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Mechanics

Research of Kovar Precise Alloy Creep Curves for Modelling of Stress Strain State

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ABSTRACT. The aim of the study is to determine the physical and mechanical properties and creep parameters of the 29NK precision alloy (Kovar) with a specified Coefficients of Linear Thermal Expansion for modeling the stress-strain state under conditions of brazing and diffusion welding. Investigations of physical and mechanical properties were carried out on the basis of the test complex "Gleeble-3800" of the firm "DSI". Energy activation and creep curves were investigated with the help of the upgraded "IDWV-TP" installation. Initially, the creep activation energy was determined by the method of small temperature discontinuity, which for metals and alloys close to the Kovar changes in a certain interval that makes it possible to determine the accuracy of the experiment. Then the other creep parameters from a series of experiments at different temperatures and pressures were determined by the approximation creep equation, with account the creep deformations in the first and second stages (Combined Time Hardening). The dependences of the physical-mechanical properties of the Kovar precision alloy on temperature under high- temperature pressure brazing and diffusion welding conditions were obtained. This makes it possible to solve the problem of computer simulation of the stress-strain state of the pressure seals, taking into account the coefficients of creep during cooling. The results of the studies carried out were used in the development of the manufacture technology of metal-ceramic units, with higher performance properties compared to analogues. The use of computer simulation of the node, taking into account the deformations of instantaneous plastic deformation and creep, at the initial stage of development of the manufacturing technology for the assemblies from dissimilar materials, the method of brazing under pressure and diffusion welding with a controlled stress-strain state, can reduce the accompanying material costs.

Key words: Kovar, physical-mechanical properties, creep curves, activation energy, creep coefficients

In engineering the metal-ceramic units of different purpose are used widely, including the high-voltage pressure seals of the electron beam guns in the units for welding and spraying. In such units the matched joints are used, such as ceramic and 29NC (Kovar) (Fe 51.14…54.5%, C 0.03%, Si 0.3%, Mn 0.4%, Ni 28.5…29.5%, Cr 0.1%, Co 17…18%, Ti 0.1%, Al 0.2%, Cu 0.2%, S 0.015%, P 0.015%), which have close Coefficients of Linear Thermal Expansion (CLTE). But, at temperatures above 400…460 °C, CLTE of Kovar increases sharply, and at temperature 900°C it is more than CLTE of ceramic in 1.8 times. That is why the level of the residual stresses can be above the acceptable level at brazing by high-temperature solders or at diffusion welding [1].

The control of the joints stress-strain state (SSS) is possible on the base of its modeling results. SSS taking into account the deformations of the prompt plasticity and creep, is not sufficiently studied, in spite of the availability of the modern calculating program complexes. But, the real results of modeling can be received, only taking into account these deformations. This was showed in the following works [1-4]. For this purpose the physical-mechanical properties of Kovar should be defined. Therefore, their study at the temperatures of the joints preparation is topical [2-4].

Analysis of the Newest Researches and Publications

The analysis of the literature showed that the dependencies of the yielding level and flexibility module on temperature for Kovar precise alloy are existing. CLTE is in the range of the following temperatures: 20–200 °C, 20–400 °C, 20–600 °C, 20–800 °C, 20–1000 °C [5,6].

The activation energy and the creep curves should be investigated for the determination of Kovar creep parameters and their change during the cooling-down process of the soldered joint. In works [7] the creep curves studied at 30–100 MPa pressure and a test time of 16–55 h, at 750 °C and 850 °C temperature, when the real regimes of pressure seals brazing are the following: the compression pressure P = 5±0.5 MPa; the pressure seals soldering temperature is 940–950 °C; the temperature stabilization time is 2 min. The cooling is stair-step with the following holdup at each step during 10…15 minutes down to 600 ºC inclusive [8]. At 550±10 ºC temperature the holdup is 30 minutes. Using of the literature data does not submit the adequate results of the SSS modeling.

The purpose of this work is the research physical-mechanical properties and creep coefficients of Kovar precise alloy.

Presentation of Basic Material

The important element of the pressure seals is the current input. They are made of materials with CLTE which is close to CLTE of ceramic. Their thickness affects the stiffness and deformation of the unit during its using, on the one hand, and the residual stress level after brazing, on the other. The most appropriate materials are precise Fe-Ni-Co alloys, such as Kovar (29NC, 33NC, 38NC). They are the basic constructive materials for production of the metal-ceramic units [5,6].

The researches of CLTE were executed by the use of Gleeble-3800 complex of DSI Company (USA) in E.O., Paton Electric Welding Institute [3].

