VAMAS

Technical Working Area 25
Creep/Fatigue Crack Growth in Components

Review of ″VAMAS TWA 25 Questionnaire on materials, testing and analysis ″

K Nikbin

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VAMAS

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Technical Working Area 25
Creep/Fatigue Crack Growth in Components Films

Review of "VAMAS TWA 25 Questionnaire on materials, testing and analysis "

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1. Introduction

Complexities as how to predict component failure at elevated temperatures under creep/fatigue conditions has lead researchers to use fracture mechanics and small laboratory test specimens' data in their analysis. Due to the non-linear and constraint effects, evident in creep damage and the fracture mechanism, it is now evident that more complex test geometries that simulate the actual component both in terms of shape, size and loading are needed to provide crack initiation and growth data for use in life assessment. As a result VAMAS TWA25 was initiated to develop a good practice guide and detailed recommendations for standards and codes to test more complex geometries using agreed test methods and validated techniques for data analysis.

In order to address the objectives set out in VAMAS TWA25 collaborative work, a questionnaire was drawn up to cover various aspects of creep/fatigue crack growth component testing and analysis. This report reviews the answers to the questionnaire and highlights the consensus reached on various topics. The results are presented in tabular form for ease of referencing and discussion and conclusions are also presented in section 2. The comments and information that were sent are included in short form in the document (sections 3-10). The table in section 11 lists the names of those who participated in this collaboration. Additional list of references related to component creep/fatigue crack growth is given in section 12. In some cases similar comments/answers have been given by more that one participant, in which case these are amalgamated. In conclusion, in the light of these results, suggestions are made as to what should eventually be prepared as a more detailed list of 'recommendations' for creep/fatigue crack growth component testing, by VAMAS TWA25 participants.

There may be a number of repetitions and possibly errors in reading hand-written text. Participants are therefore urged to send in corrections. Identifying references in the tables of the person who has made a comment is only an indication that the respondent has performed or has interest in the topic. There could also be instances where the respondent to the questionnaire in not listed in the topic but has interest in the subject. The overview provides a description of the most important points which are relevant to the present TWA25 project. These are highlighted in the results, analysis and conclusions in section 2. Generally it can be concluded from the answers that whilst many are keen to perform creep/fatigue testing of non-standard specimens very little unity exists between the participants in their testing as well as their analysis methods. The document also highlights the importance of extending advice on testing methods to cover a wider range of geometries and techniques. It is hoped that these results will in part assist the group in formulating a recommended good practice document to deal with 'Creep/Fatigue crack growth in Components' as a deliverable at the completion of the TWA25 project.

Numerous references exist with respect to this topic however not all participants have listed relevant references. The gathering of additional references could therefore be addressed at a later stage.

2. Summary of Results and Analysis

The questionnaire requested detailed relevant information regarding creep/fatigue testing in non-standard feature components. The questions covered all aspects such as choice of material, type of specimen, loading, testing apparatus, pre-and post measurement and metallography and the form of analyses employed in dealing with the data. Clearly there is a wide range of interests and views that the participants have expressed. However there are preferential themes that highlight the similarities that can be exploited in developing a good practice document. A summary of the findings of the answers to the individual sections of the questionnaire is now presented.

2.1 Choice of materials (section 3)

The range of materials and the temperatures quoted, other than a few exceptions, suggest that ferritic and the high strength steels constitute the largest proportion of material tested. These steels are of interest to the power generation and the chemical industries. These generally exhibit creep-ductile behaviour at the operating temperatures. Substantial interest is shown in weld materials, which could behave in a more creep brittle and unexpected manner. For these materials it would be advisable to produce, where available, a generic list of material properties used in assessment models. Another category of material is the nickel-base superalloys, which is mainly of interest to the aero-engine industry. It is important to take into account all the materials that operate in the creep/fatigue range regardless of their industrial applications and to make recommendations over a range of creep-ductile to creep-brittle material conditions.

2.2 Laboratory geometries (section 3a)

The standard specimen, which is proposed and verified in ASTM-E1457, is the Compact Tension (CT) test piece. Although the CT specimen is the most popular specimen, differences in size, side grooving and geometry of interest dictate that advice and information should be prepared to deal with these variations. In addition the survey clearly suggests that there is substantial interest in testing other fracture mechanics geometries. These specimens are listed in Table 1.

