**THE SHEAR TEST OF NITI ALLOY UNDER IMPACT LOADING**

**H. Huang**, H. Zhao, *Laboratoire de Mécanique et Technologie, ENS-Cachan/CNRS-UMR8535/Université Paris6, 61 Avenue du Président Wilson, 94230 Cachan Cedex, France. Téléphone : 01 47 40 20 39, Télécopie : 01 47 40 22 40, Adresse électronique : zhao@lmt.ens-cachan.fr*

**Mots clés : NiTi alloy, Martensitic transformation, Simple shear test, Split Hopkinson Pressure Bar, Digital image correlation**

## 1. INTRODUCTION

Shape memory alloys (SMAs) have the excellent ability to return an original defined shape after undergoing large deformaton, which is due to the martensitic phase transformation and twinning/detwinning transformation (Otsuka et Wayman, 1998). 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. (Pelton et al, 2004). 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 (Shaw et Kyriakides, 1998). 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 (Daly et al, 2007). Many experiments had shown that the stress-strain response of SMAs exhibits a strong rate dependence (Zhang et al, 2010). 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. The purpose of this study is to obtain quantitative, full-field information detailing the behavioral response of NiTi alloy under impact shear loading. Furthermore, the quasi-static shear test results (He et al, 2013) were used to compare with dynamic test results.

## 2. MATERIAL AND EXPERIMENTAL SETUP

### 2.1 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 (Qian et al, 2007). 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.

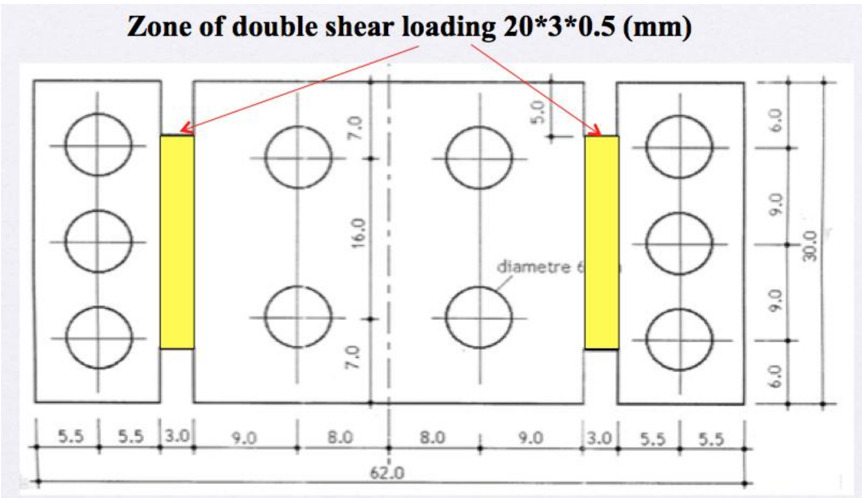


*Figure 1. The geometry of  NiTi specimen for double shear loading*

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 show in figure (1). In order to reduce the influence of free edges effects, the ratio of length and width should larger than 10 (Orgéas et Favier, 1998).

## 2.2 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 (Rusinek et Klepaczko, 2001). A double shearing device to better fit with the 60mm-diameter Split Hopkinson Pressure Bar was developed by Merle (2003), as shown in figure (2) left. In this study, a modified shear grip was designed for DIC observation, as shown in figure (2) right.

