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ECCC RECOMMENDATIONS - VOLUME 5 Part IIb [Issue 1]

GUIDANCE FOR THE ASSESSMENT OF CREEP RUPTURE, CREEP STRAIN AND STRESS RELAXATION DATA

RECOMMENDATIONS FOR THE ASSESSMENT OF WELD CREEP-RUPTURE DATA

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GUIDANCE FOR THE ASSESSMENT OF CREEP RUPTURE, CREEP STRAIN AND STRESS RELAXATION DATA

RECOMMENDATIONS FOR THE ASSESSMENT OF WELD CREEP-RUPTURE DATA

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ABSTRACT

ECCC Recommendations Volume 5 Part IIb provides guidance for the assessment of weld creep data sets to give long time strength values and weld factors.

Guidance is based on an extensive review of European experience and the outcome of a work programme involving the evaluation of various assessment procedures by several analysts using a number of working data sets for matching and dissimilar metal welds. The results of this exercise highlight the risk of unacceptable levels of uncertainty in predicted strength values without the implementation of well defined assessment strategies including critical checks during the course of analysis. The findings of this work programme are detailed in appendices to the document.

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RECOMMENDATIONS FOR THE ASSESSMENT OF WELD CREEP-RUPTURE DATA

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1. INTRODUCTION

Weld creep rupture datasets are typically sub-size, in terms of the number of weldment sources, the number of $t_{u(W)}(T, s_o)$ data points and $t_{u(W),max}(T)$. In addition, they may be the consequence of iso-thermal and/or iso-stress test matrices. Iso-stress testing is a relatively common way of characterising the creep rupture properties of weldments [1,2]. The consequent $t_{u(W)}(T, s_o)$ data point distributions may restrict the candidate procedures which can be adopted for assessment.

In addition to creep-rupture strength values for a given time and temperature, $R_{u(W)/t/T}$,[1] the associated weld reduction factors are also usually required from the assessment of weld creep-rupture datasets. Four factors are defined in [3c], these being weld strength factor (WSF), weld time factor (WTF), strength reduction factor (SRF) and time reduction factor (TRF), *i.e.*

$$\mathrm{WSF}(t,T) = \frac{R_{\mathrm{u(W)}/t/T}}{R_{\mathrm{u}/t/T}} \tag{1a}$$

$$\mathrm{WTF}(s,T) = \frac{t_{\mathrm{u(W)}/s/T}{}^{*}}{t_{\mathrm{u}/s/T}{}^{*}} \tag{1b}$$

$$\mathrm{SRF}(t,T) = \frac{\left(R_{\mathrm{u}/t/T} - R_{\mathrm{u(W)}/t/T}\right)}{R_{\mathrm{u}/t/T}} \tag{2a}$$

$$\mathrm{TRF}(s,T) = \frac{\left(t_{\mathrm{u}/s/T}{}^{*} - t_{\mathrm{u(W)}/s/T}{}^{*}\right)}{t_{\mathrm{u}/s/T}{}^{*}} \tag{2b}$$

These weld reduction factors may be defined with respect to the properties of the specific parent material(s) to which the $t_{u(W)}(T, s_o)$ data relate or to the alloy mean properties of the parent material(s). Where possible, comparison with heat specific properties is preferred, in particular for datasets comprising results from a small number of weldments.

The $t_{u(W)}(T, s_o)$ data from cross-weld tests may be assessed using the same procedures as those available for parent materials [4a,b]. In Part IIa, four strategies are identified for the assessment of sub-size $t_{u(S)}(T, s_o)$ datasets, i.e. (i) the use of data factors, (ii) the application of statistical modelling, (iii) the complementary use of creep strain data, and (iv) the complementary use of reference $R_{u/t/T}$ curves. Of these, option (iv) is the most applicable to the assessment of weld-creep data.

An important consideration is that the $t_{u(W)}(T, s_o)$ data comprises information collected for the fracture location relevant to the application for which the strength values are required [5b]. For example, if the fracture location in service is in the Type IV region of the weldment, the $t_{u(W)}(T, s_o)$ data leading to the determination of $R_{u(W)/t/T}$ should originate from tests involving specimen failure in the ICHAZ of the test weld or an appropriately simulated microstructure (*e.g.* [6]). Fracture location and the acceptability of simulated microstructures are therefore important additional considerations in the post-assessment of weld creep-rupture data.

The weldment property characteristics of ferritic steels are shown schematically in Fig. 1 in terms of strength reduction factor. Typically for such materials, fracture occurs in the parent material at high applied stresses, and rupture times are coincident with PM $t_u{}^*(T, s_o)$

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[1] The terminology used in Part IIb is as defined in [3]

properties, i.e. WSF(t,T) and WTF(s,T) are close to unity. With reducing stress, the fracture location shifts to the ICHAZ and $t_{u(W)}^*(T,s_o)$ rupture times reduce with respect to parent material $t_u^*(T,s_o)$ and the magnitudes of WSF(t,T) and WTF(s,T) reduce to a lower relatively constant value. With increasing temperature, the magnitudes of, and the time to achieve WSF$(t,T)_{min}$ and WTF$(s,T)_{min}$ reduce.

In practice, it is unlikely that WSF(t,T) and WTF(s,T) attain a constant minimum value in ferritic steels, since it is unlikely that metallurgical change will occur in the ICHAZ at exactly the same rate as that in the parent material. Nevertheless, if it can be demonstrated that WSF$(t,T)_{min}$ and WTF$(s,T)_{min}$ do attain an essentially constant value, the basis for extrapolated $R_{u(W)/t/T}$ strength values is possible if reliable long term $R_{u/t/T}$ data are available (e.g. [7,8]).

