An Overview of Small Specimen Creep Testing

T. H. Hyde, W. Sun and C. J. Hyde

Abstract In this paper, some commonly used small specimen creep testing methods, including sub-sized uniaxial creep testing, impression creep testing, small punch creep testing, small ring creep testing and small two bar creep testing, are briefly reviewed. Firstly, the reference stress method and the concept of equivalent gauge length (EGL) are described; these form the basis for processing and interpreting the data from small specimen creep tests. Then, the performance and capability of each of these small specimen creep test techniques are discussed and their relative advantages and limitations, for specific practical applications, are assessed. In particular, the suitability of each of the methods for determining "bulk" material properties is described and it is shown that an appropriate test type can be chosen for each particular case. Typical examples of the application of the small specimen creep test methods, in determining creep deformation and rupture life data, are given. Finally, the future possibilities for the exploitation of small specimen creep test techniques are briefly considered.

1 Introduction

Power plants and chemical plants may operate at elevated temperatures for extended periods of time, e.g. more than 30 years. During this time, the material used in the construction of the plants degrades and the creep strength of the material reduces. NDT and small specimen test techniques are used to sample and test the material. For this reason, various small or miniature specimen test methods have been developed and used (e.g. [1]). For example, small punch tests (e.g. [2, 3]), which can be performed at room and elevated temperatures, have been used to obtain the elastic-plastic and creep behaviour of some materials. Alternatively, test methods such as the impression creep test and the small ring creep test methods [4–7], the latter of

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which is suitable for testing highly creep resistant materials [7], have been developed and used to determine the secondary creep behaviour of materials. The latest work on small specimen creep testing involves the development of specimen types which are suitable for obtaining creep rupture data (e.g. [8]). The small test specimens used for these types of tests can be obtained from small button-shaped (scoop) samples (∼25 mm in diameter and 2–4 mm in thickness), which are removed, for example, by a non-destructive sampling technique [9].

Small specimen creep testing has become increasingly attractive because some power plant components are now operating beyond their original design life, and economic, "non-invasive" and reliable testing techniques are required when performing remaining life evaluations (e.g. [10, 11]). The ability to measure creep properties from a small volume of material has the potential to, rapidly and economically, support the development of new high temperature, exotic alloys (e.g. [12]). Also, data from small volumes of materials have a direct input into remaining life and ranking studies [5, 13], thereby improving the accuracy of plant/component life prediction. Such data can be used to generate creep constitutive laws for weld materials and for local structures generated during the welding process (e.g. [14, 15]). However, each of the specimen types has its own unique advantages and disadvantages and it may not always be obvious which one is the most appropriate test method to be used for a specific application.

This paper contains an overview of small specimen creep testing methods, their practical applications and the requirements for future development of small specimen creep testing techniques.

2 Theoretical Basis for Data Correction

2.1 Creep Deformation and Reference Stress Method (RSM)

In general, the principle of converting the non-conventional, small specimen creep test data to the corresponding uniaxial data is based on the inverse application of the reference stress method. For some components and loading modes, it is possible to obtain analytical expressions for steady-state creep deformation rate, (e.g. [16–18]). For components made from a material obeying Norton's power law, i.e., the general form of the solution is:

$$\dot{\Delta}_{ss} = f_1(n) f_2(dimensions) B\sigma_{nom}{}^n \tag{1}$$

where $f_1(n)$ is a function of the stress index, n, f_2(dimensions) is a function of the component dimensions and σ_{nom} is a conveniently determined nominal stress for the component and loading.

$$\dot{\Delta}_{ss} = \frac{f_1(n)}{\alpha^n} f_2(dimensions) B(\alpha\sigma_{nom})^n \quad (2)$$

Choosing α (= η) so that $f_1(n)/(\eta)^n$ is independent (or approximately independent) of n, then Eq. (2) can be further simplified to:-

$$\dot{\Delta}_{ss} \approx D\dot{\varepsilon}^c(\sigma_R) \quad (3)$$

where D is the so-called reference multiplier [$D = (f1(n)/(\eta)^n) f_2(dimensions)$] and $\dot{\varepsilon}^c(\sigma_R)$ is the creep strain rate obtained from a uniaxial creep test at the so-called reference stress, σ_R (= $\eta\sigma_{nom}$). The reference multiplier, D, has units of length, and can generally be defined by $D = \beta d$, where d is a conveniently chosen "characteristic" component dimension. Therefore, if the values of η and β are known, for the known loading mode and component dimensions, the corresponding equivalent uniaxial stress can be obtained from the expression $\sigma_R (= \eta\sigma_{nom})$, and the corresponding.