Table 1: List of fracture mechanics specimens

CT	Compact Tension
DENT	Double Edge Notch Tension
SENB	Single Edge Notch Bend
SENT	Single Edge Notch Tension
CCP	Centre Cracked Panel
CR	C-Ring

Table 2: List of feature/component shaped fracture mechanics specimens

Bars	cylindrical – notched, cracked, surface/circumferential flaws
Tubes, pipes	circumferentially /axially cracked, surface/circumferential flaws
Plates	under tension /bend with surface flaws
Corner cracked	under tension/Bend, surface flaws
Plates	with holes containing cracks
T-joints	usually associated with weld sections, surface flaws

It is important that test specimens should reflect, as best as possible, the stress-state of the component and the size with respect to the availability of material. For example only a small size of ex-service material may be available in a certain circumstance and therefore the testing procedure should account for this. VAMAS TWA25 recommendations will hence indicate relevant information to cover testing and analysis for the geometries to be examined.

2.3 Feature components (section 3b)

With reference to non-standard feature test components which contain cracks, indications are given from the answers to suggest that there is substantial interest in these. The main reason is the need to test geometries that will most likely replicate the stress state in the component under investigation. This will effectively give a wide variety of specimen shapes and sizes that need to be considered and optimised in a recommendation document. The simplified list is given in Table 2.

Table 2 list the generic range of ‘Feature’ geometries that are usually encountered. There will be many variations to these but those will be task specific. However, once the recommendations are drawn up, help and guidance should be given to set up, run and analyse any non-standard geometry under creep/fatigue conditions. The most important task is to draw up a relevant list of validated fracture mechanics functions which can be used to carry out analysis of the test results.

2.4 Apparatus and testing equipment (section 4)

Information is given in this section to cover equipment, loading, temperature range and methods of measuring crack initiation and growth. The type of equipment used is naturally varied. In this case it would be prudent to follow the advice given in ASTM E1457 which sets out accuracy limits that the furnace, servo-hydraulic machine, the measurement equipment crack growth monitoring etc. should achieve. In this way the user is allowed to use any equipment he finds suitable as long they adhere to accuracy limits for the variables that are outline in Table 4. In cases where it is difficult to attain the relevant limits of accuracy the user will need to be advised as to what to do at the analysis stage.

Table 3: Types of loading used for tests

Constant load (dead weight) Tension tests
Constant load (dead weight) Bend tests
Stress and strain control creep-fatigue tests
Displacement-controlled bend, cyclic/hold, with hold times at various positions in the cycle
Constant displacement
Dwell in tension or compression
Pressure loading
Thermal loading
Constant , K, COD tests
Residual stress

Table 3 lists the types of loading that are on interest. It is important to relate the type of loads used in the testing procedure to the component under investigation.

2.5 Measurements for pre, post and during testing (section 5)

Once again there are variations as to how and in which manner the relevant test variables are measured. The range of standards used is also varied. Guidance should be available on pre-test measurements of the dimensions, hardness, and in the case of welds to identify the position of the initial crack using metallography. During the test it is essential to gather as much data as possible, starting from zero load to the completion of the test even if the information might not be directly needed in the analysis.

The most important is to measure crack length and where possible the, displacement with time, local and remote from the crack. Advice should also be given on how to make measurements during the tests and in what form collect all relevant information from the beginning, starting from zero load, to the completion of the test. Where test interruptions are possible and also allowed guidance should be given for different NDE methods for measuring the crack and other variables. Post test metallography and damage measurements are a vital part of feature component testing as it is essential to derive as much information as possible from each test especially since these types of tests are usually expensive to carry out. Table 4 gives the possible list of test variables that should be recorded. Accuracies for these variables are in most cases available in available standards. These will be tabulated in VAMAS TWA25 recommendations.

Table 4: List of variables to be recorded during a creep/fatigue test

Variable	**comments**
Material information Batch and heat treatment specific	creep uniaxial properties should ideally be available Elastic/plastic properties at RT and test temperature In case of weld and HAZ properties should be made available
Specimen dimension	Dimension of specimen before and after test- to check for shape change
Initial crack length	At the start of test (EDM or pre-fatigue starter)
Loading	From load up sequence in static – to fatigue cyclic test throughout the test
Temperature	Throughout the test – in different regions of the component- to check for temperature distribution
Crack length	Using PD- throughout the test – indicating the accuracy of method
Load line displacement	Where possible: Using internal or external transducers- throughout the test – indicating the accuracy of method employed
Crack opening displacement	Using internal or external transducers- throughout the test – indicating the accuracy of method
Metallography	Pre test to identify matrix in the region of the crack- especially for weldment -post test to observe, fracture mode, damage and to observe final crack length for calibration of PD and incremental crack measurements
Hardness	Pre/post hardness- especially where welds or HAZ is concerned
NDE measurement	Where possible details of NDE before/after and during the test

