APPLICATIONS OF NiTi SHAPE MEMORY ALLOY DAMPERS IN CIVIL STRUCTURES

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Smart systems for civil structures are described as systems that can automatically adjust structural characteristics in response to external disturbances and/or unexpected severe loading toward structural safety, extension of the structure’s life time, and serviceability. One key technology toward this goal is the development and implementation of smart materials, which can be integrated into structures and provide functions such as sensing, actuation and information processes essential to monitoring, self-adapting and healing of structures.

SMAs have found applications in many areas due to their high power density, solid state actuation, high damping capacity, durability and fatigue resistance. When integrated with civil structures, SMAs can be passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes.

The purpose of the work is to test the suitability of commercially available NiTi alloys for application as seismic protection material. Two different NiTi alloys are characterized metallurgically as well as mechanically. One of these alloys is fully austenitic at room temperature while the other has an austenite start temperature above room temperature, but a martensite start temperature below room temperature. The two alloys show only a small temperature region with superelastic behavior. The damping capacity of the materials is at its maximum just below the austenite finish temperature. Combining these two different materials in one damper configuration could give a damper with a broad temperature range with good damping characteristics.

1 Introduction

Traditional restoration techniques often do not give structures sufficient resistance against maximum expected earthquakes and/or might be too invasive. Therefore, there is an ongoing effort to find techniques that can guarantee structural stability and at the same time respect the integrity of the structure. Special devices that exploit the superb damping properties of Shape Memory Alloys (SMA) are under development. SMAs have found applications in many areas due to their high power density, solid state actuation, high damping capacity, durability and fatigue resistance. When integrated with civil structures, SMAs can be passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes.
Though most of the research activities of SMAs’ applications in civil structures are still in laboratory stage, a few have been implemented for field applications and found effective [1-5].

2 Damping in NiTi materials

NiTi shape memory alloys have two unique properties: The shape memory effect which is the phenomenon that the material returns back to their original shape upon heating and the superelastic effect which is the phenomenon that the material can undergo a large amount of inelastic deformation and recover after unloading. These properties are the result of reversible phase transformations between the austenite phase at high temperatures and the martensite phase at low temperatures.

When using shape memory alloys for passive control, which means that no external power source is required and the impact forces are developed in response to the motion of the structure, the damping capacity of the material is important. NiTi materials for passive control can be both martensitic as well as austenitic. The damping comes from martensite variations reorientation in the martensitic material and from stress-induced martensite in austenitic material. The martensitic materials have a higher damping capacity than the austenitic material due to the energy dissipated during twinning-detwinning. But it has no recentering capability like the austenitic NiTi material[6].

3 Experimental

Two different NiTi alloys designated AF5 and AF30 were purchased from Grikin (China) as wires with a diameter of 2 mm. The transformation temperatures ($A_s$=Austenite start, $A_f$=Austenite finish, $M_s$=Martensite start and $M_f$=Martensite finish) of the materials as obtained by DSC are listed in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>$A_s$</th>
<th>$A_f$</th>
<th>$M_s$</th>
<th>$M_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF5</td>
<td>-5</td>
<td>4</td>
<td>-40</td>
<td>-52</td>
</tr>
<tr>
<td>AF30</td>
<td>30</td>
<td>41</td>
<td>-53</td>
<td>-67</td>
</tr>
</tbody>
</table>

Tensile tests were performed using a Dartec M1000RK servo hydraulic tensile testing machine in a heat chamber within a temperature range between -10ºC and 70ºC. The displacement was registered using an extensometer. The temperature of the specimen surface was measured using a thermocouple. The length of the specimen wires was 200mm.

4 Results and discussion

Figure 1 shows the stress-strain curves for the AF5 material. At 10ºC (Figure 1c), the material shows the lowest residual strain after unloading. At temperatures lower than the $A_f$ temperature (4ºC), the residual strain is due to retained martensite. This residual strain can be eliminated by heating the material. The residual strain observed at temperatures above the $A_f$ temperature is due to dislocation movement in the austenitic phase and cannot be eliminated afterwards.
The critical stress at which martensite formation starts increases approximately linearly with temperature until 50°C. The increase is somewhere between 6 and 7MPa/°C. At 70°C, the stress decreases. This is an indication that other mechanisms than stress induced martensite formation start taking over, i.e. dislocation movement in the austenite. The lower plateau in the stress strain diagrams of Figure 1 disappears above 40°C and the slope of the stress strain unloading becomes more like the loading slope. At 70°C, the slope is about the same for loading and unloading indicating that the temperature is higher than $M_d$.

From the curves in Figure 1, it can be calculated that the absorbed energy varies between 2 J/g at 0°C to 4 J/g at 60°C.

