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TESTING OF THE THERMOMARKER: IMPORTANCE OF HYSTERESIS

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Abstract :After a short presentation of the industrial machines used by the process of treatment of shape memory alloys, the paper will explain the special feature of the Thermomarker which falls in with two tests of working : one during the martensite-austenite transformation, one during the austenite-martensite transformation. So that the good work of the Thermomarker is bound directly to hysteresis. The authors will display not only results but also the analysis they have made to get a goodcorrelation between this working hysteresis and the hysteresis of the martensitic transformation in shape memory alloy.

I - INTRODUCTION

The Thermomarker is the first industrial application of shape memory alloys which knows a very large spreading. However it is a precision instrument and its testing remains an essential care. The working test of the thermomarker is near the end of the process, because it needs the thermomarker to be assembled. The object was to find a correlation between the working test of thermomarkers and any other way of measure of the martensitic transformation that would allow to anticipate the result of the working temperatures of the device.

II - HOW DOES THE THERMOMARKER WORK ?

The thermomarker uses the properties of a shape memory alloy spring (Cu-Zn-Al -Ni) that is the temperature sensitive component of the mechanism. The operating cycle of the thermomarker is shown in figure 1. The device is completely hidden by a special shell and only the magnifiers are visible. The appearance of the balls (green or red) is the only signal : its meaning is obvious and very reliable.

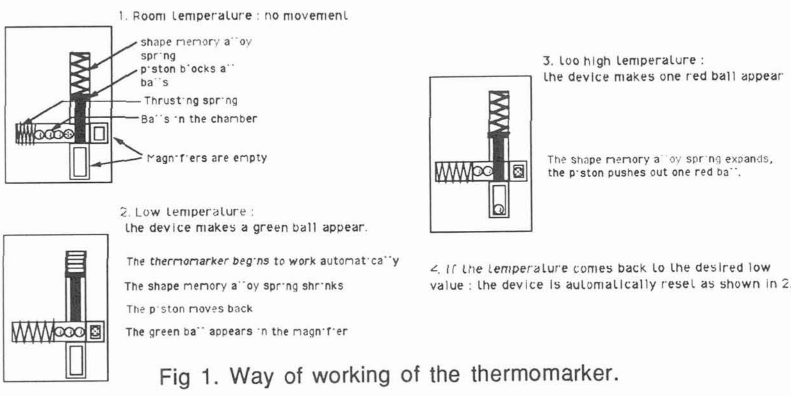

Fig 1. Way of working of the thermomarker.

III - PRODUCTION LINE OF THERMOMARKERS

The differents stages of the manufacture of Thermomarkers are shown in Fig. 2. Testing and Characterization, performed on the string of shape memory alloy, are not exactly included in the production line. This job depends on the laboratory which has got the apparatus necessary to measure with accuracy the characteristics of the martensite transformation. The informations taken out of this characterization will be used to determine the best parameters of further treatments.
In the same way, the transformation from the string to the spring of shape memory alloy is not made in the production line but is subcontracted.
So that we can consider the production line begins with the receipt of springs of Shape memory alloy.
Then we can divide this line into two parts :
• the metallurgical treatment of the spring (heat treatment, thermomechanical treatment, aging),
• the assembly of Thermomarkers (assembly, working test of each of them, resetting,etc...).

As the object of the paper is not to describe the whole production line, the different stages will not be presented in more detail. It is however interesting to outline the industrial way for metallurgical treatments of the shape memory alloy used to manufacture the Thermomarker.
The feature of this production is the know-how of the enterprise that results in specific machines able to make shape memory alloy components (as springs for example) with a high capacity and a reproductive manner.

