COMPARABILITY OF RESULTS VIA THE MINIATURISED SMALL PUNCH CREEP TEST METHOD AND TRADITIONAL UNIAXIAL CREEP TESTING

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ABSTRACT

The Small Punch (SP) test technique is capable of generating tensile, toughness and creep strength data from very small specimens. The ability to sample test material from large components almost non-destructively is accelerating the interest in SP by industry utilising such plant, in particular in the energy sector. An SP creep test Round Robin on a 1CrMoV rotor steels was organised within the EPERC network, primarily in order to contribute to the harmonisation of the test procedure for this new emerging method. In this presentation, the results of those SP creep tests performed at several temperatures and at one load level (i.e. almost equivalent to the so called "iso-stress" method for the corresponding uniaxial tests) are analised in order to check the comparability to uniaxial creep test results. A value of the activation energy Q_{SP} = 316 KJ/mol was obtained from the SP tests, quite similar to typical value of 330 KJ/mol in uniaxial testing. Moreover, the best fitting line trough the SP test results in a temperature vs time diagram was found consistent with the Arrhenius type line for the uniaxial condition. A standardisation initiative for the SP test method, including creep as well as low temperature testing for the determination of tensile and toughness properties of metallic materials, has been recently started via a CEN Workshop route.

1 INTRODUCTION

The Small Punch (SP) testing method is a miniaturised testing technique (Manahan [1] and Mao [2],) for the determination of mechanical properties in local areas of components. The main advantages of this test method, using small disk shaped specimens, punched in the centre of the flat plane, are that the material sampling operation removes only a modest amount of material (Foulds [3], Bicego[4] & [5]) from the component surface and in most cases no repair is needed afterwards. Also the test itself is rather simple to perform and inexpensive. Finally the investigated region is at the very surface of the component. For these reasons it promises to be a convenient tool for residual life analysis of high temperature components. In addition it is a valuable instrument for investigating local zones, such as HAZ in weldments, coating layers etc.

Following a questionnaire distributed to several EPERC (European Pressure Equipment Research Council) members, interested in this test method, a number of laboratories volunteered to participate in a SP Round Robin (Bicego [6]) consisting of high temperature creep tests on disc specimens, Figure 1. The participating labs were CESI in Italy, Cracow Techn. University in Poland, JRC-Inst of Energy of EC in The Netherlands, and The University of Wales at Swansea in UK (labelled UWS in Figure 1). The test material was a 1CrMoV turbine steel supplied by National Power, UK. It was decided that, although the SP technique could also be applied for fracture mechanics tests as well, the EPERC Round Robin would be limited to creep tests only.

The Round Robin was organised primarily in order to contribute to the harmonisation of the test procedure for this new emerging method. Two types of puncher ball radius were used, 2.0 and 2.5 mm, however all the results were successfully correlated on a single trend via suitable equivalent SP stress definitions proposed in the literature (Maile [7], Dobes [8]). Moreover the different clamping forces in the participating labs equipments were found to have negligible effect on test results. Main findings with a full discussion on interpartners comparability of SP results were reported by Bicego [6].

2 SP EXPERIMENTAL

The results of the SP creep tests performed at several temperatures and at one load level (i.e. almost equivalent to the so called “iso-stress” method for the corresponding uniaxial tests) showed a consistent curve of temperature vs. creep life data, i.e. limited scatter among the test laboratories: Figure 1. The significance of this interlaboratory agreement should be considered as an indication that the SP method in the “iso-load” procedure is therefore robust, and ready for industrial use for residual life analyses of components. However, the comparability of the SP iso-load curve to creep results from the traditional uniaxial creep tests needs to be verified, before SP data might find such application to residual life studies.

