The control features of thermal characteristic details from alloy with shape memory effect

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Abstract. In the article shows the properties of alloys based TINI with shape memory effects and superelasticity. For high-quality application of such properties of the alloy and the operating conditions, it is necessary to carry out a comprehensive control of thermomechanical characteristics. Therefore, it is necessary to make a standard control, carried out before the launch of a batch of material, and control of phase transformation temperatures for each billet. The article presents the control principles of thermomechanical characteristics of the workpiece material for their using in various operating conditions.

1. Introduction

Actually the most interesting are non-magnetic alloys based on TiNi provide the most satisfactory machining, significant ductility at a wide temperature range to cryogenic, have high corrosion and erosion resistance. The effects of shape memory (SME) and superelasticity of intermetallic compounds are some of the most unusual and interesting properties of metals. Properties of the effects of shape memory (SME) and superelasticity, the occurrence conditions of SME and superelasticity in titanium nickelide intermetallic compounds are associated with thermoelastic phase transformations. The area of existence of intermetallic compounds of titanium nickelide is limited by the ratio of components from 49 to 52% Ni, the rest of the content is Ti. Herewith the specific properties of shape memory (SME) and superelasticity can appear in wide temperature ranges from +120 to –200°C. However, the effects of EPF and SU appear during phase (MP-martensitic) transformations in a narrow temperature range from 2 to 50°C depending on the ratio of Ni and Ti components. These properties appear only in the TiNi matrix. The characteristics of the matrix are very sensitive to changes in the ratio of components. An increase in one of the components of the TiNi matrix by about 0.1% percent leads to temperature shifts of the martensitic transformation from 10 to 15°C with significant changes in the physical and thermomechanical properties of the material.

Therefore, it is necessary to carry out comprehensive control of the physical and thermomechanical characteristics for the qualitative application of the specific properties of Ti and Ni and from the operating conditions of the alloy. For this, it is necessary to carry out not only the standard control carried out before the start of the batch of material, but also the temperature control of the martensitic transformation of each part blank.

2. Features of phase transformations of an alloy based on Ti and Ni with shape memory effect

Under certain conditions, the transformation of austenite (A) into martensite (M) acquires the “thermoelasticity” feature. The transformation process can be initiated by a change in temperature,
stress, or a combination of both. Consequently, if at some moment the cooling is stopped, the transformation will stop at the stage at which the “stop temperature” reach it.

In from this state the temperature rise contributes to the reverse martensitic – austenitic transformation, all shear displacements of atoms go in the opposite direction, then the atoms return to their original positions corresponding to the austenitic phase of the material.

In isothermal conditions, the apply of external stress causes an increase in the temperature range of martensitic transformations. In the limiting case, during an austenitic-martensitic transition, a displacement of atoms occurs that can correspond to elastic deformation within 10% or more. This deformation is much larger than the ultimate elastic deformation of common metals, but it is realized not due to irreversible shifts in austenite or martensite, but due to the directed transformation of austenite into martensite. The reverse transformation of martensite into austenite contributes to the disappearance of a huge "superelastic" deformation, because atoms return to the initial position of the austenite lattice.

The condition diagram of the Ti and Ni system near the equiatomic composition is shown in Figure 1.

The temperatures of the martensitic and austenitic regions of the existence of the material are shown schematically in Figure 2.

The condition diagram of Ti-Ni

The range of deformation temperatures in the zone of martensitic inelasticity

Operating temperature range

Performance characteristics of alloys with SME

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Figure 1. The condition diagram of Ti-Ni

Figure 2. Dependence of reactive stresses arising in a material during thermal form restoration under conditions of counteraction against temperature:

$M_S$, $M_F$ - temperatures of the beginning and end of the direct martensitic transformation;

$A^\phi_S$, $A^\phi_F$ - thermal recovery temperatures;

$\sigma_d$ - напряжение деформации martensитной неупругости;

$\sigma_R$ - strain of thermomechanical return.
If in the process of thermal form restoration is an obstacle, then in the material (figure 2), reactive stresses are generated that exceed the deformation stresses. The temperature of the form recovery of \( A^\circ_s, A^\circ_f \) in contradistinction to \( A_s, A_f \) (temperatures of the beginning and end of the reverse martensitic transformation), has a shift to the region of elevated temperatures. The value of the reactive stresses depends on the degree of under recovery and the stiffness of the counteraction. The upper limit of operating temperatures for TiNi parts is about \( T_{max} = 280 \, ^\circ C \), which is determined by the beginning of the development of the relaxation process in the material, which leads to irreversible ductility. For example, the phenomenon of an immediate return of deformation upon removal of an external load is known as “superelasticity”; at the same time, the effect of restoration of deformation, for the realization of which requires heating to a certain temperature above the temperature of deformation, is called the "shape memory effect". In some cases, there is a combination of superelasticity and SME.

