HIGH TEMPERATURE MECHANICAL TESTING: REVIEW AND FUTURE DIRECTIONS

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The importance of reliable testing techniques for the acquisition of high temperature material property data will be considered. The role played by the High Temperature Mechanical Testing Committee over the last fifteen years is outlined together with the recent developments in verification of Codes of Testing Practice. Future developments in the field of high temperature testing will be reviewed including the trends towards testing above 1000°C and the emergence of miniature testing techniques.

INTRODUCTION

From the onset of the industrial revolution and the rise of steam power it was realised that a material's strength and other properties could be adversely affected by a rise in temperature. Thus over the years numerous attempts were made to experimentally determine material properties that represented the material's performance under conditions that were experienced by components in service; such examples are represented in the work of Rennie (1) and Fairbairn (2). In the 1920's the importance of high temperature time dependant strength (creep) was recognised which became crucial with the development of the jet engine during World War 2; a brief historical review of high temperature and time dependent mechanical testing has been presented elsewhere, Loveday (3).

In 1981 an NPL Conference addressed the issue of the importance of good testing practice to ensure the generation of reliable material property data of the appropriate accuracy for component design and life prediction. The conference brought together technical experts who considered various aspects of tensile, creep and fatigue testing under uniaxial and multiaxial states of stress together with calibration methods, the design and control of testing machines and suitable laboratory environmental conditions, Loveday et al (4).

Following the Conference, representatives from industry expressed the view that the continued benefits of pooling the shared expertise would lead to general improvements in experimental testing techniques and hence in the quality of material property data. It was proposed to build upon the NPL initiative and form an organisation dedicated to improving high temperature testing techniques. It was recognised that improved test methods were vital to improving data quality and contributors freely gave of their time and expertise with the knowledge that generic improvements were of benefit of all concerned.

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AIMS

To improve high temperature testing by :

- **Providing a Forum for Discussion**
- **Organising Conferences and Laboratory Visits**
- **Publishing Conference Proceedings and Codes of Practice**
- **Initiating Research Activities**

Table 1. Aims of the High Temperature Mechanical Testing Committee.

Thus the High Temperature Mechanical Testing Committee (HTMTC) was born which met under the Chairmanship of Dr B.F.Dyson of NPL and with Mr M.S.Loveday acting as Secretary. Membership of the Committee was by invitation and no membership fee or subscription was levied. Income to support the HTMTC's activities was primarily generated from conferences and partially from publication royalties on conference proceedings. The aims of the Committee are given in Table 1. The HTMTC is a non profit making organisation registered as a Charity (Reg.No.800892) and to protect members of the committee from personal financial loss in the event of its activities floundering, it is registered at Companies House as a company limited by guarantee, (Reg No.2149907).

PAST ACTIVITIES OF THE HTMTC

Over the years the HTMTC has organised thirteen conferences (Table 2) resulting in the publication of six books and three review articles (Table 3) covering a wide variety aspects concerning high temperature mechanical testing. In addition under the auspices of the HTMTC Woking Groups have produced six Codes of Testing Practice, (Table 4). Regrettably there is not sufficient space in this present paper to properly review the considerable technical advances outlined in the publications listed in Tables 3-4, however it will readily be apparent to anyone who peruses this extensive collection of literature of the important contribution that the HTMTC has made in the dissemination of improvements in advanced high temperature testing techniques and consequently improving the standard and quality of test methods and the measured data. Individual members of the Committee have provided significant technical input to the National and International Standards committees responsible for documentary testing and calibration standards in the fields of tensile, creep and fatigue testing. Although these conventional tests have been in use for many decades, recent advances in the control of testing machines together with the requirement for higher precision data for Finite Element computer modelling design of components and life prediction still require further developments of the testing methods. In addition sensible use can now be made of multiaxial test data to simulate the conditions actually experienced by components.