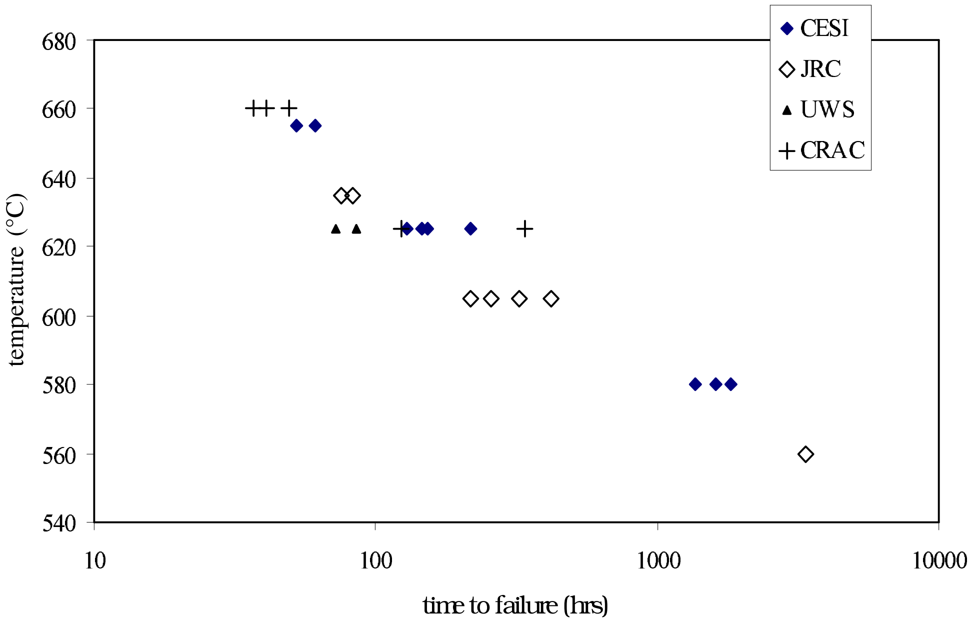

Figure 1: The Small Punch creep test results

At the time when SP test programme was decided, the following practical criterion was used, based on actual information from a 1-D creep test programme on that same steel, which was ongoing independently at the time when the SP testing was carried out :

$$F_{SP}/\sigma_{SP} = 1.5 \tag{1}$$

where F_{SP} is the load on the disk in the SP test, and σ_{SP} is the SP equivalent stress (also interpreted as the membrane stress), which may be defined as (Maile [7]):

$$F_{SP}//\sigma_{SP} = [\ \pi\ t\ (D + t)\ \sin\Phi]\ \sin\Phi \tag{2}$$

Here F_{SP} is the load on the disk, σ_{SP} is the equivalent SP stress, namely the stress which would cause rupture on a uniaxial cylindrical specimen occurring at the same value of time to failure as for the SP specimen, and $\sin\Phi$ is a measure of SP deflection during the main part of the SP test ($\sin\Phi$ is an empirical parameter, possibly a constant for each material class where $\sin\Phi$ is the angle between the load axis and the normal to the specimen surface at the point of inflection). Indeed, the intention in the SP testing was to apply 200 MPa in all tests: therefore $F_{SP} = 300$ N.

3 ANALYSIS

3.1 Activation energy

The best fit (Arrhenius type) equation to the SP creep results in Figure 1 is evaluated as:

$$1/(T+273) = 2.63\ 10^{-5} \ln t_{R,SP} + 9.83\ 10^{-4} \quad (3)$$

The SP tests, carried out at 300N/200MPA, were in the range of temperatures (T) from 655°C to 580°C. Eqn (3) can now be rearranged, in order to show a temperature dependency via a Small Punch activation energy parameter Q_{SP}: it is therefore found $Q_{SP} = 316$ KJ/mol. Quite interestingly, previous work on this steel class had given Q of 330 KJ/mol in conventional uniaxial testing.

3.2 Comparison of SP and uniaxial creep strengths

The SP isoload data set should also be compared with the corresponding uniaxial (1D, one – directional) creep test information from an isostress/isoload data set. Unfortunately, no such 1D data, at the appropriate load level, were available. At least however, from an independent uniaxial creep test acyivity carried out by the University of Swansea for this material, at T = 575° and with different levels of the stress, the results shown in Table 1 and Figure 2 were available.

Table 1: The 1D creep data for the 1CrMoV rotor steel

Stress MPa	Temp C	Time to fracture hrs	Fracture elongation %
240	575	98	22
223	575	244	22
210	575	973	16
190	575	4877	15
172	575	interrupted at 9655 hrs 8301 hrs estim. from Monkman-Grant	not av. 1.3x10-6/hr min. creep rate
143	575	interrupted at 10170 int. 46994 hrs estim. from Monkman-Grant	not av. 4.4x10-7/hr min. creep rate

By extrapolating (slightly) down to 575°C the best fit eqn.3 to the SP results, the time to rupture t_R for the mini-disk specimens at the quivalent stress condition of 200 MPa and at 575°C is obtained as: $t_{R/SP,200} = 1740$ hrs.

