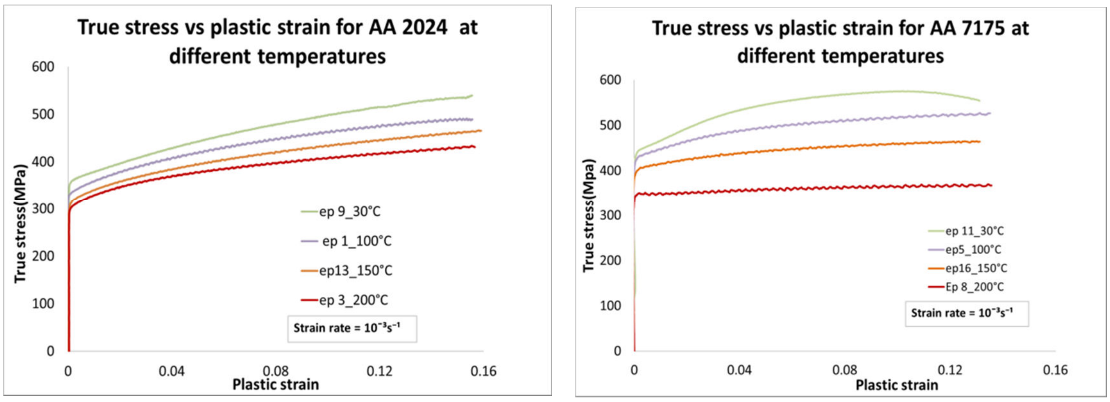


(b) 7175

Fig. 6 - Variation of flow stress as a function of strain rate at constant temperature of 30°C for various amounts of plastic strain.

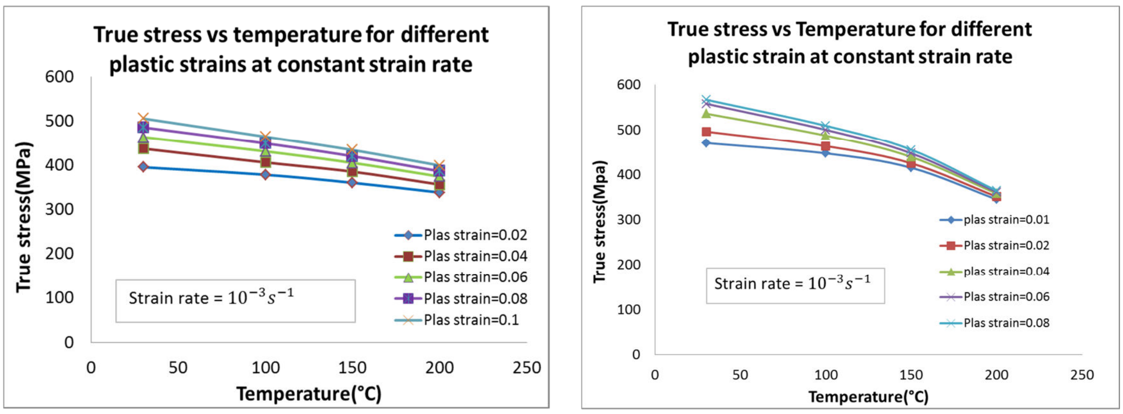
Figs.7-8 shows temperature effect on flow stress. Both alloys shows gradually decrease in flow stress with increase in temperature. AA2024 shows strain hardening even at 200°C (see Fig. 7a) but AA7175 exhibits a decrease in strain hardening at 150°C and almost no strain hardening at all at 200°C (see Fig. 7b). For AA7175 thermal softening thus begins to overcome strain hardening at a temperature of 150°C and above.

Fig. 8 shows a temperature effect on flow stress for strain rate of $10^{-3}s^{-1}$ for both alloys. According to Fig 8a, flow stress moderately decrease with the increase of the temperature. For AA7175 the flow stress is decreasing gradually up to 150°C before decreasing dramatically after 150°C (see Fig. 8b). It is clear that for AA7175 at temperature after 150°C the deformation resistance is dominated by temperature effect.



