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ACCELERATED CREEP TESTS OF ALL-WELDED METALS

POSPEŠENI PRESKUSI LEZENJA ČISTIH VAROV

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The results of accelerated small-punch creep tests (SPCTs) and conventional constant-load uniaxial creep tests carried out on T/P24 all-welded steels have shown that the SPCT is an appropriate testing methodology for the identification of a material's creep properties. A comparison of creep-testing results using the Larson-Miller parameter (*LMP*) confirmed that both testing methods give similar results over a wide range of testing-times-to-rupture. The basic idea of applying new types of T/P24 welding electrodes is to produce welded joints without any post-weld heat treatment. New types of welding consumables give softer all-weld metals with a higher initial toughness. This should result in satisfactory stress accommodation during welding and during the initial stages of exploitation.

Key words: T/P24-type weld metal, accelerated creep tests, small punch

Rezultati pospešenih preskusov lezenja na napravi z majhnim batom (SPCTs) in na navadni eno-osni napravi za lezenje pri konstantni obremenitvi na čistem varu iz jekla T/P24 so pokazali, da je SPCT primerna preskusna metoda za identifikacijo lastnosti lezenja materiala. Primerjava rezultatov lezenja z uporabo Larson-Millerjevega parametra (*LMP*) je potrdila, da obe preskusni metodi dasta podobne rezultate v širokem območju preskusnih časov do loma. Uporaba novih tipov varilnih elektrod T/P24, ki dajo mehkejši čisti var z višjo začetno žilavostjo, je osnovna ideja varjenja spojev brez kakršne koli toplotne obdelave. Med varjenjem in v začetni fazi uporabe naj bi tako narejeni varjeni spoji zadovoljivo prenašali napetosti.

Ključne besede: varilni material T/P24, pospešeni preskusi lezenja, majhni bat

1 INTRODUCTION

Reducing the consumption of energy by improving the efficiency of thermal power plants has become an important issue in the development of modern materials. Advanced power plants need to use higher working temperatures and higher steam pressures, and this requires materials with superior properties that can operate under such conditions [1,2]. The creep properties of new weld metals for high-temperature applications, i. e., for the welded components of power plants with higher steam temperatures and pressures, are extremely important. These materials exhibit a pronounced change in their microstructure during exposure to high-temperature service conditions, which determines their remnant creep life. The T/P24 steel is a new European advanced low-alloy creep-resisting steel that has little creep-rupture data, especially for weld metal and welded joints. And although T/P24 steel has been mainly promoted for tubing (T24), there is considerable interest in exploiting it for piping (P24) with thicker walls [3]. Experience has shown that the first cracks always appear in the welded joints [4-6]. Therefore, one of the characteristics of a T/P24 weld should be an ability to effectively accommodate residual stresses during welding and during the early stages of use in order to reduce the risk of cracking, enabling new "cold" repair and fabrication applications without a costly post-weld heat treatment (PWHT). It is anticipated that new T/P24 weld metals would exhibit improvements in terms of toughness and stress-relaxation properties that are specifically required for cold welding.

The aim of this study was to use the results obtained in accelerated conventional uniaxial constant-load creep tests and with the SPCT technique to evaluate the creep properties of weld metal based on the T/P24 steel composition with and without a PWHT.

The SPCT method was originally developed for estimating the fracture-appearance transition temperature of the equivalent fracture strain and fracture toughness [7-9]. In the past decade, small-punch testing has been extended to include high-temperature creep testing [10-14]. In the small-punch test, a thin circular disc is supported over a receiver hole and forced to deform into the hole by a spherical penetrator. When the evaluation of the observed dependence of the minimum displacement rate on stress and temperature was performed, these authors found that the load exponent and the measured activation energy were typical of those obtained in conventional uniaxial constant-load creep tests.

