Associated conference: 5th International Small Sample Test Techniques Conference

Conference location: Swansea University, Bay Campus

Conference date: 10th - 12 July 2018

How to cite: Jones, A.J., & Bache, M.R. 2018. Considerations for the accreditation of small punch creep testing. *Ubiquity Proceedings*, 1(S1): 26 DOI: https://doi.org/10.5334/uproc.26

Published on: 10 September 2018

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Considerations for the accreditation of small punch creep testing

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Abstract: Efforts to extend a pre-existing European Code of Practice (CoP) covering small punch creep and tensile testing into a full International standard procedure are progressing. Swansea Materials Research & Testing Ltd, in collaboration with the academic team based at Swansea University, have been proactive in anticipating some of the key recommendations from the ECISS TC 1010/WG 1 with a view to gaining accreditation for an extensive suite of small punch test equipment. Here, comparisons between the miniaturised form of small punch creep testing will be made to the expectations for calibration and measurement laid down by existing standards for creep testing of conventional scale specimens. In particular, the calibration requirements relating to load, displacement, alignment and temperature measurement will be addressed. With test reproducibility at the forefront of our attention, recent modifications to test rigs to control load application and validation exercises to define small punch temperature distribution will be described. Ultimately, the need to develop an uncertainty budget for small punch creep testing will be highlighted.

Keywords: Accreditation; Small punch creep; Equipment design; Procedures

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1. Introduction

The suite of small punch test machines currently employed for creep evaluations at Swansea Materials Research & Testing Ltd (SMaRT) has been fashioned over the previous quarter century to address a wide range of assessment requirements. Originally designed to support investigations sponsored by the power generation sector in the 1990s, more recently these rigs have been modified and increased in number to also serve the aero-gas turbine industry. With the continual advancement in material capabilities, this has required increases in the maximum test temperature and applied load in particular.

Grounded on local best practice, Swansea based academics contributed to the establishment of the original European Code of Practice [1] in small punch testing. The fundamental requirements of creep testing were applied to the small punch technique, in particular the need for thermal and mechanical stability over long time periods, exceeding thousands of hours on test. Naturally, test procedures and International standards to describe conventional scale creep tests under axial tension were consulted. However, wider and more specific aspects of the small punch test design and procedures are now worthy of consideration. A rigorous assessment of typical small punch test equipment is required in anticipation of a new European test standard to be developed through the ECISS TC 1010/WG 1 committee, designated prEN 15627 [2]. Ultimately, it is hoped that by satisfying the current suggestions for small punch calibration and compliance to the European standard, multiple laboratories will be able to gain accreditation for small punch creep testing and thus offer a consistent market for such research and commercial testing.

2. Small Punch Mechanical Calibrations

The most obvious approach to small punch equipment calibration is to take a lead from established International standards describing the best practice to be adopted for conventional scale axial creep tests under tension. In the case of the ISO 17025 accreditation schedule for SMaRT [3], this incorporates guidelines from BS EN ISO 7500-2:2006 “Metallic materials – Verification of static uniaxial testing machines Part 2: Tension creep testing machines – Verification of the applied Force” [4] and BS EN ISO 9513:2012 “Metallic materials – Calibration of extensometer systems used in uniaxial testing” [5].

With reference to a typical small punch creep test frame, Figure 1, the majority of working laboratories continue to employ vertical dead pan loading to apply an axial load through an upper rod to the punch. Depending on the design and associated tolerances, potential losses due to friction could be experienced through the crosshead bearing and between the flanks of the punch and walls of any concentric guiding clamp. To verify load application an annual verification between applied and actual load transferred through the disc should be considered. The range of load assessed should span the maximum envisaged loads during regular test campaigns with appropriate intermediate steps. This can be achieved by coupling an ISO 376 [6] certificated compression load cell device into the lower half of the load train, measuring load transferred between the load pan and the fixed base. An example of such verification performed on a single frame for a load range of 500N down to 100N is illustrated in Table 1. Acceptable tolerances for frictional losses must be agreed, but when comparing to BS EN ISO 7500-2:2006 errors equivalent or better than class 0.5 should be possible. In turn, individual weights used for calibration and subsequent testing should be formally verified to an accuracy of 0.1% on a five year cycle according to BS EN ISO 7500-2:2006. The requirement to perform regular applied load calibrations is even more pertinent to systems incorporating offset lever load application where errors are possible due to wear in rotary bearings and counterbalance settings.

