Materials Science & Engineering A 586 (2013) 358–366

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Small ring testing of a creep resistant material

C.J. Hyde [a,*], T.H. Hyde [a], W. Sun [a], S. Nardone [b], E. De Bruycker [b]

[a] The University of Nottingham, UK
[b] Laborelec, Belgium

ARTICLE INFO

Article history:
Received 29 April 2013
Received in revised form
25 July 2013
Accepted 29 July 2013
Available online 25 August 2013

Keywords:
Small ring
Creep testing
Creep resistant material
Conversion relationships
Ni-base alloys

ABSTRACT

Many components in conventional and nuclear power plant, aero-engines, chemical plant etc., operate at temperatures which are high enough for creep to occur. These include steam pipes, pipe branches, gas and steam turbine blades, etc. The manufacture of such components may also require welds to be part of them. In most cases, only nominal operating conditions (i.e. pressure, temperatures, system load, etc.) are known and hence precise life predictions for these components are not possible. Also, the proportion of life consumed will vary from position to position within a component. Hence, non-destructive techniques are adopted to assist in making decisions on whether to repair, continue operating or replace certain components. One such approach is to test a small sample removed from the component to make small creep test specimens which can be tested to give information on the remaining creep life of the component. When such a small sample cannot be removed from the operating component, e.g. in the case of small components, the component can be taken out of operation in order to make small creep test specimens, the results from which can then be used to assist with making decisions regarding similar or future components. This paper presents a small creep test specimen which can be used for the testing of particularly strong and creep resistant materials, such as nickel-based superalloys.

1. Introduction

There is a strong and increasing desire to obtain information on the creep behaviour/failure of pieces of material which are too small to manufacture conventional uniaxial specimens from (see Fig. 1). Ideally, standard creep curves (behaviour up to and including fracture) are what are required. This is the case for applications such as operating power-plant steam pipes, from which a small amount of material can be removed and tested in the laboratory. Such small amounts of material are usually extracted via the ‘scoop’ method [1], as shown in Fig. 2. These scoop samples can then be manufactured into small specimen forms and tested.

Another application of when small specimen creep testing is required is when creep information is required for the airfoil material of heavy-duty gas turbine components. The complex geometry of the internal cooling channels in turbine blades and vanes reduces the available material for creep assessment. These components are often made from nickel-based superalloys such as Inconel 738. Such materials have been used many times for high temperature application and are detailed in [2].

A third application which requires small creep samples is the execution of an exhaustive metallographic analysis in the framework of a life assessment study or the root cause analysis of a failed component. In such activities, a metallurgical evaluation is coupled with a structural integrity assessment by means of mechanical testing (tensile test, hardness measurements, creep testing, etc.). These destructive operations involve the metallographic preparation of a significant amount of cross-sections, which reduces the available material for creep assessment. A thorough creep assessment at various operating parameters is therefore not feasible.

The last application of small-size creep testing technique is when creep assessment of small turbine components, such as from aero-derivative engines, makes the extraction of conventional creep samples impossible.

In those applications, the component must be taken out of service and small specimen/s manufactured from the component, results from which can assist decisions on similar/replacement components. It is especially useful if this information can be used to predict how much longer the component can safely stay in service. Such information is extremely useful for ranking assessments [3]. By enabling the use of smaller samples to determine creep properties, creep testing can be extended to smaller components. The amount of samples that can be extracted out of one single component is increased as well, which enlarges the creep data and refines the integrity assessment.

* Correspondence to: Department of Mechanical, Materials and Manufacturing Engineering, University Park, Nottingham NG7 2RD, UK. Tel.: +44 115 9513735.
E-mail address: Christopher.Hyde@nottingham.ac.uk (C.J. Hyde).

0921-5093/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2013.07.081

There are several small specimen test types which can be used for obtaining creep properties from small amounts of material, namely sub-size conventional test specimens, impression creep (IC) specimen tests, small punch (SP) specimen tests and small ring (SR) specimen tests, which is the specimen type, the performance of which is the subject of this paper. Each specimen type has its own unique advantages and disadvantages and in some cases it may not be obvious which one is the most appropriate test method to use. This paper gives a brief description of each specimen and associated test type and describes their practical limitations.

2. Small specimen creep testing

There are currently four small specimen creep test types which are commonly used [4]. These are sub-size conventional uniaxial specimens, SP specimens, IC specimens and SR specimens, shown in parts (a), (b), (c) and (d) of Fig. 3, respectively. Fig. 4 shows the test set-up for each specimen type.

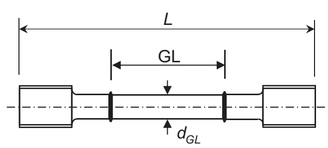

Fig. 1. Uniaxial creep test specimen (GL ≈ 30–50 mm; $d_{GL} \approx 6$–10 mm; L = 100–130 mm).

