Comparison of the Properties of Shape Memory Actuators and Thermobimetals

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Introduction

To find out the optimum type of actuator for a given application, one has to pay attention to numerous criteria like simplicity of the construction, required volume, type of activating energy, velocity of actuation process, reliability and precision, working life, economical aspects, and so on.

On the field of thermal actuators besides shape memory actuators there are some classical actuators like thermobimetals and wax actuators. The present paper deals with the comparison of the properties of shape memory actuators and thermobimetals.

1. Shape Memory Actuators

Shape memory actuators are made out of shape memory alloys and due to a thermoelastic martensitic transformation after a certain treatment they show a temperature-depending shape change (1-6). The characteristic properties of shape memory actuators can be summarized as follows:

- Performance of the complete mechanical work in a selected and relatively narrow temperature range (hysteresis)
- High mechanical work per unit volume
- Possibility to exhibit different types of shape change (elongation, contraction, bending, torsion)
- The shape memory effect can be restricted to certain parts of the element.

The properties and applications of shape memory actuators have already been described in detail in a previous paper in these proceedings.

2. Thermobimetals

2.1 Fundamental Aspects of Thermobimetals

Thermobimetals are sheet composite materials which consist of at least two components with differing coefficients of thermal expansion. Therefore a thermobimetal bends on heating or cooling. Thermobimetals are known since more than 200 years. They are used as simple and cheap elements for temperature-depending actuation in the field of measuring, controlling and regulating technics (7-9).

The most important criterium for the selection of the components of thermobimetals is the thermal expansion. The component with the smaller thermal expansion is called passive component and the component with the larger thermal expansion is called active component.

Very high thermal expansion show the alloys of manganese with additions of copper and nickel, iron-nickel alloys with additions of manganese, chromium and molybdenum as well as austenitic stainless chromium-nickel steels.

A well-known alloy with a low thermal expansion is the iron-nickel alloy with 36% nickel, which is called Invar. In addition iron-nickel alloys with 42% and 46% nickel as well as ferritic stainless steels are passive components of great importance.

To produce a thermobimetal one has to clad suited components by cold or hot rolling. In general thermobimetals are used with a final cold working rate of 20-30%.

The thermal sensitivity of a thermobimetal is characterized by the so-called specific thermal curvature ("flexivity") which can be calculated according to the formulae in the german standard DIN 1715. The specific thermal curvature is not a constant. Therefore the temperature-deflection curve of a thermobimetal is not fully linear, but it looks like the schematical curve shown in Fig. 1. The nominal specific thermal curvature of a thermobimetal according to the german standard DIN 1715 is valid for the temperature range from +20 to +130°C.

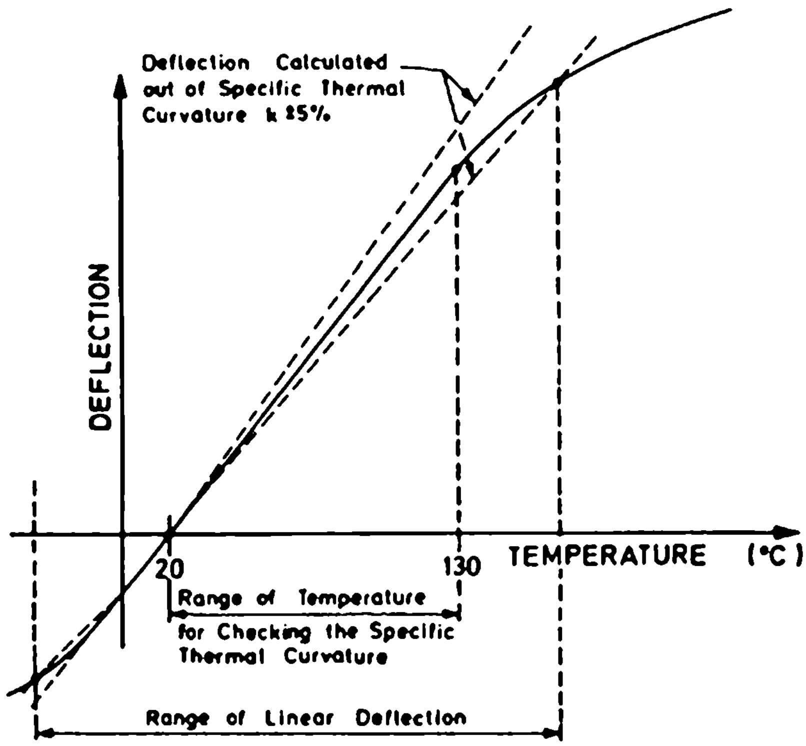

Fig. 1: Schematic temperature-deflection curve of a thermobimetal.