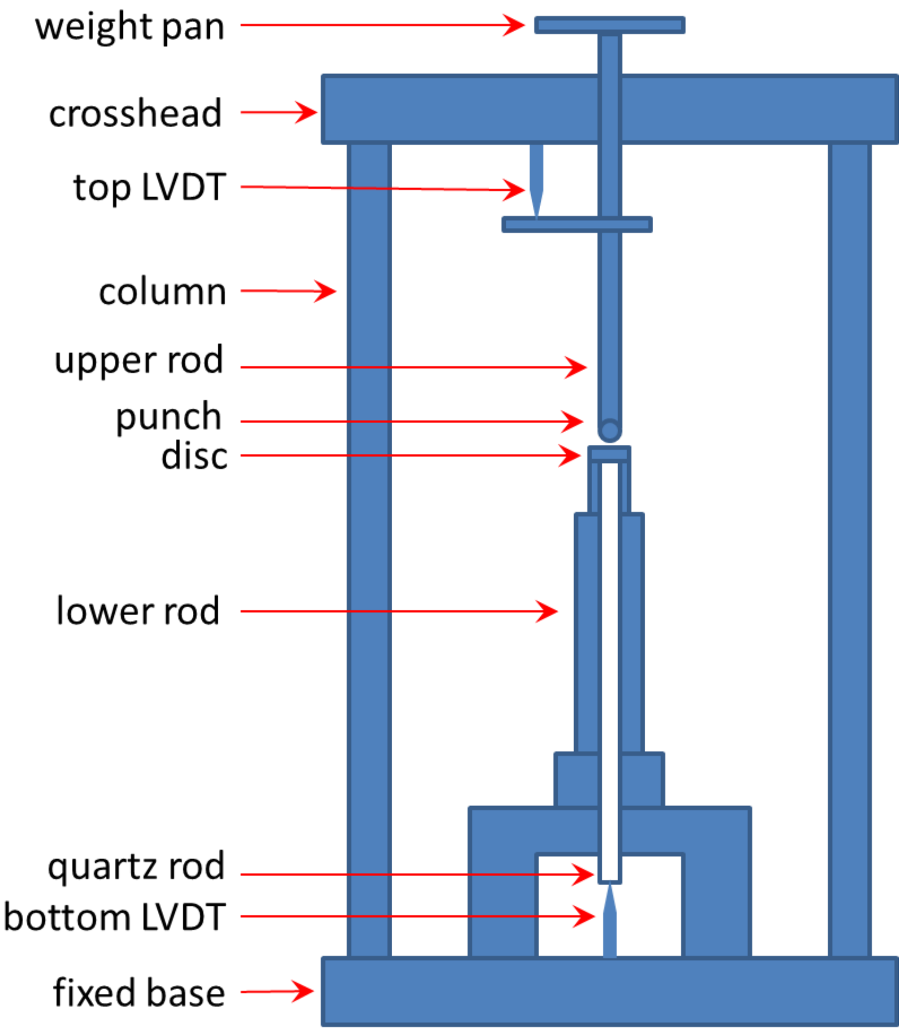

Figure 1. Principal components of a small punch creep rig.

The philosophy behind the practice to calibrate creep extensometry described in BS EN ISO 9513 is to define the performance of the complete extensometer assembly, i.e. in the case of tensile creep this is usually a complete drop leg cage instrument. This procedure recognizes the complex, multi-jointed nature of the assembly, subject to misalignment, bending displacemens and potential play between the clamping fixtures and the specimen. The cage is attached to a certified extensometer calibration rig remote from the test frame. Applied displacement is compared to the measured output, normally the electrical average of two linear variable displacement transducers (LVDTs). The entire electrical measurement system through to the eventual data logger must be incorporated into the calibration procedure.

Table 1. Load verification data for a single small punch creep rig.

Applied Force [N]	Mean true force [N]	Relative error [%]	Relative uncertainty of mean true force [%]
100	**99.869**	**0.13**	**0.55**
200	**199.705**	**0.15**	**0.55**
300	**299.771**	**0.08**	**0.55**
400	**399.885**	**0.03**	**0.55**
500	**499.607**	**0.08**	**0.55**

Displacement of a small punch disc should ideally be measured directly off the deforming specimen and preferably immediately below the contacting punch. This can be achieved through a lightly sprung, quartz rod running inside the internal bore of the lower rod, contacting the bottom LVDT fixed in space relative to the fixed base of the machine. Given the simple, direct transfer of displacement between the disc and the bottom LVDT, it is argued that the LVDT could be removed from its location for a simple remote calibration (based on BS EN ISO 9513:2012) against an extensometer calibration rig, Figure 2. Where laboratories also rely on a second top LVDT to measure the movement of the upper rod or load pan relative to the crosshead this should also be calibrated. Such LVDT devices should perform to class 0.5 or better.