2.2 Determination of Reference Parameters

If an analytical solution can be obtained, substituting two values of n into the expression $f_1(n)/\eta^n$ and equating the two resulting expressions allows the value of η to be determined. Hence, σ_R (= $\eta\sigma_{nom}$) and D can be obtained. This approach was proposed by MacKenzie [19]. However, analytical solutions only exist for a small number of, usually, relatively simple components and loadings.

If, for example, computed solutions, using the finite element method, are obtained for a creep problem, for several n values, but keeping all other material properties, loading and component dimensions the same, then σ_R can be obtained. This is done by guessing several values of α, normalising the steady-state value of displacement rate, $\dot{\Delta}_{ss}$, with respect to $B(\alpha\sigma_{nom})^n$ and hence finding the value of α which renders $[\dot{\Delta}_{ss}/(B(\alpha\,\sigma_{nom})^n)]$ independent of n (i.e. $\alpha = \sigma_R = \eta$). This process is most easily visualised by plotting $\log[\dot{\Delta}_{ss}/(B(\alpha\sigma_{nom})^n)]$ against n, for various values of α, as illustrated in Fig. 1. It can be seen that the straight lines produced, using all of the α values, have approximately the same intercept on the log axis. This intercept is equal to the logarithm of the reference multiplier, D.

2.3 Equivalent Gauge Length (EGL)

For a conventional uniaxial creep test, the creep strain at a given time is usually determined from the deformation of the gauge length (GL). If the gauge length elongation is Δ^c and the elastic portion is neglected, then

$$\varepsilon^c \approx \frac{\Delta^c}{GL} \quad (4a)$$

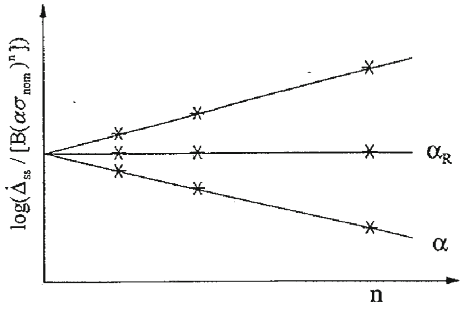

Fig. 1 Schematic diagram illustrating a method which can be used to obtain reference parameters from FE analysis

For non-conventional small specimen creep tests, an equivalent gauge length (EGL) [6, 7] can be defined, if the measured creep deformation can be related to an equivalent uniaxial creep strain, in the same form as that of Eq. (4a), i.e.

$$\varepsilon^c \approx \frac{\Delta^c}{EGL} \tag{4b}$$

The EGL is related to the dimensions of the specimen and in some cases may be related to the time-dependent deformation of the test specimen. The creep strain and creep deformation given in Eq. (4b) may be presented in a form related to the reference stress, σ_R, i.e.

$$\varepsilon^c(\sigma_R) \approx \frac{\Delta^c}{D} \tag{5}$$

in which D (= βd) is the reference multiplier, which is, in fact, the EGL for the test. In some cases, the geometric changes, which occurs due to the time-dependent deformation of the component, are small (e.g. for impression creep tests), and in such cases, the effects of geometric changes on D (EGL) can be neglected.

3 Small Specimen Creep Testing Methods

3.1 Sub-Sized Uniaxial Creep Test

"Conventional", sub-sized, "uniaxial" specimens (e.g. [20]), Figs. 2a and 3a, have been used for creep testing. Small cylindrical specimens, typically 1.2–3 mm in diameter, were electron beam welded onto conventional end pieces. Data obtained were compared with those of conventional full size creep tests; the two sets of data compared very favourably. Provided grain sizes are not too large, specimen diameters as small as 1 mm can be used to produce "bulk" material creep properties. Small