2.6 Data analysis (section 6)

Paramount to experimental testing there is the issue of analysis of the data that need to be considered. There is a wide range of methods for analysis proposed in this section. Essentially the parameters that will be recommended in a 'VAMAS TWA25' document will need to be verified and applicable to the type of geometry and the test undertaken. Experience already exists in the literature and is available in codes that use these parameters. These can be incorporated in the recommendation

Answers in section 6 indicate the range of parameters that could be included in the recommendations. Table 5 gives a short list of parameters that are mostly likely to be used. These cover creep crack initiation and growth and fatigue crack growth. It will be the task for the VAMAS TWA25 committee to propose and tabulate information for the parameters relevant to each component. Information contained in such a document will be essential to life assessment analysis.

Table 5: Relevant fracture mechanics parameters used in creep and creep/fatigue crack initiation and crack growth analyses

K	Stress intensity factor
ΔK (=ΔJ)	Stress intensity factor range
K_{cmat}, J, J_{cmat}	Creep toughness parameter
C^*, $C(t)$	Non- linear energy dissipation rate
CTOD, $\dot{\delta}$	Crack opening displacement or displacement rate criteria
Reference stress, σ_{ref}	Material independent crack tip stress scalar based on a skeletal stress or a collapse load criterion
Q^*	Activation energy rate criterion
σ_D	Stress at a distance from the crack tip
σ_{net}	Remaining ligament criterion

2.7 Finite element analysis (section 7)

In order to evaluate the relevant fracture mechanics parameters for non-linear time dependant creep crack growth of feature component geometries some participants use Finite Element analysis. In fact for more complex components verifiable FE analysis may be essential. It is evident from the range of packages used that no conformity and agreement exists in their use. In addition the boundary conditions and material properties employed will most likely be different. This will inevitably produce significant differences in the values calculated for the fracture mechanics parameters. This in turn will affect crack growth analysis and lifetime defect assessment predictions. The problem becomes more significant when non-linear reference stress and plastic collapse solutions are used and when £D analysis replace 2F analysis. It is therefore imperative that once a list of feature component specimens are drawn up solutions for the relevant stress and crack growth parameters which have been validated should accompany them. It is therefore paramount that a validated list of functions be produced in order that there is uniformity in the method of analysis. This will have a number of advantages. Firstly the codes must have available solutions for users so that there will for most cases be no need for additional FE. Secondly, although there may be some disagreement between users regarding use of a specific parameter in the document it is clear that there can be direct comparison of published results between different laboratories. Guidelines should also be made available regarding the use of FE. However these guidelines can only be general and not software package specific.

2.8 Prediction of component behaviour (section 8)

It is fundamental to VAMAS TWA25 to recommend methods that can eventually be used for assessing defects in real components. It is therefore vital to consider the modelling aspects for defect assessment in the creep/fatigue cracking of components. Participants have identified this problem by replying to the questions in section 8 in detail. The tables in section 8 are relatively self explanatory. The users have also identified crack initiation as an important aspect for life assessment that needs to be addressed. It is clear in section 8 that there is no conformity in the use of the available codes. Although in many cases the codes use the same in their modelling procedure there is still disagreement as to the use of the actual functions to be adopted. Since most these parameters listed in table 5 are non-linear and in some cases time dependent they will be highly stress sensitive and therefore more likely to give different results for the same parameter. This aspect was highlighted in the previous section dealing with FE analysis but it is true for analytical and other numerical derivations of the relevant functions. Recommendations in VAMAS TWA25 will need to take account of these differences and tabulate specific functions for the list of recommended geometries shown in tables 2 and 5 respectively.

2.9 Reporting procedures (section 9)

It is important to recommend comprehensive reporting procedures to users with respect to testing and data analysis. It is vital to recommend that as much information is collected during and after the completion of the tests. In some cases the information might not be used in the subsequent analysis; however the information should still be available for future use or analysis. A list of variables that can be measured should be drawn up. Advice is already available in some codes and standards and VAMAS TWA25 should make use of this information to make further improvements.

