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Fatigue of the Shape Memory Effect in thin Wires-Comparison between TiNi and CuZnAl

M.J. Bigeon and M. Morin

INSA Lyon, GEMPPM-URA 341, 69621 Villeurbanne cedex, France

Composites containing shape memory alloys in the form of fibres are well-known for their use as actuators in adaptative structures. However orientation of the research work concerning these materials has been mainly directed to qualitative analysis, thus a lack of data on the mechanical properties of these alloys, especially on fatigue behaviour, necessitates futher research. The aim of the present research work is to study the shape-memory effect on TiNi and CuZnAl wires.
A tensile testing machine has thus been developped specially adapted to such kind of investigations. The fatigue analysis of the shape memory was performed using wire specimens. The specimens were subjected to ranges of stresses under thermal cycles, thus the variation of transformation temperatures as well as the variation of strain between the high and low temperature phases was recorded. Finally, a comparative study is presented in case of TiNi and CuZnAl wire specimens of same diameters.

1. Tensile machine [1]

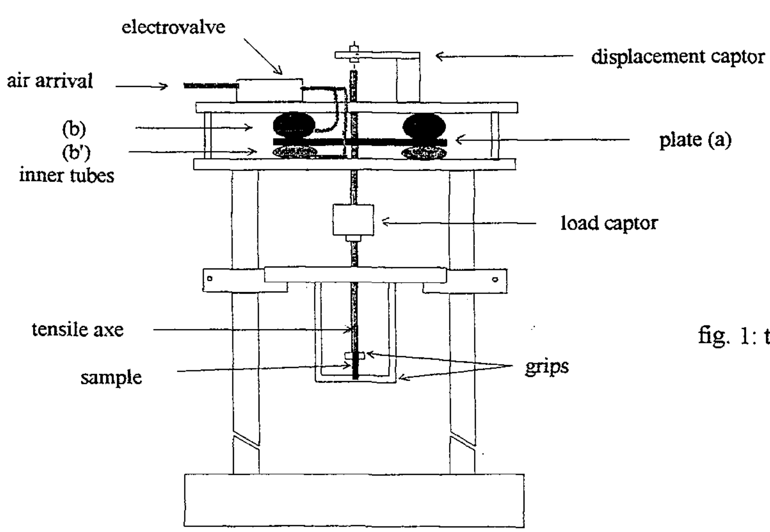


fig. 1: tensile machine.

The present tensile machine (figure 1) posseses a system of pneumatically controlled movement, essentially is the most original part of the machine. The movement of the main axis is guided by an attached plate (a) which in turn can be moved with the help of associated inner tubes, (b) and (b'). When (b) is filled up with air, the plate (a), thus the axis move downward. Similarly an upward movement is obtained using the other set of inner tubes (b'). The air distribution between the two air chambers is directed using an computer-controlled electrovalve. It is important to note that the movement of the tensile axis is elastically guided to minimize friction.

The machine is equipped with, i) a load captor, with a maximum load limit of 500 N, ii) a displacement captor which is able to measure a maximum displacement of 5 mm and iii) an extensionmeter. Each test sample is immersed in a regulated silicone oil bath in order to obtain a stable and homogeneous temperature.

2. The shape memory alloys

2.1 The martensitic transformation

The shape memory alloys (SMA) are characterized by a thermoelastic martensitic transformation. The transformation is reversible accompanied by a hysteresis (5- 20 K) and can be induced by variation of either temperature or stress. In the case of a temperature induced martensitic transformation, formation of martensitic phase starts at temperature M_s and ends at a temperature M_f. The reversible transformation occurs between temperatures frequently noted by A_s and A_f.

2.2 The shape memory effect

The one way Shape Memory Effect (SME) evolves from the formation of a high temperature phase (austenite) from an oriented martensitic phase and thereby resulting in a shape change. It might be noted that such a transformation is reversible. Oriented martensite is obtained under load at temperature below M_f and subsequent heating of the material leads to austenitic phase. The cooling is performed under a stress so as to obtain oriented martensitic phase.