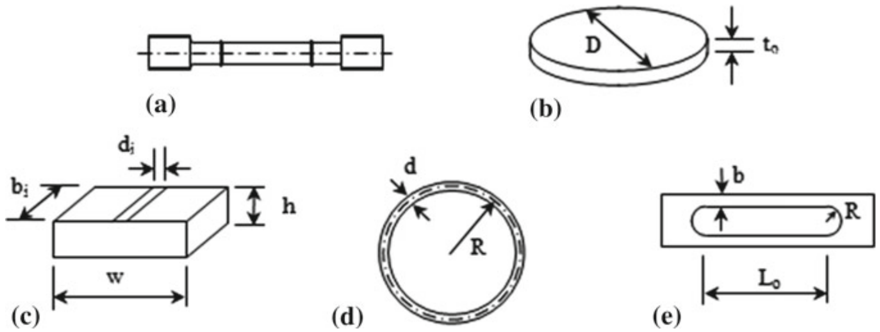

Fig. 2 Small creep test specimens: **a** Sub-size uniaxial specimen (GL $\approx$ 5–12 mm; $d_{GL} \approx$ 1–3 mm); **b** SPT specimen (D $\approx$ 8 mm; $t_o \approx$ 0.5 mm); **c** ICT specimen ($w = b_i \approx$ 10 mm; $d_i \approx$ 1 mm; h $\approx$ 2.5 mm); **d** SRT specimen (R $\approx$ 5 mm, d $\approx$ 1 mm and depth $b_o \approx$ 2 mm); and **e** TBT specimen ($L_o \approx$ 5–10 mm; b $\approx$ 1–2 mm; R $\approx$ 2–3 mm; thickness d $\approx$ 1–2 mm)

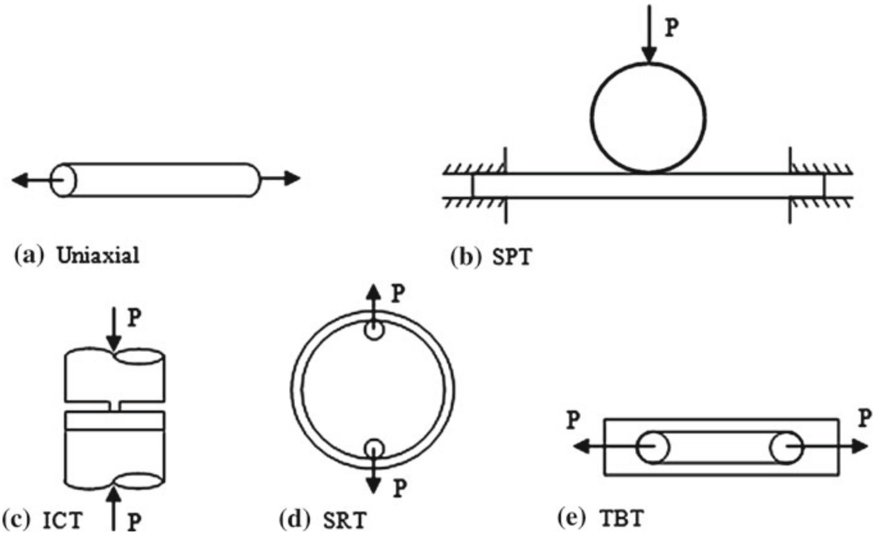

Fig. 3 Schematics diagrams showing the small specimen loading arrangements: **a** Uniaxial; **b** SPT; **c** ICT; **d** SRT; and **e** TBT

gauge lengths (<10 mm) can significantly reduce strain measurement sensitivities compared to conventional creep test specimens and can make strain measurements sensitive to relatively small temperature variations. The effects of specimen misalignment are greater when specimen diameters are small. In addition, specimen manufacture could be more complicated and more expensive than for conventional "full size" specimens.

