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Brite-Euram Contract No. BREU-CT92 -0235

Concerted Action: Long Term Creep Data Development For Advanced Power and Process Materials "CREEP"

I A Shibli

SYNTHESIS REPORT

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Summary

Key Words: Creep, standards, harmonisation, data-quality, stress relaxation

The Concerted Action was highly successful in its overall original aim of co-ordinating the generation, collation and analysis of creep data for metals commonly used for high temperature plant applications. The main achievements were as follows

- Creep and rupture strength values for a large number of materials used in high temperature plant have been agreed by European industry and recommended to/incorporated in European Standards.'
- Procedures for vetting large sets of data have been developed and validated based on the new and original concept of PATs (Post Assessment Tests).
- A system has been setup for the co-ordinated supply of data.
- Procedures for harmonisation of data production, assessment and utilisation (for existing and future plant requirements) have been developed in detail.
- Optimum data exchange and analysis methods have been developed and validated
- New data have been/are being generated on new materials (such as Grade 91 steel) through Europe wide co-operation between industry.
- Information dissemination throughout Europe has been highly effective.
- Key future data developments areas have been identified resulting in two new Thematic Network proposals (one accepted by CEC for funding (CEC Proposal Reference BET2-509) and the other likely to be submitted to CEC in the near future).
- Two new areas requiring the formulation of new standards/codes of practice have been identified. These are 'interrupted creep testing' and 'stress relaxation testing'. Proposals on these aspects submitted. under the SMT programme were accepted and work is now in progress (CEC Reference: SMT 3127. and SMT 3121)

The primary benefits to the Community from the work will arise from more cost-effective data development. Specifically the work confers the following benefits for alloy producers and plant manufacturers and operators in the power and process plant industries.

- It enables European power plant manufacturers to improve their competitiveness in a world market through better and more reliable design, data generation and data analysis practices.

- It aids in maintaining a strong European process and power engineering industry, with the resulting financial benefits and security of employment for the hundreds of the industry's supply/service companies (mainly SMEs).

- It aids in ensuring a safe and secure supply of low cost electricity] (with the resulting benefit of increased competitiveness for all European manufacturing industry including many tens of thousands of SME manufacturers) through better and more reliable design and life assessment.

- It will lead to conservation of fuel and reduced environmental impact' as a result of the acceleration of the development of higher efficiency advanced plant which will be the consequence of the larger data pools now available through this Action on new materials.

- It will accelerate the development of new materials through better co-operation between European industry in this area.

- The project has brought together a) European industrial companies themselves (particularly in the field of creep), b) European industry with the European research base and c) Industrial experts with European Standards committees. Through this co-operation European data generated over many decades is now being pooled together for quality assurance and re-analysis for the greater benefit of European industry as a whole.

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ECCC	-	European Creep Collaborative Committee
PATs	-	Post Assessment Tests
CRDA	-	Creep Rupture Data Assessment

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1 The Consortium

1.1 Partner and Co-ordinator

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1.2 Consortium Description

The Consortium, on whose behalf the work is being co-ordinated by ERA Technology, is the European Creep Collaborative Committee (ECCC). ECCC is a grouping of about 35 European organisations including 23 industrial companies. The grouping comprises universities, research institutes, plant manufacturers, alloy producers, and power and petrochemical plant operaters, A brief description of some of the (mainly) industrial participants is given below:

- Nuclear Electric Ltd is a wholly owned subsidiary of British Energy PLC which is responsible for generation of electricity from AGR and PWR stations within the UK. The installed generating capacity of the company is approximately 9 Gwatts.

- Centro Sviluppo Materiali SPA (CSM) was founded in 1963 in reply to the Italian Steel Making and Steel Using Industries' request. The nature and purpose of this centre is to earn out research and to promote industrial activities in the field of materials innovation and know-how development for steel and high technology industries. CSM has 340 employees. CSM is particularly interested in creep data development on base materials and welded joints. The CSM has considerable experience in high temperature materials and their creep laboratory is the biggest in Italy.

- Mannesmannröhren-Werke AG is a producer of pipes and tubular products in Germany. Its research division (Mannesmann Forschungsinstitut) has been involved in long, term materials testing for more than 50 years. The staff of the Mannesmann Forschungsinstitut comprises a total of about 190 persons.

- Technische Hochschule Darmstadt (Institute Fiir Werkstoffkunde) undertakes extensive work on creep-rupture testing and data evaluation of high temperature materials and development of lifetime prediction methods. Involvement in the present work increases expertise in areas relevant to both power generation and process plant.

- **Universität** Stuttgart **(Staatliche Meterialprüfung Sanstalt) (MPA)** is a wellknown research institute in the domain of material science and component and system safety. MPA intends to promotes data development for advanced power and process plant design.

- **GEC-Alsthom** is a leading manufacturer of turbine and pressure part components for nuclear and fossil fired power plant including combined cycle power stations. For design of high temperature plant, a large body of long term creep data is 'essential. This project co-ordinates testing and data analysis. requirements throughout Europe to maximise the information database available to the power plant design engineer to permit the design of high quality machinery which is competitive in the world market.

- British Steel (Technical Division): Long-term creep data development is essential to the following aspects of British Steels corporate aims: a) to maintain a broad product range, b) to differentiate its products from those of other producers by brand marketing and product quality, and c) to increase its sales of finished products which contribute higher margins.

- PowerGen PLC is one of the UK electrical power generation companies formed from the Central Electricity Generating Board. In the UK market for electricity] generation, its aim is to become the most cost effective supplier and the data development activities are fundamental to this aim.

- Electricity de France **(EdF)** is the French national electricity! generation utility. Development of creep data are fundamental to the optimised performance of its plant.

- **Electricidade** de Portugal **(EdP)** is the Portuguese national utility responsible for the design, erection and operation of power plants. and the distribution of electricity to its consumers.

