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Equipment for creep testing under tensile stress and hydrostatic pressure

B. D. CLAY*, N. G. NEEDHAM†, E. RAYNER, G. W. GREENWOOD
Department of Metallurgy, University of Sheffield, Sheffield, UK

The design and operation of equipment is described that permits creep tests to be made under independently controlled tensile stresses and superimposed hydrostatic pressures at elevated temperatures. The range of usefulness and applications of the equipment are briefly indicated.

1. Introduction

It has long been known [1] that the ductility of materials is greatly increased when high hydrostatic pressures are superimposed. More recently, it has also been shown that relatively low hydrostatic pressure ~ 10 MN m^{-2} can have a marked effect in enhancing the creep ductility of metals and alloys [2, 3]. In the latter case, there is evidence that the effect is related to the retardation or prevention of growth of cavities along grain boundaries that would otherwise rapidly link together to result in sudden fracture. Theoretical aspects of cavity growth are well developed from the point of view of vacancy condensation [4] but are much less well established for situations where the growth may be dependent on the mode of deformation of the material or where processes of crack propagation may predominate.

Experiments to determine the effect of hydrostatic pressure on creep have generally been severely restricted to tests on small specimens [5] or at relatively low temperatures contained within pressure vessels that were heated externally [2, 3, 6]. The time of heating and cooling of specimens within such vessels can be unacceptably large and the specimens so small that their behaviour may not be representative of bulk material. For example, both the size and the number of grains across the specimen cross section may be important [7] and this feature emphasises the advantages of larger specimens. Moreover, such specimens are more amenable to the measurement of precise density changes caused by creep [8]. The consequent necessity for using larger loads with larger specimens has been overcome in the present equipment by load intensification through a cam.

The present paper describes equipment that permits the study of the influence of simultaneously but independently applied tensile stress and hydrostatic pressure on creep under carefully controlled conditions with a heater within the pressure vessel close to the specimen.

2. Description of the apparatus

The apparatus consists essentially of a cylindrical pressure vessel, with its axis vertical, sealed by end closures, containing complete creep testing equipment which can readily be inserted and removed by overhead hoist. An external circuit allows the vessel to be filled with argon up to a pressure of 60 MN m^{-2} and a heater inside the vessel is capable of heating specimens to 550°C with negligible thermal gradients. Tensile loads up to 2.4 kN are applied through a cam and specimen extension is monitored by transducer.

It is convenient to consider the apparatus in terms of its three main components:

(a) the pressure vessel with associated pump, pressure circuit and safety devices;

(b) the heater, temperature monitoring and control and thermal insulation;

(c) the specimen loading system and measurement of creep strain.

2.1. The pressure vessel and associated circuit

The design of the vessel incorporated the proven features of a smaller vessel used for heat

*Present address: Central Electricity Generating Board, Berkeley Nuclear Laboratories, Berkeley, Gloucestershire, UK.
†Present address: British Steel Corporation, Swinden Laboratories, Moorgate, Rotherham, Yorkshire, UK.