2.3 The studied parameters

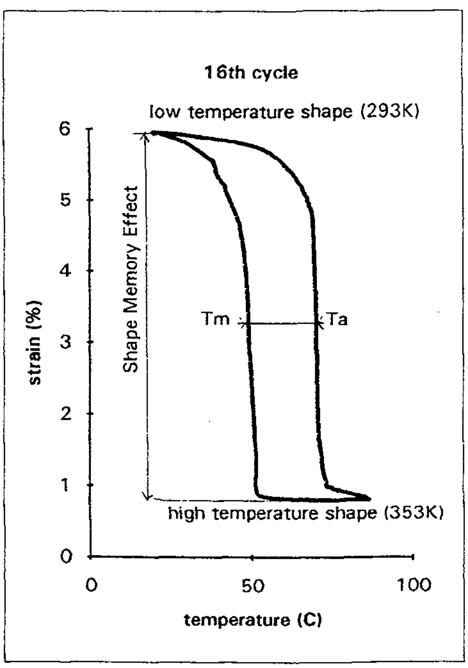
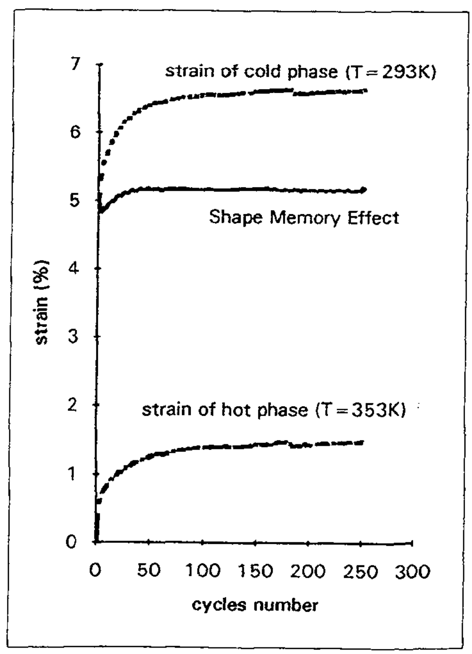


fig. 2:
TiNi under
100 MPa.



The schematic transformation cycle is shown in figure 2. The wire-specimens were placed in a temperature regulated silicone bath and were subjected to a constant stress ranging from 0 to 100 MPa. The bath temperature was varied from 20 C and 85C in one cycle and the specimens were subjected to a maximum of 280 cycles. Strain-temperature curves were recorded at each interval of 2^n cycle (Fig.2). Also the percentage strain of a specimen corresponding to the minimum and maximum temperature of 20 and 85°C was recorded as a function of the number of cycles (Fig.2).

During the direct transformation, under cooling, the sample length increased in the direction of the applied stress. During heating, the sample regains its original form due to 'shape memory effect', well known as 'Assisted Two Way Shape Memory Effect' (ATWSME).

3. The studied alloys

The wire specimens of diameter 0.5 mm were obtained from Trefimetaux and Swissmetal companies. The transformation temperatures were measured by calorimetric analysis. The grain size were measured under an optical microscope. It is to add that the specimens were chemically treated in order to facilitate the microscopical observation.

3.1 CuZnAl

Cu - 11% Al - 14% Zn (at. %)
M_s=37°C, M_f=34°C, A_s=43°C, A_f=46°C.

The material had a 'bamboo' structure and the grain size was observed to be on the order of 0.5 mm. Such microscopical observations explains the observed maximal recoverable strain value similar to that often obtained in the case of a single crystal. Heat treatment consisted of betatizing at 1123K during 30 minutes. The specimens were then quenched in water at room temperature and subsequently aged consecutively at 373K for 30 minutes and at 343K for 30 minutes.

3.2 TiNi

Ti - 45.2% Ni - 6% atm Cu (at. %)
M_s=38°C, M_f=30°C, A_s=53°C, A_f=62°C.

The wires were observed to have a fibrous structure. The final treatments are 35% of cold work and an annealing at 700K for one hour.

4. Some results and discussion

4.1 Dispersion in the results

In order to estimate the dispersion in the results similar tests were perfomed on three specimen wires of CuZnAl under identical conditions. The dispersion on temperatures was ~2K and was less than 0.25% regarding strain values.

4.2 CuZnAl

The number of cycles was observed to hardly influence the transformation temperatures.

The amplitude of ATWSME was observed to depend on the number of thermal cycles and on the applied stress-value (figure 3).

Under a low applied stress (25 - 50 MPa), the shape memory effect (SME) reaches a maximum during first few cycles and then decreases. Higher the applied stress faster the maximum value of SME was attained. At the same time a comparatively faster decrease of SME was observed with increasing stress. However under 75 MPa, a maximum was not observed, SME decreased in the course of cycles and the sample was broken after 16th cycle. Thus, one can conclude that there exits an important influence of the applied stress on SME.

The observed variations of the shape memory effect can be explained in two ways considering the formation of dislocations [2]. During the first cycles, the internal stresses associated with dislocations are added to the external applied stress to facilitate the transformation process, well-known as training of the specimen [3]. However, during the later stages of the imposed cycling (dependent on the applied stress) martensitic transformation is largely reduced due to large increase in the number of dislocations. The absence of 'training' at 75 MPa is thus due to the high density of dislocations.