In contrast to the effective self alignment of conventional creep load trains under tension, achieved for example through the employment of universal joints and validated through cold modulus checks, more rigorous attention to the alignment of small punch rigs will almost inevitably be expected into the future. Alignment checks of universal tension and low cycle fatigue machines usually employs a strain gauged specimen subjected to a range of tension and compression loads in accordance with ASTM E1012-14 or BS ISO 23788:2012 [7,8]. However, given the small scale of the small punch disc specimen and limited free access to the lower surface of the disc within the bore of the clamp (typically 4mm in diameter) it would be prohibitive to apply the same strain gauge techniques directly off a specimen under load. The upper and lower loading rods could be strain gauged around their external surfaces, however, to allow for checks against bending. The necessity for such detailed checks on alignment could be debatable. Good design and manufacturing practice can optimise the axiality of the upper and lower rods relative to each other and the machine columns. The employment of a deep throated linear bearing has been adopted at SMaRT to improve axial alignment of the top rod as it traverses the top crosshead. Finally, detailed checks between the opposite halves of the load train using clock gauges, precision edges and set squares are also performed on a regular basis, at least annually.

Figure 2. LVDT interfaced to a certificated calibration rig.

3. Operating Procedure

Again, the most rigorous aspects of the conventional creep standards have been adapted for our small punch creep testing procedure. Specifically, this refers to BS EN ISO 204:2009 "Metallic materials – Uniaxial creep testing in tension – Method of test" and BS EN 2002-005:2007 "Aerospace series – Test methods for metallic materials. Part 005: Uninterrupted creep and stress-rupture testing" [9,10].

The disc sample to be tested should be prepared carefully to the relevant dimensions and surface finish. After manufacture best practice would be to clean the disc in ethanol to remove remnants of polishing media and stored in a desiccator until ready for test. During insertion of the disc specimen into the supporting load train and clamping jig, the operator should wear nitrile gloves to avoid contamination by salts, particularly relevant to tests performed on titanium alloys. A standard clamping pressure between the disc and the support jig still requires agreement, but once defined the design of the clamping jig should allow for the application of measured torque via a calibrated wrench.

Despite the small height of the disc specimen, a two (minimum) or preferably three zone radiant furnace is recommended to perform testing (subjected to regular validation of temperature stability), given that specimen temperature is ultimately reliant on thermal conduction through the mass of the central clamping jig. Minimising the axial thermal gradient of the jig is advised through control of the separate heating zones. In respect of temperature measurement, to monitor tests below 1000ºC pre-welded type N thermocouples are procured from an ISO 17025 accredited supplier, manufactured from certificated batches of wire. Otherwise, the laboratory is required to self calibrate thermocouples according to an appropriate standard procedure [11]. Throughout the course of a test the bead of a single thermocouple remains in contact with the upper surface of the disc via a vertical port machined into the wall of the die clamp. The thermocouple bead, therefore, makes contact within the constrained, clamped periphery of the disc. The specimen is brought up to test temperature in a controlled fashion to avoid over heating. It should be emphasized that during the heat up stage the upper rod and weight pan is mechanically supported such that the tip of the punch is suspended clear of the upper disc surface by a few millimetres. The central assembly sitting within the furnace is allowed to stabilize at the test temperature for a minimum of two hours.

This soak period has been established through thermal distribution checks of an instrumented disc. Thermocouples were spot welded to the top and bottom surfaces of a disc in the locations indicated in Figure 3, in addition to the usual monitoring thermocouple in contact within the clamped periphery (at position P). The distribution of temperature was measured over a range of typical test temperatures up to 800ºC. Minimal variations (±1ºC) were noted between the central locations on the top or bottom disc surface (T1 and B1). However, a difference of up to 10ºC was measured between the disc periphery (P) and the centre (T1, B1), with the centre consistently the cooler position. Exposure of the central disc area to free space allowing radiated heat loss has been presumed to be the cause of this difference.