- **Laborelec** is the Belgian Laboratory of the Electric Power Industry and is a co-operative organisation founded by the Belgian Electricity supply companies. Its function is to conduct all necessary scientific and technical research to improve the existing means of power generation, transmission and distribution. Laborelec personnel = 250.

- Technical University of **Denmark/Elkraft-Elsam**: Elsam and Elkraft are. the Danish power utility companies supplying respectively the western and eastern parts of the country. The corporate strategy is to improve efficiency of power generation processes and for this, materials data on new improved power plant steels are of vital importance, Further there is an incentive to prolong the life of existing plants, and for this, knowledge of creep properties is of importance.

- **Graz** University of **Technology (GUoT)** acts as a **national** representative of Austrian companies, which are involved in the manufacture, fabrication and application of heat resistant and high temperature materials in a wide range of industrial sectors.

- ABB is a manufacturer of high temperature plant and the availability of creep data is of central importance for safe and economic design of such plant.

- **Swedish Institute** for **Metals** Research (SIM R) collects and assesses high temperature mechanical properties as a basis for the evaluation of characteristic strength values for engineering design for a number of different type of industrial organisations in Sweden. The values are frequently included in material standards.

- **Instituto Scientific Breda SpA (ISB)** is the successor and unique heir of the Instituto Richerche Breda IRB. ISB is working on applied and/or industrial research projects, failure analyses, and engineering and material utilisation. ISB has 50 employees. The characterisation and explanation of the creep behaviour of metals is a long ruining tradition of ISB.

- ENEL/CRAM

  ENEL Spa (former Italian Electricity Board) is one of the largest utilities in the world. ENEL Spa is in charge of generation. transmission and distribution of electricity all over Italy. ENEL employs about 97000 people. ENEL devotes to R&D activities a staff of about 1000 highly qualified researchers and technicians and' has an annual budget of more than 150 MECU. The Environmental & Materials Research' Centre (CRAM) is in Milan and employs about 150 people.

- DSM is an international company producing plastics. fertilisers and chemical products. DSM is based in Geleen, the Netherlands. and employs 18.000 person: world-wide (about 10.000 in Europe),

- **Siemens is** a large German based power plant manufacturing company

- National Power is the largest UK based fossil power plant operator.

- ESB: Eire Electricity Supply Board is a power generation company in Ireland

- VDEh is the materials organistion/union of Germany and is a member of the European creep committee.

- **Ansaldo** are power plant boilermakers and are based in Italy.

- BNS: Bureau de Normalisation de la Siderurgie is a Standards organisation from France

- **IRD/Rolls** Royce is a large UK based company with major power plant activities.

- **Electrabel** is a Belgian electricity supply company

- Other organisations involved in the project are:

  - GEC **Alsthom Stein Industrie**, France

    GEC **Alsthom Man Energie,** Germany

  - **CISE Spa, Italy**

    Universite di Ancona, Italy

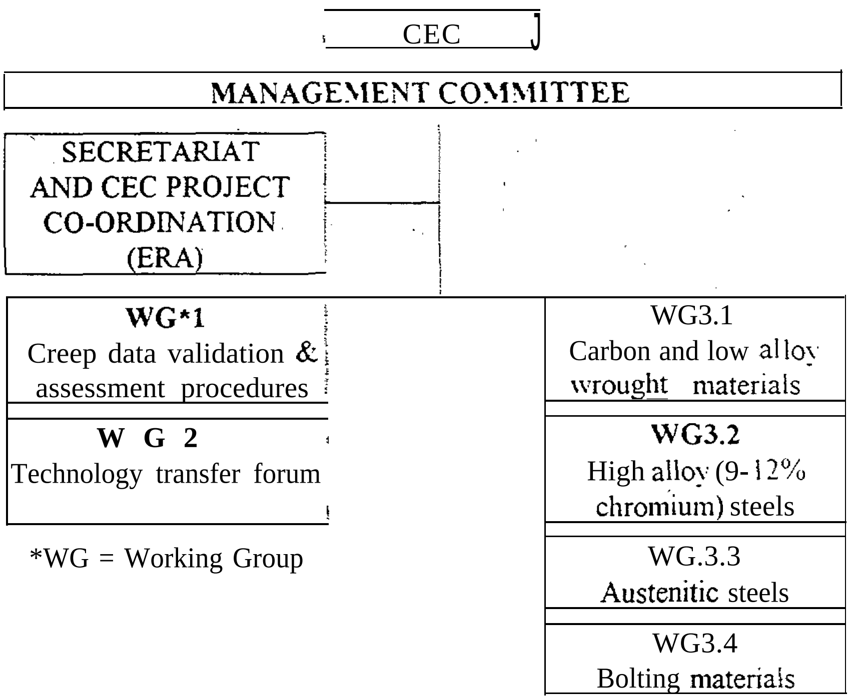
  - **Nuovo Pignore Spa, Italy**

    TNO is the welding institute of Netherlands

2 Technical Achievements

2.1 Overview

The structure of the Concerted Action is shown below



During the project, the four working groups (WG3.1 to WG3.4) collated and exchanged data on high temperature materials and processed these data in accordance with recommendations generated by WG1. The key development areas of these working groups are shown in the figure above.

The overall subject is technically complex and a difficult area for interaction smcc in each country there are long established national methods and standards leading to natural prejudice. However, within the Concerted Action it has been possible to harness the knowledge and enthusiasm of the national experts and encourage the exchange of experiences in the efforts towards harmonisation of European procedures governing creep testing and data analysis. European collaboration has also been used to collect, collate and analyse creep test data on a wide range of steels from many sources. Such data were analysed using methods of the Concerted Action to establish approp -i ate long term strength values for high temperature design purposes.