3.2 Impression Creep Test (ICT)

The impression creep testing technique involves the application of a steady load to a flat-ended rectangular indenter, Figs. 2c and 3c, placed on the surface of a material at elevated temperature, and the small load-line displacement is measured. The displacement-time record from such a test is related to the creep properties of a relatively small volume of material in the immediate vicinity of the indenter. Tests are usually performed with a constant load level, at a fixed temperature. For the rectangular indenters, the reference stress approach has been used as the basis [4] for determining the corresponding equivalent uniaxial stress, σ, and creep strain, ε^c. These are related to the mean indenter pressure, $\bar{p}$, and creep displacement, Δ^c, via relationships [4]:-

$$\sigma = \eta \bar{p} \tag{6a}$$

$$\varepsilon^c = \frac{\Delta^c}{\beta d_i} \tag{6b}$$

The η and β in Eq. (6) are non-dimensional conversion factors. The η and β values for the recommended geometry ($w \times b_i \times h = 10 \times 10 \times 2.5$ mm) are $\eta \approx 0.4$ and $\beta \approx 2$ [4], for an indenter width of $d_i = 1$ mm. These are independent of material properties and do not vary with impression depth provided Δ^c is relatively small compared to the specimen thickness, h. The technique has been used for a wide range of materials (e.g. low alloy ferritic CrMoV steels, stainless steels, high chromium martensitic steels such as P91 and T91 [21], and P92). A typical set of data obtained from such tests for a 1/2 CrMoV steel is shown in Fig. 4. The slight fluctuations in the data are mainly caused by temperature variations within the furnace and within the laboratory. However, it can be seen that these variations are typically well within $\pm 1 \mu$m.

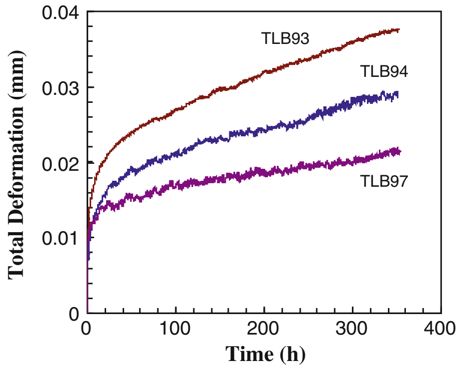

Fig. 4 Impression deformations with time at 90 MPa and 600 °C obtained from ex-service 1/2CrMoV steam pipe samples

3.3 Small Punch Creep Test (SPT)

The small punch creep test involves the application of a central load, through a spherical punch or a ball, to a thin disc, at high temperatures. A typical small punch test specimen and experimental set-up are shown in Figs. 2b and 3b, respectively; typical specimens measure 8 mm in diameter and 0.5 mm in thickness (e.g. [2]). The test involves the measurement of relatively large deformations, producing a deformation curve leading to fracture. The fact that fracture occurs is a particularly attractive feature of this type of test as the possibility of estimating the creep rupture data for the material exists. Empirical relationships between the applied load, P, the "membrane stress", σ, the equivalent strain at the edge of contact, ε, and the total deformation, Δ, have been obtained. For the case of $a_p = 2.0$ mm and $R_s = 1.25$ mm, the P/σ ratio and the strain, ε, for $\Delta > 0.8$ mm, are given by [15, 22]:-

$$P/\sigma = 1.72476\Delta - 0.05638\Delta^2 - 0.17688\Delta^3 \tag{7a}$$

$$\varepsilon = 0.17959\Delta + 0.09357\Delta^2 + 0.00440\Delta^3 \tag{7b}$$

The variation of the maximum P/σ, with a_p, R_{sp} and t_o, for $\Delta > 0.8$ mm, has been obtained and this leads to an expression for σ of the form:-

$$\sigma = \frac{0.3}{K_{sp}} \frac{P a_p{}^{0.2}}{R_s^{1.2} t_o} \tag{8}$$

where a_p, R_s and t_o are the radius of the unclamped region of the disc between the supports, the radius of the punch and the initial thickness of the disc, respectively; K_{sp} is a non-dimensional correlation factor, which is determined empirically for the particular material. The units for Eqs. (7b) and (8) are: dimensions and deformation in mm, stress in MPa and force in N. Typical creep deformation versus time curves are shown in Fig. 5, which exhibits similar behaviour to that of typical uniaxial curves,

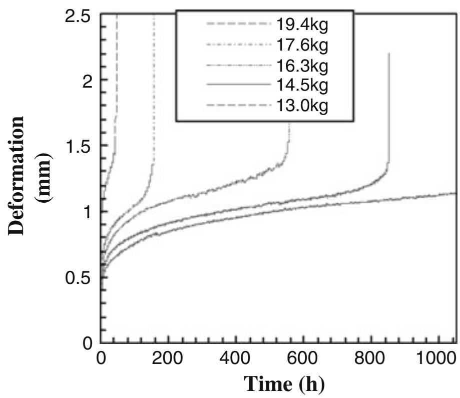

Fig. 5 Typical small punch test data for a P91 steel at 650 °C

i.e. there appears to be “primary”, “secondary” and “tertiary” regions. However, a high level of local plasticity occurs at the start of the test, which could have a significant effect on the material, and therefore, the subsequent “creep dominant” deformation.

