

STUDY OF THERMOMECHANICAL FATIGUE FOR SHAPE MEMORY ALLOYS TYPE CuZnAl

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Abstract: The paper presents the design elements of a prototype installation for the study of specific thermal/mechanical fatigue of shape memory alloys, and fatigue curves obtained respectively.

Keywords: *shape memory alloys, fatigue curve, prototype installation*

1. Introduction

Memory shape alloys from some installations are submitted to mechanical stresses and to thermal stresses so that their integration within a fatigue calculus system supposes taking into consideration their function.



Figure 1. Actuators

Memory shape alloys have a series of properties alike the other ordinary metallic materials. Between those, an important characteristic is their capacity of changing the geometric shape from a low temperature to a high one.

Under certain circumstances, shape changing can be reversible so that the materials can memorize two geometric shapes such as the high temperature shape and low temperature shape.

These transformations accomplish because of an effect named memory shape effect. By memory shape effect, one can understand that the material can make labor work when passing from the cold shape to the warm one.

The pieces subjected to variable (cyclic) stresses destroy to stresses, which are inferior to static fracture resistance. The maximum cyclic stress

when a material does not brake calls fatigue resistance of the material.

In order to dimension the constructive shape of an element with memory shape from a mechanic device, a series of numeric values are necessary, among these values being also fatigue resistance, labeled by the minimum value of the deformation recovered after a certain number of use cycles.

In addition, besides the phenomena met in classic crystalline materials, memory shape alloys present supplementary connection mechanisms at phase change, which are characteristic only for memory shape alloys.

Taking into consideration a device where memory element makes a double sense memory shape effect, within work system (resort coupling uses for recovery), fatigue resistance limit defines by the number of cycles until recovery tension lowers to a minimum value (approximately 70% from the initial one).

According to the cycling type, a memory shape alloy can present irreversible deterioration phenomena of the microstructure defined by specific categories of fatigue.

If cycling though double effort, fatigue is thermal and by cycling through simple effort of memory shape thermo-mechanical fatigue appears.

The fatigue of metals is the phenomenon that produces the breakage of different pieces, under temperature variation conditions and other work parameters, too.

Mechanical fatigue implies breakage production in the following stages: defects accumulation, cracks formation and conduction, in stationary regime at first and non stationary at final breakage.

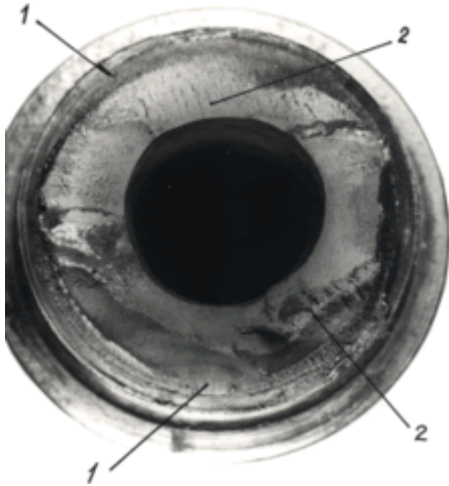


Figure 2. Fatigue cracks appeared in the areas marked with 1, they conducted in the interior of the piece and the final breakage produced quickly in the areas marked with 2.

The breakages that appear when applying some variable loads are called fatigue breakages probably because it noticed generally they appear only after a considerable period.

A fatigue breakage is very dangerous because it appears as a preliminary warning. The proper fatigue breakage is fragile, without important global deformations. At macroscopic scale, breakage surface is usually perpendicular on the direction of the main normal stress.

A fatigue breakage can be easily recognized based on the aspect of the fracture surface, which presents a smooth area and a rough area.

Many times, the way breakage advanced is indicated by a series of concentric circles, which advance from the initial point of the breakage towards the interior of the section.

The stresses producing fatigue breakage at high temperature cannot appear due to some mechanic causes. Fatigue fracture can be produced by variable stresses due to temperature, under conditions where stresses due to mechanic causes do not produce.

Thermal stresses produce when the variation of a piece dimension is stopped in a certain way.

If the breakage appears due to a single appliance of thermal stresses, the stress calls thermal shock.

If the breakage appears after many appliances of some thermal stresses of low values, the solicitation calls thermal fatigue. In the equipments working at

high temperatures, there are usually created the premises for breakages due to thermal fatigue.

