Considerations for the Accreditation of Small Punch Creep Testing

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Contents

Historical Background – Swansea Facility

- Suite of small punch creep frames at Swansea developed over the previous quarter century to address a wide range of assessment requirements
- Originally designed to support the power generation sector in the 1990s
- Rigs now modified and increased in number to also serve the aero-gas turbine industry
- Continual advance in material capabilities - <u>increases in the max test temp and load</u>
- 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)

- [1] CEN, 2007. CEN Workshop Agreement - Small Punch Test Method for Metallic Materials CWA 15627

Preparations for SP Standards

- The 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 [2]
- Expectation - by satisfying the following suggestions for small punch calibration and compliance to the European standard, multiple laboratories will be able to gain accreditation for small punch creep testing
- Longer term - offer a consistent market for research and commercial testing

- [2] prEN 15627 “Metallic materials - Small punch test method”, working document, ECISS TC 1010/WG 1 committee

Mechanical Calibrations

- Obvious approach to small punch equipment calibration - take a lead from established International standards describing conventional scale axial creep machines

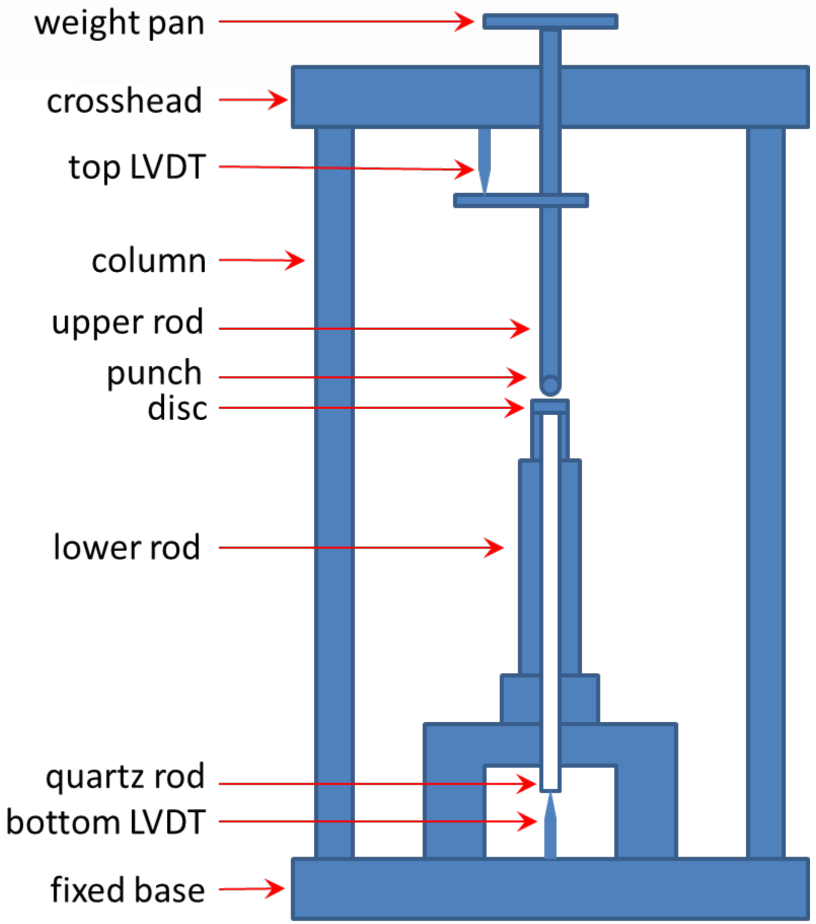
- ISO 17025 accreditation schedule for SMaRT [3] incorporates:
  - BS EN ISO 7500-2:2006 "Metallic materials – Verification of static uniaxial testing machines Part 2: Tension creep testing machines – Verification of the applied Force"
  - BS EN ISO 9513:2012 "Metallic materials – Calibration of extensometer systems used in uniaxial testing"

- [3] ISO 17025 laboratory accreditation schedule, "Constant load creep testing", UKAS Laboratory 7772, 2018.