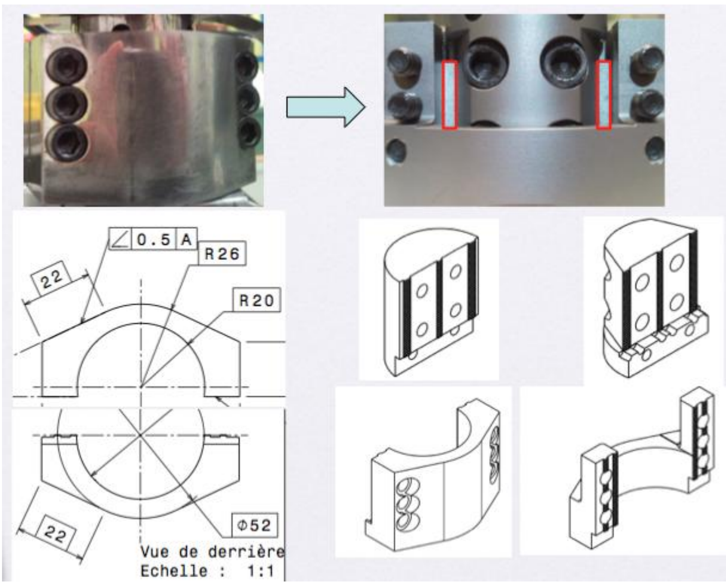



*Figure 2.  The geometry of  Double shear grip*

## 2.3 Split Hopkinson Pressure Bar (SHPB)

Split Hopkinson Pressure Bar was used to perform dynamic test, as shown in figure (3). The apparatus was composed of the projectile, input and output pressure bars, all of them were made of aluminum and have the same diameter 60 mm. The wave speed was 5150m/s. the Lengths of projectile, input bar and output bar were 0.8m, 4.5m and 2m, respectively.

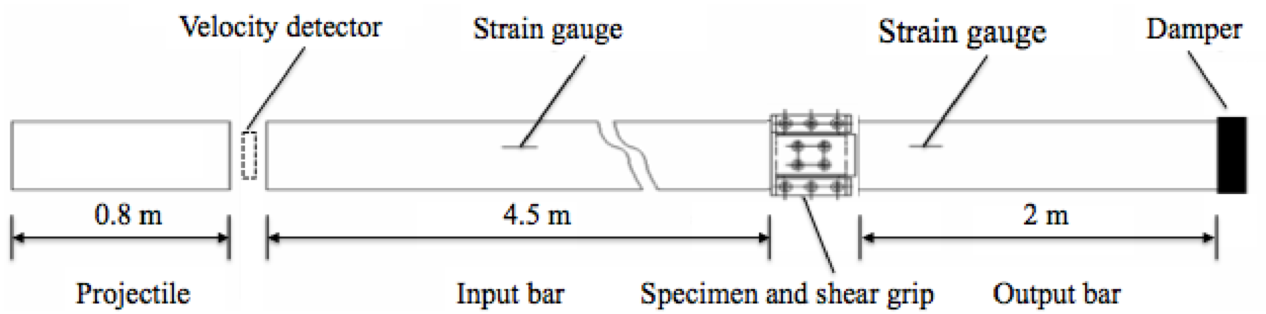



*Figure 3. Schematic drawing of Hopkinson bar and clamping device*

## 3. DYNAMIC SHEAR TEST PROCEDURE

The test at moderate impact velocity around 0.8m/s were performed on the advanced Split Hopkinson Pressure Bar, the shear grip with specimen placed between the input and output pressure bars, as shown in figure 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.

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*160pixels. 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%.

## 4. TEST RESULTS

### 4.1 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 figure (4), which is compared with the quasi-static shear loading (He et al, 2013).