The Concerted. Action established a good rapport with those responsible for developing European Standards and its guidance is now frequently requested

2.2 Overall Achievements

By far the most significant achievement of the Concerted Action has been European harmonisation and standardisation of data generation (ie testing), data exchange and data analysis methodologies. This is against a background of sometimes conflicting continuing national developments, in particular in the UK, Germany, France and Italy. New procedures and concepts have been developed. Thus. for example, the ‘post (data analysis) assessment test’ or 'PAT' is a new concept developed by WG1 to assess the authenticity of data analysed and of design strength predictions for high temperature plant

Different working groups were responsible for the development of different types of materials. Each working group consisted of a number of organisations from different count ries of Europe, The interaction between these working groups and the interaction of all within WG 1 resulted in a close and complex collaboration between the organisations of the different European countries.

The nature of the work was such that technical visits to partner laboratories were not required apart from visit to the laboratones of the organisations hosting meetings, Electronic exchange of data and communication between the participating organisations was frequent. Meetings of the working groups provided an opportunity to familiarise participants' with the working of creep committees/groups in different countries of Europe, and also their testing and data analysis practices.

The organisation of the 'Information Days' was a typical example of the type of inter-European collaboration achieved through this Concerted Action. Thus the event, on 18th October 1995 was organised by ERA, hosted by VDEh (Dusseldorf- Germany) with speakers from four European countries making presentations and delegates from over 16 countries having attended the event

In terms of technical achievements, the Concerted Action identified new areas of work. Specifically) two new SMT projects and a Thematic Network on Creep Data Development for weldments have been spawned. A further Thematic Network to specifically fill gaps in the scope of the existing database for parent material data is also planned.

2.3 Specific Achievements

The participants in the Action concentrated their work on properties and materials most needed to achieve a coherent body of data. Hence the focus was on materials such as low and high alloy steels. austenitic steels and bolting materials, used in high temperature plants. Both existing materials (such as 0.5CrMoV, 2.25Cr1 Mo and Type 316 steels) and new materials such as Grade 91 and 92 were investigated.

Regarding the validation of methodologies for new data generated and implementation of quality assurance programmed to obtain high quality data, the Action developed quality assurance procedures both for data generation and data analysis. These methodologies were applied to both existing and new data.

The achievements in terms of original industrial and technical objectives are described below:

1) With regard to the setting up of procedures for vetting data, this was achieved through the development of PATs (Post Assessment Tests), This is a new and original concept and allows the assessor to reject suspect data.

2) As regards the co-ordinated supply of data, a system was set up and used by the working groups.

3) -Approaches for harmonizing of standards for data production, assessment and utilisation (for existing and future plant requirements) were developed in detail.

4) Data exchange and analysis methods were developed and validated.

5) Information dissemination throughout Europe was highly effective. Information days open to European industry and meetings with ECISS representatives were organised.

6) Key future data developments areas were identified, particularly weldments.

7) Regarding areas requiring the formulation of new standards/codes of practice. two new areas were identified. These were interrupted creep testing and stress relaxation testing. Proposals on these aspects submitted under the SMT programme were accepted and work is now in progress.

2.4 Technical Benefits

Volume 1: Overview

This gives an introduction to Volumes 2 to 5 and provides guidance as to their use

Volume *2:* Terminology Document

This volume has provided the essential common basis for communication by all participants within the Concerted Action. It has unified terms and terminology used in different European countries and has been highly effective in optimizing co-ordination between technical workers, experts and industry in Europe.

The terms and terminology included in this document are recommended for use by all working groups of the Concerted Action, to ensure a common understanding particularly during exchange of data between partners and groups. The terms and terminology included are representative of best practice to which all future tests and "programmed may be expected to comply and become reflected in revisions of testing standards. However, it is recognised that not all existing data, although produced from valid standard test practices, will have a complete set of information.

The document consists of five sections which have been outlined below together with examples of some of the technical work.

Section 1: Material Details

This Section contains recommendations for material type, material source, manufacturing details. product details, chemical composition, heat treatment etc.

Section 2: Test Types - Descriptions

This Section makes recommendations on test conditions and terminology used for different test types such as stress rupture, creep rupture,' creep test. stress relaxation (both uniaxial and component tests). Included are type of measurements to be made and their definition. Thus, for example, terms used in creep and stress relaxation tests are defined in an unambiguous manner a; shown in Figs. 1.2 and 3.

Section 3: Test Details

This Section contains terms and terminology for the following: test environment, specimen details, test conditions such as measurement and control of temperature and load, definition of loading, elastic and in-elastic strains, test machine details, and test results.

Section 4: Standard Terms and Symbols

This Section describes symbols to be used throughout Europe to denote different material and test conditions. An example of this is shown in Table 1.

Section 5: Data Assessment, Collation and Storage - Definitions of Terms Used

This Section has produced a unified definition of terms used in data assessment. collation, exchange and storage

In addition to the above, a country and laboratory code system has been devised so that, in future, the source of all creep data within Europe can be easily identified.

The terms and terminology in this volume contain explanation for clarification purposes.

It is intended that this document should be reviewed at regular internals and amended as required.,

Volume 3: Acceptability Criteria for Creep, Creep Rupture, Stress Rupture and, Stress **Relaxation Data '**

Prior to the assessment of creep, creep rupture, stress rupture and stress relaxation properties, there is a need to confirm the integrity of the input data, both in terms of the pedigree of the material used and the ***testing*** practices adopted to generate the information. This volume considers the minimum material and testing pedigree information requirements for existing and future creep property data..

In formulating the acceptability criteria for assessment input data, there was a predictable dilemma. One potential course of action was to require that all data were accompanied by (i) a comprehensive list of material details and (ii) evidence to confirm that testing has been performed to conform with an acceptable modem specification. This would give complete confidence in the relevance and quality of the data, but could exclude a significant fraction of the currently available test information (some of which extends to ven long durations).