According to Fig. 1 the range of linear deflection is the temperature range in which the measured thermal deflection does not deviate more than ± 5% from the calculated value using the nominal specific thermal curvature. Beyond the range of linear deflection, there is a decreasing, but for many applications sufficient deflection. Hence the range of application often exceeds the range of linear deflection.

The upper limit of application is the highest temperature at which no permanent change of the properties of the thermobimetal occurs. This temperature corresponds to the recrystallization temperature of the thermobimetal for long time application and the usual cold working degree of 20-30%.

The great number of possible component combinations has lead worldwide to more than 100 sorts of thermobimetals. In Table 1 there are listed the components and some additional data for

Thermo-bimetal	Active Component	Passive Component	Spec. therm. Curvature 10^{-6}/K c)	Range of Linear Deflection °C	Upper limit of Application °C
TB 1577 A a)	FeNi20Mn6	FeNi36	28,5	−20 to +200	450
TB 20110 a)	MnCu18Ni10	FeNi36	39,0	−20 to +200	350
MS b)	MnNi15Cu10	FeNi32Co6	43,6	+20 to +230	350
RS b)	X12CrNi18 8	FeNi32Co14Ti1,5	18,0	−20 to +400	650
RR b)	X12CrNi18 8	X8Cr17	9,5	−20 to +600	550

a) Denotation according to DIN 1715.

b) MS, RS, RR are trade names of G. RAU GmbH & Co., Pforzheim.

c) Nominal value for the temperature range from +20°C to +130°C.

Table 1: Components and properties of thermobimetals.

different sorts of thermobimetal. In Fig. 2 there are shown examples for different types of thermobimetal-elements like strips, discs, spiral and helical coils, in which the respective shape change is based on the temperature-depending bending of the sheet composite material.

Thermobimetals especially are used as simple and cheap actuators in a large number of technical fields like automotive industry, electrotechnical fields and heating systems (8,9).

2.2 Comparison of the Properties of Shape Memory Actuators and Thermobimetals

The different basis for the shape change of shape memory actuators and thermobimetals naturally implies drastic differences concerning the properties of these two groups of elements.

The properties of shape memory actuators have already been explained in detail in a previous paper in these proceedings.

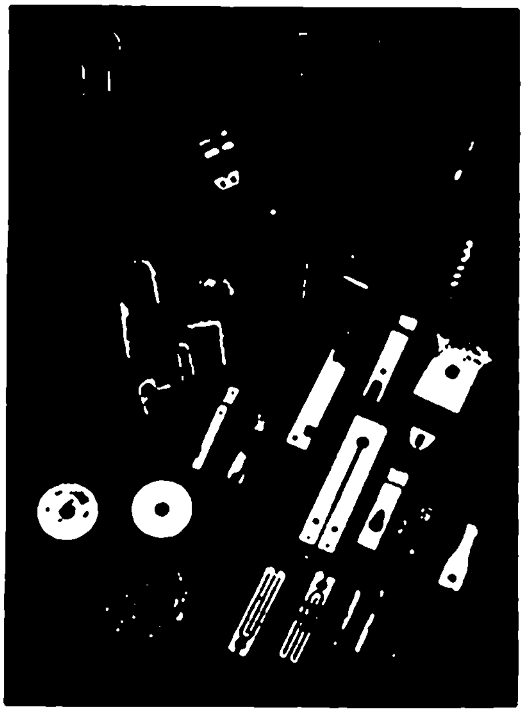

Fig. 2: Examples of possible types of thermobimetal-elements.

The characteristic properties of thermobimetals can be summarized as follows:

- Linear deflection versus temperature change (no hysteresis)
- Linear deflection up to about 600°C
- Limit of application about 650°C
- Extremely high stability of the effect of shape change (up to about 20 millions of thermal cycles).

The greatest difference between thermobimetals and shape memory actuators is noticed at the temperature-deflection curve. Fig. 3 shows the temperature-deflection curve for a cantilever strip of Cu-Zn-Al with a two-way bending effect of 1% and for the standard thermobimetal TB 1577A with the same dimensions. The shape memory element shows at the free end a reversible deflection of about 25 mm in a temperature range of about 40 K. By a two-way effect of more than 1% naturally one would get an even greater deflection. The standard thermobimetal TB 1577A with the same geometry shows a deflection of about 1,5 mm for the mentioned temperature range of 40 K. If one looks for a temperature range of 200 K then the thermobimetal makes a deflection of about 7,5 mm (7).

As one can see in Fig. 3 the temperature-deflection curve of shape memory elements with a two-way effect exhibits a hysteresis which amounts to 10-30 K depending on the type of alloy and the material treatment. In contrast to the shape memory actuators thermobimetals show practically no hysteresis in the temperature-deflection curve. But with thermobimetals one can fabricate mechanically dished discs, so-called snap action discs, which show a sudden displacement and a hysteresis in their temperature-displacement curve. In general thermobimetal snap action discs are used in applications with a relatively small displacement and force (9).

