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THERMOMECHANICAL FATIGUE WITH COMPRESSIVE STRESS OF A Cu-Al-Ni SHAPE MEMORY ALLOY

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Abstract - The thermomechanical fatigue of a Cu-Al-Ni shape memory alloy has been studied. For this test, a static compressive stress has been applied to cylindrical samples during a large number of thermal cycles (about 10,000). The influence of the applied stress and of the number of thermal cycles on high and low temperature strains has been measured as well as the memory strain amplitude. The effect of a thrust limiting the deformation in the martensitic state, and also of a previous cycling has been analysed.

I.- Introduction.

Many applications of martensitic alloys in shape memory devices require a large number of thermal cycles and also a stable and reliable shape memory effect. However, one of the problems is to characterise the thermomechanical fatigue of these alloys. From such a point of view, several investigations have recently been carried out on the fatigue properties of many shape memory alloy, such as Ti-Ni (1), Cu-Zn-Al (2), Cu-Al-Ni (3) or Cu-Al-Mn (4). Some of these studies concern the classical fatigue of the austenite or of the martensitic phases (5), and other the fatigue of the pseudoelastic effect (6), but very few involve the thermomechanical fatigue during stress induced shape memory thermal cycles (7).

In the present study, the thermomechanical fatigue behaviour of a polycrystalline Cu-Al-Ni shape memory alloy has been investigated during large numbers of stress induced shape memory thermal cycles.

II.- Experimental procedure.

The industrial alloy studied in this work has a composition of 82.5 wt pct Cu - 13.5 wt pct Al - 4 wt pct Ni. The cylindrical samples (5 mm diameter and 10 mm long) were prepared from rods of 8 mm diameter. They were heated at 850°C for 15 min in air furnace, quenched into water at room temperature and then reheated in boiling water for 15 min. The transformation temperatures measured with a differential scanning calorimeter were : M_{s10} = 65°C and A_{s90} = 62°C (corresponding respectively to 10% and 90% martensite volume).

A specific machine has been built to test the thermomechanical fatigue of the shape memory alloys. This machine can test four samples simultaneously. The specimens are alternatively immersed in two oil baths respectively at room temperature and at 170°C. The limit temperatures of the thermal cycles are 35°C on cooling and 150°C on heating. These temperatures are controlled with a thermocouple situated inside a proof sample.

During the thermal cycles, the samples are submitted to a static stress, and the strain amplitude is measured and sent to a computer. Each sample is held in a kind of pincers (figure 1) with a calibrate spring wich allows the application of the static stress and with a linear displacement transducer which measures the strain amplitude.

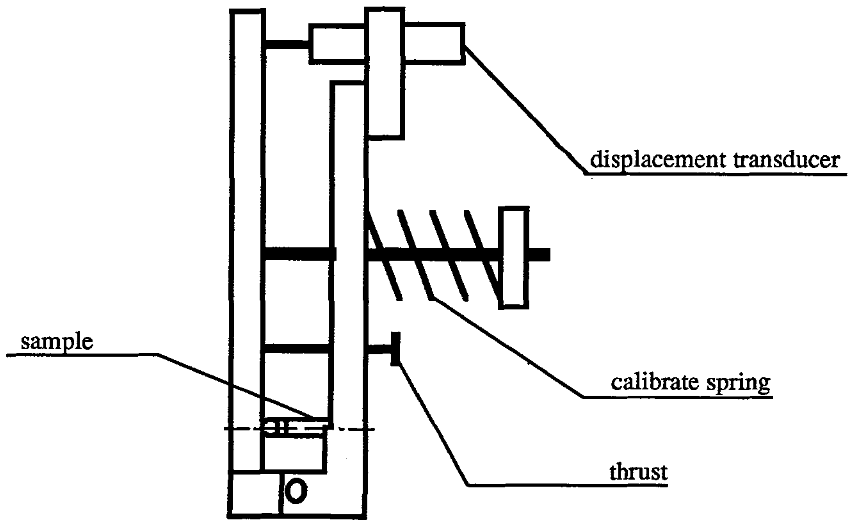

Figure 1 : pincers use for the thermomechanical fatigue

This machine allows two operating modes:

In the first mode, the samples are alternatively immersed in the two baths, and the strain amplitude is measured when the limit temperatures of the thermal cycles are reached. This mode allows the measurement of the low and high temperature strain, and also of the shape memory effect versus the number of the thermal cycles.

Every two hundred thermal cycles, the second mode is activated. The sample are held in the high temperature bath, and a slow thermal cycle (5K/min) is programmed for this bath. The strain amplitude is measured versus the temperature during this complete thermal cycle. This mode allows the measurements of the transformation temperatures.

III.- Results.

a- Effect of the applied stress.

The first test has been carried out with a high stress (100 MPa) and for more than 10,000 thermal cycles. The figure 2 shows the evolution of the deformation of the sample at low temperature (martensitic phase), at high temperature (austenite phase) and also of the amplitude of the shape memory effect (which is the difference of the two previous curves).