Methods available for assessing the creep rupture properties of weldments are introduced in Sect. 2.2. The quantity of data for a specific weldment type/configuration is usually limited. It may be possible to expand the size of the dataset for assessment by also considering 'comparable' data. Guidance on 'comparability' is given in Sect. 2.3. Specific recommendations for weld creep-rupture data assessment (WCRDA) are given in Sect. 2.4.

2. WELD CREEP-RUPTURE DATA ASSESSMENT

2.1 OVERVIEW

The ECCC recommendations for the assessment of weld-creep data are based on a review of WCRDA procedures (Appendix A) and an evaluation of their effectiveness in Appendix B.

2.2 ASSESSMENT METHODS

The options for assessing weld-creep data are invariably determined by the scope of available observations and the position in the weldment at which fracture occurs (the fracture location being inextricably linked to the metallurgical constitution of the weldment). In certain circumstances and with care, it is possible to apply the same procedures available for parent material (i.e. Part I), either to assess:

- all weld creep $t_{u(W)}(T,s_o)$ data (irrespective of the fracture location), or
- only weld creep $t_{u(W)}(T,s_o)$ data for a given fracture location (invariably the anticipated in-service fracture location): this being the preferred of these two options.

The ultimate objective of a WCRDA is invariably to determine one or more of the weld factors defined in Eqns. 1 and 2, e.g. WSF(t,T).[2] Consequently, two further options are to examine:

- all $t_{u(W)}(T,\mathrm{WSF})$ data, determined using $t_u^*(T,s_o)$ properties for the specific heat(s) of parent steel(s), this being the preferred WSF based option, or
- all $t_{u(W)}(T,\mathrm{WSF})$ data, determined using the alloy mean $t_u^*(T,s_o)$ properties.

Potentially the biggest problem associated with the assessment of weld creep data is extrapolation to determine long time $R_{u(W)/t/T}$ strength values. In circumstances where the fracture location shifts from the parent material to the ICHAZ, the weldment properties of ferritic steels are assumed to have the WSF(t,T) characteristics represented by the schematic given in Fig. 1. With a knowledge of reliable WSF$(t,T)_{min}$, it is possible to extrapolate with reference to the long term $R_{u/t/T}$ strength values of the parent material relating to the ICHAZ in which long term fracture occurs.

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[2] The text focuses on the use of WSF(t,T) for brevity. It is not the intention to preclude the use of WTF(s,T), SRF(t,T) and TRF(s,T).

In dissimilar metal welds (DMWs), the fracture location may be adjacent to one fusion boundary, either just inside the HAZ or the weld metal and associated with a compositional gradient between the parent and weld metals. If the compositional differences are significant, the combined use of WSF$(t,T)_{\min}$ and PM or WM reference $R_{u/t/T}$ strength values may be inappropriate.

For weldment data, for which creep fracture is in the main weld metal, it may be possible in pre-assessment to demonstrate that the properties of the weld metal are comparable to those of a parent material grade of the same pedigree for which there exists long duration $R_{u/t/T}$ strength properties (e.g. [7,8]). In these circumstances, extrapolation may be made with reference to the $R_{u/t/T}$ properties of the 'comparable' reference material.

2.3 COMPARABILITY

The quantity of data for specific weldment types/configurations is usually limited. Nevertheless, it may be acceptable to expand the scope of the dataset to be assessed by including '*comparable*' data.

At a simple level, weldments constructed from parent material(s) procured to the specified requirements with the specified filler metal(s), but with different welding procedures, may be regarded as 'comparable' if (i) the consequent thermal histories result in properties which are contained within a $R_{u(W)/t/T}$±20% scatterband and (ii) fracture locations are in the same metallurgical region of the weld.

It is therefore possible that weld metal pedigree and welding process may be relatively unimportant for weld-creep data for which fracture is in the inter-critical HAZ (e.g. in ferritic weldments). However, this must be verified during pre-assessment using the $R_{u(W)/t/T}$±20% rule.

The concept may be extended in certain circumstances. For example, parent material pedigrees can be relatively unimportant for weld-creep data for which fracture occurs in the main weld at a significant distance from the fusion line (e.g. certain austenitic weldments). In such circumstances, it may be appropriate to use data determined using testpieces removed from 100% weld metal samples. However, there is potentially less scope for combining data from welds produced by different welding processes when the fracture location is in the weld metal. As above, the recommended test for comparability is that the data can shown in pre-assessment to occupy a databand within ±20% of $R_{u(W)/t/T}$.

When the creep fracture location is in the vicinity of a fusion boundary (e.g. in DMWs), there is usually little scope for extending the dataset with 'comparable' data. In these circumstances, properties are sensitive to parent material / welding consumable composition, welding process and heat treatment details.

A common source of comparable $t_{u(W)}(T,s_o)$ data is that determined from simulated material. Ideally, microstructures should be Gleeble simulated with input parameters based on direct measurements from target weldments. Where this information is unavailable, computer modelling techniques may be used which have been validated for the weldment materials in question and an appropriate range of weld geometries/dimensions [5b].

2.4 RECOMMENDATIONS

The ECCC-WG1 WCRDA evaluation activity reported in Appendix B has led to the following recommendations. The following are specifically aimed at assessments leading to strength values to be externally published by ECCC, but may be used for other purposes.

1) At least two WCRDAs should be performed by two independent weld-metallurgical specialists using their favoured proven methodology.

2) Prior to the main-assessment, a pre-assessment should be performed which takes cognisance of the guidance given in Sect. 2.5.