The dilatometric cooling curve of Kovar alloy at the initial diameter of the sample equal to 6 mm is shown in Fig. 1. The analysis of the dilatometric curve of Kovar precise alloy showed that up to 430 ºC temperature the Kovar CLTE equals to 4.17 ($\alpha \cdot 10^6$), at more higher temperature it equals to 15.6 ($\alpha \cdot 10^6$). The received results are in accordance with the literature data [5,6].

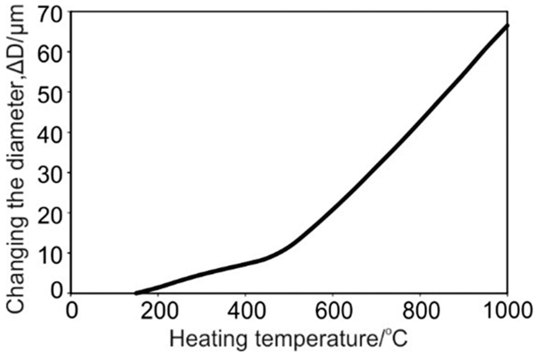


Fig.1. Dilatometric cooling curve of Kovar.

The creep activation energy and its curves were researched by the use of „Installation for diffusion welding in vacuum of turbine parts" (IDWV-TP) (Admiral Makarov National University of Shipbuilding) modernized unit. The scheme of the detectors location on this unit is shown in Fig. 2.

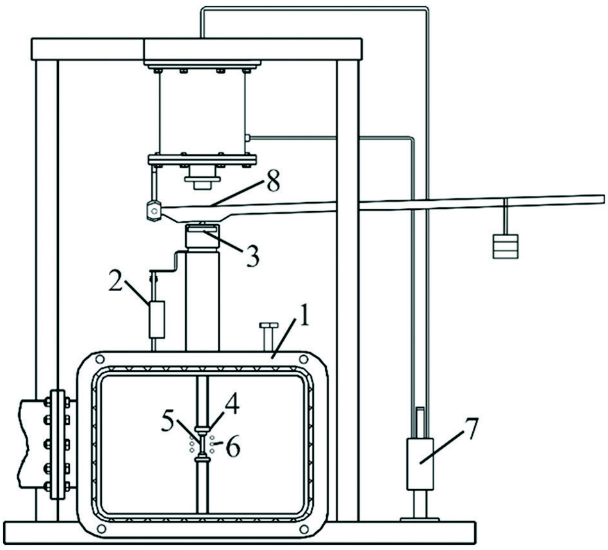
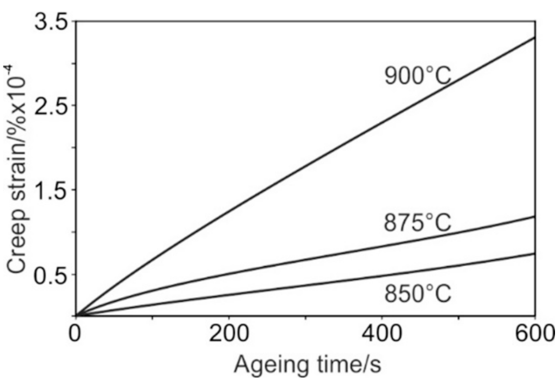


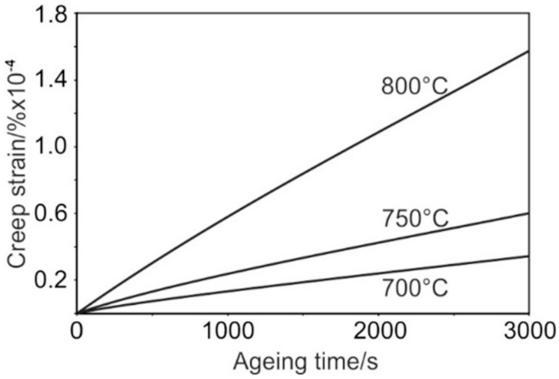
Fig. 2. Scheme of detectors location and the tested sample on the modernized unit IDWV-TP: 1 – a vacuum operational chamber; 2 – a detector of shifting (LIR-14.00PS11); 3 – a detector of loading (RTN C3/1t); 4 – ceramized plates or ceramic; 5 – a sample for testing; 6 –a heating installation (inductor); 7 – a hydraulic pump; 8 – a lever mechanism of loading.

IDWV-TP unit is equipped with the system of automatic support of the specified temperature of type TRM-251 and high-precision detectors of shifting and loading LIR-14.00PS11 and RTN C3/1t type, accordingly, with possibility of control and recording of the process on the PC hard disc. The heating is executed by the use of the high frequency current with the power of sources which equals up to 60 kW. The accuracy of the shifting measurements is 1±0.2 μm at the loading of 0.1 H. This unit has two loading mechanisms: a lever mechanism for the loading consistency and a hydraulic mechanism.