The compromise has been to define minimum requirements (See Tables 2 to 5(b)) to ensure the acceptability of existing data which have been regarded, traditionally as reliable. but to recommend tighter acceptability criteria for the future. The basis for the recommendations relating to material pedigree and testing practice acceptability criteria are detailed in this Volume

A survey was performed of the principal and national and international standards relating to creep rupture and creep strain testing. A first aim was to see if there were significant differences between the standards, to see if the data generated would have to be classified according to testing practice before they were entered into a common assessment procedure. A second aim was to check if recommendations should be given to improve existing standards or to prepare new standards as a better basis for the generation of data in the future. Finally it was questioned whether recommendations were needed for the assessment of raw test data eg for deriving time to specific strain data from the original creep curve data.

The survey led to an, overview of 9 different testing standards. in use world-wide or at a stage just prior to formal introduction.

In addition to the overview on testing standards. the creep and creep rupture testing practices of leading laboratories in several European countries were reviewed. This also provided assistance with the definition of minimum testing practice requirements (a) for existing creep and creep rupture data for assessment and (b) for data to be gathered in the future.

All types of testing are considered. ie creep testing up to a given plastic or creep strain, creep rupture testing with strain measurement and pure stress rupture testing without strain measurement.

A formal list of recommendations concerning creep and rupture testing practices are given in this volume and form the basis of recommendations to ECISS

As a consequence of the work leading to the preparation of Volume 3 (Issue 1). strong submissions have been made to COCOR highlighting the urgent requirement for modern European standards for uninterrupted creep rupture testing, interrupted creep rupture testing, uniaxial stress relaxation and model bolt stress relaxation testing. There is strong evidence to indicate that these submissions will be accepted and that the recommendations detailed in Volume 3 will provide the basis for the new standards.

Volume 4: **Guidance for Data Collation and** Exchange

A major aim was collection and combination of test data from the participating laboratories in a systematic manner and with the least misunderstanding, prior to assessment of strength values for Standards. Full recommendations for the collation and exchange of data are given in the body of this volume. The physical format by which data are transferred is based on Microsoft Excel spreadsheets. These have been designed following a detailed review of the Action participants' and other organisations' electronic databanks, and paper-based methods of data storage. The contents of the spreadsheets are compatible with Volume 2 (Terms and Terminology) and Volume 3 (Data Generation). Together with the accompanying recommendations for their use, the spreadsheets were prepared over a period of 2 years, that included trials of preparing sample data sets and of their exchange, Documents defining how the data may be downloaded from, and uploaded into the Concerted Action members' databanks are included in this volume, and the recommended format of documentation that should accompany spreadsheets containing data is also recorded.

Volume 5: Guidance for Data Assessment

This volume provides guidance for the assessment of large creep rupture. creep strain and stress relaxation data sets. Issue 1 concentrates on creep rupture data assessment (CRDA). It recognises that it is not practical at the present time to recommend a single European CRDA procedure and promotes the innovative use of post assessment acceptability criteria to independent]> test the effectiveness and credibility of creep rupture strength predictions.

The guidance is based on the outcome of a two year work programme involving the evaluation of a number of assessment procedures by several analysts using large working data sets. The results of this exercise highlight the risk of unacceptable levels of uncertainty in predicted strength values without the implementation of a well defined assessment strategy including critical checks during the course of the analysis.

Guidance for the assessment of creep strain data and stress relaxation data are contained in Issue *2* of this Volume 5.

Overview of the CRDA

The recommendations for the assessment of creep rupture data are based on a comprehensive review of CRDA procedures and an extensive evaluation of their effectiveness. The evaluation programme was performed by members of the Concerted Action using four large. inhomogeneous. multi-cast. multi-temperature working data sets, especially compiled for the exercise. The four alloys were 2 ¼CrMo, 12 CrMoVNb, 18Cr11Ni and 31Ni20CrAlTi (Incoloy 800), and were selected to represent the spectrum of materials covered by the four WG3.x working groups. The results of the evaluation programme have strongly influenced the recommendation< listed in this volume:

As it is not practical at the present time to recommend a single CRDA methodology consequent}'. the recommendations do not impose restrictions on the use of any procedure- provided that the results determined satisfy certain conditions and a set of post assessment acceptability criteria. The post assessment' acceptability criteria are the key to the CRDA recommendations and have been devised to give the user maximum confidence in the strength predictions derived through a series of independent post assessment tests (PATs) on the results of the analysis.

Although the implementation of these recommendations requires significant additional effort, this is regarded as entirely justified. The evidence, presented in this volume, from the CRDA evaluation **exercise has** clearly demonstrated that, without pre-assessment, repeat main assessments and post assessment tests, the uncertain associated with predicted strength values (in particular extrapolated strength values) is unacceptably high.

A laudable goal for the future has been identified as the development of a European state-of-the art CRDA procedure, and a number of target requirements for such a methodology are identified in Table 6.

Recommendations for the Assessment of Creep Rupture Data

The results of the CRDA evaluation exercise highlight the risk of unacceptable levels of uncertain) in predicted strength values without the implementation of certain precautionary checks during the course of assessment. The findings of this exercise have led to a number of" recommendations for performing CRDAs.

Pre-Assessment

Pre-assessment is an important step in the analysis of creep r-L pture data. It involves (a) characterisation 'of the data in terms of its pedigree. distribution and scatter (random/systematic). and (b) data reorganisation (if deemed necessary by the findings of (a)). In certain CRDAs it includes preconditioning/data reduction as routine. An important by-product from pre-assessment data distribution analyses is information which could be influential in the planning of future creep testing programmes.