2.10 Discussion and Conclusions

It has become clear that the direction of this project has to consider two application routes. The first is relevant to actual test methods and measurement techniques and the second is the design analysis and life prediction methodologies that need to be performed to interpret feature tests under creep/fatigue loading conditions. Both these aspects are interconnected and fully dependent on each other. For purely testing methods, it is relevant to establish recommendations for standard bodies such as ASTM, CEN and ISO documents which deal strictly with laboratory testing techniques. In practice this would mean improving and updating ASTM E1457 and other national or International standards, which are being presently developed. With respect to analysis and defect assessment, it is clear that there is little conformity in the use of the codes, models and the relevant fracture mechanics functions that are used. The Round Robin exercise which has also been planned in VAMAS TWA25 should address the needs of the standard bodies such as ASME, BS and API who deal with design life assessment methodologies. Once the Round Robin for analysing two feature tests is complete it will be possible to present more specific recommendations regarding the relevant use of models for creep and creep/fatigue crack growth.

The questionnaire has produced detailed answers to specific questions regarding test and analysis methods in the creep/fatigue regime. Although the subject is difficult to generalise, due to the range of geometries and testing interests, there appears to be a regime of conformity that can be established. VAMAS TWA25 can use this as the basis of its final recommendations. IN the following sections the answers received to the questionnaire are presented in the same format in which they were posed.

3. Materials

3.1 Low alloy Steels — High Chrome steel

Denomination	Condition	Temp. [°C]	Participant
Low to high alloyed steels	Mainly new and service exposed welds, various welds, T-pieces, headers etc.	500-750	[5], [21]
low alloy steels	Listed materials in specified quality heat treated - parent, weld metal and x-weld	to 550	[4], [21]
9-12 Cr	Listed materials in specified quality heat treated - parent, weld metal and x-weld	to 625	[4], [21]
	Steels, forge and cast	to 625	[6], [21]
NF616 (9-12Cr) HR1200 (9-12Cr) TAF650 (9-12Cr) SVS304	Weldment	- -	[3] [15]
CrMoV	Weldment Parent/weld	- 540-580	[3], [21] [12]
P91 (9Cr1Mo)	Base material and welds Normalise + temper Welds, base metal, dissimilar metal welds	570-580 RT-565 600-650	[6] [7] [10]
	With and without PWHT, parent and weld	600	[17]
	Weldment, x-weld, simulated HAZ	600-700	[21]
	Sub-critically treated and renormalized welds	Q+T	[18]
P92	Base material and welds Welds, base metal, dissimilar metal welds	570-580 600-650	[6] [10]
	Weldment, x-weld, simulated HAZ	700	[18],[21]
E911	Base material and welds Welds, base metal, dissimilar metal welds Weldment, x-weld, simulated HAZ	570-580 600-650 700	[6], [10], [21]
	Generally welded, some with PWHT	550	[10]
	Parent weld	540-580	[12]
	Parent, weld, HAZ & type IV (PWHT 3h)	500-550 (705)	[16]
	With and without PWHT, parent &weld	550	[17]
	Base material and welds	570-580	[6]
	Weldment, x-weld and simulated HAZ	700	[21]
½ CMV	Parent, weld, HAZ & type IV (PWHT 3h)	500-550 (705)	[16]
1CrMoV	Parent Generally welded, some with PWHT	500-600 550	[9],, [21] [10]
1 ¼ Cr-½Mo	Sub-critically treated welds and renormalized welds	Annealed or N+T	[18]
2 ¼ Cr-1Mo	Sub-critically treated welds and renormalized welds	Annealed or N+T	[18]
2 ¼Cr or 3Cr-1M – V	Sub-critically treated welds and renormalized welds	Annealed or N+T	[18]
HCM 25	Weldment, x-weld, simulated HAZ	700	[18]
CMn-steels	Weldment, x-weld, simulated HAZ	300-400	[18], [21]
12Cr(W-Co)	Parent/weld	550-650	[9]