The decrease in SME might also result from martensite stabilization [4], however calorimetric measurements did not indicate the presence of stabilized martensite.

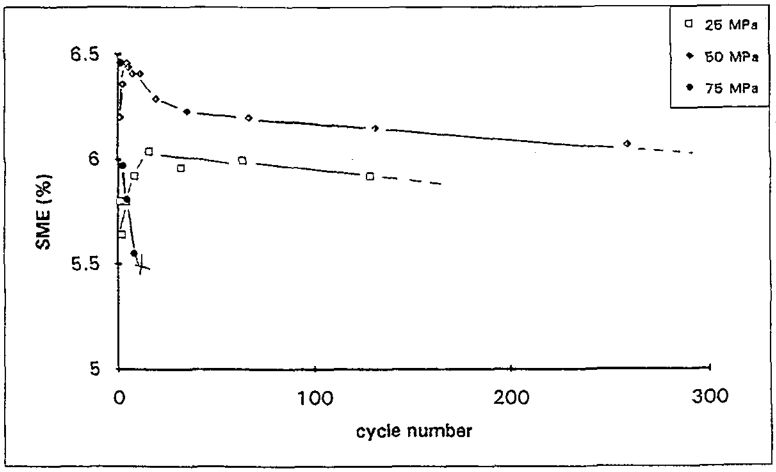


fig. 3: ATWSME in CuZnAl versus the number of thermal cycles under 25, 50, 75 MPa.

4.3 TiNi

In comparison with CuZnAl wires, similar results were obtained in the case of TiNi.

4.3.2 The transformation field and cycling (fig 4 and 5)

For a low value of applied stress, the transformation temperatures was observed to remain more or less constant during the cycling process. However at relatively higher stresses, the temperature As did not change in the course of cycling although M_s was observed to be higher resulting in a decrease in the hysteresis by almost ten degrees.

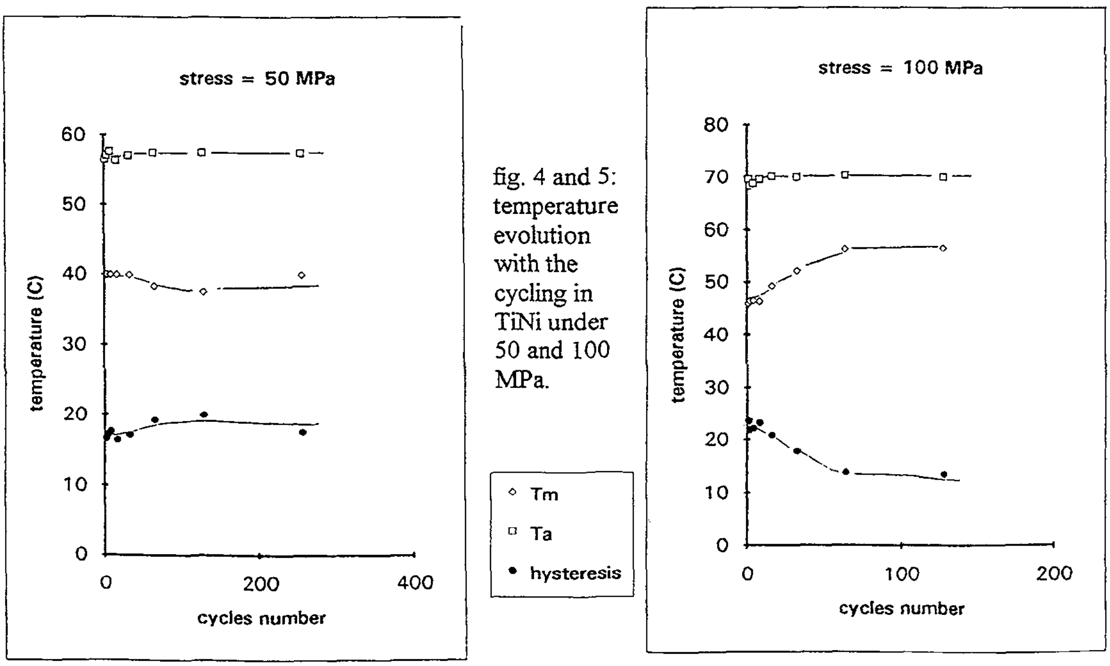


fig. 4 and 5: temperature evolution with the cycling in TiNi under 50 and 100 MPa.

4.3.2 Influence of applied stress

The TiNi alloy shows a small training effect [5]. Figure 6 shows little change in SME during cycling under 25 or 100 Mpa. However a small change in SME was observed at 50 and 75 MPa. On the contrary in the case of CuZnAl wires, SME did not decrease during cycling.