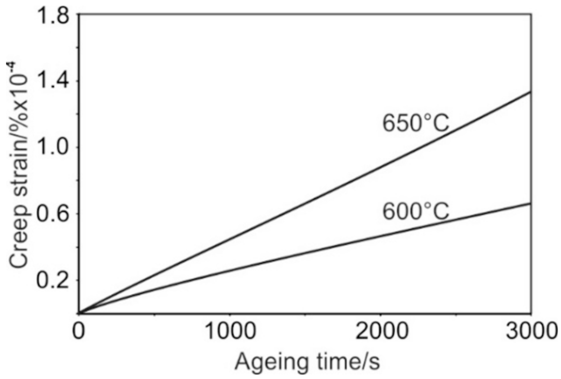
The tests were carried out at a constant compression load.The equations of creep speed are the same at testing with constant load and stress as it is shown in works [9-11]. When using temperature small jumps method [9] the relation of the creep speeds just before and after temperature change should be used. The experimental creep curves for Kovar alloy are shown in Fig. 3.



(a) creep curves at compression pressure which equals to 20 MPa



(b) creep curves at compression pressures which equal to 25 MPa



(c) creep curves at compression pressures which equal to 80 MPa

Fig 3. The experimental creep curves for Kovar.

The deformation at the first and at the second stage of creep is described by the «Combined Time Hardening» equation:

$$\varepsilon = C_1 \cdot p^{C_2} \cdot \frac{t^{C_3+1}}{C_3+1} \cdot \exp\left(-\frac{C_4}{T}\right) + C_5 \cdot p^{C_6} \cdot t \cdot \exp\left(-\frac{C_7}{T}\right), \quad (1)$$

Where $C_1 \ldots C_7$ –are the coefficients, which are identified on the experimental creep curves, and $C_1>0$; $C_5>0$; $C_4=(\Delta H_{n(1)}/R)$; $C_7=(\Delta H_{n(2)}/R)$; $C_2=m_{(1)}$; $C_6=m_{(2)}$; the indices 1 and 2 at ΔH_n and m_1 relate to the first stage of creep , and m_2 – relate to the second stage of creep.

The temperature small jumps method [9] had been executed for the definition of the creep activation energy ΔH_n:

$$\Delta H_n = \frac{RT_1T_2}{T_2 - T_1} \ln \frac{\dot{\varepsilon}_2}{\dot{\varepsilon}_1}$$

from the creep speed equation at the steady-state stage:

$$\dot{\varepsilon} = Bp^m \exp\left(-\frac{\Delta H_n}{RT}\right),$$

where, $\dot{\varepsilon}_1$– a creep speed at temperature T_1; $\dot{\varepsilon}_2$ – a creep speed at the same stress after temperature increase up to T_2; R – the universal gas constant; p – a creep stress; B, m – the parameters of the material creep.

The tests were executed at the constant load. In this case the steady state creep speed $\dot{\varepsilon}$ is connected with the stress p by this equation [12]:

$$\dot{\varepsilon} = B_1 p^m,$$

where B_1, m – are the constants.

In the range from 600 to 900 °C temperature and from 20 to 25 MPa pressure, the received creep activation energy value is ΔH_n = 262 kJ/mol, in the range from 600 to 650 °C temperature and from 80 to 85 MPa pressure, the activation energy equals ΔH_n = 250 kJ/mol. It is correlated with the literature data [7].

The experiments were executed at constant load with the increase of temperature from 25 to 30 °C at the range of equal creep mechanisms action, in which B, m are constant.

The parameter m is calculated by the use of the equation:

$$m = \frac{\lg\dot{\varepsilon}_1 - \lg\dot{\varepsilon}_2}{\lg p_1 - \lg p_2}.$$

The parameter B is calculated from the creep speed equation at the steady-state stage.

The constant m at 20–25 MPa pressure and 80–85 MPa pressure equals to 4.55 and 4.9, accordingly. It is also in accordance with the works [7].

Another coefficients of the equation (1) were calculated from some creep curves at different temperatures and stresses and by the use of the high-temperature creep equation with the use of the Defined Material Models Behavior addition of Software ANSYS complex (the 10th version). Kovar precise alloy creep coefficients for the equation (1) are shown in Table 1.