Industrial application:
High temperature steam turbine components [4] [6]
Steam pipes in fossil fuelled power plants [5]
Advanced power plants (see for example COST522: materials for ultra efficient low emission power plants) [6]
Conventional heaters [7]
Power generation steam pipe, pressure vessel and steam turbine [10]
Materials for advanced power plants where the operating temperature has been increased in order to increase the thermal efficiency and reduce the emissions [11]
Component for power plant [12]
AGR internal structures, headers and steam pipe-work components [16]
Seam welded piping, vessels, headers and girth-welds [18]
Used in high temperature pressure parts in coal fired steam plants [18]
CrMoV use for component tests [3]
P22 use for boiler tube and piece (e.g. T,Y-heavy section components and valve) [9]
1CrMoV use for turbine rotor [9]
12Cr (W-Co) developed for USC plant [9]

3.2 Austenitic stainless steel

Denomination	Condition	Temp. [C°]	Participant
Low to high alloyed steels	Mainly new and service exposed welds, various welds, T-pieces, headers etc.	500-750	[5], [21]
-	weldment	-	[8]
304	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16]
316	Solution treat or pre-strain	RT-565	[7],[16]
	Parent, weld &HAZ (As-welded + PWHT)	500-650	[18]
	Weldment, x-weld and simulated HAZ	-	[21]
AISI 316	Welds, base metal, dissimilar metal welds	600-650	[10]
316SS	--	550-650	[14]
	Generally welded, some with PWHT	to 650	[10]
316H	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16]
316L	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16]
	With and without PWHT, parent &weld	550	[17]
316L (N)	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16], [21]
321	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16]
321SS	Generally welded, some with PWHT	to 650	[10]
347SS	Generally welded, some with PWHT	to 650	[10]
347 weld	Parent, weld &HAZ (as-welded + PWHT)	500-650	[16]
Esshete 1250	Weldment, x-weld and simulated HAZ	-	[21]

Industrial application:
Steam pipes in fossil power plants [5]
Nuclear headers [7]
Electricity power generation [8]
Power generation steam pipe, pressure vessel and steam turbine [10]
Nuclear power plant [14]
AGR internal structures, headers and steam pipe work components [16]
High temperature pressure parts in coal fired steam plants [21]

3.3 Nickel based superalloys

Denomination	Condition	Temp. [C°]	Participant
General	Weld	-	[3], [21]
General	Parent	700-900	[9], [21]
General	Weld	1000	[13]
General	Weld	-	[14]
IN738	Industrial solution treat & age	750-1100	[7]
CMSX4	Industrial solution treat & age	750-1100	[7], [21]
IN100	Industrial solution treat & age	750-1100	[7], [21]
NF709	Welds, base metal, dissimilar metal welds	600-650	[10]
NiCrMo	Parent/weld	540-580	[12]

Industrial application:
Turbine blade of engine, gas turbine blade [9]
Fossil power plant applications and gas turbines (aircraft and land-based) [13]
Gas turbine blade [7]
Materials for advanced power plants where the operating temperature has been increased in order to increase the thermal efficiency and reduce the emissions [11]

3.4 Titanium based alloys

Denomination	Conditions	Temp. [C°]	Participant
Titanium alloys	Parent material; possibly friction stir welded	300-550	[2],
TiAl intermetallic compound	Weldment, Weld, HAZ	650-750	[3], [21],[15]

Industrial application:
New materials for turbine engine and aerospace structural materials [2]
Aluminium based alloys

Denomination	Conditions	Temp. [C°]	Participant
High temperature Al alloys	Parent material; possibly friction stir welded	to 200	[2], [21]

Industrial application: Light weight aerospace structural materials [2] , [21]

3.5 Plastics

Description	Conditions	Temp. [C°]	Participant
-	Injected moulded plastics Fusion welded plastics	-	[1]

3.6 Additional information

As plastics find their way into engineering structures, the time dependent properties become more important [1].

Participant: [8]	main requirements is for data on weldment to established for dressed/undressed butt welds and filled welds and perform and the creep fatigue loading at long term (>20000h).

4. Geometries

4.1 Detail the type of fracture mechanic /specimen/components that have been tested in your institution

Specimen Type	Remarks	Participant
CT- Compact Tension	Various sizes According to ASTM E1457 Limited experience on miniaturised specimen	[9], [17],[12], [21] [12],[2], [11], [16] [3], [15], [10], [6], [18], [7], [21]
DENT- Double Edge Notch tension	Various sizes and dimensions	[7], [21], [6],[16]
SENB - Single Edge Notch Bend	Various sizes and dimensions	[17], [21], [3], [15]
SENT - Single Edge Notch Tension	Various sizes and dimensions	[6], [17], [21], [4]
CCT- Centre-Cracked Panel	Various sizes and dimensions	[17], [21], [6],[13] [1], [7]
3PB, 4PB -3 point and 4 point	Various sizes and dimensions	[18], [21], [13], [16], [7]
C-Ring	Various sizes and dimensions	[21]