Applied Load

- Reference to a typical dead weight rig
- Potential sites for friction:
- Crosshead -> linear bearing
- Punch location into clamping assembly
- ISO 376 [4] certificated compression load cell device into the lower half of the load train
- Annual verification expected, e.g.

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



- [4] ISO 376:2011 “Metallic materials -- Calibration of force-proving instruments used for the verification of uniaxial testing machines”.

Applied Load – Additional Considerations

- Allowable errors ?
- BS EN ISO 7500-2:2006 [5] = errors equivalent or better than class 0.5
- Calibration weights verified to within 0.1% accuracy on a five year cycle [5]
- Test weights calibrated to within 0.5% accuracy on a five year cycle to maintain the 1% loading requirement from traditional creep standards[6]
- The weight of the load pan assembly (weight pan, upper rod and punch) must be measured on an annual basis.
- Regular applied load calibrations are even more pertinent to systems incorporating offset lever load application where errors are possible due to wear in rotary bearings and counterbalance settings

- [5] BS EN ISO 7500-2:2006 "Metallic materials – Verification of the static uniaxial testing machines Part 2: Tension creep testing machines – verification of applied force"
- [6] BS EN 2002-005:2007 "Aerospace series – Test methods for metallic materials Part 005: Uninterrupted creep and stress rupture testing

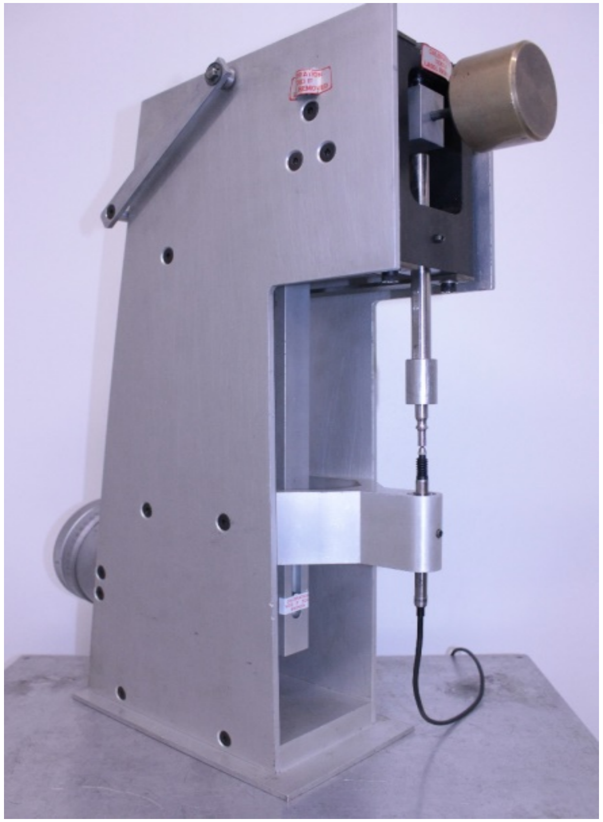
Extensometry

- Calibration of creep extensometry described in BS EN ISO 9513 [7]
- Define the performance of the complete extensometer assembly, i.e. in the case of tensile creep, a complete drop leg cage instrument
- The procedure recognizes the complexity of the assembly
- The cage is remotely attached to a certified extensometer calibration rig
- Applied displacement is compared to the measured output from two linear variable displacement transducers (LVDTs) – dual average
- The entire electrical measurement system through to the eventual data logger must be incorporated into the calibration procedure

- [7] BS EN ISO 9513:2012 "Metallic materials – Calibration of extensometer systems used in uniaxial testing"

LVDT Calibrations

- For small punch, the displacement is measured directly off the deforming specimen and preferably immediately below the contacting punch
- Achieved through a lightly sprung, quartz rod running inside the internal bore of the lower rod, contacting the bottom LVDT (fixed in place relative to the base of the machine)
- Simple, direct transfer of displacement between the disc and the bottom LVDT
- 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
- Additional LVDT to measure the movement of the upper rod or load pan relative to the crosshead should also be calibrated
- LVDT devices should perform to class 0.5 or better.