2 EXPERIMENTAL PROCEDURE

T/P24 low-alloyed-type flux-covered manual metal arc welding electrodes were used for the experiments. The undiluted all-weld metal chemical composition of the experimental consumables is shown in **Table 1**. The T/P24-type weld metal was tested in two conditions:

Table 1: Chemical composition of the T/P24 all-weld metal in mass fraction, *w* /%
Tabela 1: Kemična sestava masnih deležev čistega vara T/P24, *w* /%

C	Si	Mn	P	S	Cr	Mo	V	Ni	Ti	B	Nb	N
0.043	0.3	0.57	0.01	0.007	2.62	0.9	0.2	0.03	0.008	0	0.006	0.002

Table 2: Mechanical properties of the T/P24 all-weld metal at different temperatures
Tabela 2: Mehanske lastnosti čistega vara T/P24 pri različnih temperaturah

Material	Test temperature T /°C	Yield stress $R_{p0,2}$ /MPa	Tensile strength R_m /MPa	Elongation Δl /%	Reduction of area ΔA_r /%	Hardness HV3
T/P24 (as-welded)	20	725	841	19	65	299
	500	626	720	15	62	
	620	450	471	19	68	
T/P24 (PWHT)	20	547	648	22	72	212
	500	451	471	20	73	
	620	313	323	22	83	

- In the as-welded condition, without any heat treatment after welding,
- With a PWHT after welding (690 °C, 2 h; 150 °C/h to 400 °C, cooling in air).

A series of standard Charpy-V impact tests was performed on specimens from the all-welded T/P24 steel at different test temperatures in order to determine the transition temperature. The mechanical properties were determined with tensile tests at room temperature and at elevated temperatures (**Table 2**). The SPCT technique was used for creep-rupture measurements with disk-shaped test specimens that were cut from the weld with a diameter of 8 mm and a thickness 0.5 mm. The SPCTs were carried out at temperatures from 580 °C to 640 °C, and at loads from 250 N to 520 N. At least three tests were performed for each testing condition. Besides the SPCT specimens, a conventional constant-load tensile-test specimen was also cut from the all-welded metal, and conventional constant-load creep tests were performed at temperatures between 600 °C and 660 °C and at initial stresses of 60 MPa to 180 MPa.

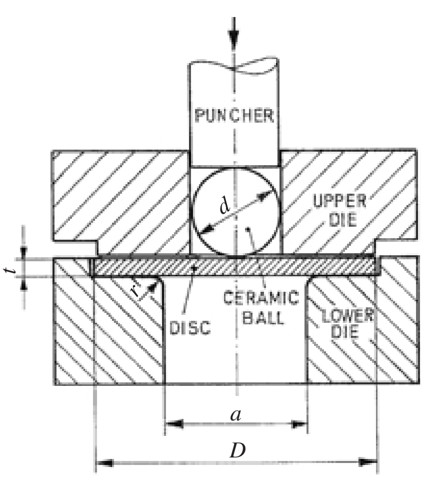

Figure 1: Schematic illustration of the dies in the small-punch creep-test equipment
Slika 1: Shematični prikaz orodja majhnega bata za preskuse lezenja

As shown in **Figure 1**, the small-punch test equipment used is similar to a constant-load cantilever creep machine. The test specimens are placed on the central axis of the lower die of the specimen holder and fixed by the upper die so that there is a loose fitting, i. e., neglecting the friction between the upper die and the specimen. The ball and the puncher are inserted into the hole in the upper die of the holder. The assembled specimen holder is then put into reverting grips and suspended in the creep machine. During the test a constant load acts on the specimen by means of a ceramic ball of diameter d = 2.5 mm. The diameter of the hole, a, is equal to 4 mm, and its shoulder radius, r, is equal to 0.2 mm. The temperature of the specimen is measured by means of a thermocouple positioned close to the specimen. The displacement of the punch, i. e., the central deflection of the disk specimens, is measured using an inductive transducer with a high measuring accuracy (and a repeatability of approximately 1 μm), and is recorded continuously by a computer.

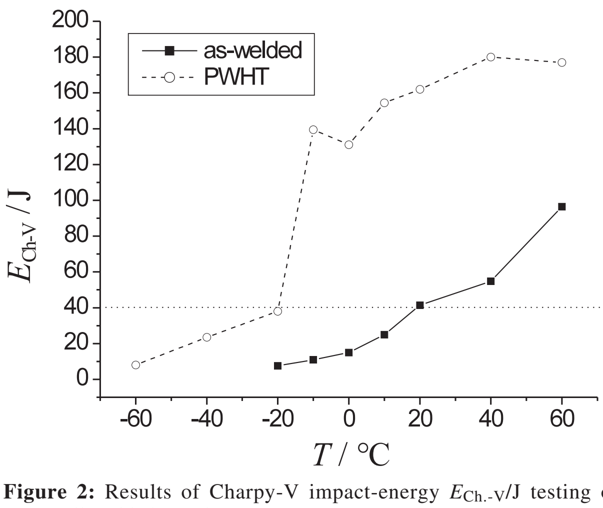

Figure 2: Results of Charpy-V impact-energy $E_{Ch.-V}$/J testing of T/P24 all-welded metal
Slika 2: Rezultati preskušanja Charpy-V udarne energije $E_{Ch.-V}$/J na čistih varih T/P24