3.4 Small Ring Creep Test (SRT)

This small specimen type (patent application PCT/GB2008/001547) is an elliptical ring (a particular case of which is that of a circular ring), diametrically loaded in tension, as illustrated in Figs. 2d and 3d. Load-line deformation versus time curves are obtained during the test. It is designed to be “flexible” to enable small strains to be related to relatively large deformations. However, the deformations do not significantly affect the conversion parameters, i.e. η and β, which enables highly accurate secondary creep properties to be obtained.
The steady-state creep solution for the load-line deformation rate, $\dot{\Delta}_V$, of an elliptical ring, obeying a Norton’s law ($\dot{\varepsilon}^c = B\sigma^n$), has been obtained, based on the principles of virtual complimentary work and stationary complimentary energy. The conversion relationships (η and β) for a range of geometries have been obtained by use of the reference stress approach. Detailed analytical procedures have been reported [6]. The main relationships are:

$$\dot{\varepsilon}^c(\sigma_{ref}) = \frac{d}{4ab\beta}\dot{\Delta}_V \tag{9a}$$

$$\sigma_{ref} = \eta\frac{Pa}{b_o d^2} \tag{9b}$$

For a circular ring (a = b = R), Eq. (9) become:-

$$\dot{\varepsilon}^c(\sigma_{ref}) = \frac{d}{4R^2\beta}\dot{\Delta}_V \tag{10a}$$

$$\sigma_{ref} = \eta\frac{PR}{b_o d^2} \tag{10b}$$

The test results for circular (a/b = 1) and elliptical (a/b = 2) rings, with R/d = 5, for a P91 steel at 650 °C, with a range of equivalent uniaxial stresses, are shown in Fig. 6.

3.5 Small Two-Bar Specimen Creep Test

A new small specimen test type, suitable for use in obtaining both uniaxial creep strain rate data and creep rupture life data, is shown in Figs. 2e and 3e [8]. The specimen has a simple geometry and can be conveniently machined and loaded

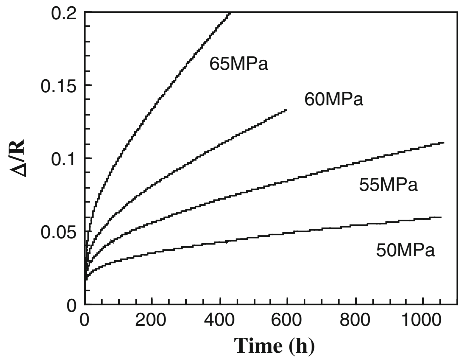

Fig. 6 Deformation (Δ/R) versus time curves obtained from circular rings for a P91 steel at 650 °C

(through pin-connections) for testing. Conversion relationships between the applied load and the corresponding uniaxial stress, and between the measured load-line (pins) deformation, and the corresponding uniaxial minimum creep strain rate, have been obtained, based on the reference stress method. The η-value (≈1) is found to be practically independent of dimension ratios, and the β-value varies with dimension ratios, and for $L_o/b = 4.5$ and $R/b = 1.25$, $\beta = 1.46$ [8]. Test results obtained from the two-bar specimens, for a P91 steel, at 600 °C, Fig. 7, have been used to validate the test method. It can be seen that the deformation curves obtained from the two bar test specimens are the same as those for a typical uniaxial specimens.