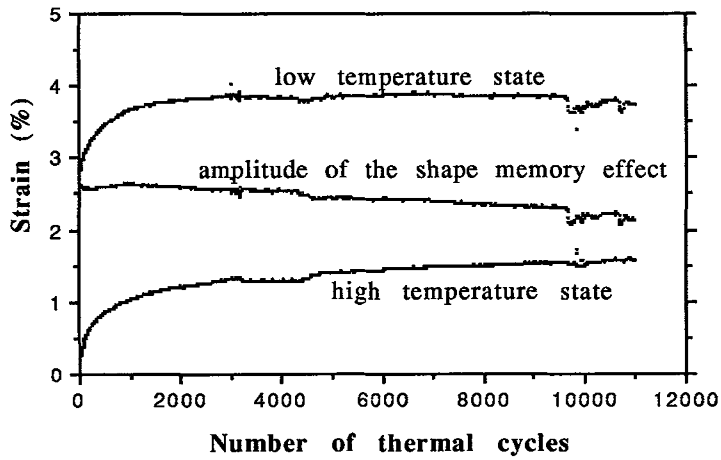

Figure 2 : Strains versus number of thermal cycles

These curves show first that the amplitude of the shape memory effect in compression (2.5%) is very little affected by the number of cycles, even for that high amplitude of deformation. Nevertheless, the cycling induces an important austenite deformation of the sample (1.5%) in the direction of the stress. This deformation is approximatively the same for the two phases. It is creep like and two stages are seen : a first stage (until about 1000 cycles) were the increase of deformation is large, and next a second stage were the deformation is weak and linearly dependent with the number of thermal cycles.

Figure 3 shows the temperature M_{50} and A_{50} of half-transformation versus the number of thermal cycles. These temperatures are not appreciably affected by the cycling.

Other tests, conducted with smaller stresses exhibit the same behaviour: very low decrease of the shape memory effect and increase of the deformation of the samples in the martensite and in the austenite states with the number of the cycles. These deformations are however decreasing when the applied stress is decreasing. Finaly, figure 4 shows the variation of the shape memory effect with the magnitude of the applied stress.

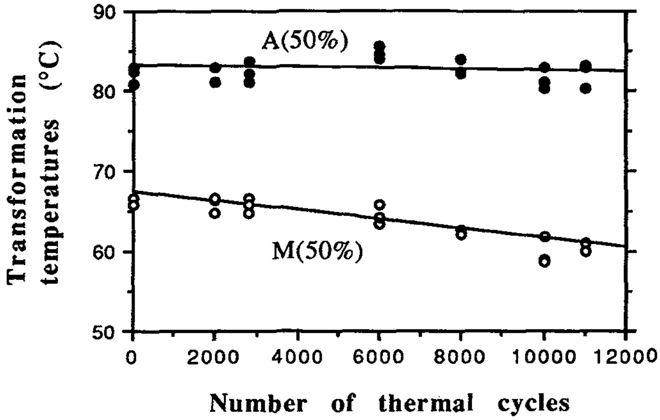

Figure 3 : Evolution of the transformation temperatures versus the number of thermal cycles

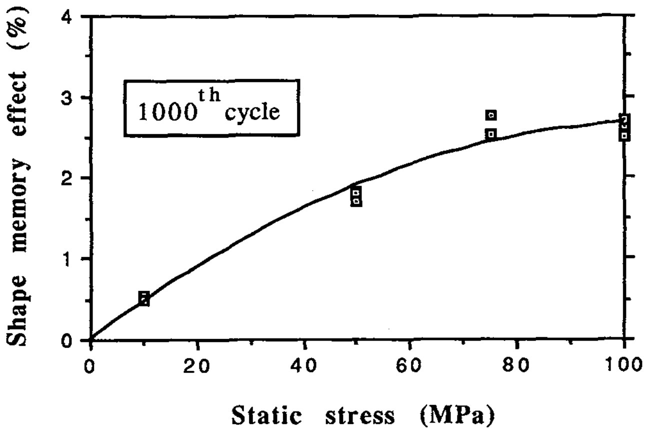

Figure 4 : Influence of the static stress on the shape memory effect

From these experiments, we can conclude that Cu-Al-Ni presents a good behavior for the thermoelastic fatigue: low variations of the transformation temperature and low decrease of the shape memory effect during thermal cycling. Nevertheless, an important creep like deformation of the samples is mesured, especially for the large applied stress. Two experiments have been made to lower this deformation and also to increase the amplitude of the shape memory effect: a thrust to limit the deformation in the martensitic state and a precycling with a high applied stress.

b- Effect of a precycling.

The precycling consists of ten thermal cycles with a static stress larger than the test stress. A precycling has been used with a stress of 100 MPa for the first ten cycles, and for four different test stresses (10, 25, 50 and 75 MPa). This treatment does not improve the deformation of the sample during thermal cycling, but the shape memory effect is increased. The figure 5 compares the amplitude of the shape memory effect obtained after and without precycling. The effect of the precycling is particularly significant if the precycling stress is large with respect to the test stress.