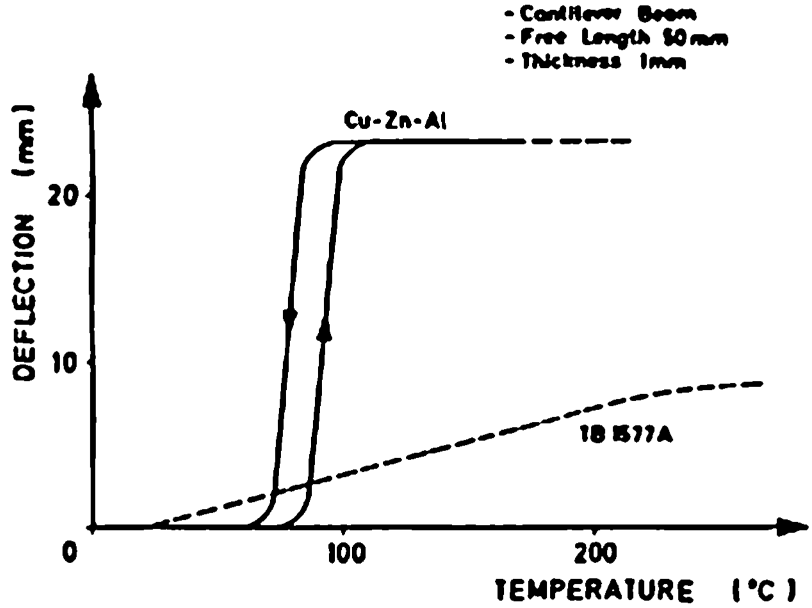

Fig. 3: Temperature-deflection curves of a cantilever strip of Cu-Zn-Al with a two-way bending effect of 1% and of a standard thermo-bimetal TB 1577A with the same dimensions (at room temperature flat strip, thickness 1 mm, free length 50 mm).

If one uses the corresponding formulae from the technical literature for the standard thermobimetal TB 1577A with a temperature change of 100 K, one gets a working capacity per unit volume of about 0,02 MJ/m³. With a greater temperature difference naturally one gets a greater working capacity (8).

Shape memory actuators with a two-way effect exhibit a working capacity per unit volume of about 1-5 MJ/m³ depending on the group of alloy, the magnitude of effect and stress. This working capacity is achieved with a temperature change of only about 30-40 K and is much greater than with thermobimetals. In Table 2 there are shown some mechanical properties of shape memory alloys and thermobimetals. Since the admissible stresses for thermobimetals and shape memory actuators are nearly of the same magnitude, the great working capacity of shape memory actuators is primarily due to the great displacement (magnitude of effect).

Thermobimetals can show only bending as a type of shape change, so that in general the material volume does'nt work completely. In contrast to this, certain types of shape memory actuators like straight tensile wires with homogeneous stress distribution use 100% of the working capacity of the volume.

Shape memory elements exhibit a higher strength in the austenitic state than in the martensitic one. Therefore these elements only on heating can generate work against a bias force. On the contrary on cooling the low-temperature structure with a small strength is formed, so that external forces which are opposite to the element reversion would cause a degradation of the shape memory effect. On the other hand thermobimetals can generate work both on heating and on cooling.

Property	Shape Memory Alloys a) NiTi	Cu-Zn-Al	Cu-Al-Ni	Thermobimetals at 20°C b)
Admissible Stress σ_{adm} (N/mm²)	250	75	100	200-250 c)
Tensile Strength (N/mm²)	800-1000	400-700	700-800	600-900
Elongation (%)	40-50	10-15	5-6	2-10

a) The properties depend on different parameters (e.g. alloy composition and temperature).

b) Final cold working rate of 20-30%.

c) The thermobimetal type RS (Table 1) is an exception and can be loaded up to 500 N/mm².

Table 2: Some mechanical properties of shape memory alloys and thermobimetals.

As one can see in Table 1 for thermobimetals the range of linear deflection covers values from -20 up to about 600°C and the maximum limit of application for long time is 650°C. In addition thermobimetals exhibit a high stability of the shape change effect.

Shape memory alloys can exhibit A_s-temperatures between about -150°C and +150°C depending on the group of alloy. In contrast to the thermobimetals shape memory actuators show a restricted stability of the shape change effect (7).

3. Closure Remark

Both shape memory actuators and thermobimetals have specific properties which, depending on the requirements, can lead to advantageous solutions. For technical and economical reasons a mutual interchangeability of these actuators is possible only for a very limited number of applications.

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