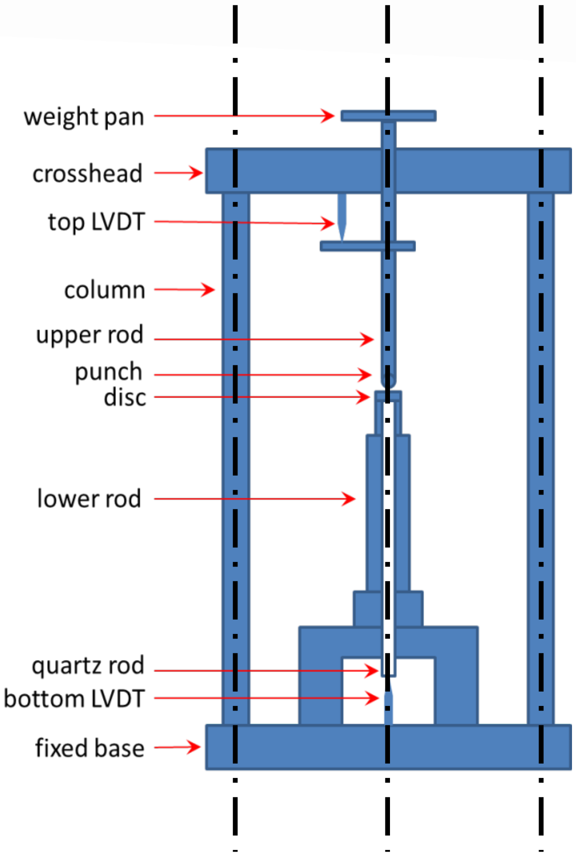
Alignment

- Conventional tensile creep load trains have effective self alignment via universal joints and validated through cold modulus checks
- More rigorous attention to the alignment of small punch rigs will almost inevitably be expected as part of accreditation assessment
- Alignment checks of universal tension and low cycle fatigue machines - strain gauged specimen subjected to a range of tension and compression loads in accordance with ASTM E1012-14 or BS ISO 23788:2012 [8,9]
- Small scale of the small punch disc specimen - limited free access to the lower surface of the disc within the bore of the clamp (typically 4mm in diameter)
- Prohibitive to apply similar strain gauge techniques directly off a specimen
- Upper and lower loading rods could be strain gauged around their external surfaces, however, to allow for checks against bending

- [8] ASTM E1012-14 “Standard practice for verification of testing frame and specimen alignment under tensile and compressive axial force application”
- [9] BS ISO 23788:2012 “Metallic materials – Verification of the alignment of fatigue testing machines”

Alignment - Comments

- Necessity for such detailed checks on SP 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
- Deep throated linear bearing 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 (eccentricity), precision edges and set squares are also performed on a regular basis, at least annually



Temperature

- Use of suitably calibrated thermocouples - determine correction factors (externally supplied or inhouse calibrations)
- PC based temperature logging system employed and calibrated against a certificated thermocouple simulator on an annual basis
- Temperature corrections from complete temperature measurement system must be applied to values obtained on test by the logging system (i.e. thermocouple correction + data logger correction applied)

Operating Procedures

- Most rigorous aspects of conventional creep standards adapted for our small punch creep testing procedure
  - BS EN ISO 204:2009 “Metallic materials – Uniaxial creep testing in tension – Method of test”
  - BS EN 2002-005:2007 “Aerospace series – Test methods for metallic materials. Part 005: Uninterrupted creep and stress-rupture testing”
- Disc sample prepared carefully to the relevant dimensions and surface finish
- Clean the disc in ethanol to remove remnants of polishing media and store in a desiccator until ready for test
- Once clean, the operator should wear nitrile gloves whilst handling specimen to avoid contamination by salts (e.g. titanium alloys !)
- Standard clamping pressure to constrain the disc still requires agreement - once defined the design of the clamping jig should allow for the application of measured torque via a calibrated wrench

Temperature Control – Furnace and Thermocouples

- Two (minimum) or preferably three zone radiant furnace is recommended (subjected to regular validation of temperature stability)
- Specimen temperature is ultimately reliant on thermal conduction through the mass of the central clamping jig
- Sample temperature measurement:
  - For tests below 1200°C, pre-welded, mineral insulated, type N thermocouples are procured from an ISO 17025 accredited supplier, manufactured from certificated batches of wire
  - Else, the laboratory is required to self calibrate thermocouples according to an appropriate standard procedure [10]
- Above 1200°C or long duration tests – type R or S for low drift (non insulated – problematic ?)