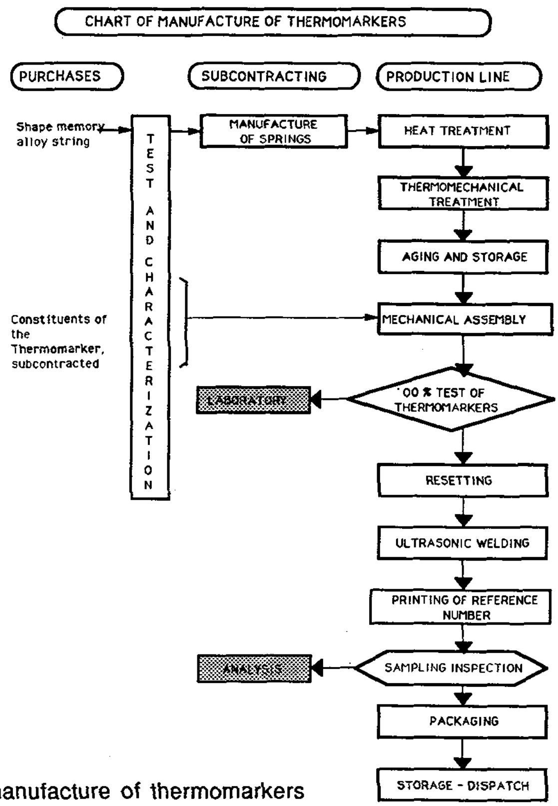

Fig. 2 - Chart of manufacture of thermomarkers

III - 1. Heat treatment

It is performed in a specific furnace with automatic hardening that ensures the reliability and the homogeneity of temperatures for the whole production. We will see later the results of the working test of the thermomarkers and their weak dispersion.

III - 2. Thermomechanical treatment

To realize this treatment, a specially adapted thermal shock machine is used. This machine is made of two superposed rooms, with a temperature control in each of them. In the upper room, high temperature is kept. In the other, we maintain a low temperature. A constant stress is applied to the CuZnAl springs inside a lift that removes them from one room to the other.
Every part of the machine is monitored by a computer so that thermomechanical cycles can be programmed.

III - 3. Aging

To be sure that the working temperature of the thermomarker is included in the tolerance interval, we must wait for the stabilization of the alloy [1]. For that we use several drying ovens.

III - 4. 100% test machine

III - 4.1 Method for the test of working temperature

The working test of thermomarkers consists in the measurement of the temperatures of coming out of the green ball and the red ball.
Therefore we must apply to the thermomarker a temperature cycle that causes the appearance of the balls, figure 3.
The parameters of the temperature profile are very important. They have a large influence (up to 2°C) on the accuracy of the measure at the time of the coming out of the ball, because of the inertia of thermomarkers.
The test is divided into four stages :
A : a steep slope to go from the room temperature to T1,
B : a gentle slope to go from T1 to T2 : it is the useful level to test the green ball,
C : a steep slope to go from T2 to T3,
D : a gentle slope to go from T3 to T4 : it is the useful level to test the red ball.

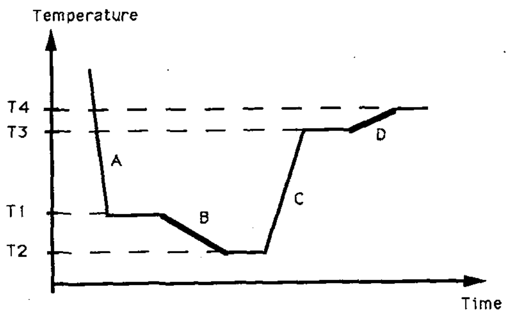

Fig 3 - Evolution of temperature during the test

Each stage is separated from the next one by a level in order to stabilize the temperature into the thermomarker. The thermomarkers are placed in the machine, then the cycle starts.
During A and C, nothing happens. During B and D, the controller waits for the coming out of the green (B) or red (D) balls. As soon as he sees one ball appearing he types the number of the thermomarker on the keyboard. A specific software read the temperature on the channel associated and records it in a file.
At the end he saves the file of temperature that will be used to match the data with the tolerance interval.

III- 4.2 The equipment

It is a temperature controlled room (about 360 dm3) with a sceen so that the controllers can see the thermomarkers during the test.
Every thermomarker is fitted out with a thermocouple that measures the temperature in the device. This thermocouple is connected to a data acquisition instrument that scans 32 channels.

III- 4.3 Results - Working hysteresis

A couple of temperatures is associated with every thermomarker : one for the green ball, called BV, one for the red ball, called BR.
We define the working hysteresis of the thermomarker as Hm = BR - BV.

Since the beginning of the production more than 20 000 measurements have been recorded that corroborate the distribution of Hm shown on fig.4 (for which 2 400 points are displayed only).
The average is 13.2°C and the standard deviation is about 1.3.
The accuracy of the measures of BV and BR is ± 0.5°C.
The distribution of Hm is almost symmetrical for average ±2°C ; beyond this interval, that regroups 89% of the values, it is interesting to remark the range until Hm ≈ 20°C.