4 Application of Small Specimen Creep Testing

4.1 Some Practical Aspects of Small Specimen Creep Testing

Production of test specimens involves extraction of material samples (using the scoop technique, for example) and machining them to make the specimens. Depending on

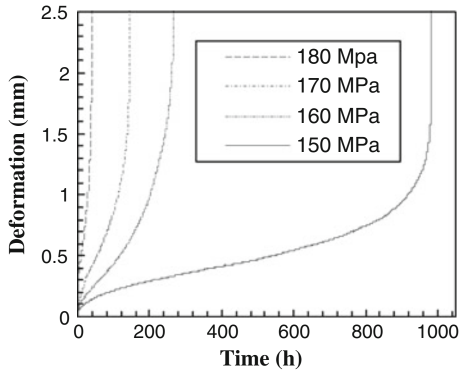

Fig. 7 Deformation versus time curves obtained from two bar specimens for a P91 steel at 600 °C

the accessibility of the site from which the sample is to be extracted, etc., and the production of specimens can be a costly process. However, the overall production costs of the ICT, SRT and SPT specimens are comparable to the costs associated with the production of standard uniaxial creep test specimens; sub-size uniaxial specimens may involve electron beam welding as well as machining processes and hence these specimens are likely to be more expensive [20].

Dead-weight machines are often used for standard uniaxial creep tests and the test equipment is therefore relatively inexpensive; the small specimen testing is recommended to be carried out on servo-electric screw thread machines [21], which may be more expensive to operate than dead-weight machines.

Conventional sub-sized uniaxial creep test specimens, Fig. 2a, have cross-sectional areas and "test volumes" which are large enough to ensure that bulk material properties are obtained, provided the grain sizes or other significant metallurgical features are small compared with the test volumes and cross-sectional areas. Practical experience indicates that the "test volumes" of the other small specimens are generally large enough to produce accurate bulk material data.

4.2 Choice of Small Specimen Test Types

Various factors can influence the choice of which small specimen test type is to be used for a particular application; these factors include the type of data required, e.g. creep strain rate data or creep rupture data, the material to be tested, etc. The test conditions may also be important factors in specimen type selection. Apart from the sub-size uniaxial specimen type, of the other methods described in this paper, only the SPT and TBT methods are capable of producing, directly, creep rupture data. If the temperatures and the test environment for these specimens do not produce excessive oxidation, then it would be acceptable to use these methods. However, research is ongoing into the interpretation of the SPT data, to obtain corresponding uniaxial data, and a generally accepted approach has not yet been developed (e.g. [22]).

The ICT method can be used to obtain creep strain data, but this requires the use of an indenter made from a material which has a creep strength which is two to three orders of magnitude greater than that of the material to be tested. For example [7], a Ni-base superalloy indenter has been used successfully to test P91, P92 and 316 stainless steel specimens. It is also necessary to avoid the possibility of environmental effects by use of an inert gas or a vacuum, if necessary.

The SRT method can also be used to obtain creep strain data, but unlike the ICT method, which required the indenter material to have very high creep strength, the loading pins for the ICT tests can have a creep strength which is even lower than that of the material to be tested. Hence, Ni-base superalloy materials can also be tested and the tests will produce accurate data. Which of the ICT and SRT specimen types is chosen to be used will depend on the strain magnitudes for which data is required.

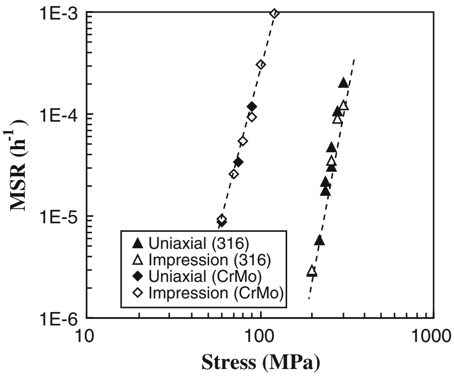

Fig. 8 Minimum creep strain rate (MSR) data for 316 stainless steel at 600 °C and 2-1/4Cr1Mo weld metal at 640 °C, obtained from uniaxial and impression creep tests

4.3 Determination of Creep Data from Small Specimen Tests

4.3.1 Minimum Creep Strain Rate Data

Minimum creep strain rate data obtained from ICT specimen tests carried out on 0.5CrMoV steel, at 640 °C, and on a 316 stainless steel, at 600 °C, are given in Fig. 8 [5]. Also shown in Fig. 8 are the corresponding uniaxial creep test data. It can be seen that, in all cases, excellent agreement exists between the uniaxial creep test data and the corresponding ICT data. Figure 9a shows the results obtained from uniaxial creep data and the corresponding SRT data for a P91 steel, at 650 °C. It can be seen that the two sets of results agree very well. It should be noted that the stress levels for which the ring test results were obtained produced easily measurable deformations with high accuracy. These types of results would be at the limit of what would be achievable, with acceptable accuracy and sensitivity of measurement, from impression creep tests. Figure 9b shows the uniaxial and SRT test data for an Inco718 Ni-base superally, at 800 °C. It can be seen that use of the SRT method, even for a highly creep resistant material (Ni-base), produces very good agreement between the SRT and uniaxial data.