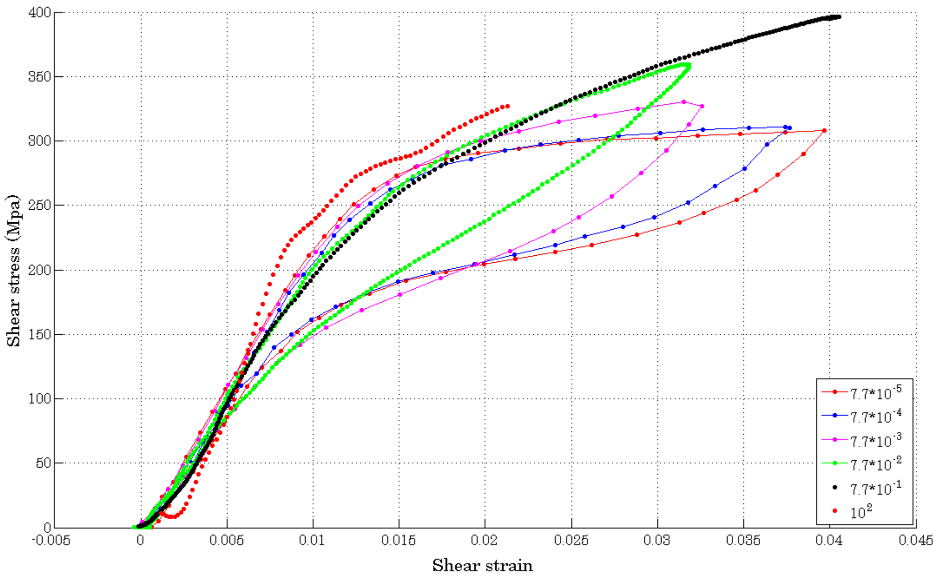
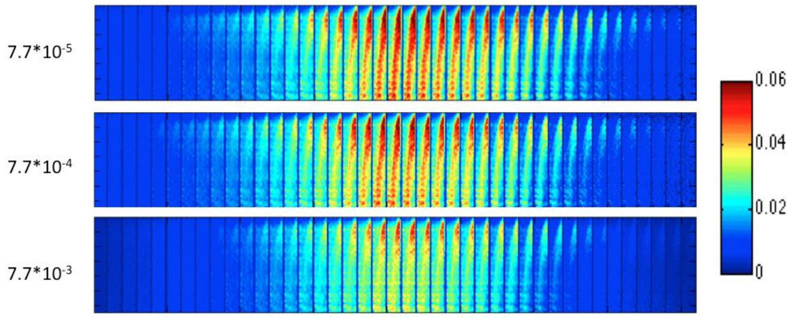


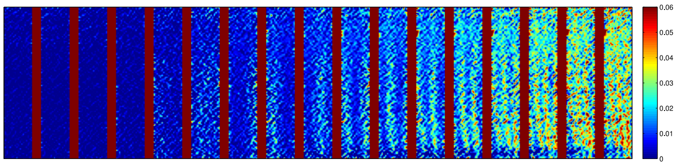

*Figure 4. Shear stress-strain curve*

### 4.2 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 figure (5), which is compared with the shear strain maps of quasi-static test.




(a) Shear strain maps under quasi-static shear loading (He et al, 2013)



(b) Shear strain maps under dynamic shear loading

*Figure 5. Shear strain maps*

## 5. 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

Daly S., Ravichandran G., Bhattacharya K., "Stress-induced martensitic phase transformation in thin sheets of Nitinol", Acta Materialia, **55**, (2007), pp. 3593-3600.

He H., Dominique S., Stephane P., Feifei S., Han Z., "Experimental observation of phase transformation front of SMA under impact loading", ICF Proceeding, 13th International Conference on Fracture, June 16-21, 2013, Beijing, China.

Merle R., "Mise en oeuvre et analyse d'un essai de double cisaillement en grandes deformations sous solicitations dynamiques", 2003.

Orgéas L., Favier D., "Stress-induced martensitic transformation of a NiTi alloy in isothermal shear, tension and compression", Acta Materialia, **46**, 15, (1998), pp. 5579-5591.

Otsuka K., Wayman C.M., "shape memory materials", Cambridge University Press, Cambridge, (1998). ISBN 0-521-66384-9.

Pelton A., Duerig T., Steckel D., "A guide to shape memory and superelasticity in nitinol medical devices", Minim Invasive Ther Allied Technol, **13**, (2004), pp. 218-221.

Qian L., Zhou Z., Sun Q., Yan W., "Nanofretting behaviors of NiTi shape memory alloy", Wear, **63**, (2007), pp. 501-507.

Rusinek A., Klepaczko J.R., "Shear testing of a sheet steel at wide range of strain rates and a constitutive relation with strain-rate and temperature dependence of flow stress", Int. J. of Plasticity, **17**, (2001), pp. 87-115.

Shaw J.A., Kyriakides S., "Initiation and propagation of localized deformation in elastic-plastic strips under uniaxial tension", Int. J. of Plasticity, **13**, 10, (1998), pp. 837-871.

Zhang X., Feng P., He Y., Sun Q., "Experimental study on rate dependence of macroscopic domain and stress hysteresis in NiTi shape memory alloy strips", Int. J. of Mechanical Sciences, **52**, (2010), pp. 1660-1670.