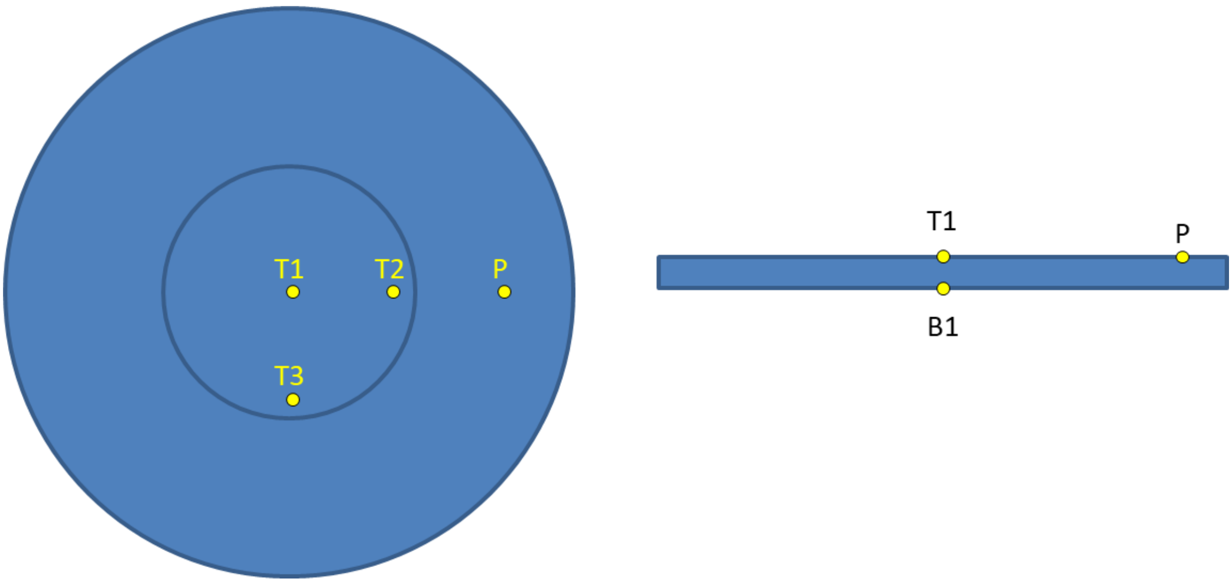

Figure 3. Thermocouple placement during temperature distribution measurements, plan and side views.

The original CoP recognized the probability of temperature variations across the specimen and recommended "validation measurements" to calculate acceptable off set control of test temperature. However, local practice is moving towards the best practice of any form of mechanical testing by ensuring the monitoring thermocouple is in contact with the specimen within the critically stressed volume. This is achieved using a thermocouple located within the hollow quartz rod used to measure displacement, with the thermocouple bead touching the lower face of the disc immediately below the point of punch contact on the upper face.

The proposed tolerances for variation in the specimen temperature during test currently envisaged in prEN 15627, Table 2, are actually more demanding than those employed under conventional creep testing, for example as defined within BS EN ISO 204. Working within these bounds is achieved during the course of long duration tests through adjustments to the furnace temperature control system as necessary. An appropriate laboratory environment is maintained and a PC based temperature logging system is employed and calibrated against a certificated thermocouple simulator on an annual basis.

The applied load is made up from a combination of selected, certificated weights plus the mass of the weight pan, upper rod and punch. The mass of the upper half of the load train is verified every twelve months and each individual set of rods recorded against specific machines. In the interests of health and safety, it is recognized that the applied mass required to perform tests on disc specimens of standard diameter and thickness (i.e. 8 to 9.5mm x 0.5mm respectively) in advanced engineering materials and nickel based supaeralloys in particular is becoming problematic [12]. A significant stack of weights is employed, usually balanced without circumferential constraint on the load pan. The issue can be addressed by deliberately increasing the mass of the upper rod and only requiring a few relatively small weights on the load pan to discriminate between the required load for individual tests. This can be achieved by employing a high density alloy for the rod or increasing the rod diameter. In turn this should lead to an improvement in rod stability and alignment within the load train.

Table 2. Permitted temperature deviations based on prEN 15627.

Test temperature, T [ºC]	**Permitted deviation [ºC]**
$T \leq 600$	± 2
$600 < T \leq 800$	± 3
$800 < T \leq 1000$	± 4
$1000 < T \leq 1100$	± 5
$T > 1100$	By agreement

The condition of the hemispherical punch tip is observed between each test, both for general condition, oxidation etc by eye and for form against a shadowgraph. This becomes more pertinent as advances in material creep strength demand ever increasing test temperatures and loads to be employed. During some campaigns it may be necessary to treat the punch as a consumable item to be replaced each test.

Given the sensitivity of some metallic systems to strain rate and the preference for a repeatable method of load application, it is recommended that the load pan be released in a single, smooth action. Historically, this has been achieved using a simple mechanical lever, however, more recently a fine threaded mechanical release has been incorporated to selected frames in a similar fashion to conventional creep frames, Figure 4.

4. Discussion

By comparing to the best practice employed for conventional scale creep testing under tension, the authors hope to initiate a debate relating to the requirements of research and commercial test laboratories alike in preparation for accreditation against the forthcoming European standard for small punch creep testing. We are confident that many of the issues discussed here are routinely addressed by most laboratories, however, more rigorous and test specific expectations from the various accreditation bodies must also be taken into account. Some of the suggestions made here relating to load calibration, alignment checks, temperature measurement and load application may be deemed demanding in terms of time, effort or cost, but they are typical of the issues raised by accreditation surveillance teams.

Ultimately, accreditation bodies will expect laboratories to develop uncertainty budgets to support small punch creep testing, similar to those derived for conventional creep tests [13]. It is recognized that this task is far from straight forward and detailed consideration should be directed at this requirement into the future.

Figure 4. Capstan style load release mechanism.

Acknowledgments: These are independent views expressed by the authors for consideration by the international small punch testing community and the ECISS TC 1010/WG 1 committee currently formulating the relevant European Standard for small punch creep.

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