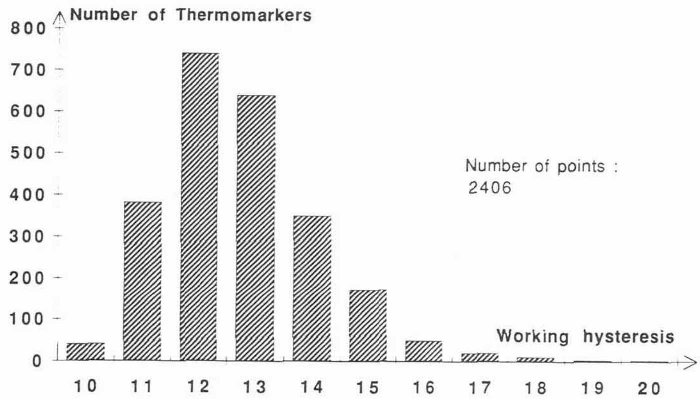

Fig.4 - Dispersion of Working Hysteresis

IV - Relation between the working hysteresis and the hysteresis of the shape memory alloy

L.Buffard [1] had studied the physical aspects of this problem. More modestly, our aim was to know if it were possible to find a correlation between these two kinds of hysteresis and to anticipate the result of the working test for the thermomarkers by a measurement of the hysteresis directly on the alloy.
During the useful life of the thermomarker, the alloy is submitted to temperature cycles that provocate the transformation of phase and make the balls appear. The green ball comes out during the martensitic transformation, the red one during the reverse transformation. So that, these two characteristics of the thermomarker are pointed out in the chart of the hysteresis of the alloy transformation.

IV -1. Equipment and method

We have seen in III-4 the equipment used to measure BV and BR.
The hysteresis cycle of the shape memory alloy transformation is measured with a Differential Scaning Calorimeter (DSC Mettler).
The method is to cut off a sample from a spring of thermomarker which has some interesting characteristics and to put it in the calorimeter where it undergoes a temperature cycle. The hysteresis curve of the sample is obtained, and can be compared with the mechanical hysteresis Hm = BR - BV.

IV - 2. Measurement

IV - 2.1 Common relation

To determine a common relation between hysteresis and Hm, thermomarkers with Hm close to the average of 13.2°C have been selected. BV and BR have been traced back on the charts of the hysteresis curve, fig.5. The figure shows the transformation curve and the values of Hm for two samples representative of the whole of the samples cut off, which, in this part of the study, are such as Hm = 13°C±1.

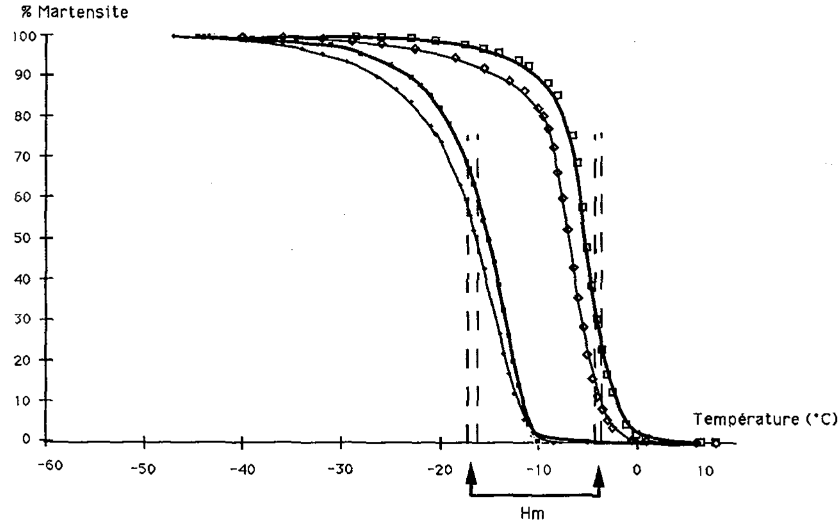

Fig 5 . Common relation between Hm and the hysteresis of CuZnAl(Ni) Alloy

The two curves have the same trend : the hysteresis is the same but a small difference between the temperatures of transformation is noticed.
In the same way, the different values of BV and BR square with the same martensitic percentage in the spring :
• BV is equivalent to 60% of martensite,
• BR is equivalent to 20% of martensite.