After initial deformation, materials with SME are able to spontaneously take the initial shape that they had before deformation, with slight heating (for example, at \( 2 \pm 50 \, ^\circ C \)) depending on the type of transformation and alloy composition [2].

A necessary condition for the manifestation of the SME is that in the process of reverse transformations, the pseudo-shear deformation opposite to the corresponding deformation during martensitic transformations. The following conditions are necessary for the manifestation of SME in the material:
- the formation of an ordered crystal lattice;
- thermoelastic character of martensitic transformations.

The specific properties of alloys with SME manifest not only in the fact that they possess the property of “shape memory”, but also have superelasticity, which can reach up to 10% of the deformation. This deformation can manifest itself in the vicinity of the martensitic transformation intervals and propagate to temperatures of 200 \( ^\circ C \) higher than the reverse martensitic transformation interval in the corresponding metallurgical and thermomechanical processing. In industry, it is customary to mark alloys in the austenitic state - TH1 and martensitic - TH1-K. Therefore, it is possible to have structures made of materials having the property of superelasticity in the range of operating temperatures. This phenomenon is associated with the rhombohedral (R) transformation. The research of the electronic structure and structural instability of TiNi show the rhombohedral transformation is preceded by a transition with a change in the localization of electrons and a change in the topology of the Fermi surface. The Fermi order in TiNi is located in the vicinity of the state of acute density. Accordingly, even a slight increase or decrease in the concentration of electrons or their redistribution in energy leads to a change in the concentration of Ni atoms in the matrix and a change in transformation temperatures [3].

3. The method for determination of phase transformation temperatures.
One of the methods for determining the temperature of phase transformations providing indestructible control is the ultrasonic method. The method is based on the principle of estimating the attenuation coefficient in a material as a measure of the scattering and absorption of ultrasonic energy in the intervals of phase transformations during thermal cycling. The anomalous properties of the attenuation coefficient are due to changes in the elastic moduli of the crystal lattice that occur during cooling or heating of the alloy during phase transformations [4].

The dynamic attenuation coefficient is estimated by changing the voltage level of the 1st videopulse from a series of echo pulses reflected from the opposite face of the sample.

The figure 3 shows a diagram of the recording of the amplitude of the first bottom echo pulse during the control of the workpiece during the phase transition according to the scheme \( B2 \leftrightarrow R \leftrightarrow B19 \) (B2-austenite with cubic lattice structure, B19 - martensite with rhombic lattice structure).
Figure 3. The addiction ultrasonic control attenuation coefficient from the temperature

The introduction of ultrasonic vibrations into the sample with a frequency $f = 3 \div 5$ MHz is carried out by the contact method. To ensure stable contact between the sample and the quartz piezoelectric transducer, a lubricant based on organosilicon oil and graphite powder is used. The cooling and heating rate of the workpiece should be within 8 deg./min. The structural diagram of an ultrasonic unit with a list of equipment necessary for monitoring is presented in figure 4.[5]

Figure 4. The structural scheme of an ultrasonic setting

The figure 5 shows the design of the ultrasonic camera.
Figure 5. The scheme of the ultrasonic camera:
1-camera, 2-workpiece, 3-piezo transducer

The TiNi based alloys have high sound absorbing properties. In order to increase the sensitivity during attenuation measurements according to the 1st of the reflected pulses, the following requirements are imposed on the geometry of the controlled samples: the samples must have a strictly cylindrical shape; end surfaces must be flat and strictly parallel; the surfaces of the end surfaces must be perpendicular to the axis of the cylinder.

According to the characteristics of the use of details for specific operating temperatures, this method allows the using of batches of materials that correspond to the technical requirements of the product. Например, для авиационной промышленности нижний температурный порог для работы соединений трубопровода составляет –60°C. Accordingly, the temperatures of martensitic transformations should be lower than –80°C, which requires the use of cryogenic liquid in the technological processing of workpieces. In shipbuilding, the temperature of operation of pipelines is higher than 0°C and the lower threshold of martensitic transformations is within –20°C.

The represented ultrasonic method for monitoring phase transformations for workpieces as applied to thermomechanical coupling (TMS) couplings allows comprehensive monitoring of physical and thermomechanical characteristics. Importantly this method is applicable for 100% control of alloy with SME details, sorting of workpieces (such as TMS couplings) with diameters of 12–40 mm and lengths of 10–100 mm, in temperature ranges from –196 to + 300°C.

References
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