3) The results of the two WCRDAs should predict $R_{u(W)/t/T}$ to within 10% at $T_{min[10\%]}$, T_{main} and $T_{max[10\%]}$ at the maximum test time for each temperature.[1,3]

4) Whenever possible and in particular when the variation in WSF(t,T) from cross-weld data is ≥10% between $0.8.t_{u(W),max}$ and $t_{u(W),max}$, long duration test data for well qualified simulated material with an appropriate weldment microstructure should be used to support long time $R_{u(W)/t/T}$ strength and WSF(t,T) predictions.[2]

The appropriate weldment microstructure is that in which rupture occurs after long times of design life magnitude at the main application temperatures

5) Long time $R_{u(W)/t/T}$ strength and WSF(t,T) predictions should not be based exclusively on simulated weldment microstructure test data.

6) Test data for simulated weldment microstructures should only be used when material *comparability* has been confirmed by hardness and microstructure integrity checks of hardness, transformation product and grain size.

7) The following guidance is given for the extrapolation of $R_{u(W)/t/T}$ beyond $t_{u(W),max}$ for a given temperature. The results of the assessment should be plotted as WSF(T) versus log t_u. With reference to Fig. 2,

- if the variation in WSF(t,T) between $0.8.t_{u(W),max}$ and $t_{u(W), max}$ is ≤10%, $R_{u(W)/t/T}$ may be extrapolated to $3.t_{u(W),max}$
- if the variation in WSF(t,T) between $0.8.t_{u(W),max}$ and $t_{u(W),max}$ is >10%, extrapolation is not advisable

8) The results of the main-assessment should satisfy the requirements of the post assessment acceptability criteria given in Sect. 2.6.

9) During subsequent use of the master equation derived from the WCRDA, strength predictions based on extended time and extended stress extrapolations must be identified.

Extended time extrapolations are those beyond $3.t_{u(W),max}$ at temperatures within ±25°C of that specified.[4] Results from tests in progress may be included when above the -20% scatterband limit at the appropriate duration.

Extended stress extrapolations are those in the ranges '$0.9.s_{o,min}$ to $s_{o,min}$' and '$s_{o,max}$ to $1.1.s_{o,max}$'.

Quantification of the uncertainties associated with extrapolated strength values and those involving extended extrapolations should be a goal for the future.

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[3] $T_{min[10\%]}$ and $T_{max[10\%]}$ refer to the minimum and maximum temperatures for which there are greater than 10% data points. T_{main} is the temperature with the highest number of data points.

[4] Note the significant difference between this requirement and that for full-size datasets in Part I [4a].

2.5 PRE-ASSESSMENT

Where possible, pre-assessment should be performed according to the guidance given in Part I [4a]. However, there are important additional considerations for weld-creep data.

An evaluation of the 'comparability' of weld-creep data is an integral part of pre-assessment and will consider factors such as fracture location and whether the data are consistently contained within a $R_{u(W)/t/T}$±20% databand.

Pre-assessment should include:

(i) confirmation that the data meet the material/process pedigree and testing information requirements recommended in ECCC Volume 3 Part II [5b].

(ii) confirmation that the material/process pedigree of all weldments and/or heats of simulated HAZ meet the specification set by the instigator(s) of the assessment.

It may be permissible to use data for welds in which the weld metal pedigree and welding process are not exactly as specified when fracture is in the inter-critical HAZ (e.g. in ferritic weldments). However, such data must fall within ±20% of $R_{u(W)/t/T}$.

Similarly, it may be permissible to use data for welds in which the parent material pedigree is not exactly as specified when fracture is in the main weld at a significant distance from the fusion line (e.g. certain austenitic weldments). As above such data must fall within ±20% of $R_{u(w)/t/T}$.

When the fracture location is close to the fusion line (e.g. for DMWs), there is rarely scope for considering data for which the material and process pedigree are not exactly as specified.

When data is used for welds which do not specifically meet all material/process pedigree requirements, the evidence for data acceptability should be clearly stated.

(iii) an evaluation of the distribution of broken and unbroken testpiece data points with respect to temperature and time (e.g. Tables B?); identifying $t_{u(W),max}$, $s_{o,min}$, and the temperatures for which there are (a) ≥5% broken specimen test data ($T_{[5\%]}$) and (b) ≥10% broken specimen test data ($T_{[10\%]}$).

If the assessment is performed only on data for which the fracture location is in the target microstructural constituent, a data distribution table should be prepared specifically for the assessed observations. The table heading should clearly state whether it covers (a) all data or (b) data for a specific fracture location.

It is acceptable to consider data for temperatures within ±2°C of principal test temperatures to be part of the dataset for that principal test temperature (e.g. test data for 566°C may be considered together with data for 565°C).

(iv) an analysis of the distribution of welds at each temperature, specifically identifying (a) the main weld, i.e. the weld having the most data points at the most temperatures, and (b) the best-tested welds.

(v) a visual comparison, in isothermal log s_o versus log t_u diagrams, of all broken and unbroken data points for all relevant available parent material, weld metal, cross-weld and simulated-microstructures. Each cross-weld data point should be identified with respect to fracture location.

(vi) a re-organisation of the data if the results of the first assessment identify the need.

The reason(s) for excluding any individual data points which are acceptable in terms of *(i)* and *(ii)* above, should be fully documented. In practice, it should not usually be necessary to remove data meeting the requirements of [5b], providing the material specification is realistic.

2.6 POST ASSESSMENT

It is unlikely that the results from the main assessment of a weldment dataset will meet all the requirements of the post assessment tests defined for full-size datasets.[5] Of the three main categories listed in Part I, only tests associated with PAT-1 and PAT-2 are applied, i.e. those covering:

- the physical realism of the predicted isothermal lines, and
- the effectiveness of the model prediction within the range of the input data

These are investigated in the following post assessment tests.[6]

Physical Realism of Predicted Isothermal Lines

PAT-1.1a Visually check the credibility of the fit of the isothermal logs_o versus log t_u* lines to the individual $t_u(T, s_o)$ data points over the range of the data

PAT-1.1b Visually check the credibility of the shape and the relationship of the isothermal log s_o versus log t_u* data lines with respect to available relevant reference lines, ideally established according to the requirements of Part I.