Remark : The percentages of martensite are not the real values because the alloy is not in the same situation in the calorimeter and in the thermomarker. In the thermomarker, the shape memory alloy spring is subjected to stresses depending on the position of the components of the thermomarker.
First of all, the alloy is subjected to the standard steel spring. The resulting stress depends on the position of the piston. This strengh is the only one during the martensitic transformation.
During the reverse transformation an other cause of stress appears : the strength necessary to push the red ball in the magnifier. The evolution of this strength has been already studied by the authors [2].
The existence of this stress changes the cycle of hysteresis of the alloy when it is inside the thermomarker. We have not tried to follow the evolution of it because it would need an important equipment incompatible with industrial goals. We have just tried to obtain a good correlation between Hm and the hysteresis of the alloy measured in a standard calorimeter.

IV - 2.2 Analysis of particular cases

We have seen that most of the production has a good behaviour.
What does the correlation become when Hm moves from the average ?

To conclude to a satisfactory relation between the control using DSC and the industrial working test of thermomarkers, it is necessary to know if a too large (or too small) Hm is the effect of a larger (smaller) cycle of hysteresis of the alloy.
For that purpose some thermomarkers with a Hm out of tolerances (≠ 13°C±2) have been selected ; then the spring has been measured with DSC. The results speak volume :
• when Hm is small (11°C), the percentages of martensite corresponding to BV and BR change : 50% for BV, 35% for BR,
• when Hm is large (17°C), BV corresponds to 70% of martensite and BR to 10% of martensite.

On both cases the hysteresis measured with the calorimeter is still the same :

A90-M10 = 9°C
A50-M50 = 10°C
A10-M90 = 13 to 15 °C.

In fact, the hysteresis of the alloy is almost constant for the whole of the production. The dispersion of Hm is not a consequence of changes in the hysteresis of the alloy.

V - Discussion

A limit of the study, as presented above, is the difference between what is measured. Indeed, BV and BR are an indication of the martensitic transformation of every part of the shape memory alloy spring. On the contrary, the temperatures measured with DSC are an indication of a very small part of this spring.
To have a good idea of the dispersion of the transformation into the spring, five samples have been cut off, at regular intervals on the length of the spring. Figure 6 shows the extremes of the five curves of transformation. Depending on the piece of the spring that is considered, the percentage of martensite for BV and BR can increase of about 20 %.

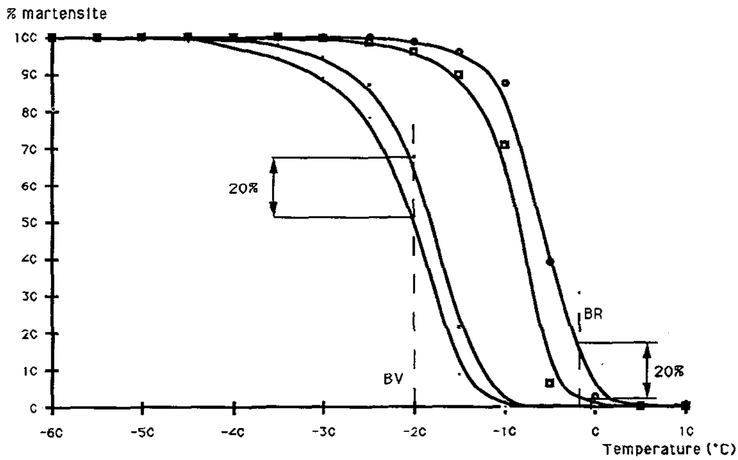

Fig 6. Dispersion of the transformation into the spring

The study allows to draw the following conclusions :
• The hysteresis of the martensitic tranformation for a shape memory alloy spring is very repetitive ; its dispersion is much better than the dispersion for the working hysteresis of the thermomarkers.
• The measurement of samples using calorimetry is a good indication for most of the production of springs.
• The extremes of Hm are not a result of a different hysteresis of the alloy.

This last point shows that the working hysteresis depends on other parameters.
The main way to explore is the influence of the stress applied to the string during its working :
• influence on the hysteresis cycle of the alloy,
• influence of the changes of these mechanical stresses.
It is necessary thus to measure the martensitic transformation using a method that takes into account the whole of the spring and which it is easier to reproduce the mechanism of the stresses applied to the spring.

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