4.3.2 Creep Rupture Life Data

For SPTs, using the empirical relationship (Eq. (8)) for the stress, σ, which relates to the corresponding stress in a uniaxial creep rupture test, the uniaxial rupture lifetimes can be estimated by using a suitable K_s value. Taking the value of K_s to be 1.275, creep rupture data, based on small punch tests of P91, at 650 °C has been obtained, see Fig. 10, as compared with the corresponding uniaxial data. The agreement between the two sets of data, on the log (σ) verses log (t_f) plots, is good.

Creep deformation curves obtained from two-bar specimen tests are shown in Fig. 7 for a P91 steel at 600 °C. The creep rupture data obtained from these tests

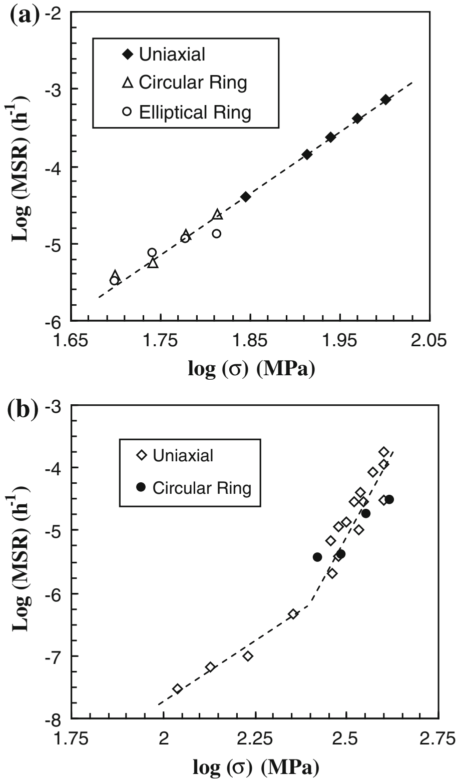

Fig. 9 **a** Minimum creep strain rate data for a P91 steel at 650 °C obtained from uniaxial and ring tests. **b** Minimum creep strain rate data for a Nickel base superalloy at 800 °C obtained from uniaxial and ring tests

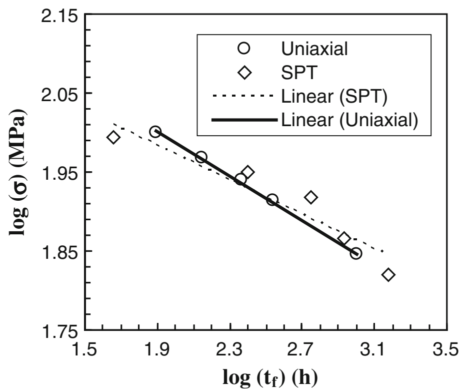

Fig. 10 Converted creep rupture data (using Eq. (8), with $K_s = 1.275$) obtained from a SPT on a P91 steel at 650 °C, compared with corresponding uniaxial data

are compared with the corresponding uniaxial data in Fig. 11. The results given in Figs. 7 and 11 clearly show that the two-bar specimen type is capable of producing the full uniaxial creep strain curve. Specific considerations have also been given to the design and dimension ratio ranges to be used for these specimens; this will be reported in a future paper.

