I－B 348

EXPERIMENTAL STUDY ON SHAPE MEMORY ALLOY DAMPER

University of Tokyo Member Krzysztof WILDE
University of Tokyo Student Member Yi ZHENG
University of Tokyo Fellow Yozo FUJINO

1. INTRODUCTION

The superelastic behavior of shape memory alloys (SMAs) provides a stress-strain relation which is characterized by large hysteresis, superelastic effect, large ductility and variation of the material properties at different level of strain. Those properties can be effectively used in a design of SMA dampers for vibration control of bridges. In this paper, a device utilizing bending of SMA bars is experimentally tested.

2. SHAPE MEMORY ALLOY PREPARATION PROCEDURES

The shape memory alloy used in the experiment has been produced starting from pure material, i.e. Grade 1 (AWS) Titanium (3 mm high purity wires) and electrolytic Nickel (10 mm square bars). Starting material has been chemically etched. Ni bars have been heated in water up to about 90°C and immersed in the bath of 50 HNO_3, 30 H_2SO_4, 20 H_2O+NaCl 3g/100 ml. Afterwards they have been polished in a 10% vol. NaOH solution and rinsed in cold water. Ti wires have been polished by immersing in the bath of 45 HNO_3, 8-10 HF, 45 H_2O. Melting procedure has been performed in a Vacuum Induction Furnace. The nominal alloy composition is $Ti_{49.3}Ni_{50.7}$at% due to the small weight loss during the melting procedure.

The shape memory effect and superelastic properties are strongly related to the thermomechanical treatments suffered by the material. The best superelastic effect is obtained by proper combination of cold work and some partial intermediate annealing. Whilst in the case of wires it is quite simple to increase the degree of cold work (evaluated as the percentual modification of the total area) in the case of larger bars it is more difficult to guarantee an homogeneous microstructure. In order to take care of this effect the cold working procedure of these bars has been started at a larger diameter. The as cast ingot after removal of minor surface defects has been hot forged (furnace temperature 1000° C) to a roughly squared bar of about 35-38 mm edge. With the same operating temperature the bar has been rolled trough a squared shape of 35 mm down to about 16.7 mm square.

The cold work procedure has been started consisting of a deformation of the bar not exceeding about 20% and subsequent full annealing at about 750° C for 10 minutes. By this procedure square shaped bars have been obtained with an edge of 14.5 mm. The obtained bars have been cut with an abrasive wheel and machined to the desired cylindrical dimension. This machining step is quite crucial as it should be performed as slow as possible to avoid any significant temperature increase that could result in a modification of the superelastic properties. The obtained specimens have been thermally treated in 400°C in an inert atmosphere of argon : SMA type 1 was treated for 600 s and SMA type 2 for 1800 s.

3. EXPERIMENTAL TESTS

The 'uniform'-moment bending device is shown in Figure 1. The specimen is hold at its ends by two locking devices, made from two plates securely fasten together by high tension bolts. A sloped arm, ending with a hinge, is welded to each locking device. The slope of the arms is selected to have the hinge center on

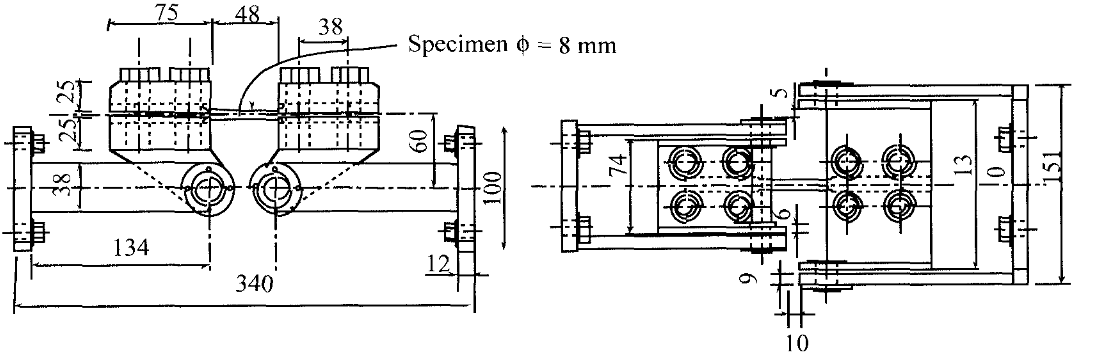

Fig.1 Device for uniform-moment bending test

the same vertical line as the beginning of the testing part of SMA bar, in the undeformed configuration. The horizontal arm with vertical plate is connected to the hinge for connection to the reaction wall and actuator.