(a) 2024 (b) 7175

Fig. 7 - True stress versus plastic strain for different temperature at constant strain rate

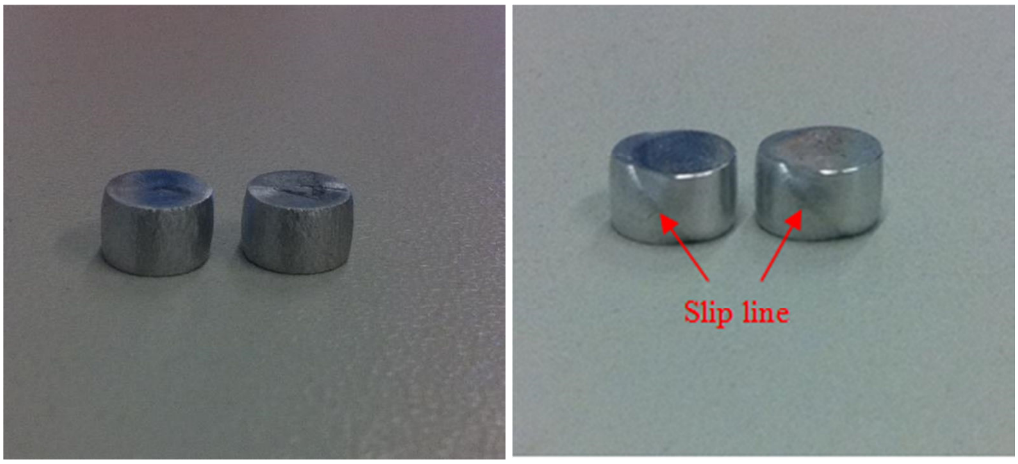


(a) 2024 (b) 7175

Fig. 8 - Variation of flow stress as a function of the temperature for a strain rate of 10^{-3} s^{-1} for various amounts of plastic strain.

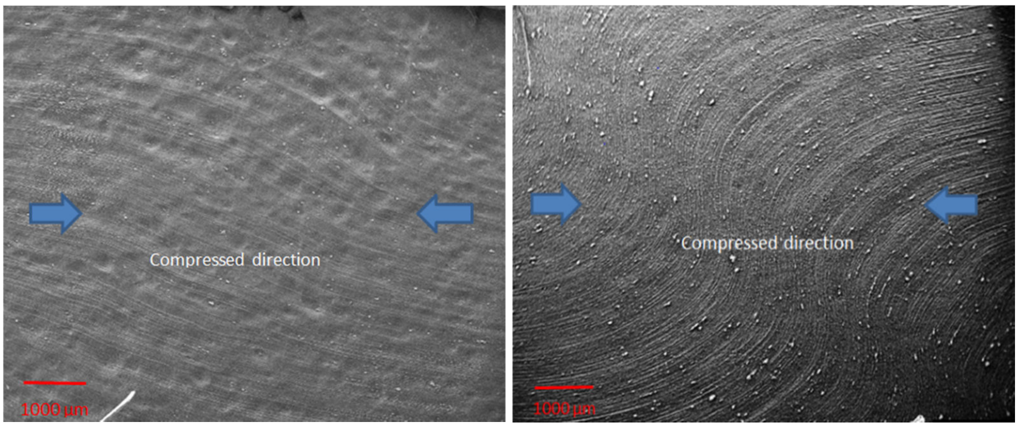
Fig. 9 shows the specimen after quasi static compression test. AA2024 shows very small barreling effect and keeps a circular cylindrical shape (see Fig 9a) whereas AA7175 shows a strong barreling effect and macroscopic slip planes across the specimen (see Fig 9b). Fig. 10 shows the microstructure of both alloys after quasi static compression test. Fig 10(a) shows that the microstructure remains quasi homogeneous for AA2024. By contrast, for AA 7175 the microstructure shows heterogeneous plastic deformation (see fig. 10b).

Fig 11 shows the specimen after dynamic compression test at a strain rate of 2200 s^{-1}. The microstructure of the AA2024 specimen is homogeneous (see Fig.12a) whereas the microstructure of the AA7175 specimen exhibits a cross shape band. According to Fig. 12, the deformation of the specimen made of AA2024 remains (quasi) homogeneous. By contrast, one can clearly observe crossed shear localization bands (ASB) within the specimen made of AA7175 in Fig. 12 (b). The presence of these bands explains the premature failure of the specimen made of AA7175 featured by the drop in stress observed on the stress-strain curve in Fig. 5(b) for strain rate of 2200 s^{-1}.