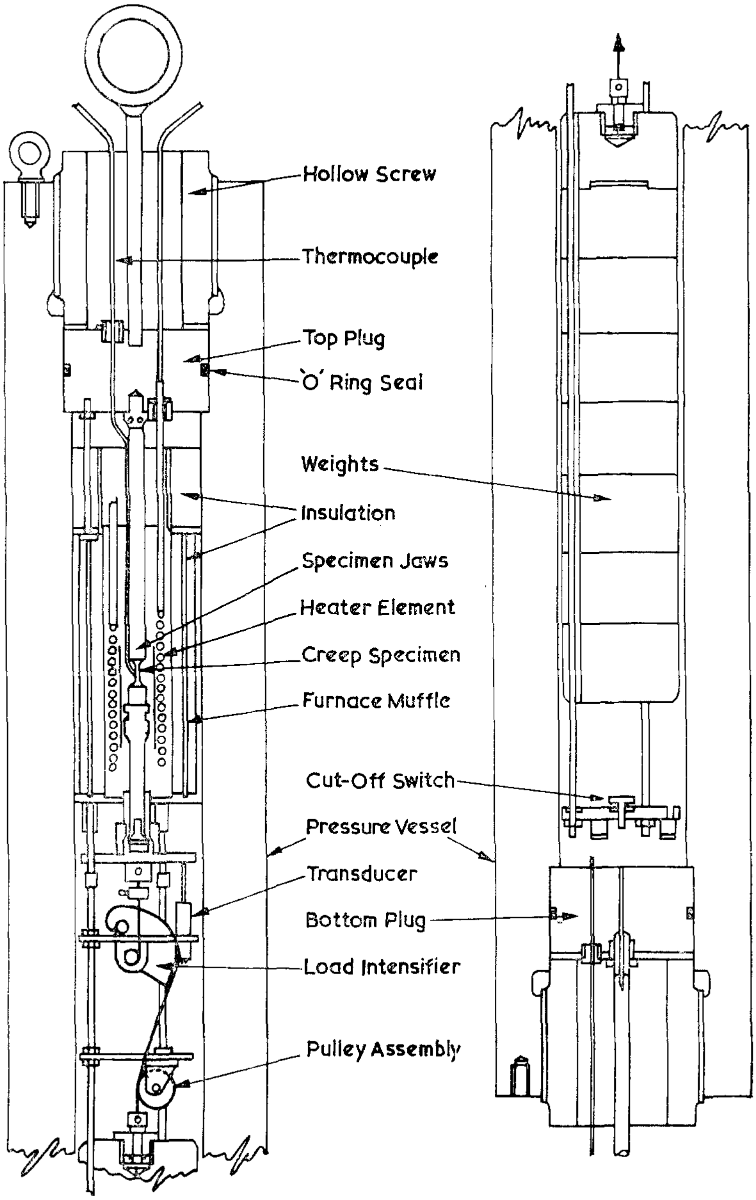

Figure 1 A schematic diagram of the apparatus. Scale 1 mm ≡ 6 mm.

treatments under pressure and described previously [9]. An overall diagram of the pressure vessel and the creep testing equipment contained in it is given schematically in Fig. 1. The equipment assembled ready for loading into the pressure vessel is shown in Fig. 2. The cylindrical tube that forms the main body of the vessel is constructed from EN 24 steel and at each end hollow nuts retain end plugs which have a circumferential groove containing an "O" ring and PTFE backing rings on either side. Electrical continuity through the end plugs for thermocouples is achieved by sheathed insulated wires passing through metal to metal seals [9]. Four thermocouples enter the vessel via the top plug whilst the wires to the transducer and to a microswitch below the weights enter through the bottom plug. The microswitch switches off the heater when the specimen fractures.