Table 1. Kovar coefficients for the creep equation (1)

T,°C; (P, MPa)	C_1	C_2	C_3	C_4	C_5	C_6	C_7
900; (20)	2.30e-29	4.55	-0.274	26200	1.11e-29	4.55	26200
875; (20)	3.56e-29	4.55	-0.334	26200	3.06e-30	4.55	26200
850; (20)	9.80e-30	4.55	-0.355	26200	8.05e-30	4.55	26200
800; (25)	3.54e-30	4.55	-0.470	26200	4.67e-30	4.55	26200
750; (25)	2.58e-29	4.55	-0.460	26200	4.67e-30	4.55	26200
700; (25)	4.76e-29	4.55	-0.450	26200	1.00e-29	4.55	26200
650; (80)	2.68e-34	4.90	-0.390	25000	4.52e-34	4.90	25000
600; (80)	2,96e-33	4.90	-0.400	25000	9.55e-34	4.90	25000
850-875; (20)	1.81e-29	4.55	-0.167	26200	2.00e-30	4.55	26200
750-800; (25)	1.52e-30	4.55	-0.180	26200	4.85e-30	4.55	26200

The received results were used for modeling of the electron beam guns pressure seals metal-ceramic joint SSS, which are used in welding and covering equipment. It allowed to increase their operating capacity and to develop the technology of brazing with the controlled SSS in Ukraine [4,8].

Conclusion. Kovar precise alloy creep curves are received by the experimental methods from which the coefficients for the equation were received for the description of the first and the second stages of the creep depending on the cooling. They are used for the pressure seals unit SSS modeling. It allows to develop their production technology with higher operating properties comparing with the foreign analogs.

მექანიკა

კოვარის ზუსტი შენადნობის ცოცვადობის მრუდების შესწავლა დაძაბულ-დეფორმირებული მდგომარეობის მოდელირებისათვის

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**ადმირალ მაკაროვის სახ. გემთმშენებლობის ეროვნული უნივერსიტეტი, საშემდუღებლო დეპარტამენტი, მიკოლაივი, უკრაინა*
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კვლევის მიზანი იყო **29NK** ზუსტი შენადნობის (კოვარის) ფიზიკურ-მექანიკური თვისებებისა და ცოცვადობის პარამეტრების განსაზღვრა წირითი სითბური გაფართოების მოცემული კოეფიციენტით დაძაბულ-რეფორმირებული მდგომარეობის მოდელირებისათვის რჩილვისა და დიფუზიური შედუღების პირობებში. ფიზიკურ-მექანიკური თვისებების კვლევა ჩატარდა ფირმა **DSI**-ის საცდელი კომპლექსის **„Gleeble 3800“**-ის საფუძველზე. აქტივაციის ენერგია და ცოცვადობის მრუდები გამოკვლეულ იქნა გაუმჯობესებული **„IDWV-TP“**-ის დანადგარის მეშვეობით. თავდაპირველად, ცოცვადობის აქტივაციის ენერგია განისაზღვრებოდა მცირე ტემპერატურის ნახტომის მეთოდით, რაც გარკვეულ შუალედში იცვლება კოვართან ახლოს მდგომი ლითონებისა და შენადნობებისთვის. ეს კი საშუალებას გვაძლევს განვსაზღვროთ ექსპერიმენტის სიზუსტე. შემდეგ, ცოცვადობის აპროქსიმაციული განტოლების გამოყენებით განისაზღვრა ცოცვადობის დანარჩენი პარამეტრები ცდების სერიიდან სხვადასხვა ტემპერატურისა და წნევის პირობებში პირველ და მეორე ეტაპზე ცოცვადობის დეფორმაციის (**Combined Time Hardening**) გათვალისწინებით. განსაზღვრულ იქნა კოვალის ზუსტი შენადნობის ფიზიკურ-მექანიკური თვისებების დამოკიდებულება ტემპერატურაზე წნევით მაღალტემპერატურული რჩილვისა და დიფუზიური შედუღების პირობებში. ეს შესაძლებელს ხდის გადაიჭრას წნევის სარქველების დაძაბულ-

დეფორმირებული მდგომარეობის კომპიუტერული მოდელირების პრობლემა ცოცვადობის კოეფიციენტების გათვალისწინებით. ჩატარებული კვლევების შედეგები გამოყენებულ იქნა ლითონკერამიკული ერთეულების დამზადების ტექნოლოგიის განსავითარებლად, რომელთაც ანალოგებთან შედარებით უკეთესი საექსპლუატაციო თვისებები აქვთ. განსხვავებული მასალებისგან დამზადების ტექნოლოგიის შემუშავების საწყის ეტაპზე, მყისიერი პლასტიკური დეფორმაციისა და ცოცვადობის გათვალისწინებით კვანძის კომპიუტერული მოდელირების გამოყენებით და კონტროლირებად დაძაბულ-დეფორმირებულ მდგომარეობაში წნევით მაღალტემპერატურული რჩილვისა და დიფუზიური შედუღების მეთოდით შესაძლებელია თანმხლები მატერიალური ხარჯების შემცირება.

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