2.1. Subsize uniaxial, small punch and impression creep tests

2.1.1. Subsize, uniaxial creep specimen testing

Conventional, sub-size and miniature, uniaxial creep specimens (see part (a) of Figs. 3 and 4) can be tested in the same way as full size, conventional, uniaxial creep specimens and results can be expected to be very much comparable [5]. A major advantage of this test type is that it enables the user to obtain not only the creep behaviour of the material but also the fracture/failure time of the sample. Problems with this specimen type include the manufacture of the specimen as it is often the case that the screw-ends have to be electron beam welded onto the gauge section. Also, although it is recommended that the gauge section be at least 1 mm in diameter, it is not entirely clear what the minimum value of this dimension should be in order to ensure that 'bulk' creep properties are obtained; it is necessary to ensure that enough grains exist through the thickness of the specimen. Also, for small gauge sections of 1 mm, oxide scale formation during long duration creep testing in air can significantly reduce the section. It is therefore recommended to test these creep specimens in a protective environment to reduce the influence of oxide formation on the creep lifetime.

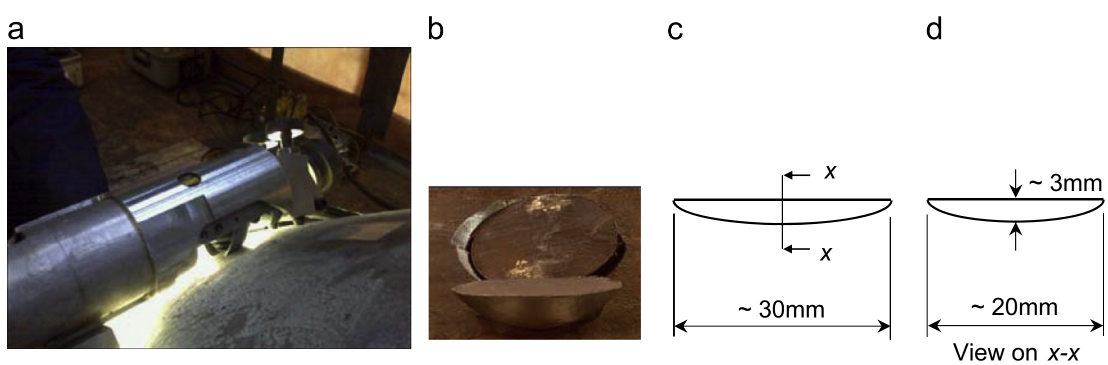

Fig. 2. Scoop sample (a) extraction of, (b) close-up image, (c) schematic representation of a typical scoop sample and (d) schematic representation through *x*–*x*.

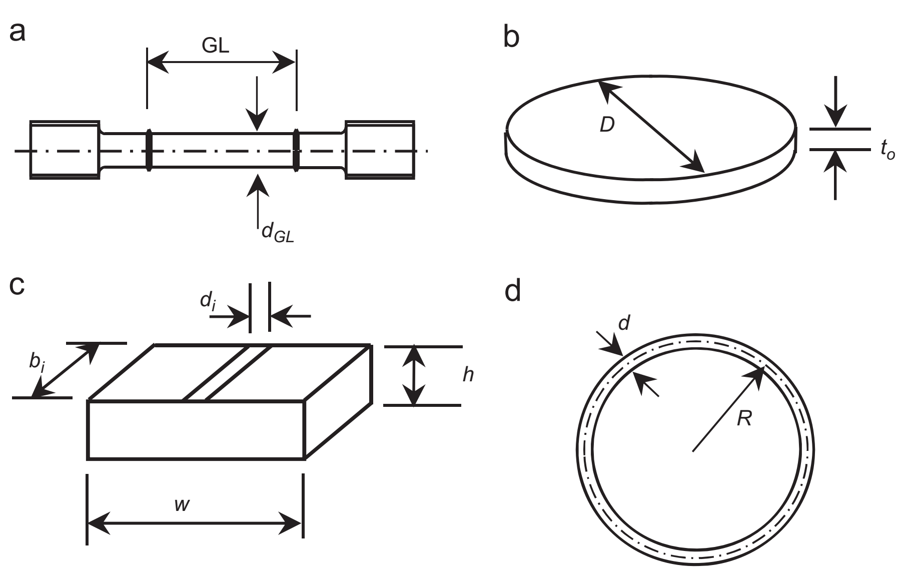

Fig. 3. Shapes and typical dimensions of small creep test specimens: (a) conventional sub-size uniaxial specimen (GL ≈ 5–12 mm and $d_{GL} \approx 3$–5 mm) and conventional miniature uniaxial specimen (GL > $3d_{GL}$ and $d_{GL} < 3$ mm); (b) SP test specimen ($D \approx 8$ mm and $t_o \approx 0.5$ mm); (c) IC test specimen ($w = b_i \approx 10$ mm, $d_i \approx 1$ mm and $h \approx 2.5$ mm) and (d) SR test specimen ($R \approx 5$ mm, $d \approx 1$ mm and depth $b_o \approx 2$ mm).