![Figure 1: Stress-strain curves for the AF5 material at various temperatures](image)

Figure 2 shows the stress-strain curves for the AF30 material. The minimum residual strain is observed at 40°C which corresponds well with the measured $A_f$ temperature of 41°C (Table 1). Below 41°C, the temperature is not high enough for the austenite to fully recover such that some of the stress induced martensite remains. The critical stress at which martensite formation start increases approximately linearly with temperature. The increase is somewhere between 6 and 7MPa/°C. Just like in the case of the AF5 material.
Both materials show a very limited temperature range just around $A_f$ in which superelastic behavior is observed. By pre-stressing the material in a damper, the application range can be extended but this takes place at the expense of the amount of energy which is dissipated per cycle. Moreover, by cyclical loading of the material (training) before application as a damper material, the temperature range with superelastic behavior is extended.

5 Damper designs

Several attempts have been made to develop dampers to reduce the structural damage caused by earthquakes. Conventional design principals use the presumption that a certain amount of plastic deformation can be tolerated provided the building does not collapse. The purpose of these principals is to dissipate the energy caused by seismic activity. The disadvantage of this type of control is that it may lead to a great deal of damages on the structure [5]. By using shape memory alloys in seismic dampers one may reduce plastic deformation in the structure and at the same time dissipate energy. This chapter will give a brief outline of some design principles for seismic dampers making use of shape memory alloys. The common denominator of these dampers is that they focus on the design and construction of the damper.

5.1 The MANSIDE damper

The MANSIDE (Memory Alloys for New Seismic Isolation Devices) project was an EU-supported project with the purpose to investigate the possibilities to make use of shape memory alloys in passive control of buildings [7]. The project was completed in 1999, and the result was a damper which works in two separate systems: one isolation system for buildings and bridges, and one dissipation system as braces for framed structures. Figure 3 shows the damper which consists of two concentric steel tubes attached to two separate parts of the controlled structure (e.g. between two floors in a building).
The kernel of the damper is a bundle of austenitic shape memory alloys wires, configured as one re-centering group, and one energy dissipating group. The wires in the re-centering group are wound around two bolts and pre-stressed to function as springs. In the energy dissipating group the wires are wound as two nooses around three bolts and pre-stressed. Two of the bolts in the latter are attached to the inner tube, while the third bolt is attached to the outer tube. Mutual movement leads to a stretch in one noose stretches while the other shortens. Full scale experiments show that the damper is very stiff when exposed to small deformations, and at the same time flexible when exposed to large deformations. [7].

Figure 3: Seismic damper with two groups of shape memory alloy wires [7]

5.2 NiTi damper for damper of tension, compression and torsion

Han et al. have developed a seismic damper which simultaneously damp tension, compression and torsion. The damper consists of two concentric tubes and NiTi wires that run through the tubes (see Figure 4). The purpose is to dissipate energy through deformation of the NiTi-wires independent of load type. Experiments with scaled models show that the damper dissipates the same amount of energy independent of the size-ratio between the inner and outer tubes[8].
Clark et al. (1995) have conducted an investigation on seismic dampers made of multiple NiTi-wires wrapped around cylindrical support posts as shown in Figure 5. The tested dampers are test models and mainly two configurations were tested: 1) 100 loops wrapped in one layer and 2) 70 loops wrapped in three layers. The purpose of the investigations is to gather data for further development of seismic devices to be used in real structures. The results showed that the damper design principles are applicable to seismic control but more thorough analyses and research work is needed before an actual damper may be developed [9].

5.4 Seismic damper with composite NiTi-wires

A damper system which has the objective to effectively perform as an energy dissipation device when subjected to load in an environment with varying temperature has been proposed[10, 11]. To accomplish this multiple NiTi-wires of different alloys will be employed in a damper. Different NiTi-alloys exhibit optimal energy dissipation capabilities at different temperatures. By taking advantage of this, the general idea is to optimize the damper dissipation capacity for the entire working temperature range.
Figure 6 shows a schematic drawing of the proposed damper system. Multiple wires are attached between two rigid plates in a parallel coupled configuration. This is only a principal suggestion of the damper construction and a detailed construction need to be further developed.

![Figure 6: Principal drawing of the new damper system of composite NiTi-wires](image)

6 Conclusions

Special devices that exploit the damping properties of NiTi Shape Memory Alloys (SMA) are under development. This is challenging because the materials show a very limited temperature range just around $A_f$, in which superelastic behavior is observed. By pre-stressing the material in a damper, the application range can be extended but this takes place at the expense of the amount of energy which is dissipated per cycle. Moreover, by cyclical loading of the material (training) before application as a damper material, the temperature range with superelastic behavior is extended. In addition, combining two different materials in one damper configuration could give a damper with a broad temperature range with good damping characteristics.

REFERENCES