From the 1D results shown in Figure 2 the best fit along the linear portion of the curve provides:

$$\sigma_{1D} = 316.8\ t_R^{-0.0613} \quad (4)$$

which then allows the determination of the uniaxial rupture life at 200 MPa and 575°C: $t_{R/1D,200}$

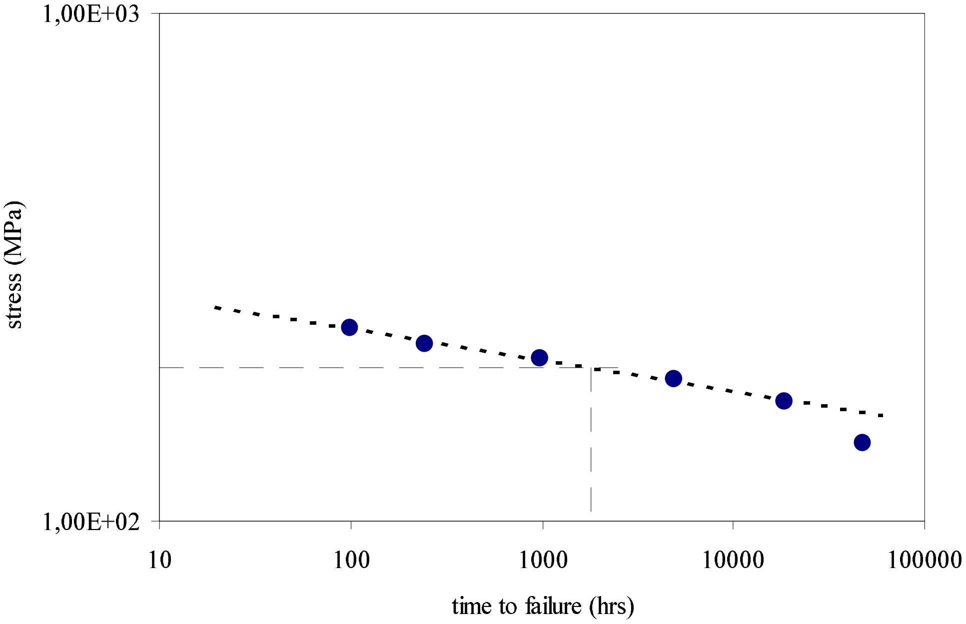

Figure 2: The uniaxial creep test results at T = 575°C

= 1814 hrs.

These two values of time to rupture, 1814 and 1740 hrs, distincly obtained from 1D and SP creep testing activities, referred to the same condition of 575°C and 200 MPa, are clearly in substantial agreement.

3.2 Comparison of SP and uniaxial creep strengths

In Figure 3 the SP creep results are shown together with the SP Arrhenius fit; a corresponding uniaxial Arrhenius curve fitted to the condition 575°C & 1814 hrs as evaluated above, and with the slope defined by the uniaxial value for the activation energy Q = 330 KJ/mol as previously described, is superimposed too. It is clear here again that the two types of information, SP and 1D, are fully consistent.

4 ACKNOWLEDGEMENTS

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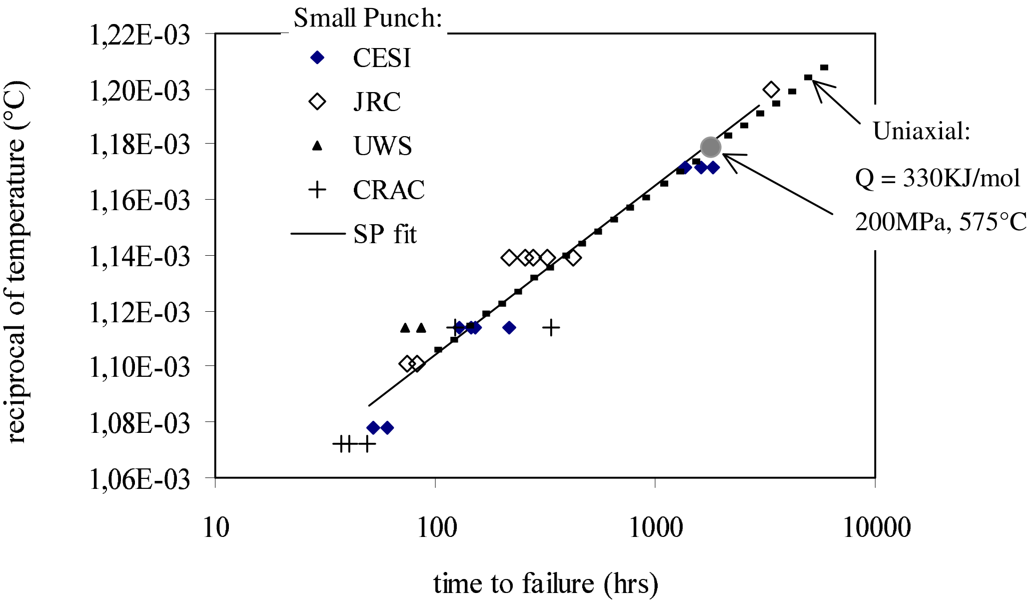

Figure 3: SP (data and fit) vs uniaxial creep behaviour

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