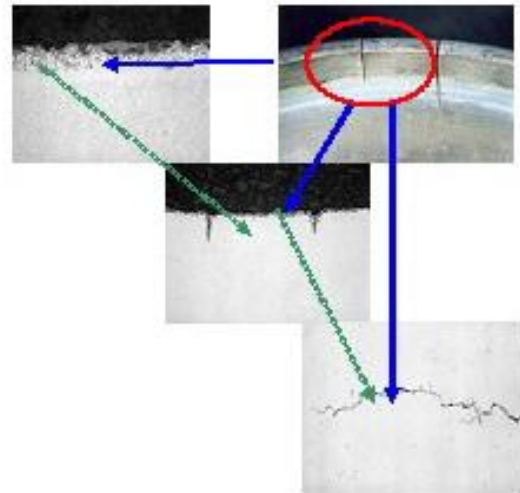


Figure 3. Cracks appeared due to thermal fatigue.

2. Experimental installation

In order to study thermo-mechanical phenomenon of memory shape alloys it designed and realized a prototype with a complex configuration.

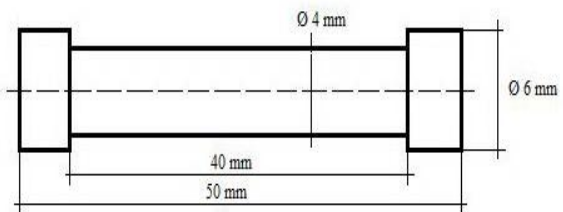


Figure 4. Standard samples, from memory shape alloys type CuZnAl, for thermal fatigue test.

The number of cycles necessary for a loading is 104 – 105 cycles and functioning time for the achievement of these cycles is of the order of tens hours.

Standard sample made of memory shape alloy will be subjected to traction, being caught into the dies, loading realizes by a system of levers, and at their ends, some weights are attached.

Samples with memory shape alloys were tested with the chemical composition presented in table 1.

Table 1

| Cu | Zn | Al | Fe | Si | Mn |
|------|------|------|-------|-------|-------|
| 75.4 | 18.6 | 5.85 | 0.021 | 0.026 | 0.007 |

Conventional notation: Cu_{75.4}Zn_{18.6}Al_{5.85}.

The scheme of the prototype installation presents in figure 5.

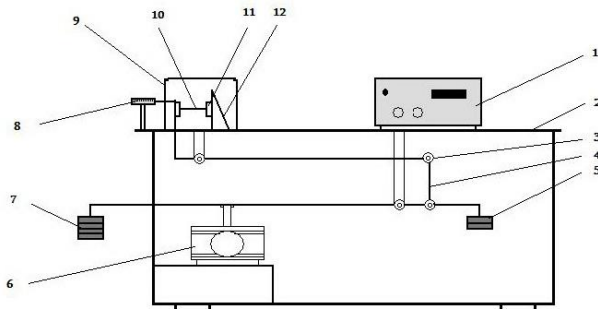


Figure 5. Prototype installation for thermo-mechanical fatigue testing: 1 – command panel; 2 – rigid metallic frame; 3, 4 – system of bearings and levers for load multiplication on the sample; 5 – counter weight; 6 – engine assembly, reducer and arm for weight lifting; 7 – weights; 8 – comparator; 9 – shell of the heating chamber; 10 – sample made of memory shape alloy; 11 – jigs; 12 – fixed die.

The dies used for traction are positioned in a metallic chamber, foreseen with a transparent visiting cover. The sample will be cyclic heating and cooled in the range of temperatures 40–100°C, by means of an installation that blows warm and cold air.

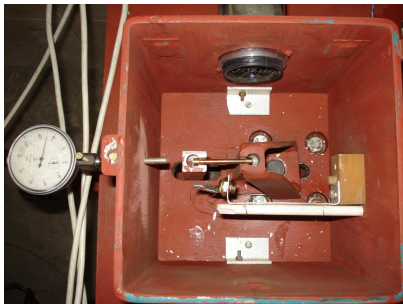


Figure 6. Metallic chamber where the jigs are positioned, measurement system of temperature of sample.