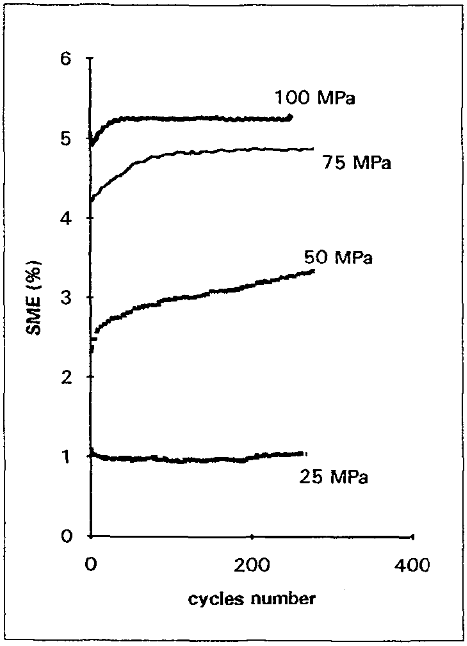


fig. 6: SME of TiNi under different applied stresses. Evolution during a thermal cycling from 273K to 353K.

Figure 7 shows the shape memory effect as a function of the applied stress at the end of 2nd and 128th cycle. ATWSME was observed to increase with the applied stress until it attains a saturation at some higher stress. Regarding the training effect, the increase in SME was observed to be more important at the higher end of cycling; this is clear from the difference of SME vs. stress curves at 2nd and 128th cycle shown in figure 7. It is to be noted that at low stress, the training effect did not occur at all. The first appearence of the same was observed to be at around 50 MPa but was less important compared to the case of CuZnAl alloy. In a word we can say that the training is faster with the increase in stress.

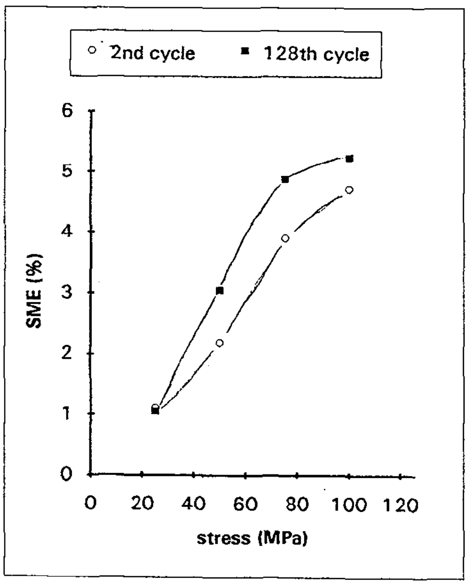


fig. 7: SME versus the applied stress at the second and 128th cycles.

The figure 8 shows the temperatures versus the applied stress for the 2nd cycle. The transformation temperatures were observed to increase with the applied stress. However this is well known that transformation temperatures of shape memory alloys increase under increased stresses.

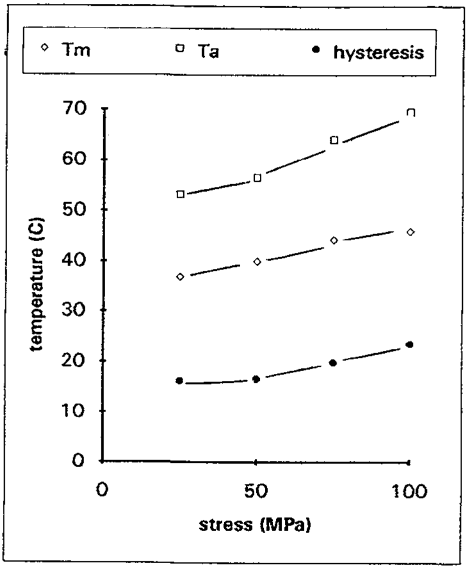


fig. 8: temperatures Ta and Tm and hysteresis of the transformation at the second thermal cycle versus the applied stress.

4.4 Comparison between TiNi and CuZnAl

The cycles in the case of TiNi were observed to be more stable compared to those of CuZnAl. The transformation in the first case was comparatively faster in addition to a three time increase in the hysteresis. Also a higher stress can be applied in case of TiNi and the stress to inducing training effect was also noted to be higher. It was felt that a possible limite in applied stress is to be measured similar to that in the case of CuZnAl. Under identical stresses, the strain corresponding to the high or low temperature phase shows similar variation in the course of cycling and this is true in either material.

5. Conclusion

The results on shape memory effect are obtained during 256 cycles. Each cycle is considerably long (~7 minutes) due to the process of heating and subsequent cooling of the bath between 25 to 80 C. However in future installations the sample will be electrically heated directly in a silicon bath.. Thus the number of cycles can be increased in order to determine the failure of the wire samples.

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