4.2 References

Participant: [14]	Marie et C. Delaval : « Fatigue and creep-fatigue crack growth in316 stainless steel cracked plates at 650°C », Proc. HIDA2 conference, Stuttgart (GER), 2000 S. Chapuliot, T. Chaudat, V. Mineau and D. Moulin : « Fatigue growth of semi-elliptical cracks in plates subjected to bending. », Proc ASME PVP, Montreal (CANADA), 1996 F. Curtit, R. Piques, S. Chapuliot et P Cambefort : « Propagation de fissures semi-elliptiques en fatigue-fluage dans des plaques d'acier 316L(N) sollicitées en flexion à 650°C. » J. Phys. IV, vol 10, pages 305-310, 42e colloque de métallurgie de l'INSTN, 2000

4.3 Specimens feature tests under static or cyclic loading at high temperature

Feature specimen Type	Remarks	Participant
Bar - Cylindrical	Round, smooth, notched, cracked	[9], [21], [3], [15], [12],[7], [16], [21]
Tubes,/pipes Circumferentially /axially cracked	Straight, Bent notched tubes under static loading, thermal fatigue Pipes under pressure/bending/fixed displacement loads	[11], [18] [6]
Plates	Welded under bending and tension, cracked	[17], [10], [14]
Corner crack tension/Bend	Constant load/constant displacement loading	[21]
T-joints	Various sizes and welds	[18], [10]
model headers	-	[18]
flat	Central hole under tensile load and cyclic thermal shock (ratcheting)	[6]
Bi-axial specimens	-	[6]
SC blade PC blade	Under TMF loading (at high temperature gas test rig (up to 1000C)	[6], [21]
fillet and cruciform	Welded	[10]
Cross type	Roughly 25mm square welded	[18]

4.4 Are you most interested in crack initiation or growth data at high temperatures.?

Choice	Remarks	Participant
both	Majority interest in both regimes	[1], [5], [6],[7], [10], [12], [13], [14], [16], [17], [21]
	Preliminary steady state crack growth; ;possible some initiation from sharp notch	[2]
	Mainly initiation and early growth	[4]
crack initiation	And also cavity initiation	[8]
crack growth	-	[18]
-	Mainly interested in creep, CCG and thermal fatigue	[11]

4.5 What standard specimens and/or feature components are you interested in investigating?

Type	Remarks	Participant
Centre-cracked panel	-	[13], [21]
3 point bend	Small size for CCG	[11], [21],[16]
4 point bend	-	[13], [21]
CT	-	[2], [10], [11], [5], [16], [17],[21], [18], [13]
CCB	-	[16] [12], [21]
SENT	-	[12], [16], [17] ,[7], [21]
DENT	-	[12], [17]
SENB	-	[12], [21]
Cylindrical -	Cylindrical standard	[7]
Branches	-	[16]
Large single edge	Notched bend testpieces	[2], [4]
Pipes/Tubes	Large scale pipe (simplified shape)	[9], [18]
Plates	-Large flat	[16], [17], [10]
Blade	Type TMF	[6]
C shape	-	[12]
Tubes	Pressurised, pressurised & end load tubes with notches and weldment	[18]
Cylinder	Hollow pressure vessel	[10] [16]
T Joints	-	[18]
Model headers	-	[18]
Plant	-	[16]
General	Interrupted testing supported by metallography of crack growth and rupture specimens	[8]
General	Specimens for which multi-axial stress condition can be estimated	[15], [21]

4.6 What are your recommendations for the most generic type of cracked component /feature tests that should be considered?

Participants:	
[1] :	Prefer the centre crack panel that has a relatively slow changing *K* versus *a* and the net section stress can be understood. More test data at low K can be acquired, which is the most important for life prediction
[5] :	Welds
[6] :	Laboratory component has to simulate the multiaxiality, the stress state and the damage mechanism of the real component. For components with inhomogeneous material (welded components) these conditions have to be simulated as well, including residual stresses.
[8] :	Pressure vessel (intersection supported by compact tension)
[9] :	Large scale pipe (simplified shape)
[10] :	Large flat plates, hollow cylinders and CT
[15] :	Weldment
[16] :	Pressurised pipes or cylindrical vessels
[17] :	Plate, pipes and joints
[18] :	Piping with cyclic loading, pressured and pressurised /end load/ bent cylindrical comp.