According to the weights attached to levers system, the sample will be stressed with a load whose size is directly proportional with the used weight. This proportionality achieved by means of the levers system. For a weight of 5 kg, traction force on the sample ends will be of 500 kgf.

During experiments, the sample made of memory shape alloy will suffer an elongation, which will be determined with a comparator.

The parameters followed on command panel and a computer using the software named XMEM can control the entire experimental process. As well, the number of heating-cooling cycles will be recorded by XMEM software.



Figure 7. Detail of XMEM software in function.

A very important problem of this installation is the synchronization of the thermal cycle with mechanical cycles. Importance that consists in the fact that memory shape alloys need to determine thermo-mechanical fatigue during material education. Material education realizes in double-effect memory shape materials.

The samples were also analyzed by means of a dilatometer to observe modifications on the characteristic points and implicitly if ‘amnesia’ phenomenon appears – if the alloy losses its memory shape effect.

3. Experimental results

The samples are subjected to a variable, chosen arbitrarily, thermal /mechanical fatigue cycles. After a certain number of cycles, the specimen was analyzed dilatometric, following contraction changes during heating (EMF) and how the temperature transformation martensite - austenite varies.

The $\text{Cu}_{75.4}\text{Zn}_{18.6}\text{Al}_{5.85}$ alloy in quenching and 3% range elongated presents the martensite – austenite transformation domain at 65.8°C and 102.2°C temperatures. After 100 cycles, the domain have moved at the 40,7°C and 99,5°C temperatures.

The maximum of contraction have a growth from 25 μm to 75 μm . At 6000 thermal/mechanical fatigue cycles we have a contraction from 180 μm .

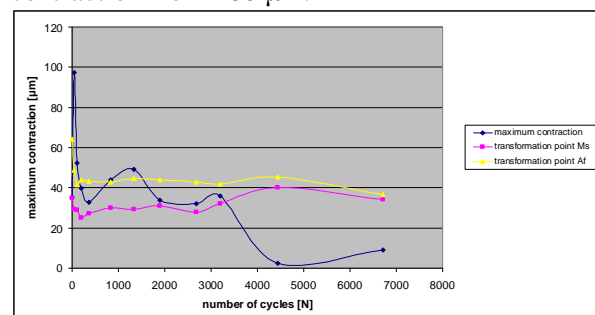


Figure 8. The maximum variation of contraction function the number of cycles of thermal / mechanical stress.

After 12865 thermal fatigue/mechanical cycles on the sample surface, subjected to experimental tests on the prototype installation, have appeared some cracks (figures 9 and 10).

Experimental tests on this sample have been stopped. If it had continued, these cracks could be moved inside the sample, and finally they would have broken it.

Following shows the appearance of microcracks micrographs at 500X magnification.



Figure 9. Microcracks on surface sample from $Cu_{75.4}Zn_{18.6}Al_{5.85}$ alloy, magnification 500 X.

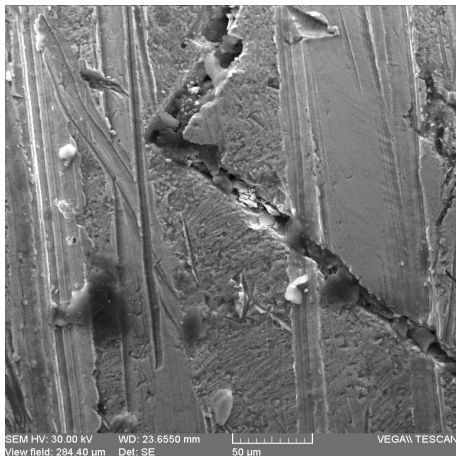


Figure 10. Microcracks on surface sample from $Cu_{75.4}Zn_{18.6}Al_{5.85}$ alloy, magnification 1000 X.

4. Conclusions

The applications of memory shape alloys impose the determination of functioning period for pieces that work under the conditions of under load cyclic heating.

The determination of the characteristics for a memory shape alloy allows components producers to assure a certain guarantee on these products.

The achievement of the prototype installations, as well the creation of a standard of thermo-mechanical fatigue for a series of analyzed alloys would be a solution for the producers of memory shape components.

The development of thermal/mechanical fatigue process is characterized by a diminution of contraction, and finally the destruction of the sample.

4. References

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