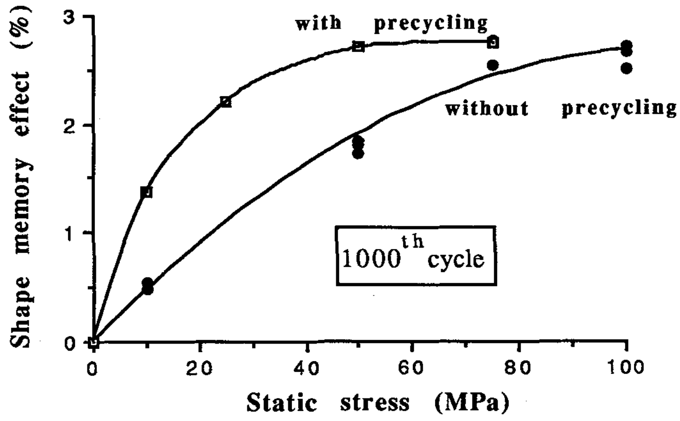

Figure 5 : Effect of the precycling on the shape memory effect

c- Effect of a thrust.

With the thrust (figure 1) the deformation of the sample in the martensite phase is limited. Figure 6 shows the deformation of the austenite phase during thermal cycles with a static stress of 75MPa for two samples. The first one without thrust, and the second with a thrust limiting the deformation in the martensite state at 2%. The limitation of the deformation in the martensitic state induces a decrease of the deformation in the austenite state.

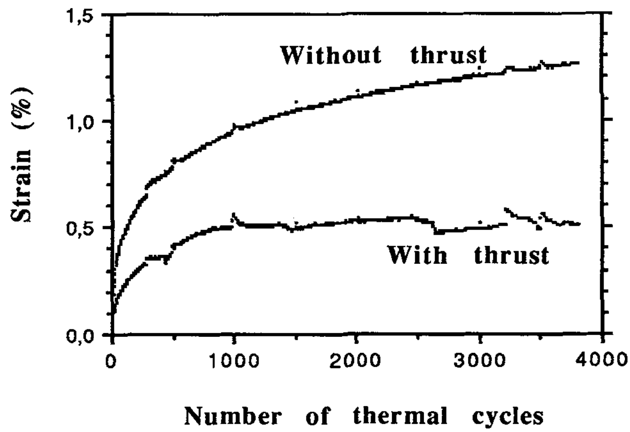

Figure 6 : Influence of a thrust on the austenitic strain

d- Effect of a thrust with a precycling.

The effect of the thrust in addition to the precycling has been studied. Samples have been precycled with a stress of 100 MPa, and then cycled with a static stress of 50 MPa in two different cases: without thrust and with a thrust limiting the martensite deformation to 1%. The results are shown in figure 7. With the thrust, the martensite deformation is limited to 1%, but the austenite deformation is decreased from 1% to 0.5%.

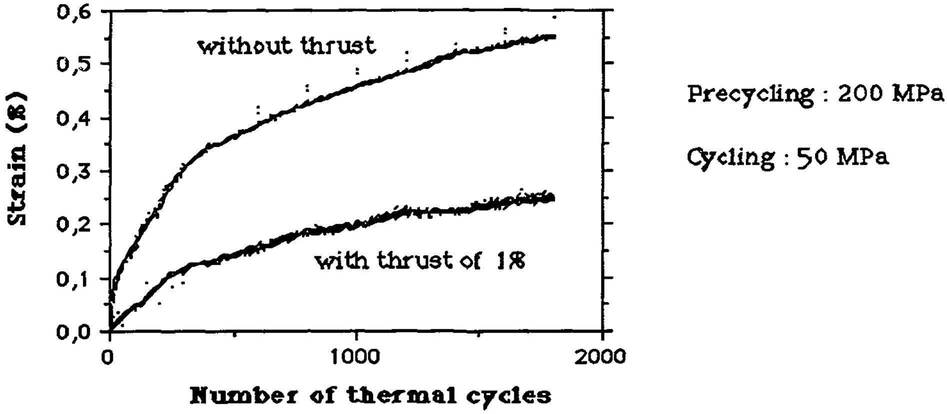

Figure 7 : Effect of a thrust after a precycling

IV.- Conclusion.

The behaviour of the Cu-Al-Ni submitted to thermomechanical fatigue in compression mode has been studied :

- Even with a strong stress (100MPa), the stress assisted shape memory effect is very little decreased by the thermal cycling.
- Up to 2,5%, the stress assisted shape memory effect is linearly dependent on the applied stress, and then saturates.
- During the cycling, the sample in the austenite and in the martensite state is creep like deformed. This deformation is particularly significant for the first thousand cycles.
- The precycling improve the amplitude of the stress assisted shape memory effect, particularly if the precycling stress is strong with regard to the cycling stress.
- A thrust limiting the deformation of the sample in the martensite state, decreases significantly the creep like deformation.
- It is possible to use the precycling and the thrust simultaneously. In this case, the advantages of this two actions are conserved.

V.-References

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