179 Small punch creep testing of power generation materials

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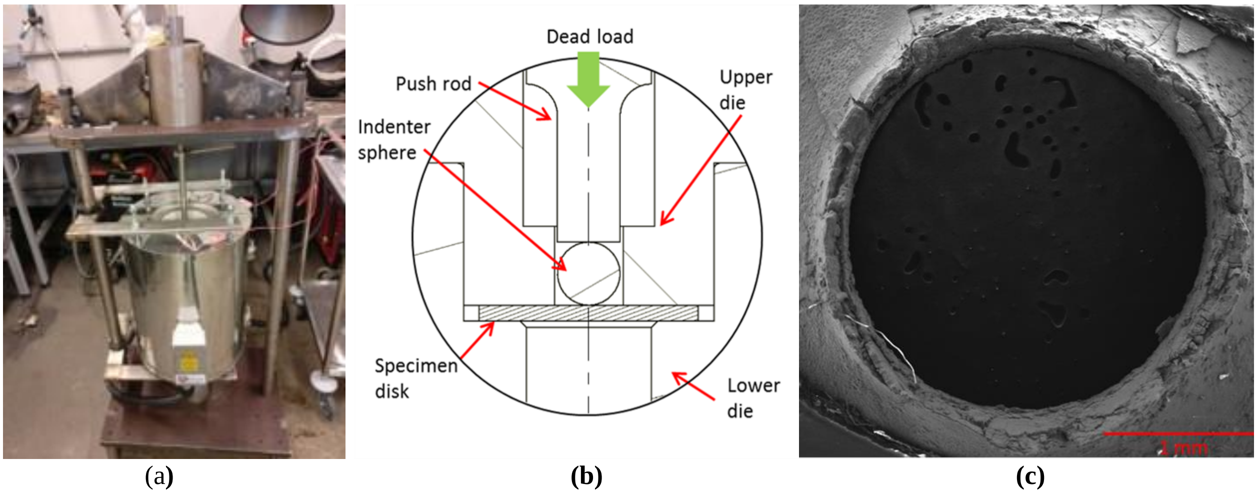
Abstract. A high temperature small punch creep test apparatus has been manufactured at NUI Galway to examine the creep response of 9Cr steels. Testing was performed between 596°C and 658°C. Initial findings are presented here regarding the temperature sensitivity of the material and the corresponding effect on minimum displacement rates and time to failure. The ring-shaped fracture surfaces of tested thin disk specimens are examined via scanning electron and optical microscopy, to identify the deformation process leading to failure; either plasticity or creep dominated. The test apparatus produced the characteristic creep curve, of displacement versus time. Increasing temperature leads to an increase in minimum displacement rate and a corresponding decrease in time to failure. The failure mode is predicted to be dominated by plasticity induced damage due to the high load applied for these initial tests.

Introduction.

Small punch creep (SPC) testing has been proposed for the power generation sector as a minimally invasive method of quantifying remaining life in existing components [1]. This work is focused on the development of an SPC test rig (see Figure 1a) for 9Cr materials, a family of materials in service globally [2]. Considerable numbers of plants in the EU are reaching the end of their original design lives, and life extension programs of these ageing plant are underway in place of decommissioning them [3]. There is an urgent need for modern, accurate methods of estimating the remaining lives of plant components; small scoop sampling coupled with SPC testing has been suggested as a possible solution to this issue [4]. Figure 1b shows the experimental apparatus set-up; a thin sample is clamped between an upper die, held in place with two tensioning screws. A 2 mm silica nitride indenter sphere is placed on the sample in the aperture of the upper die and the push-rod is lowered into contact with the indenter sphere. The tensioning screws are then tightened to 1 Nm. The entire die, specimen and push-rod assembly is then encapsulated by a tube furnace; the ends are then sealed with insulation material and brought to the required temperature. The temperature of the dies, furnace wall, outer furnace surface and linear variable displacement potentiometer are recorded for the duration of the test. A LabView program has been developed to record the displacement of the push-rod. A sphere and push-rod arrangement were selected to minimise the effects of rod misalignment, which can occur when the indenter is part of the push-rod. Evidence of damage to the indenter spheres was observed; hence a new sphere is used for each test. The specimens are extracted from a thin-walled tube of P91 and are machined into 7 mm diameter disks with an average thickness of 0.5 ±0.013 mm, and a surface roughness (Ra) of 0.6 ± 0.15 µm. SPC tests were performed at temperatures in the range 596 to 658°C, as part of the calibration and commissioning of the apparatus. Scanning electron and optical microscopy were performed on the failure surfaces and of the specimen cross section to obtain the regions of maximum plasticity and creep-induced damage, respectively.



