Experimental analysis of rate dependence of NiTi alloy under shear loading

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Résumé :
Shape memory alloys (SMAs) have the excellent ability to return an original defined shape after undergoing large deformation, which is due to the martensitic phase transformation and twinning/detwinning transformation\cite{1}. The effect of shear dominated deformation in SMA and resulting phase transformation attractive for a variety of applications, including mechanical applications such as ductile fracture and biomedical applications such as heart artery stents, etc.\cite{2} Technically, the observation of the bands and the influence of strain rate on the propagation of the martensitic transformation have been initiated sixteen years ago\cite{3}. New measuring techniques, such as Digital Image Correlation (DIC) that catches the measurable difference of strain between elastically loaded austenite and mechanically transformed martensite have been used in the last decade\cite{4}. Many experiments had shown that the stress-strain response of SMAs exhibits a strong rate dependence\cite{5}. However, the previous attentions were paid on the strain rate sensitivity of SMAs mostly in compression and tension test, shear test results are rarely reported in literature\cite{6}. The purpose of this study is to obtain quantitative, full-field information detailing the behavioral response of NiTi alloy under different shear loading rates. Furthermore, the comparison of quasi-static and dynamic shear test results was also discussed.

Abstract :
Shape memory alloys (SMAs) as an optimal design solution to many engineering problems, due to their ability to exhibit fully recoverable deformations under substantial loads. While many uniaxial tension experiments of shape memory alloys have been published in the literature, relatively rare experimental studies address their behaviour in shear test. In this study, the simple shear test of NiTi alloy under quasi-static loading ($7.7 \times 10^{-4}$ mm/s – 7.7 mm/s) and dynamic loading (0.8 m/s) were conducted. In all the experiments, the isothermal, global, mechanical responses were measured, meanwhile the digital image correlation (DIC) was used to measure the full field quantitative strain maps and observe the evolution of the phase transformation. The results show that the deformation behaviour of NiTi alloy under quasi-static and dynamic loading are quite different.
Mots clefs : NiTi alloy, Martensitic transformation, Simple shear test, Strain rate dependence, Digital image correlation

1 MATERIAL AND EXPERIMENTAL SETUP

1.1 NiTi specimen

The material studied was from NiTi polycrystalline cold-rolling sheets, straight annealed with dark oxide surface (Johnson Matthey Inc., USA). The metallurgical composition is 50.7 wt.% Ni and 49.3 wt.% Ti[7]. The experiment was performed at room temperature, clearly above the characteristic temperature $A_f$, so that for stress-free condition the specimen is in a full austenite state. The overall size of the specimen was 62mm in length, 30mm in width, and 0.5mm in thickness. The length of shear zone was 20mm, and the width was 3mm, as shown in Fig. 1. In order to reduce the influence of free edges effects, the ratio of length and width should larger than 10[8].

![Zone of double shear loading 20*3*0.5 (mm)](image)

*Figure 1. The geometry of NiTi specimen for double shear loading*

1.2 Double shearing grip

Double shearing test can be realized which might prevent from geometrical instabilities. Divers versions of this test had been developed in the past decades[9]. A double shearing device to better fit with the 60mm-diameter Split Hopkinson Pressure Bar was developed[10], as shown in Fig. 2 left. In this study, a modified shear grip was designed for DIC observation, as shown in Fig. 2 right.
2 SHEAR TEST PROCEDURE

2.1 Quasi-static test

The NiTi shear test under different strain rates ($10^{-4} / s - 10^1 / s$) were performed on modified hydraulic MTS 810 testing machine. Experiments were conducted at five different prescribed velocities: $7.7 \times 10^{-4} \text{mm/s (2.6}\times10^{-4} /s)$, $7.7 \times 10^{-3} \text{mm/s (2.6}\times10^{-3} /s)$, $7.7 \times 10^{-2} \text{mm/s (2.6}\times10^{-2} /s)$, $7.7 \times 10^{-1} \text{mm/s (2.6}\times10^{-1} /s)$ and $7.7 \text{mm/s (2.6 /s)}$. The temperature was 25°C and the humidity was 45%.

2.2 Dynamic test

The test at moderate impact velocity around 0.8m/s was performed on the advanced Split Hopkinson Pressure Bar, the shear grip with specimen placed between the input and output pressure bars, as shown in Fig. 3. A labview program was used to record the signals from the strain gauges on the input bar (trigger signal) and output bar, meanwhile, sent a TTL signal (5 volts) to trigger the high-speed camera.

![Figure 2. The geometry of Double shear grip](image)

![Figure 3. Schematic drawing of Hopkinson bar and clamping device](image)
The high-speed camera Photron Fastcam SA5 equipped with telecentrique G1 (Edmund Optics, field of view 2/3 Sensor 8.8 mm, working distance 98-123mm) was used to observe the deforming process of NiTi specimen. The frame rate was 54250 images/second. The resolution was 768*160 pixels. Shutter speed was 1/54250 s. Moreover, two cold spotlights were used for lightening, which were enough for the high-speed camera and not heating the specimen. The room temperature was 24.4°C and the humidity was 34%.

3 TEST RESULTS

3.1 Shear stress-strain curve

The strain gauges attached on the input bar and output bar were used to measure shear stress, and shear strain was calculated from the mean of shear strain in the shear zone. The shear stress-strain curve is shown in Fig. 4, which is compared with the quasi-static shear loading.

![Shear stress-strain curve](image)

*Figure 4. Shear stress-strain curve*

3.2 Shear strain maps

A first analysis of DIC results allows give quantitative information on the phenomena during the test. The dynamic shear strain maps are as shown in Fig. 5, which is compared with the shear strain maps of quasi-static test.
4 CONCLUSION

By using modified double shear device and Digital image correlation, the macroscopic shear stress strain response and shear strain maps were observed in this study, which provides original experimental results of NiTi alloy under dynamic shear loading. According to the results, the slop of shear stress-strain curve under dynamic shear loading is larger than that under quasi-static shear loading, and more shear bands were observed in dynamic shear strain maps, comparing with quasi-static test results.
References