The bottom plug also incorporates a tube for

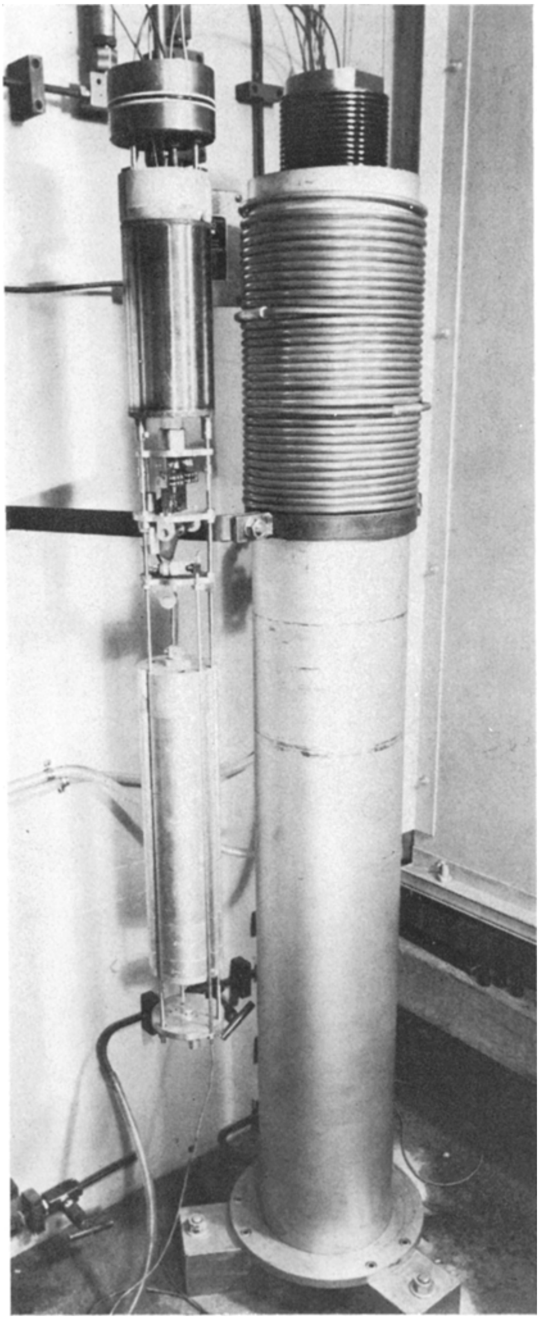

Figure 2 The heater, thermal insulating unit, load intensifier and weight frame attached to the top plug and suspended by overhead hoist ready for loading into the pressure vessel.

the introduction of high purity argon gas from the compressor which can increase the gas pressure up to 60 MN m^{-2}. The gas pressurization system includes a reservoir, pressure gauges and complete safety protection including a Bourdon type pressure relay that switches off the heater if the maximum pressure is exceeded. As on ultimate safeguard there are also burstings discs that release the gas if the pressure exceeds 65 MN m^{-2}.

2.2. The heating and control system

The heating device comprises sheathed heating elements similar to those used in some domestic electric cooker hot plates. A particularly valuable feature of elements of this type is that the resistance wire is fully insulated and is straight and of low resistance near its ends so that there is negligible heat dissipation in the region where the wire passes through the plug. In the central region of the element the resistance wire is coiled within the sheath and the heat dissipation per unit length is high. The heating element is wound in the form of a double helix and inserted within this is a copper cylinder to minimize temperature gradients.

There is substantial thermal insulation to ensure that the central volume of the hot zone is at a uniform temperature whilst minimising the heat input and keeping the walls of the pressure vessel relatively cool. The main insulating component which surrounds the heater comprises two concentric stainless steel cylinders welded to horizontal plates at top and bottom and containing alumina powder in compartments separated by baffles to impede convection currents. This unit is supported from the top plug by three threaded rods. To reduce further the effects of convection currents, a series of syndanio blocks fit between the main insulation unit and the top plug and these are easily attached and removed to allow access to the top grip of the specimen. The final impediment to gas circulation is the packing an alumina powder around the specimen and retaining it by asbestos string wrapped around and recessed into a collar. When the grip is screwed into position the string brushes against the copper cylinder inside the heating element thus sealing to prevent convection.

The specimen and heater temperatures are monitored by chromal/alumel thermocouples in insulated stainless steel sheaths. Three thermocouples are positioned at intervals along the specimen with the control thermocouple in contact with the copper cylinder within the heater. The temperature changes during test are limited to $\pm$ 1°C by the controller and the temperature gradient along the specimen is within $\pm$ 2°C. All thermocouples are continuously monitored by a multipoint recorder which also activates alarm relays to switch off the heater if any thermocouple reaches a temperature which exceeds its present limit.

2.3. The specimen loading system

The system for the tensile loading of the specimen consists of top grips attached to the top plug and lower grips that are connected to a load intensifier and weights surrounded by a frame suspended from the main insulation unit as in Fig. 1. The grips can easily be interchanged to accommodate specimens of different sizes.

The principal component of the force intensifier is a cam giving an 8:1 magnification of the gravitational force on the hanging weights. The cam is pivoted on the upper fixed plate attached to the weight frame. The frame is built around three vertical stainless steel rods that fit into the base of the main insulation unit and extend almost to the bottom plug of the pressure vessel when the apparatus is in a working position. The main plates of the frame are bolted to these rods and they also act as a guide for the moving weight assembly and for the anchor plate to which the lower grip of the specimen is attached. Six stainless steel tapes connect the anchor plate to the axle of the cam and these transmit the magnified tensile load on to the specimen. A single similar tape connects the moving weight assembly to the periphery of the cam.