Predicted $R_{u(W)/t/T}$ values should never exceed $R_{u/t/T}$ values for the specific parent material or the alloy mean $R_{u/t/T}$+20%.

It is unlikely that $R_{u(W)/t/T}$ will fall below x0.4 the alloy mean.

PAT-1.2 Produce isothermal curves of log s_o versus log t_u* at 25°C intervals from 25°C below the minimum temperature to 25°C above the maximum application temperature.[7]

For times between 10 and 10.$t_{u,max}$ and stresses ≥0.8.$s_{o,min}$, predicted isothermal lines must not (a) cross-over, (b) come-together or (c) turn-back.

PAT-1.3 Plot the derivative ∂(log t_u*)/∂(log s_o) as a function of log s_o with respect to temperature to show whether the predicted isothermal lines fall away too quickly at low stresses (i.e. s_o ≥0.8.$s_{o,min}$) (e.g. …..

The values of -∂(log t_u*)/∂(log s_o), i.e. n_r in $t_u^* \propto (s_o)^{nr}$, should not be ≤1.5.

It is permissible for n_r to enter the range 1.0-1.5 if the assessor can demonstrate that this trend is due to the material exhibiting either sigmoidal behaviour or a creep mechanism for which n_r =1., e.g. diffusional flow.

Effectiveness of Model Prediction within Range of Input Data

PAT-2.1 To assess the effectiveness of the assessed model to represent the behaviour of the complete dataset, plot log t_u* versus log t_u for all input data (e.g. Fig

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[5] The underlying background to the development of the original post assessment tests for parent material CRDA

[6] The post assessment tests may be conveniently performed in a spreadsheet such as MS-Excel

[7] The maximum application temperature for which predicted strength values are required

The log t_u* versus log t_u diagram should show

- the log $t_u^* = \log t_u$ line (i.e. the line representing an ideal fit),
- the log $t_u^* = \log t_u \pm 2.5.s_{[A\text{-}RLT]}$ boundary lines,[8,9]
- the log $t_u^* = \log t_u \pm \log 2$ boundary lines,[10] and
- the linear mean line fit through the log t_u*(log t_u) data points for $100 < t_u < 3.t_{u,max}$.

The model equation should be re-assessed:

(a) if more than 1.5% of the log t_u*(log t_u) data points fall outside one of the $\pm 2.5.s_{[A\text{-}RLT]}$ boundary lines,[11]

(b) if the slope of the mean line is <0.78 or >1.22, and

(c) if the mean line is not contained within the ±log 2 boundary lines for 100< log t_u <100kh.

PAT-2.2 To assess the effectiveness of the model to represent the behaviour of individual weldments, plot at temperatures for which there are ≥10% data points (at least at $T_{min[10\%]}$, T_{main} and $T_{max[10\%]}$):

(i) log s_o versus log t_u* with individual $t_u(T, s_o)$ data points

(ii) log t_u* versus log t_u, with

  - the log $t_u^* = \log t_u$ line (i.e. the line representing an ideal fit),
  - the log $t_u^* = \log t_u \pm 2.5.s_{[I\text{-}RLT]}$ boundary lines,
  - the log $t_u^* = \log t_u \pm \log 2$ boundary lines, and
  - the linear mean line fit through the log t_u*(log t_u) data points for $100 < t_u < 3.t_{u,max}$ (extrapolated to 100kh).

and identify the individual weldments.

(a) Log t_u* versus log t_u plots for individual weldments should have slopes close to unity and be contained within the $\pm 2.5.s_{[I\text{-}RLT]}$ boundary lines.[12] The pedigree of weldments with $-\partial(\log t_u^*)/\partial(\log t_u)$ slopes of <0.5 or >1.5 and/or which have a significant number of log t_u*(log t_u) data points outside the $\pm 2.5.s_{[I\text{-}RLT]}$ boundary lines should be re-investigated.

If the material and testing pedigrees of the data satisfy the requirements of [5b] and the specification set by the assessment instigator (e.g. WG3.x), the assessor should first consider with the instigator whether the scope of the weldment specification is too wide. If there is no metallurgical justification for modifying the specification, the effectiveness of the model to predict individual weldment behaviour should be questioned.

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[8] $s_{[A\text{-}RLT]}$ is the standard deviation of the residual log times for all the data at all temperatures, i.e. $s_{[A\text{-}RLT]} = \sqrt{\{\Sigma_i(\log t_{u,i} - \log t_u^*)^2/(n_A - 1)\}}$, where $i = 1,2, \ldots n_A$, and n_A is the total number of data points

[9] For a normal error distribution, almost 99% of the data points would be expected to be within log $t_u^* = \log t_u \pm 2.5.s_{[A\text{-}RLT]}$ boundary lines.

[10] i.e. the $t_u^* = 2.t_u$ and $t_u^* = 0.5.t_u$ boundary lines

[11] Experience has shown that the $\pm 2.5.s_{[A\text{-}RLT]}$ boundary lines typically intersect the t_u = 100h grid line at $t_u^* \leq 1$kh and $t_u^* \geq 10$h respectively [4a]. The explanation for those which do not is either an imbalance in the model fit (and hence the PAT-2.1a criterion) or excessive variability in the data set. In the latter case, consideration should be given to the scope of the material specification (in conjunction with the assessment instigator, e.g. WG3.x)

[12] $s_{[I\text{-}RLT]}$ is the standard deviation for the n_I residual log times at the temperature of interest, i.e. $s_{[I\text{-}RLT]} = \sqrt{\{\Sigma_j(\log t_{u,j} - \log t_u^*)^2/(n_I - 1)\}}$, where $j = 1,2, \ldots n_I$.