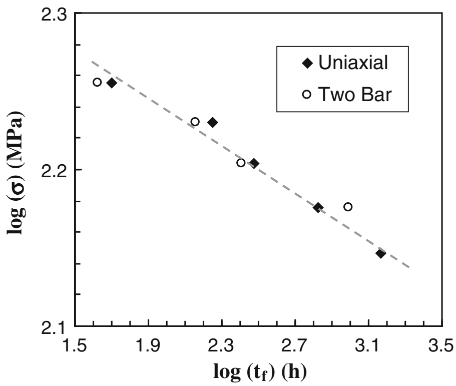

Fig. 11 Creep rupture data obtained from two bar and uniaxial specimens for a P91 steel at 600 °C

5 Discussion

The material extraction process and small specimen manufacture is, in general, more costly than is the manufacture of conventional uniaxial creep test specimens, but not prohibitively so. Test equipment for standard creep testing has been in existence for many decades and compared to the servo-electric types of test machines recommended by the authors [21], the cost is less. Testing, data recording and data processing for the small specimen and conventional specimen types of test are of similar complexity. Hence, although obtaining small specimen results is more costly compared with uniaxial tests, this should not prohibit the use of small specimens, especially as it may be the only practical and reliable method available to obtain some types of creep data.

It has been shown that all of the small specimen test types described in this paper are capable of providing very accurate data. In the case of two of the methods (SPT and ICT) a great deal of test data and test experience exists and there is growing confidence in the use of such methods for practical proposes. The SRT method is relatively new and hence less data is available, but the results of the testing of a Ni-base material (Fig. 9b) are particularly encouraging.

The concept of EGL (equivalent gauge length) is very useful for assessing the relative sensitivities of the small specimen test methods. The EGLs of SPT and ICT specimens are low whereas the SRT specimens have very high EGL which are of the same order of magnitude as the gauge lengths of conventional uniaxial specimens. These can be seen in Table 1.

Provided care is taken, there is no reason why oxidation effects (or the question of whether bulk properties are being obtained) should cause a problem. Also, by performing stepped load or stepped temperature tests, additional information such as the creep stress exponent or the activation energy can be obtained [5, 23].

At this relatively early stage in the development of small specimen creep test methods, there would be considerable benefit to be gained by collaborating with

Table 1 Summary of correlation formulae

Specimen	σ_{nom}	η	β	βL_{nom} (EGL)
Uniaxial	$\frac{4P}{\pi {d_{GL}}^2}$	1	1	GL
ICT [4]	$\frac{P}{b_i d_i}$	~0.4	~2.0	$\sim 2d_i$
SRT (elliptical) [6]	$\frac{Pa}{b_o d^2}$	0.892	~0.3−0.7	$\frac{4ab\beta}{d}$
SRT (circular) [6]	$\frac{PR}{b_o d^2}$	0.892	0.448	$\frac{4R^2\beta}{d}$
SPT* [22]	$\frac{P}{2\pi R_s t_o}$	$\frac{0.6\pi}{K_s}\left(\frac{a_p}{R_s}\right)^{0.2}$	–	–
Two-Bar [8]	$\frac{P}{2bd}$	~1	~1.4	βL_o

*Large deformation effects and complex geometry and deformation behaviour for the SPT make it difficult to define material and deformation independent parameters

a view to producing codes of practice for performing small specimen tests, for all specimen types.

6 Concluding Remarks and Future Work

Impression creep testing is suitable for determining minimum creep strain rate data, particularly at relatively high stresses. It has been extensively used as a "ranking test" and for determining creep properties for HAZs. Sophisticated measurement systems, capable of measuring very small deformations, and high accuracy of temperature control, are required. The potential effects of the impression deformation on the conversion relationships may need to be considered.

The small punch technique involves the measurement of relatively large deformations. Significant local plasticity and complicated deformation modes occur during the test. At present, there is no sound mechanics-based method which is universally accepted for data interpretation. However, it is believed that creep rupture properties could be related to small punch test results and the test method and the results could be very useful for power plant material ranking assessment. Future research into the understanding of the effects of the large initial plastic deformation and hardening on the subsequent creep process is necessary.

The small, ring-type specimen test involves relatively large deformation in relation to its' overall dimensions, which is associated with relatively low strains. The method is suitable for determining minimum creep strain rate data, particularly at relatively low equivalent uniaxial stresses. A unique application of this test type is for obtaining data for highly creep resistant materials. Future developments involve the establishment of time-dependent geometric correction functions to compensate for the effects of geometry changes during the deformation process.

The creep test data obtained from the small two bar specimen tests, for a P91 steel, have shown good correlation with corresponding uniaxial test data. This indicates that this specimen type is capable of producing full uniaxial creep curves. Further experimental data and validation are necessary; research is currently being undertaken in order to provide the necessary data and validation.

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