[21] :	Geometries relevant to the stress state of the component under assessment

4.7 What in your view constitutes a component?

Participants:	
[6] :	Pressure tests of pipes of industrial size are often proposed and used like in HIDA as well. But the experiences shows that this type of laboratory components tests which needs particular safety precautions has certain limits in terms of level and flexibility of loading due to the existing facilities in comparison with loading by external forces. The test duration is another crucial issue: the conversion of the findings from the experiment to real components needs test conditions, which simulate the real damage mechanisms. For reasons of costs and duration of R&D projects the test duration is sometimes too short to meet this requirement. In addition geometrical differences between laboratory components of the same type (wall thickness, ovality, etc.) and interaction of various influences (stresses from loading, residual stresses etc.) can complicate the test data analysis. In conclusion I mean that actions for harmonising test methodology and interpreting results from laboratory component tests are necessary.
[9] :	Pressure vessel Component is an actual size structural part, with realistic loading: pressure and/or bending
[11] :	Pipes, elbows, pipe joints, vessels
[12] :	Model should reflect in service geometry and also pipes, pressure vessels, elbows and bends pressure or weldment must have a sufficient thickness to give a desirable tri-axiality.
[18] :	
[21];	Non-standard geometries relevant to the stress state of the component under assessment

4.8 References

Participant:	
[15] :	A.T Yokobori Jr, M. Shibata, M. Tabuchi and A. Fuji : « Materials at high temperatures », vol. 15 (2), pages 57-62, 1998 A.T Yokobori Jr, M. Shibata, M. Tabuchi and A. Fuji : « Engng. Fract. Mech », vol. 62, pages 23-32, 1999

5. Test apparatus and procedure

5.1 List the type of loading you use or would use in tests

Type	Remarks	Participants
Tension	-	[1], [10], [11], [17], [18], [21]
Constant load (dead weight)	-	[2], [5], [17], [18], [21], [12], [9]
Stress and strain control high temperature creep-fatigue testing machine	-	[3], [15]
Displacement-controlled bend, cyclic/hold, with hold times at various positions in the cycle	For large SENB specimens	[4], [21], [16]
Constant displacement	e.g. constant strain range	[7], [17], [21], [9]
Dwell in tension or compression	-	[7], [21], [11], [10], [8]
Pressure	-	[8],[10],[11], [16], [18], [6]
Bending	-	[8], [10], [17], [21]
Thermal	-	[16], [21]
Displacement-controlled	-	[16], [21]
Constant displacement , K, COD	-	[10]
Residual stress	-	[16]
Plates bending	-	[14]

From Participants: [6]:

control parameter (s)		units	Static max	Dynamic max	RAMP RATE, sec-1 max
internal pressure:	pressure	MPa	25	-	
tension-1	Force	kN	200	200	2
	Stroke	mm	+50	+50	
tension -2	Force	kN			
	Stroke	mm			
Bend	Force	kN	200	200	2
	Stroke	mm	+50	+50	
	Angle	°			
Torsion	Torque	kNm	200	200	2
	Angle	°			
Temperature		°C	700		Thermal shock, rate depends on specimen geometry (heat transfer)

5.2 List the types of heating apparatus you use for testing standard geometries and feature component.

Type	Remarks	Participants
Induction heating	For creep and + thermal heating	[1], [11], [21]
RF induction	-	[7]
Convection heating	-	[1], [21]
Conventional furnace	Custom-wound RF coil within furnace	[7]
Electric resistance tube furnaces	-	[2], [4], [21], [17]
Pipe, furnace	-	[5]
Local electrical heating element	e.g. from manufacturer KANTAL	[6]
Furnace	For standard geometry and the majority of feature components. Accuracy for temp control is important	[8] [16], [21]
Internal heating	-	[16]
Electric furnace	For standard specimen (CT or Round-bar)	[9]
Infra-red	-	[10]
Large hollow cylinder	-	[10]
Induction cylinders	-	[10]
Resistance	For CT, plates and tubes	[10]
Resistance furnace	- For creep	[12] [11]
Steam	Under investigation	[18]