The distribution of the log t_u*(log t_u) data points about the log t_u* = log t_u line reflects the homogeneity of the dataset and the effectiveness of the predictive capability of the model. Non uniform distributions at key temperatures should be taken as a strong indication that the model does not effectively represent the specified material within the range of the data, in particular at longer times.

The model equation should be re-assessed if at any temperature:

(b) the slope of the mean line through the isothermal log t_u*(log t_u) data points is <0.78 or >1.22, and

(c) the mean line is not contained within the ±log 2 boundary lines for 100 < log t_u <100kh

Repeatability and Stability of Extrapolations

PAT-3 is not regarded as a viable post assessment test for weld creep data, in particular for observations associated with a change in fracture mechanism. For such circumstances, guidance is given in recommendation 7 (Sect.2.4).

3. SUMMARY

ECCC Volume 5 Part IIb provides guidance for the assessment of weld-creep datasets. The recommendations are specifically aimed at assessments leading to strength values to be externally published by ECCC, but may be used for other purposes. The principal objective is to minimise the uncertainty associated with strength predictions by recommending a rigorous pre-assessment, the implementation of post assessment acceptability criteria and the performance of duplicate assessments.

4. REFERENCES

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3 ECCC Recommendations Volume 2, 2001, 'Terms and terminology for use with stress rupture, creep rupture, creep and stress relaxation: Testing, data collation and assessment', ed. Morris, P.F, Orr, J., Servetto, C. & Seliger, P., publ. *ERA Technology Ltd, Leatherhead*, (a) Part I 'General terms and terminology and items specific to parent material', (b) Part IIa 'Terms and terminology for welding processes and weld configurations', (c) Part IIb 'Terms and terminology for weld creep testing', (d) Part III 'Terms and terminology for post service exposed creep data'.

4 ECCC Recommendations Volume 5, 2001, 'Guidance for the assessment of creep rupture, creep strain and stress relaxation data', ed. Holdsworth, S.R. & Merckling, G., *publ. ERA Technology Ltd, Leatherhead*, (a) Part I 'Generic recommendations and guidance for full-size datasets', (b) Part IIa 'Recommendations for the assessment of sub-size creep-rupture data', (c) Part IIb 'Recommendations for the assessment of weld creep-rupture datasets', (d) Part III 'Recommendations for the assessment of post exposure (ex-service) creep data'.

5 ECCC Recommendations Volume 3, 2001, 'Recommendations for data acceptability criteria and the generation of creep, creep rupture, stress rupture and stress relaxation data', ed. Holdsworth, S.R., Granacher, J., Theofel, H., Klenk, A., Buchmayr, B. & Gariboldi, E. *publ. ERA Technology Ltd, Leatherhead*, (a) Part I 'Data acceptability criteria and data generation: Generic recommendations for creep, creep rupture, stress rupture and stress relaxation data', (b) Part II 'Data acceptability criteria and data

generation: Creep data for welds', (c) Part III 'Recommendations for creep testing of PE (ex-service) materials'.

6 Buchmayr, B. et al, 1990, 'Experimental and numerical investigations of the creep behaviour of the dissimilar weldment GS-17CrMoV5.11 and X20CrMoV12.1', *Steel Research*, No. 6/90, 268-275.

7 PD6525, 1992, 'Elevated temperature properties for steels for pressure purposes', *British Standards Institution*.

8 ECCC Data Sheets, 1999, Ed. Robertson, D.G., Publ. ERA, Leatherhead, September.

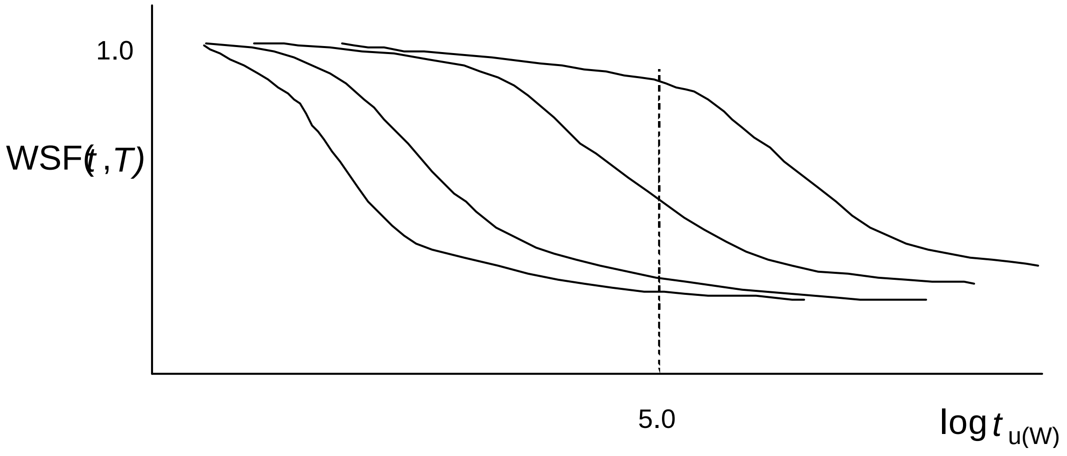

Fig. 1 Schematic representation of weldment property characteristics of ferritic steels

If $\Delta\mathrm{WSF}(t,T) \leq 0.1.\mathrm{WSF}(t,T)$ between 0.8. $t_{\mathrm{u(W),max}}$ and $t_{\mathrm{u(W),max}}$
- $R_{\mathrm{u(W)}/t/T}$ may be extrapolated to 3. $t_{\mathrm{u(W),max}}$