3 RESULTS AND DISCUSSION

3.1 Charpy-V impact energy

The evolution of the Charpy-V impact energy of the all-welded metal T/P24 as a function of the test temperature is shown in **Figure 2**. The Charpy-V impact energy of this all-welded metal is higher than 40 J at room temperature, which is the recommended minimum impact energy for cold welding [15]. The cracking of a welded joint produced with such a consumable during welding or during its initial use is not expected. The diagram in **Figure 2** shows that the Charpy-V impact energy of the PWHT all-weld metal T/P24 is much higher than that without a PWHT (in just the as-welded condition), and that it achieves 40 J, even at –20 °C.

3.2 Accelerated small-punch creep-test results

Accelerated creep tests were performed on a small-punch test device. The dependence of the applied load, *P,* on the time-to-rupture, t_r, in the small-punch creep tests can be described by means of a modified form of the Dorn equation, i. e., an Arrhenius-type equation [10]:

$$t_r = B \cdot P^{-n} \cdot \exp\left(\frac{Q}{RT}\right) \qquad (1)$$

where *P* /N is the load acting on the disc, *Q* /(kJ/mol) is the activation energy, *n* is the load exponent, *R* = 8.314 J/(mol K) is the universal gas constant, *T* /K is the absolute temperature and *B* is the constant of the modified Dorn equation.

The small-punch creep tests were performed at loads of (250, 300, 400, 430, 460, 490 and 520) N and temperatures of (580, 600, 620 and 640) °C (to obtain the activation energy, *Q*, and the load exponent, *n*). From the small-punch creep-test results obtained at constant load with at least three different temperatures it is possible to calculate the line slope in the diagram ln t_r vs. 1/*T*, which represents the activation energy, *Q*. In a similar way we can calculate the load exponent, *n* (the line slope in the diagram ln t_r vs. ln *P*) from the creep-test results at constant temperature with at least three different loads. The results are shown in **Figure 3**.

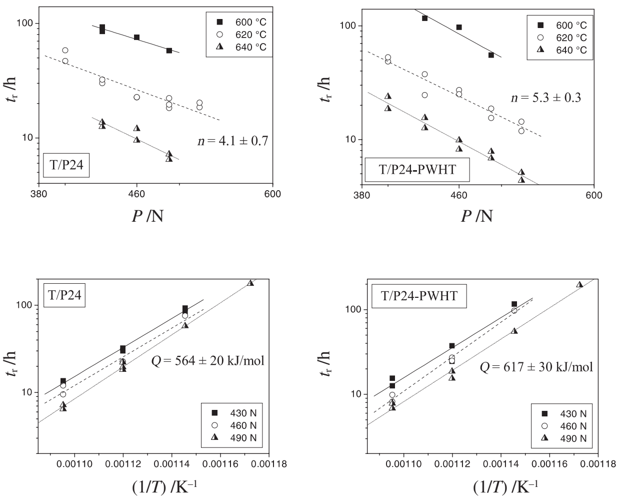

Figure 3: Results of small-punch creep testing of T/P24 all-welded metal, t_r – time to fracture

Slika 3: Rezultati preskusov lezenja z majhnim batom čistih varov T/P24, t_r – čas do loma

From **Figure 3** we can see that the activation energy, *Q*, is somewhat higher for the case of the PWHT of T/P24 (Q = 617 ± 30 kJ/mol) than in the case of the as-welded condition (*Q* = 564 ± 20 kJ/mol), and the load exponent, *n,* is also higher in the case of the PWHT (*n* = 5.3 ± 0.3) than in the case of the as-welded condition (*n* = 4.1 ± 0.7). However, we can say that both values for the activation energy, *Q,* and for the load exponent, *n*, are very close to each other.