The HTMTC Council comprises eighteen members representing industry, research organisations and academia from the UK and mainland Europe and in addition there are approximately sixty corresponding members who receive all the committee papers and who represent the majority of organisations across Europe who are involved with high

PAST CONFERENCES

- **Techniques for High Temperature Fatigue Testing** (UKAEA Preston, 1983)
- **Measurement of Crack Growth at High Temperature** (Rolls Royce Derby,1984)
- **Techniques for Multi-axial Creep Testing** (CERL/ERA Leatherhead, 1985)
- **Mechanical Testing> 1000°C** (NEI/IRD Newcastle, 1986)
- **Fretting Fatigue and Wear** (GEC, Rugby , 1988)
- **Mechanical Testing of Engineering Ceramics at High Temperatures** (NPL, London, 1988)
- **Temperature Measurement and Control in High Temperature Mechanical Testing** (INCO, Hereford, 1989)
- **Harmonisation of Testing Practice for High Temperature Materials** (Italy, 1990)
- **The Practicalities of Mechanical Testing at Elevated Temperatures in Controlled Environments.** (ERA Technology, Leatherhead, 1990)
- **Ultra High Temperature Mechanical Testing.** (Petten, Netherlands, 1992)
- **The Practicalities of Thermo-Mechanical Fatigue Testing.** (Rolls Royce, Derby, 1993)
- **Local Strain and Temperature Measurements in Non-Uniform Fields at Elevated Temperatures.** (Berlin, Germany, 1996)
- **The Practicalities of Thermocouple Calibration and Usage for Materials Testing.** (NPL,London, 1996)

Table 2. Past Conferences Organised by the HTMTC.

temperature testing. In 1996 a Memorandum of Understanding was signed between the HTMTC and the European Structural Integrity Society (ESIS) under which the HTMTC operates as Technical Committee 11 of ESIS whilst retaining autonomy. Currently active Working Groups under the auspices of the HTMTC include : a) Notch Creep Testing, b) Cyclic Stress-Strain Measurement, c) Modulus Measurement, d) Thermocouple Measurements for Mechanical Testing, e) Thermal Mechanical Fatigue and f) Alignment Measurements.

In some cases research programmes have been initiated to validate Codes of Practice, a typical example being the work undertaken to investigate the influence of testpiece size effects and notch spacing on double circumferencial notched used to generate a triaxial stress state in uniaxial loaded cylindrical bars, Al-Abed (5).

FUTURE DEVELOPMENTS IN HIGH TEMPERATURE TESTING

The recent focus of research in the field of materials processing, with major research programmes funded by both the DTI and EPSERC in the UK has highlighted the need for reliable thermophysical and mechanical material property data of known pedigree for Process Control and Modelling. Machines have been developed to allow high temperature flow stress data under plane strain compression at high rates,Shi et al.(6), and guidelines for Hot Axisymmetric Compression testing have been published, Roebuck et al (7) for the

BOOKS

1. **'Techniques for High Temperature Fatigue Testing'.**
Ed. G.Sumner and V.B.Livesey.Pub: Elsevier Applied Science (1985)
2. **'Techniques for Multiaxial Creep Testing'.**
Ed. D.J.Gooch and I.M.How. Pub: Elsevier Applied Science. (1986)
3. **'Mechanical Testing of Engineering Ceramics at High Temperatures'**
Ed. B.F.Dyson, R.D.Lohr and R.Morrell. Elsevier Applied Science. (1989)
4. **' Harmonisation of Testing Practice for High Temperature Materials'**
Ed. M.S.Loveday and T.B.Gibbons. Pub: Chapman & Hall. (1992)
5. **'Ultra High Temperature Mechanical Testing'.**
Ed. R.D.Lohr and M.Steen. Pub: Woodhead. (1995)
6. **' Local Strain and Temperature Measurements in Non-Uniform Fields at Elevated Temperatures'.** Ed. J. Ziebs, J. Bressers, H. Frenz, D.R.Hayhurst, H.Klingelhoffer and S.Forest. Pub: Woodhead.(1996).

PAPERS / REVIEW ARTICLES

1. **'Mechanical Testing >1000°C'** M.S.Loveday and R.B.Evans.
Redaktion Materialprufung 30(3) 53-57 (1988).
2. **'Mechanical Testing: High Temperature Attainment, Measurement and Control'.** R.D.Lohr, M.S.Loveday and T.K.White.
High Temperature Technology, 8 (4) 290-297. (1990).
3. **' Taking the Test in Thermo-Mechanical Fatigue'**
P.R.McCarthy. Materials World, 468-470. (1994).