The precise demarcation between the end of pre-assessment and the start of the main-assessment may be unclear and in certain CRDAs, the final assessment is only perform ed after a number of iterative steps back into pre-assessment. At least one analysis is usual as part of p-e-assessment. in order to characterise the trends and scatter in the data.

Post Assessment Acceptability Criteria

The CRDA post assessment acceptability criteria fall into three main categories, evaluating:

- the physical realism of the' predicted isothermal lines.
- the effectiveness of the model prediction within the range of the input data. and
- the repeatability and accuracy of the extrapolations

These are investigated in a number of post assessment tests which may be conveniently performed in a spreadsheet such as Excel.

Radical advances have been made with respect to the creep rupture data assessment of large datasets typical of those used to determine strength values for European design and product standards. in a far reaching data assessment exercise, WG 1 have demonstrated that high uncertainties associated with extrapolated creep rupture strength values are possible if appropriate precautions are not taken during analysis. To minimise the level of such uncertain. WG1 have devised a series of effective post assessment tests (PATs) which provide an independent check on the results from any creep rupture data assessment procedure. This is an original concept and is already being adopted in a new state-of-the-a'rt analysis procedure under development by a British Standards working panel These recommendations and the background information relating to creep rupture data assessment are detailed in Volume 5

Table 1

An example of unified terms recommended for use in creep and stress relaxation tests

NAME	UNIT(S)	SYMBOL
4.4 Test Piece (Section 3.2)		
Dimensions	mm	
Diameter	"	d_o
Thickness	"	th
Width	"	w
Diameter of tubular specimens	"	o.d i.d
Original Gauge Length	"	L_o
Parallel Length	"	L_c
Extensometer Length'	"	L_e
Reference Length	"	L_r
Transition Radius	"	r
Notch Root Radius	"	r_n
Diameter at Notch Root	"	d_n
Notch Angle	degree (°)	α
Directionality		
Longitudinal		L
Transverse		Tr
Through Thickness	-	T-r
Location in Test Material*		
Axial/Centre/Core		
Mid Radial		
etc.		

(*Since this is product dependent, it should be stated, in written, or diagrammatic form, along with the test results)

Table 2

Minimum material pedigree information requirements for existing creep rupture and stress relaxation data

CATEGORY	MINIMUM INFORMATION REQUIRED[a]
Material Codes	- cast/heat number and/or material code used by testing laboratory[b] - country code[c]
Material Pedigree	- alloy name[d] - chemical composition (product or cast/heat)[e] - product form (with dimensions if available) - heat treatment time[f]/temperature/cooling medium

Table 3

Minimum material pedigree information requirements for new creep rupture and stress relaxation data generated after 1.1.95

CATEGORY	MINIMUM INFORMATION REQUIRED[a]
Material Codes	- cast/heat number - material code used by testing laboratory - country code[c] - laboratory code[g]
Material Pedigree	- specification and/or grade name - chemical composition (product or cast/heat)[e,h] - supplier/material manufacturer (country code)[c,g] - primary melt process[g] - deoxidation practice[g] - secondary melt process (if appropriate)[g] - ingot or continuous cast[g] - cast/heat weight[g] - product form - product dimensions (and heat treated size if different)[g] - processing route[g] - product manufacturer[g] - heat treatment time[f]/temperature/cooling medium[g,i] - testpiece location/orientation[g,i] - RT tensile properties[g,h] - HT tensile properties[g,h,j] - impact energy[g,h] - hardness[g,h] - microstructure[g,k]

NOTES (a) the reporting of additional information is not precluded see [1]
(b) unique cast/heat number is preferred, but may not be known
(c) country of testing laboratory (same codes used to refer to country of supplier/material manufacturer)
(d) alloy type, specification/grtie or7rde;omorletaryna*
(e) mandatory elements depend on alloy type and are defined in Table 1.5 of issue 2 of [1]
(f) it is not practical for heat treatment times to be mandatory, but highly recommended that the information is reported when known
(g) additional requirements for tests started after 1.1.95
(h) the origin of the properties shall be traceable via the testing laboratory
(i) testpiece location/orientation information is mandatory either as material pedigree or testing information (see Table 4b)
(j) if specified in the material standard
(k) the laboratory shall be in a position to supply a micrograph on request

Table 4a
Minimum testing information requirements for existing creep rupture data

CATEGORY	MINIMUM INFORMATION REQUIRED[a]	COMMENTS
Test	- type of test	- uninterrupted; interrupted creep, creep rupture, stress rupture
Standard	- testing standard(s) obeyed	- eg. [3-11][b]
Testpiece	- details if not uniaxial smooth round bar - notch geometry & dimensions	- if appropriate - if appropriate
Temperature	- specified value	
Stress	- applied stress (σ_0)	
Test Results	- test duration (t) - continuing, broken, unbroken - total plastic strain $\varepsilon_p(t)$ and/or creep strain $\varepsilon_f(t)$	 - as appropriate - as appropriate

NOTES: (a) the reporting of additional information is not precluded. see [?]
(b) it should be demonstrated that testing performed according to an unlisted standard at least meets the minimum requirements listed in Table 3b

Table 4b
Lowest common testing practice specification associated with the requirements of (3-11)

Testpiece	- diameter (do) - preference length (L_r) - shape tolerance - measurement tolerance	- ≥3mm - ≥3d₀ - ≤±0.04mm - ≤±0.01mm
Machine	- types	- all, if load controlled
Temperature	- thermocouple number of thermocouples - calibration - measurement equipment - permitted tolerance - frequency of measurement: - laboratory ambient limits	- base metal or rare metal - sufficient - error of thermocouple determined - tolerance/resolution sufficient - ≤±3/4/6/8°C up to 600/800/1000/1100°C (indicated) - sufficient - sufficiently constant
Load	- permitted tolerance - time of load application	- ≤±1% - as rapid as possible without shock
Strain	- tolerance - uninterrupted - tolerance - interrupted	- ≤max[±0.01%, ±10μm] - ≤max[±0.02%, ±20μm]