Specimen extension is monitored by a displacement transducer between the lower grip anchor plate and the fixed plate on which the cam is pivoted. Electrical connections to this transducer are fed through the bottom plug.

As the specimen extends under load, the weights move downwards at a rate eight times faster than the linear extension of the specimen. When the specimen fractures, the weights drop down onto the base plate of the weight frame and depress the plunger situated on it which operates a microswitch which cuts off the power supply to the heater. The base plate can be moved up the guide rods when less than the full length of weights is employed so that the weights always drop through only a short distance if the specimen fractures suddenly. To reduce the volume of gas in the vessel, spare weights can be supported by a second base plate bolted to the ends of the guide rods. The weights are made up of a number of interchangeable elements which can be joined in any combination. By this means it is possible to apply a wide range of loadings between 3 and 30 kg which, after the 8:1 intensification factor through the cam, transmits forces of between 0.24 and 2.4 kN to the specimen.

3. Operational performance and results

The equipment has now performed satisfactorily over operating periods which, in total have exceeded 10 000 h. The pressure vessel can be unloaded and a new specimen inserted in under 1 h and the safety devices built in to the system permit the apparatus to be left unattended almost indefinitely. There have been very few instances where significant leaks have developed anywhere in the system and any slight gas loss over a long period of time can be automatically compensated by automatic operation of the compressor.

Experiments with the equipment have enabled extensive quantitative information to be obtained of the increase of ductility with pressure. More surprisingly, experiments have also indicated an effect of hydrostatic pressure in decreasing the creep rate to an extent which is much greater than anticipated (Fig. 3). The size of specimen used in the experiments permits the density changes occurring during creep to be measured with high precision and the systematic variation of density change after periods under different tensile stresses and hydrostatic pressures is shown in Fig. 4.

The operational performance has confirmed the effectiveness of the design philosophy and apparatus for the study of the behaviour of materials under increased loads and at higher

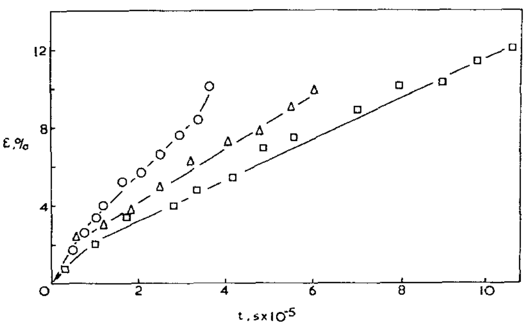

Figure 3 Creep curves for OFHC Copper at 500°C under a tensile stress of 24.2 MN m^{-2} and hydrostatic pressures of ○ 0.1 MN m^{-2}; △ 3.5 MN m^{-2}; □ 6.2 MN m^{-2}.

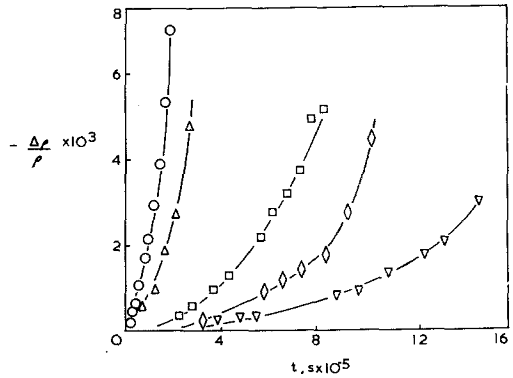

Figure 4 The fractional decrease in density of OFHC Copper after successive intervals of creep at 500° C under a tensile stress of 27.6 MN m^{-2} and hydrostatic pressures of ○ 0.1 MN m^{-2}; △ 3.5 MN m^{-2}; □ 6.2 MN m^{-2}; ◇ 10.4 MN m^{-2}; ▽ 13.8 MN m^{-2}.

temperatures and hydrostatic pressures could be confidently constructed on similar principles.

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