Table 3. Books and Review Article issued under the auspices of the HTMTC.

measurement of data for forging and rolling process control models. New test methods have been developed for measuring friction coefficients at high temperatures including a D.C. heated pin-on-disc, Gee et al.(8), and a Large Friction Rig attached to a 7000kN press, Loveday(9). Testing techniques are also under development for measuring the strength of materials in the mushy zone close to the melting point for data relevant to process modelling of castings, Spittle et al (10).

The testing of miniature testpieces has recently been the focus of interest which allow samples to be trepanned from full-sized components to assist in the prediction of the residual life of safety critical plant, Parker (11). Another exciting development has been the construction of a small multi-purpose testing apparatus in which small ~ 1mm x 2mm rectangular cross section testpieces, 20mm long, can be heated to ~ 1000°C in a few seconds using DC heating and loaded in tension or compression under computer control using customised LabView software, Roebuck (12). The benefits offered by the use of such testing comparison of methods are significant, however it is important that such methods are verified by results obtained with conventional sized testpieces.

CODES OF PRACTICE

1. **' A Code of Practice for CONSTANT-AMPLITUDE LOW CYCLE FATIGUE TESTING at elevated temperature'**
   G.B.Thomas, R.Hales, J.Ramesdale,R.W.Suhr and G.Sumner. Pub: NPL (1986).
   also in Fatigue & Fracture of Eng. Mat. & Structures, 12 (2) 135-153, (1989).
2. **'A Code of Practice for the use of Ni-Cr-BASE ALLOY EXTENSOMETERS FOR THE MEASUREMENT OF CREEP STRAIN'**
   M.S.Loveday and T.B.Gibbons, Pub: NPL, (1987).
3. **'A Code of Practice for INTERNAL PRESSURE TESTING OF TUBULAR COMPONENTS at elevated temperature'**
   I.M.How, R.J.Brown, M.C.Coleman,I.H.Craig, W.M.Hamm, R.C.Hurst and P.C.Meecham. Pub: NPL. (1989).*
4. **'A Code of Practice for TORSIONAL CREEP TESTING OF TUBULAR TESTPIECES at elevated temperature.'**
   D.W.Rees, M.W.Brown, T.Hyde, R.D.Lohr, C.J.Morrision and M.J.Shammas. Pub: NPL , (1990).*
5. **' A Code of Practice for NOTCHED BAR CREEP RUPTURE TESTING: PROCEDURES and INTERPRETATION OF DATA FOR DESIGN'.**
   G.A.Webster, B.J.Cane, B.F.Dyson and M.S.Loveday. Pub: NPL. (1991).*
6. **'A Code of Practice for the MEASUREMENT OF MISALIGNMENT INDUCED BENDING IN UNIAXIALLY LOADED TENSION-COMPRESSION TESTPIECES'**
   J.Bressers, S.Holdsworth, P.Harris, C.Larsen, M. Sanders, and G.L.Tjoa. Pub: European Commission, EU 16138 EN. (1995).

* Also published in 'Harmonisation of Testing Practice for High Temperature Materials', Ed. M.S.Loveday and T.B.Gibbons. Pub: Elsevier Applied Science. (1992).

Table 4. Codes of Practice issued under the auspices of the HTMTC.

For all measurement methods it is important that there is a clear understanding of the likely precision of the test technique and that traceability can be demonstrated to the National Measurement System, Dyson et al.(13). In particular it is important to assess the likely scatter in the results attributable to the measurement method as opposed to that due to material inhomogeniety. Guidance is now provided in the ISO 'Guide to the Expression of Uncertainty in Measurement' (BSI PD 6461 Pt3. 1995) and in some of the testing standards e.g. Uniaxial Creep Testing, EN 10291 (1998). In the case of high temperature creep testing, a Certified Reference Material,CRM 425, is now available from the Institute for Reference Materials and Measurements (IRMM), at the JRC, Geel, Belgium ,for proficiency testing, bench-marking for intercomparison studies, for assistance in accreditation and for helping to assess scatter in data attributable to test methodology, Gould and Loveday (14).

CONCLUDING REMARKS

There have been considerable improvements achieved in the field of High Temperature Mechanical Testing during the last decade wide promulgated by the activities of the

HTMTC. Novel techniques are still emerging largely in response to the demand for improved data necessary for computer based modelling methods.

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