If $\Delta\mathrm{WSF}(t,T) > 0.1.\mathrm{WSF}(t,T)$ between 0.8. $t_{\mathrm{u(W),max}}$ and $t_{\mathrm{u(W),max}}$
- extrapolation is not advisable

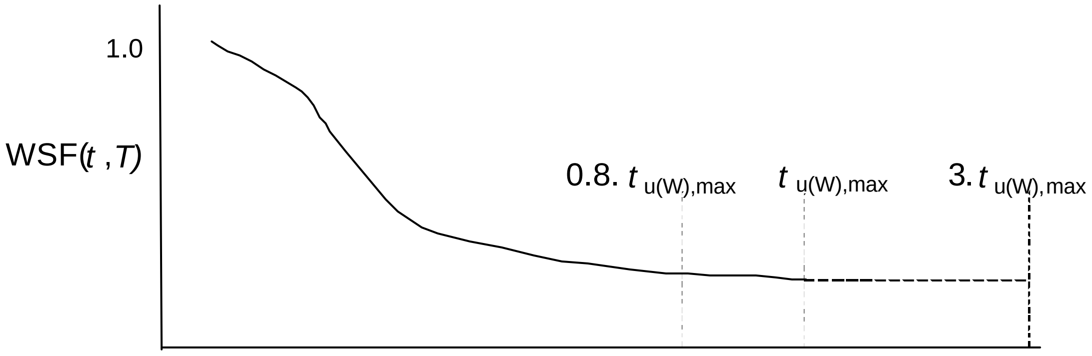

Fig. 2 Extrapolation criteria for weld-creep data

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APPENDIX A

REVIEW OF WELD-CREEP ASSESSMENT PROCEDURES

P Auerkari

VTT, Finland

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1 Introduction

Major high temperature installations make extensive use of weldments for joining components to full-scale functional structures, where the operating medium is contained separate from the outside environment. In addition, welds are necessary and widely used for repairs of defects or other deficiencies that can originate from manufacturing or service.

Unfortunately, particularly in ferritic steels that are common structural materials in high temperature plant, weldments are often the potentially weakest links against creep. This is because of the metallurgical structures produced by common welding processes, especially in the heat affected zone (HAZ) of the weldment. In addition, welding is a common cause of defects that exacerbate this weakness, and often it is not easy to find remedies to alleviate these weak areas.

Although weldments therefore tend to be the weak spots in e.g. pressure equipment operating at high temperatures, their design does not account for the weakness of weldments directly. Instead, design is nominally based on the properties of the parent material and welds are accounted for by e.g. placing them in locations of low stresses. This nevertheless requires a feeling of the actual difference in the design strength between the weldment and the parent material, and for this purpose e.g. so-called stress reduction factors have been used. This stress reduction factor (SRF) is defined as

$$\text{SRF} = \text{creep strength of the weldment / creep strength of the parent material} \qquad (1)$$

whereby creep strength must be defined for the same conditions (e.g. to creep failure in 10^5 h at 550°C in air for a uniaxial standard specimen).

However, it is known that there is also a difference between results from different specimen sizes.

ECCC (European Creep Collaborative Committee) has launched a project to evaluate the methods on assessing weldments for service in the creep regime. As a part of this effort, the current expert opinions and practices worldwide are reviewed on assessment of creep testing results of weldments.

For this purpose, ECCC has circulated a questionnaire (see appendix) in 1998 to explore the views and practices of professional experts involved in assessment of weldments for high temperature service. The resulting individual answers to the questionnaire are held confidential, and used only to evaluate the overall views of the experts. These overall views in turn are used to formulate widely accepted, technically well founded European ECCC guidelines on assessing creep testing results of weldments.

Below, the issue of assessment is treated in the order of the questions in the questionnaire (see appendix). By February 8, 1999, a total of 13 answers was obtained for an inquiry that was sent to more than 50 experts.

2 Assessment of creep testing results

2.1 The questionnaire

The questionnaire is shown in the appendix. This questionnaire has been circulated among the known experts by the secretariat of EC3. In total 13 experts have returned answers, and these are summarised anonymously below.

2.2 Detailed comments on the questionnaire

The actual answers are shown in Tables 1 to 12.

Table 1. The expert answers to question 1.1 regarding importance of creep data assessment for weldments.

Expert No.	Vitally important	Important	Not very important
1	X		
2	X		
3	X		
4	X		
5	X		
6		X	
7	X		
8		X	
9		X	
10			X
11	X		
12	X		
13		X	

Summary to Q1.1: Vitally important 8/13, important 4/13, not very important 1/13.

This result may not be very surprising, as many of the experts represent members of EC3 and the Weld Creep project, and hence have natural interest in the issue of creep data assessment for weldments.

Table 2. The expert answers to question 1.2a regarding frequency of creep data assessment for weldments.

Expert No.	**Daily**	**Few times a week**	**Few times a month**	**Few times a year**	**Less often or never**
1			X		
2			X		
3				X	
4				X	
5				X	
6					X
7			X		
8			X		
9				X	
10					X
11		X			
12			X		
13				X	

Summary to Q1.2a:

Few times a week 1/13; few times a month 5/13; few times a year 5/13; less often/never 2/13.

Table 3. The expert answers to question 1.2b regarding quantity of creep data assessment for weldments.

Expert No.	**None**	**1-10 welds a year**	**11-100 welds a year**	**More than 100 welds a year**
1		X		
2		X 1)		
3			X	
4		X		
5			X	
6		X		
7		X		
8			X	
9		X		
10	X			
11			X	
12		X		
13		X		

1) = procedures

Summary to Q1.2b: None 1/13; 1-10 / year 8/13; 11-100 / year 4/13

Table 4. The expert answers to question 1.3 regarding the purpose of assessment.