The experimental work was carried out using the hydraulic actuator at the Bridge and Structure Laboratory, University of Tokyo. The actuator, with a load rating of 20 kN and a 100 mm stroke length

Key words: shape memory alloy, Nitinol, uniform moment bar damper, experiment
Address: Hongo 7-3-1, Bunkyo-ku, Tokyo 113, Japan Tel: 035802-331; Fax: 03-5989-7292

was used to induce a specified uniaxial displacement to the test devices. Each test used a linear variable displacement transducer to measure the displacement. The force was measured by a load cell mounted on the end of the actuator's arm. For data acquisition a NEC PC98 computer was used. The signals were digitized by a digital analog Portable Data Logger, T301. The direction and magnitude of the actuator's piston stroke was controlled by a displacement mode control.

The harmonic tests were carried out. Frequencies of 0.001 Hz was used and for one test series the amplitude was varied as: 1 mm, 5 mm, 10 mm, 20 mm, 30 mm, 40 mm, 50 mm and 60 mm. This tests were performed to obtain the force displacement characteristics of the bending damper. The fatigue tests for bending tests were performed for the input displacement of 60 mm with the frequencies varying from 0.003 Hz to 0.03 Hz. The purpose of this tests was to determine the fatigue behavior of SMA bending damper.

4. TEST RESULTS

The results of bending tests are shown in Figure 2. For both type of SMA bars, hardening due to elastic response of martensite resulted in increase of specimen stiffness from a displacement of 40 mm. The envelope of the hysteresis of the specimen type 1 has slightly higher slope at the range of displacement from 10 mm to 40 mm than slope of specimen type 2. The residual displacement for the specimen type 1 was smaller than the residual displacement of specimen type 2.

The results of fatigue tests are presented in Figure 3. Both type specimens were first subjected to 8 cycles of the simple harmonic test with increasing input displacement. The same specimens were tested for fatigue at a displacement of 60 mm. For the tested range of frequencies both types of SMA showed no dependence of the force-displacement relations on frequency. The specimen of SMA type 1 was damaged after 35 additional cycles. The specimen type 2 was damaged after 31 additional cycles. The hysteresis of both types of SMA bars was not deteriorating with increasing number of cycles. The damage of the specimens occurred due to fracture in a plane perpendicular to bars' axis at the end of testing part of the specimen.

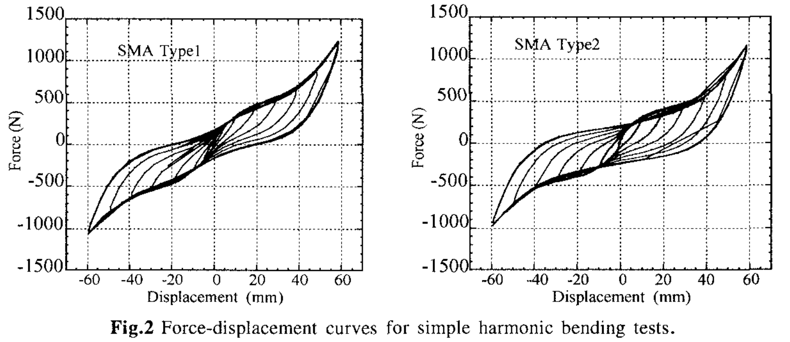

Fig.2 Force-displacement curves for simple harmonic bending tests.

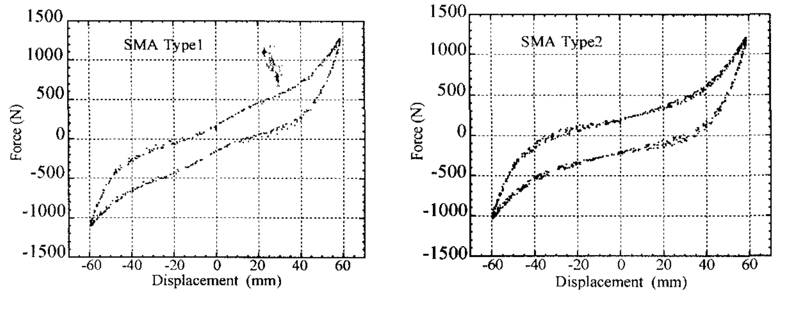

Fig.3 Force-displacement curves for simple harmonic bending tests.

4. CONCLUSIONS

The results of bending tests confirmed a variable response of NiTi bars at different levels of displacement. The specimen type 1 had smaller residual displacement and more stable hysteresis than the specimens type 2. Both types of the specimens had long fatigue life. The hysteresis of tested specimens did not deteriorate with the increase of number of input cycles.

REFERENCES

1) Wilde K., Zheng Yi, Gardoni P., Fujino Y., "Experimental and analytical study on shape memory alloy damper" Proceedings of Smart Systems for Bridges, Structures, and Highways, San Diego, California, March 1998.