3.3 Accelerated conventional constant-load creep tests

In parallel with the small-punch creep tests we have also performed conventional constant-load creep tests at testing temperatures of (600, 620 and 660) °C and with initial stresses of (60, 80, 100, 130, 160 and 180) MPa. The creep-test results are shown in **Table 3**.

Table 3: Results of conventional constant-load creep tests

Tabela 3: Rezultati konvencionalnih preskusov lezenja pri konstantni obremenitvi

Testing parameters	T/P24	T/P24 PWHT
600 °C / 130 MPa	/	499 h
600 °C / 180 MPa	210 h	93 h
620 °C / 100 MPa	698 h	532 h
620 °C / 130 MPa	242 h, 306 h	211 h, 287 h
620 °C / 160 MPa	153 h	81 h
660 °C / 60 MPa	405 h	360 h
660 °C / 80 MPa	159 h	138 h

3.4 Evaluation of accelerated creep test results

The results of the creep-rupture measurements obtained with different testing parameters can be expressed using a Larson–Miller-type aging parameter (*LMP*), which is the most widely used parameter for describing creep-rupture data. The *LMP* is expressed as follows:

$$LMP = (T + 273) \cdot (C + \lg t_r) \cdot 10^{-3} \qquad (2)$$

Where *T* is the test temperature (in degrees Celsius), t_r is the time-to-rupture (in hours) and *C* is a constant (*C* = 20).[15]

All the creep-rupture data for the all-welded metal T/P24 in two different conditions, i. e., with and without a PWHT, obtained with small-punch and conventional constant-load devices, are converted to a *LMP* and plotted on a single graph, either against the applied load *P* (small-punch creep-test data) or against applied stress σ (uniaxial creep-test data) in **Figure 4**. It is clear that the rupture strengths of both kinds of creep tests conducted at various temperatures are well characterized by a straight line using the *LMP*. It was confirmed once

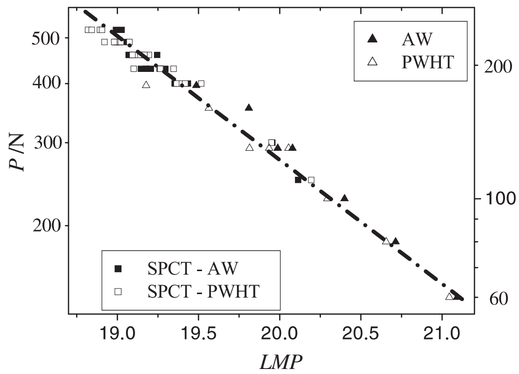

Figure 4: The creep rupture data of SPCT and conventional constant-load creep testing of T/P24-type weld metal expressed with *LMP*

Slika 4: Rezultati časov do loma pri lezenju čistih varov T/P24 na napravi z majhnim batom in na konvencionalni napravi pri konstantni obremenitvi izraženi z *LMP*

again [16] that during the accelerated creep measurements the load, *P* /N, applied during the small-punch creep testing has to be approximately 2.1 times larger than the stress, σ /MPa, applied during uniaxial constant-load creep testing with the same time-to-rupture.

4 CONCLUSIONS

We have investigated the possibilities of using the accelerated small-punch creep-testing (SPCT) method for the assessment of the creep properties of as-welded material. The main advantage of SPCTs in comparison with conventional constant-load creep tests is the small amount of material required for testing to establish the creep activation energies and the load exponents of the investigated material. We have found that SPCTs on small-scale test specimens were successfully applied for characterizing the creep resistance of T/P24 all-welded metal in the as-welded condition as well as in the PWHT condition.

It was determined that the examined T/P24-type weld metal was more creep resistant during accelerated creep tests if, after welding, there was no PWHT. However, the difference is not large. At longer times-to-rupture during conventional uniaxial constant-load creep testing, very similar results for the rupture times in the as-welded condition and for the PWHT condition were found. So we can conclude that according to the accelerated creep-test results of the investigated T/P24-type weld metal, no PWHT of the welded metal is required. The toughness at room temperature is high enough for cold welding (>40 J) and the creep resistance of the welded metal is almost the same in the as-welded condition as in the PWHT condition.

A comparison of the creep-testing result using the Larson–Miller parameter confirmed that for similar rupture times during accelerated creep tests, the load, *P* /N, for small-punch testing should be 2.1 times larger than the stress, σ /MPa, for uniaxial creep-testing.

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