Table 5

Minimum testing information requirements for new creep rupture data generated after 1.1.95

(a) Information Common to Test Series[a]

CATEGORY	MINIMUM INFORMATION REQUIRED[b]	COMMENTS
Test	- type of test	- uninterrupted, interrupted creep, creep rupture, rupture
Standards	- testing standard/code(s) obeyed, (including calibration standard/code(s) for load, temperature & strain, if not mandatory in testing standard/code[c])	- requirements of ISO/DIS 204 with recommended amendments, as a minimum for uninterrupted testing (see Table 5a) - equivalent minimum requirements for interrupted testing (Table 5b)
Testpiece	- reference length[c] - notch geometry - special features[c]	method of determination, refer to standard/code if appropriate - if appropriate
Machine	- environment[c]	- if not air
Test Results	- assurance of integrity	- confirmation that results are subject to internal audit of integrity (if not required by

(b) Information Unique to Individual Test[a]

CATEGORY	MINIMUM INFORMATION REQUIRED[b]	COMMENTS
Testpiece	- location & orientation[d] - diameter[c] - reference length[c] - details if not uniaxial smooth round bar - notch geometry	 if appropriate if appropriate
Machine	- environment[c]	if not air
Temperature	- specified value - heating soaking/time[c], - laboratory ambient limits	 - if outside minimum requirements (Tables 5a,5b) - if outside minimum requirements (Tables 5a,5b)
Stress	- applied stress (σ_o)	
Test Results	- test duration (t) - continuing, broken, unbroken initial plastic strain ε_i total plastic strain $\varepsilon_p(t)$ or creep strain $\varepsilon_f(t)$ rupture ductilities[c] - test Integrity	- date - from hot tensile or creep test? - $\varepsilon_p(t) = \varepsilon_i + \varepsilon_f(t)$ - Ar & Zr, or cannot be measured - reference to details of non standard incidents[e]

NOTES (a) when Table 4a information is not common to every test in series it must be reported in Table 4b
(b) the reporting of additional information is not precluded, see [?]
(c) additional information requirements for test programmes started after 1.1.95
(d) testpiece location/orientation information is mandatory either as material pedigree or testing information (see Table 2)
(e) eg. non standard interruptions, significant scaling, fl[illegible] surface or within gauge length

ERA TECHNOLOGY

Table 6
Target requirements for a state-of-the-art CRDA procedure

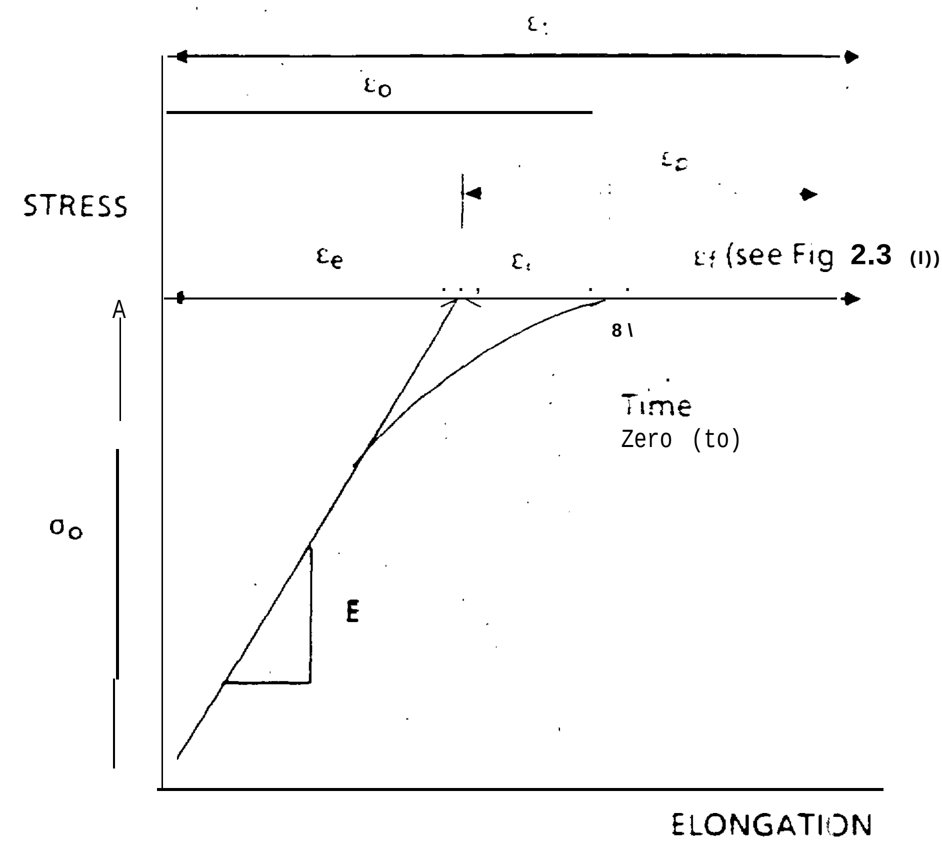
The target requirements for a modern state-of-the-art creep rupture 'data assessment procedure are:

- well defined acceptability' criteria for input data and guidelines for the treatment of unfailed tests,
- the means of generating a predictive equation with time as the experimentally dependent variable.
- a sound statistical base,
- an assessment including cast by cast analysis which is capable of incorporating metallurgical effects (eg. composition, oxidation),
- validity checks for extrapolation (eg. credibility of extrapolations with respect to data sets for individual casts),
- guidelines' to minimise subjectivity associated with 'metallurgical judgment',
- an indication of the reliability of creep rupture strength predictions for durations up to 350,000h, with associated confidence limits, and
- manpower efficiency, ie. maximizing on the use of computer power in a user friendly way.