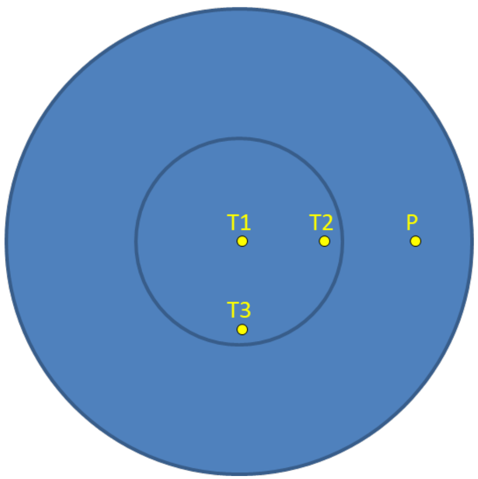
- [10] ASTM E220 – 13 "Standard Test Method for Calibration of Thermocouples By Comparison Techniques.

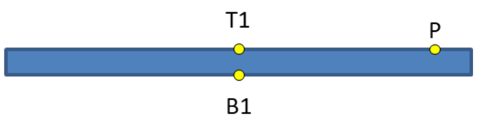
Test Temperature Control

- Throughout the test - tip 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 specimen is gradually raised to test temperature to avoid over heating
- During heating the upper loading assembly 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
- Maximum soak periods must be imposed for selected alloys (e.g. nickel based superalloys sensitive to precipitation coarsening/dissolution)

Temperature Distribution

a. Lancaster & Jeffs





- Soak period established through thermal distribution checks of an instrumented disc
- Thermocouples spot welded to the top and bottom surfaces of a disc in addition to the usual monitoring thermocouple in contact within the clamped periphery (position P)
- Temperature distribution measured over a range of typical test temperatures up to 800°C.

- Minor variations (±1°C) between central locations top & bottom of disc surface (T1 and B1)
- Difference up to 10°C was measured between disc periphery (P) and centre (T1, B1), with the centre consistently the cooler position.
- Presumed reason for difference is from exposure of the central disc area to free space allowing radiated heat loss

Test Temperature Tolerances

- Original CoP recognized the probability of temperature variations across the specimen
- "Validation measurements" to calculate acceptable off set control of test temperature
- Local practice is moving towards the best practice of any form of mechanical testing - ensuring the monitoring thermocouple is in contact with the specimen within the critically stressed volume
- Achieved using a thermocouple within the hollow quartz rod used to measure displacement - thermocouple tip touching the lower face of the disc immediately below the point of punch contact on the upper face
- Proposed tolerances for temperature control currently stated in prEN 15627 are actually more demanding than those employed under conventional creep testing (e.g. BS EN ISO 204).
- Need to demonstrate a stable laboratory environment is maintained

Load Practicalities

- Condition of punch tip observed between each test, both for general condition, oxidation etc by eye and for form against a shadowgraph
- 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

Load Application

- Applied load is made up from a combination of certificated weights plus the mass of the upper load train (weight pan, upper rod and punch)
- Mass of the upper load train verified annually and each individual set of rods recorded against specific machines

- Given the strain rate sensitivity of some metallic systems 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 achieved using a simple mechanical lever
- Recently a fine threaded mechanical release has been incorporated to selected frames in a similar fashion to conventional creep frames

Concluding Remarks

- Initiate debate on the requirements of test laboratories in preparation for accreditation
- Forthcoming European standard for small punch creep testing is required to underpin future laboratory surveillance
- Recommendation to ECISS TC 1010/WG 1 committee - separate prEN 15627 into:
  - a) creep
  - b) monotonic testing
- Compare SP creep requirements to expectations from conventional creep under tension
- Some of the suggestions relating to 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 uncertainty budgets to support small punch creep testing (Normal expectation of all new standards).

Contact Details

QUESTIONS

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- Laboratory Tour – Thursday Afternoon

UKAS TESTING

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