Expert No.	Design assessment	Qualification of mat's/manufact.	Ex-service life assessment	Other
1		X	X	
2		X	X	X1)
3	X	X	X	
4				X2)
5			X	
6	X	X		
7	X	X		
8	X		X	
9	X	X		
10				
11		X	X	X3)
12			X	X4)
13	X	X		

1) comparison uniaxial/multiaxial & repair welding
2) provision of creep rupture data for life assessment of welds in service using R5
3) development of new procedures/processes
4) creep modelling for life assessment

Summary to Q1.3: Design 6/12; qualification 8/12; life assessment 7/12; other 4/12

Table 5. The expert answers to question 1.4 on written guideline/qualification procedure for assessing the creep testing results of weldments.

Expert No.	No	Yes Description
1	X	
2		X: partly Stoomwesen rules but these are insufficient
3		X: CEGB doc. OED/STB(s)/87/0022/R, adapted for cross-welds 1)
4		X: PD6605 & EC3 guidelines; see also 2)
5	X	
6	X	
7		X: confidential
8		X: internal procedure
9	X	
10	X	
11	X	
12		X: EC3 guidelines
13	X	

1) also R5 type assessments are sometimes used
2) Hales, Osgerby & Dyson, 1997: Proc. 7th Int Conf Creep and Fracture of Eng Mater and Structures, Univ. of California, p. 749-758

Summary to Q1.4: No 7/13; Yes 6/13

Table 6. The expert answers to question 2.1 regarding preassessment criteria.

Expert No.	**None**	**ECCC criteria**	**PD 6605 criteria**	**Case-specific or more general**
1				X[1)]
2		X		X[2)]
3				X[3)]
4		X	X	
5				X[4)]
6		X		
7		X		
8		X		
9				X
10	X			
11				X[5)]
12		X		
13				X[6)]

1) using creep properties of parent metal and French standard NF A89-010
2) code values and extrapolated values within the scatterband of the code
3) testing by external testing houses, BS standard criteria apply; results must also reflect the likely in-service failure mode
4) data is often sparse and criteria have to be relaxed
5) validation in terms of parent/weld properties and composition, appropriate weld procedure, metallography to exclude anomalous results due to defects etc.
6) criteria of German "Arbeitsgemeinschaft Warmfeste Stähle", similar to ECCC criteria

Summary to Q2.1: None 1/13; ECCC 6/13; PD 6605 1/13; other 7/13

Table 7. The answers to question 3.1 on assessing the results from creep tests on weldments.

Expert No.	**Procedure description**
1	Cross-weld and weld metal specimens
2	Cross-weld, isostress and/or component tests; also BM, sim. HAZ and WM
3	No fixed method, usually to compare weld procedures, heat treatments etc.
4	PD6605, cross-weld and weld metal specimens
5	Normally sampling of cross-welds to ensure all potential failure sites
6	Parametric fitting to determine optimum model representation and/or ISO type approach, depending on size of dataset. Data from cross-welds or from weld pads, weldments prepared in line with procedure of interest. Do not assess simulated structures.
7	Comparison with parent and relationship to standard; influence of test duration
8	-
9	Cross-weld
10	-
11	Cross-weld to identify failure mechanisms, other and biaxial for details
12	BM and WM for CDM model, combined for XW, multiaxial verification
13	Comparison of cross-weld and corresponding parent material results

Summary to Q3.1: No answer 2/13; some description 11/13

Table 8. The answers to question 4.1 on acceptability criteria on testing results when using the results for interpolation/extrapolation of data.

Expert No.	**Acceptability criteria**
1	Same as for parent metal
2	On average 5 specimens, 100 – 4000 h, fracture location & supporting info
3	Increasing caution with increasing range of extrapolation
4	ECCC and PD6605
5	Usually PD 6605
6	ECCC PATs 1 and 2; PAT3 impractical for small datasets
7	Extrapolation factor ≤ 3 in time, sufficient no of specimens, scatter
8	Data within a scatterband of ± 20% (in stress) of published data
9	Extrapolation, at least 30 kh of testing time
10	-
11	Anomalous results investigated by metallography
12	Often consider one cast at one temp; ECCC PATs apply only selectively
13	Compare to parent (with scatterband of steel) to obtain stress reduction factors

Summary to Q4.1: No answer 1/13; description 12/13

Table 9. The expert answers to question 4.2 on supporting metallography.

Expert No.	**No**	**Yes Description/reference**
1		X
2		X: location of fracture and damage, possible defects
3		X: all failures to ensure that failure mechanism is relevant
4		X: methods are different for ferritic, austenitic and DMWs [1)]
5	X	
6		X: at least to define fracture path / location in weldment
7		X: fracture location
8		X: to distinguish weld, fusion line and HAZ
9		X: location of fracture
10	X	
11		X: to examine anomalous results such as early failures, weld defects
12		X: failure location, creep damage characteristics
13		X: rupture location

1) for ferritic type IV failures: Coleman & Miller, 1994. Maintenance and Repair Welding in Power Plant, AWS-EPRI Conf Nov 30-Dec 2, Orlando Florida; for austenitic welds: Senior, 1990. Cavitational damage in AISI type 347 type weld metal arising from creep deformation. Mater. Sci and Eng A130, pp 51-58.

Summary to Q4.2: No 2/13; Yes 11/13

Table 10. The expert answers to question 4.3 on supporting FE analysis or comparable.

Expert No.	No	Yes Description/reference
1	X	
2		X: sometimes together with component testing
3		X: mostly independently of testing, sometimes to support experiments
4		X
5	X	
6	X	
7	X	
8	X	
9		X: only in single cases
10	X	
11		X: only in specific programs where creep strain is addressed
12		X: for component test modelling
13	X	

Summary to Q4.3: No 7/13; Yes 6/13 (many for limited applications)

Table 11. The expert answers to question 4.4 on other supporting methods.