Statistical methods should be investigated to:

- establish a procedure for the treatment of unfailed tests.
- 'set guidelines for choosing the optimum distribution of the data set (ie. normal. log normal log logistic etc.),
- establish tests of significance to minimise subjectivity where metallurgical judgement is required.
- produce an overall quotable value for errors, and
- produce a statistical confidence level for the preferred equation (ie. replacing the current empirical ±20% stress lines)

For the assessment of creep curves, there is the added requirement of a capability to fit curve families.



DESCRIPTORS

E	-	**Elastic modulus**
σ_o	-	**Applied stress***
ε_e	-	**Elastic strain**
ε_i		**Initial plastic strain**
ε_o		**Initial total strain (to time zero)**
ε_p	-	**Total plastic strain**
ε_f	-	**Creep strain during test**
Time Zero	-	**Start of creep test (phase (iii))**

Initial Total Strain $(\varepsilon_o) = \varepsilon_e + \varepsilon_i$

Total Strain $(\varepsilon_t) = \varepsilon_o + \varepsilon_f$

Total **Plastic** Strain $(\varepsilon_p) = \varepsilon_i + \varepsilon_f$

***Stress applied to initial cross section measured at room temperature (see DIS.204 Clause 3.8)**

Fig.1: Loading curve for creep/stress relaxation

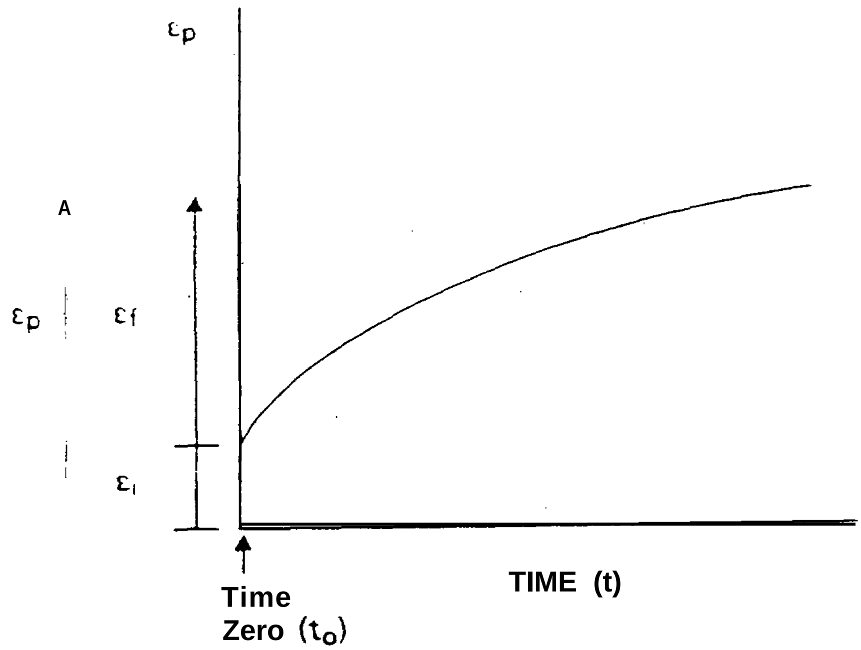


Fig.2: Creep tune

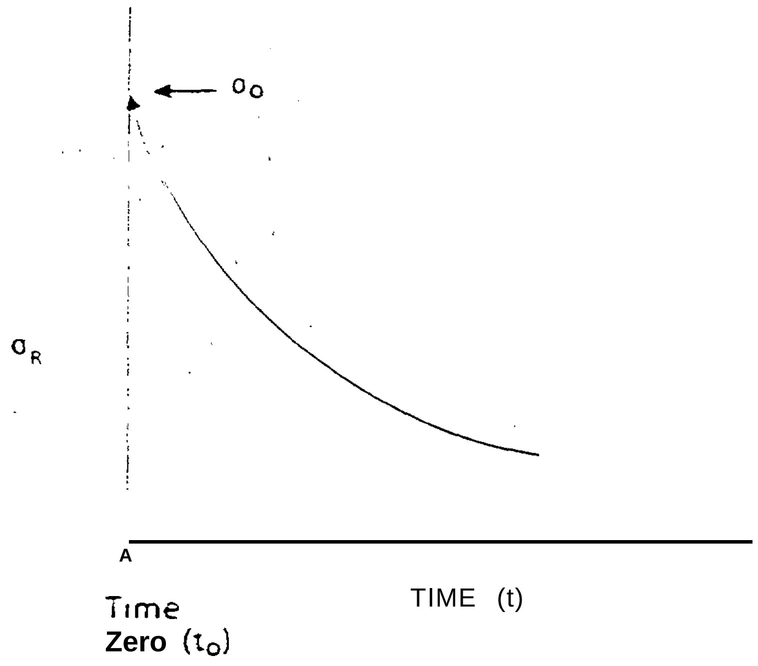


Fig.3: Stress relaxation curve

3 Exploitation Plans

3.1 Objectives of Partners

The principal objective of the **alloy producers** are m increase the cost-effectiveness of their materials development activities thereby giving them a competitive edge in world m: arkets.

The principal objective of the **plant manufacturers** is to increase the cost-effectiveness of their creep data development activities in order to (i) develop more efficient desig ıs and (ii) underwrite designs more efficiently than competitors (ie improved demonstration of fitness-for-purpose) through availability of validated long-term data.

Both of these factors will lead to improved competitiveness in world marl :ets.