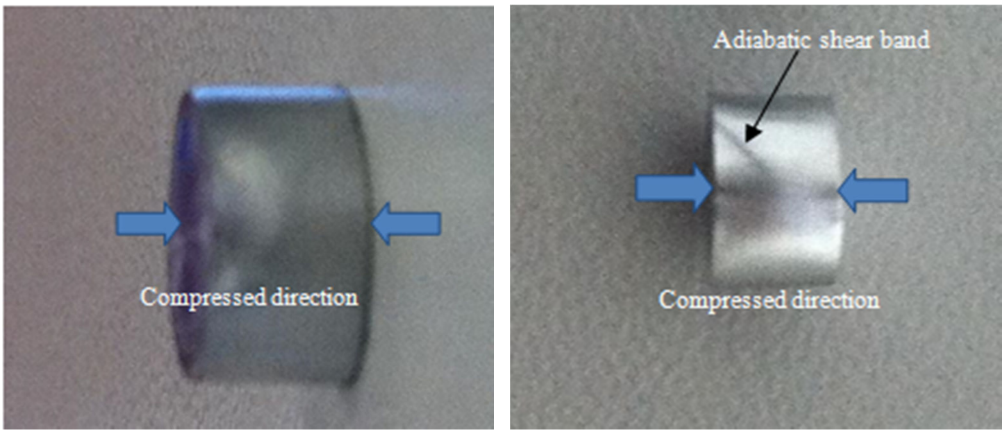
(a) AA2024 (b) AA7175

Fig. 9 - Specimen shape after quasi static compression



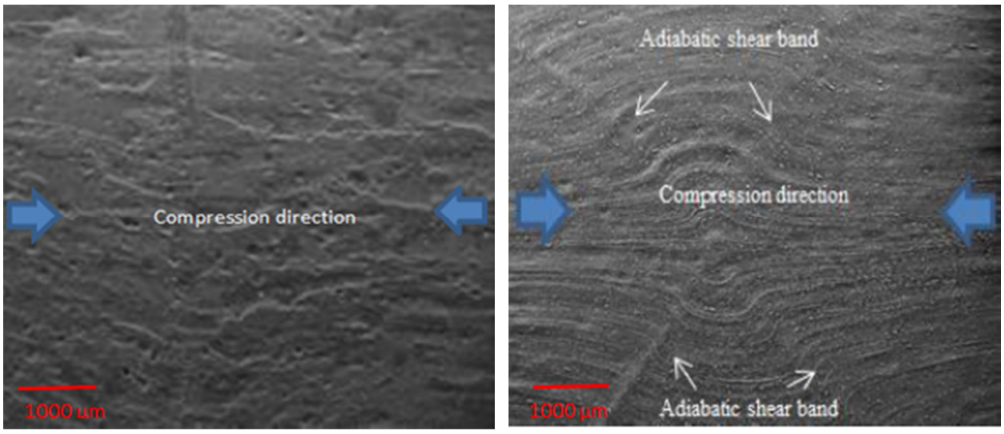
(a) AA2024 (b) AA7175

Fig. 10 - Microstructural view of specimen for quasi static compression at 0.003 s^{-1}



(a) AA2024 (b) AA7175

Fig. 11- Specimen shape after dynamic compression at 2200 s^{-1}



(a) AA 2024 (b) AA 7175

Fig. 12 - Microstructural view of specimens for compression at 2200 s^{-1}

CONCLUSIONS

No strain rate sensitivity is observed for both AA2024 and AA7175 in tension within the quasi static range between 0.001 s^{-1} and 0.1 s^{-1}. There is only a slight strain rate dependence in compression for both alloys in the considered range. AA2024 shows work hardening at larger strain compared to AA7175. Both alloys are strongly temperature dependent. Strain hardening effect is only significant at temperature lower than 150°C for AA7175. Fracture analysis and microstructure study shows an important role of shear localization in the quasi static and dynamic failure of AA7175.

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