Expert No.	None	Yes Description/reference
1		X: bending tests
2		X: component tests especially for repairs
3		X: cavitation levels sometimes used; internal procedures apply
4		X: see ref in 1.4
5	X	
6	X	
7	X	
8	X	
9	X	
10	X	
11		X: ductility levels are investigated
12		X: Component testing
13	X	

Summary to Q4.4: None 7/13; Yes 6/13

Table 11. The expert answers to question 5 on other supporting guidelines

Expert No.	None	Yes Description/reference
1	X	
2		X: CSR tests
3	X	
4	X	
5		X: R5 vol 6 & 7
6	X	
7	X	
8	X	
9	X	
10	X	
11		X: with sufficient data many statistical methods
12	X	
13	X	

Summary to Q4.4: None 10/13; Yes 3/13

Table 12. The expert answers to Section III question on additional comments

Expert No.	None	Yes Description/reference
1	X	
2		X: avoid too high stress, more info needed of austenitic & DMW
3		X: questions related to inter-outage periods rather than design life
4		X: XW simplistic
5	X	
6	X	
7	X	
8	X	
9	X	
10	X	
11		X: size effects!
12		X: small data sets important
13		X: stress reduction factors should be used

Summary to Q4.4: None 10/13; Yes 3/13

APPENDIX: QUESTIONNAIRE ON ECCC WELDMENT ASSESSMENT

EXPERT QUESTIONNAIRE

I. Introduction

ECCC (European Creep Collaborative Committee), the European body to prepare guidelines and materials assessment for service in the creep regime for e.g. European standardisation, has launched an effort to evaluate the methods on weldments in this area. As one part of the effort, the current expert opinions and practices worldwide are reviewed on assessment of creep testing results of weldments.

For this purpose, ECCC asks for your expert help. Please answer the following questions, and add any comments you may have. All individual answers are held confidential and treated in such a way that no individual recipient of the questionnaire can be later identified. The results of the questionnaire (but not individual answers or names of recipients) are used to formulate the European ECCC guidelines on assessing creep testing results of weldments. The review will become public, and will be published also in the Information Days of ECCC. Your effort is much appreciated, as the results aim to provide widely accepted, technically well founded guidelines for assessment of the creep testing results of weldments.

II. Questionnaire

1. Background information

1.1 How important for you is the correct assessment of creep testing data of weldments?

[ ] vitally important [ ] important [ ] not very important

1.2 How extensively do you need to assess experimental creep data of weldments?
frequency:
[ ] daily [ ] few times a week [ ] few times a month [ ] few times a year [ ] less often / never
quantity per year:
[..] none [ ] 1 to10 welds a year [ ] 11-100 welds a year [ ] more than 100 welds a year

1.3 What is the purpose of the assessment in your case? (multiple choices are possible)

[ ] Design Assessment
[ ] assessment/qualification of materials or manufacturing procedures
[ ] life assessment of ex-service welds
[ ] other (please specify)
....

1.4 Do you have a written guideline or qualification procedure for assessing the creep testing results of weldments?

[ ] no [ ] yes (please provide description/reference if possible) ....

....

....

2. Pre-assessment criteria of creep testing results from weldments

Pre-assessment criteria include typically those for e.g. confirmation of the material and testing specifications and grouping of the test results for initial testing of the data quality.

2.1 What pre-assessment criteria do you require for the creep testing results of weldments?

[ ] none [ ] ECCC criteria [ ] PD 6605 [ ] case-specific or more general criteria (please specify)

....

....

3. The main assessment methods and criteria

3.1 How do you normally assess the results from creep tests of weldments (e.g. cross-weld specimens, weld metal specimens, other)? Please specify / provide a reference.

....

....

4. Post-assessment: criteria and analysis of weld creep testing data, and supporting methods

Post-assessment refers here to acceptability for predicting creep behaviour of the data, such as extrapolation and interpolation, and the quality of predictions e.g. in terms of physical realism and repeatability.

4.1 When you predict creep behaviour beyond the data, by extrapolation or interpolation, which acceptability criteria you would use for the results ?

....

....

4.2 Do you use metallographic assessment to support the assessment of weld creep testing results?

[ ] no [ ] yes (please specify and provide reference if possible) ....

....

....

4.3 Do you use finite element (FE) calculations or comparable methods to support the assessment?

[ ] no [ ] yes (please describe briefly and provide reference if possible)

....

....

4.4 Which other methods or techniques do you use for the assessment of weld creep testing results? Please specify and provide reference if possible.

....

....

5. Other supporting guidelines

5.1 Do you know of alternative methods or approaches for assessment of creep testing results from weldments? Please provide a reference.

....
....

....
....

III. Additional expert comments and recommendations

Please provide here any additional comments, recommendations or other information you may have on the subject of assessment of creep tests for weldments:

....
....

....
....

....
....

THANK YOU !

Please return this questionnaire to:

Pertti Auerkari
VTT Manufacturing Technology
PO Box 1704, FI-02044 VTT, Finland
fax +358-9-456 7002

If you have any questions or other comments, please do not hesitate to send them to the above address, or via e-mail to Pertti.Auerkari@vtt.fi, or or by phone +358-9-456 6850.

Your contact information: **Date:**

Name:

Company/affiliation:

Address:

Tel: **Fax:** **E-mail:**

APPENDIX B

REVIEW OF WG1 WELD-CREEP DATA ASSESSMENT EXPERIENCE

S R Holdsworth

ALSTOM Power, Rugby, UK

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