The principal objectives of the plant operators are to obtain more c ›st-effective validated data to improve the reliability, availability and performance and life assessment of their plant

3.2 Strategy

The exploitation strategy comprises three elements as follows

First, **exploitation** of the results of the project by alloy producers, plant manufacturers and plant operators for their own internal purposes to meet the objectives listed above. Individual companies began this process as soon **as** validated data and data assessment m ethodologies became available during the project and have continued it since then.

Second, exploitation of the results through individual company member representations on. and contact with, European and International Standards Committees. A major reason for undertaking the project was to develop a coherent body of data and accurate means of assessing these data to generate reliable rupture strength values for use in Standards, Accurate Standards' containing reliable strength values are essential if European alloy producers and plant manufacturers are to sell their products in world markets against strong competition from the USA anti Japan, For the: ;e reasons, extensive links have now been established between ECCC and Standards Committees.

Significant exploitation has occurred through the supply of strength value to ECISS via these **link as follow's:**

- The **assessed** strength values for steel Grade 91 were provided to ECISS TC29 for Standard EN 10216-2 and were accepted. by ECISS, as **values to be** included in the Standard. The values were also provided to ECISS TC28 for the forging Standards. Strength values for steel grade X20 CrMoV12 1 based or I mean values of strength values in BS 6525 and DIN 17175 were provided to ECISS TC29 and ECISS TC28. In addition. **comments on strength values** for the steel grade 9Cr- 1 Mo in the annealed condition were provided to ECISS TC29. With the exception of steel grade 9Cr-1 Mo N-T. WG3.2 has therefore provided all requested data for the relevant alloys in the new EN standards WG3.2 suggested that ECISS TC29 considered including steel grades P92 and P 122 in the new EN 10215 tube standard and this suggestion will be considered for the next revision of the standard.

- Strength values on stainless steel materials supplied to ECISS committees TC22/23 and TC28 on the following preliminary European Standards (prEN's):

prEN 10028-7	Flat products of stainless steels
prEN 10222-5	Forgings of stainless steels
prEN 10269	Fastener Materials

- The following data on bolting steels have been analysed by WG3.4 and communicated to relevant European Standards committees:

General Name	Composition	Steel Name/Number
Priority 1		
Durehete 1055	1%CrMoVTiB	20 CrMoVTiB4.10
'X19'	11%CrMoVBbN	X19 CrMoNiNbVI 1.1 (.14913)
-	1%CrMoV	21CrMoV5.7 (1,7709)
Nimonic 80	Ni+Cr20%AlTi	NiCr20TiAl (2.4952)
Priority 2		
Durehete 900	1%CrMo	42 CrMo5.6
Durehete 950/A 193.B 16	1%CrMoV	40 CrMoB4.7 (1.7711)
'x22'	12%CrMoV	X21 CrMoNiV12.1 (1.4923)
A286	25Ni15Cr2TiMoVB	X5 NiCrTiVB25.15.2 (1.4980)
Warm Worked Esshete 1250	15Cr10Ni6MnMoNbV	

Thirdly, exploitation of the results in terms of identifying gaps in the present scope of data and knowledge bank and performing further studies to fill these gaps. In this respect two new SMT projects and a Thematic Network on 'Creep Data Development for Weldments' have been spawned. A further Thematic Network proposal to specifically fill gaps in the scope of the existing database for parent materials is also planned.

4 References

Detailed guidelines concerning the generation, collation and assessment of stress rupture. creep strength and stress relaxation data have been produced in a suite of five volumes (as described in Section 2.4) and distributed to approximately 200 organisations Europe-wide. Negotiations are now being held with publishers to produce these volumes as a book.

5 Collaboration Sought

The collaboration established within the Project is now being continued and extended through new projects and collaborations spawned by the work, specifically two new SMT projects and a Thematic Network on Creep Data Development for Weldments. A further Thematic Network to specifically! fill gaps in the scope of the existing database for parent material data is also planned.

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Distribution

CEC	(3)
J William"son	(1)
I A Shibli	(1)
Project File	(1)
Information Centre	(1)

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Appendix 1
List of Partners

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Appendix 1
List of Partners

- **ERA Technology** Ltd (ROR), UK - Co-ordinator
- **Nuclear Electric Ltd (1),** UK
- **Centro Sviluppo Materiali SPA (CSM)** (ROR). Italy
- **Mannesmannröhren-Werke** AG (I), Germany
- **Technische Hochschule Darmstadt (Institute Für Werkstofflk uncle),** (ROR), Germany
- **Universität Stuttgart (Staatliche Meterialprüfung Sanstalt)** (NIPA), (ROR). Germany
- **GEC-Alsthom, (I), UK**
- **British Steel (Technical Division), (I),** UK
- **PowerGen** PLC, (1), UK
- **Electricity de France (EdF), (1),** France.
- **Electricidade de Portugal (EdP),** Portugal.
- **Laborelec (1), Belgium**
- **Technical University of Denmark,** (Univ), Denmark
- **Elkraft, (1), Denmark**
- **Elsam: (I), Denmark**
- **Graz University of Technology (GUoT)**, (Univ). **Austria**
- **ABB,** (I), **Switzerland**
- **Swedish Institute for Metals Research** (SIMR). (ROR), Sweden
- **Instituto Scientific Breda SpA (ISB)**, (ROR), Italy
- **ENEL/CRAM, (I),** Italy
- **DSM,** (ROR), Italy

- Siemens, (1), Germany
- National Power, (I), UK
- VDEh, (ROR), Germany
- Ansaldo, (1), Italy
- BNS, (ROR), France.
- IRD/Rolls Royce, (I), UK
- Electrabel, (I), Belgium
- GEC Alsthom Stein Industrie, (1), France.
- GEC Alsthom Man Energie, (I), Germany.
- CISE Spa, (I), Italy
- University di Ancona, (Univ), Italy
- Nuovo Pignore Spa, (I), Italy
- TNO, (ROR), The Netherlands