(a) (b) (c)

Figure 1. a) NUIG SPC test apparatus, b) Section view schematic of indenter, die and specimen inside of furnace and c) SEM image of ring fracture surface of sample tested at 600°C

Results

Figure 2a shows the displacement versus time outputs from three tests of P91. In place of a creep strain versus time results the SPC method produces equivalent plots, similar to the approach of Cortellino [5]. The SPC test generated typical creep curves. The initial portion of the curves, contains significant plastic bending and primary creep effects [6]. This is followed by secondary, steady-state creep and finally, the displacement rate accelerates in the tertiary portion of the curve prior to failure, evidenced by the near vertical portion of the curves. Here the indenter sphere (see Figure 1b) fully penetrates the specimen, generating the ring failure surface in Figure 1c Utilising a least-squares fitting procedure, the minimum displacement rate (MDR) was extracted from the secondary creep behaviour. Time to failure is plotted against MDR in Figure 2b, highlighting the relationship between temperature, MDR and time to failure. Increasing temperature had a significant effect on the time to failure of the samples, with a ~60°C increase in temperature producing an ~80% reduction in time to failure. The high load levels were expected to generate considerable plastic deformation within the specimens, leading to a dimple type fractured surface.

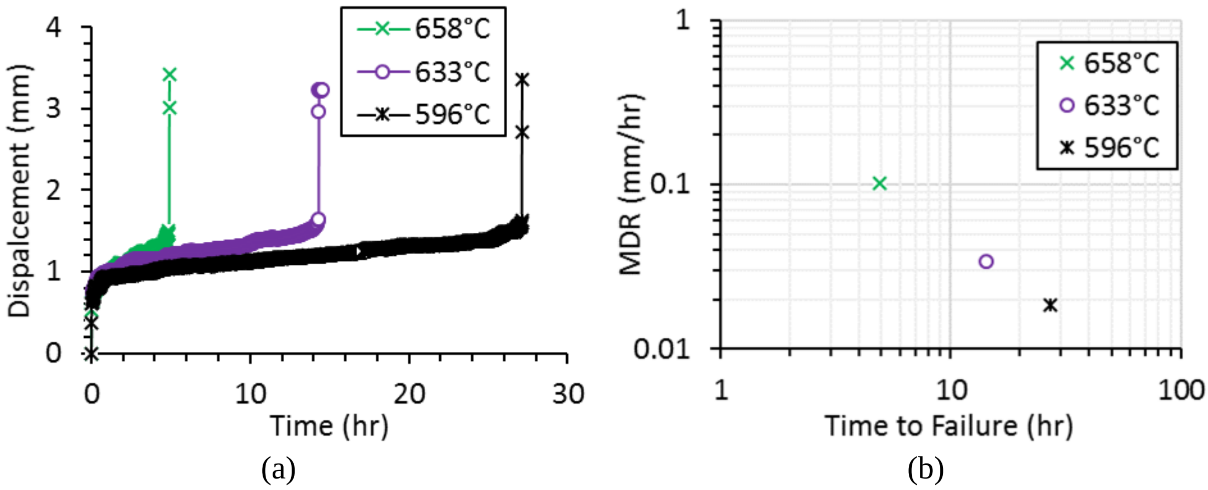


Figure 2. a) Displacement versus time curves and b) minimum displacement rate versus time to failure for P91 tested at 658, 632 and 595°C.

Conclusions

A new small punch creep test apparatus has been developed at NUI Galway and initial tests have been conducted on P91 steel for commissioning. The system is shown to produce the expected creep relationships between temperature, minimum displacement rate and time to failure. The high load and temperatures result in a plasticity-dominated failure mechanism, where dislocation mechanics dominated over the diffusion processes associated with power plant component failures. Evidently, careful control of temperature within the apparatus is key to the generation of reliable, repeatable test data. At the load studied the effects of temperature are considerably enhanced; future work will focus on lower loads (more time consuming) and an examination of the temperature dependence will be performed. This early qualification work will allow testing of thermally aged specimens to be performed, with a view to investigating the effect of simulated aging on the creep behaviour of P91.

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