5.3 Give the temperature range you test at for the corresponding material.

Material	Temp range [^oC]	Remarks	Participants:
Low alloy steel	500-600	According to ASTM E1457-98	[12], [21]
Low alloyed to medium alloyed	500-600	-	[5], [21]
Low alloy ferritic steel	550	-	[4]
Ferritic	500-590 550-700	-	[16] [21]
Austenitic	500-650 600-750	-	[16], [6] [21]
CMn steels	300-450		[21]
CMo	575-625	-	[18]
Titanium	500	-	[2]
Aluminium	150-200	-	[2]
Ceramic	<1500>		[15], [3]
Plastics	RT	-	[1]
Superalloys	1000	-	[1]
9-12%Cr steels	625	-	[4]
	up to 700 (argon)	- gas Pressure test rig	[6]
	550...600	- Thermal shock test rig	[6]
	Up to 1000	- High temperature test rig for TMF	[6]
RF coil	Up to 1200	-	[7]
Furnace	To 750,600-650	-	[7], [11]

5.4 Indicate how temperature is measured and to what degree of accuracy.

Type and degree of accuracy	Remarks	Participants:
Calibrated thermocouples	Especially for Pt Rh/Pt type thermocouples	[6]
Temperature measured PT/PTRH uncertainty +/- 1.4 °C	Max temp measured with extensometry 1000 °C without extensometry 1200 °C	[21]
PT/PTRH thermocouple	RF induction-spot weld. and furnace-bead	[7]
Type K thermocouples, measurement tolerance: +/- 0.5 °C, equipment	- Resolution: +/- 0.1 °C	[4], [14], [16], [18]
Thermocouples +/- 1 °C	-	[10]
Thermocouple, +/- 2 °C up to 600 °C and +/- 3 C° above 600 °C	Used in specimen & air	[17]
S-type thermocouples	-	[5]
TC (platinum/RH) +/- 2 °C	-	[1], [2]
Optical (+/- 5 °C)	-	[1]

5.5 In accordance with which available standards, if any, do you calibrate your equipment?

Type	Remark	Participants:
ASTM standards, ASTM 1457	-	[1], [18], [21]
ASTM E-83	Calibration of extensometer	[2]
ASTM E-4	Calibration of test machine	[2]
ASTM E-633	Used for T/C to 1000 °C in air	[2]
ASTM E606	-	[7]
BS EN 10002	Displacement transducers	[10]
BS EN 10002-3	Force	[4]
BS EN 10002-4	Extensometer	[4]
BS EN 60584	Thermocouples	[10]
BS 7500 Pt 1 and 2	Load cells	[10]
BS 507500/2-1999	-	[21]
DIN	-	[17]
DIN IEC 584:	Thermocouples, tolerances in house calib.	[6]
Reference certified materials	Thermocouple	[12]

5.6 What criteria/standard, if any, do you use to validate the test?

Type	Remarks	Ref.
Compare crack tip curvature in the specimen to that in the component.	If curvature is different they re-evaluate the data.	[1]
ASTM standards		[17], [18], 21]
ASTM E1457	Where applicable	[2], [5]
Heat tinting	-	[7]
DC potential drop	-	[7]
Inspection of fracture surface	-	[7]
Crack initiation and growth	-	[8]
Initiation 0.5mm of crack extension	internationally accepted criterion	[11]
Extend of prior creep deformation	-	[12]
R5 procedures	Tests generally used to provide validation	[16]
Past experience	-	[21]

5.7 What in your view constitutes crack initiation?

Participants:	
[6]: [18] : [21]:	The initiation criterion has to define a technique relevant during the tests to measure crack depth. From experience PD-measurements of 0.1 mm is quite usual. Considering the CT1 specimen we know different initiation criterions: Crack of 0,004 W. That gives about 0.1 mm. Definition of crack initiation in the „2-criteria-approach“: 0,2 0,5 mm respectively Normally use crack growth criteria (u 0.1, 0.5mm) in practice instant when creep zone begin to move away from starter notch. have also speculated this may be minimum in ACPD versus time plot There is no clearly defined initiation limit- it depends on modelling and NDE techniques to identify the smallest crack size. It could also be defined as the period before steady state crack growth.

5.8 References

Participants:	
[15] :	A.T Yokobori, Jr, M. Shibata, M. Tabuchi and A. Fuji: «Journal of Materials Science letters» vol. 15(1996), pages 2002-2007

6. Measurements for Pre, Post and during testing

6.1 Do you perform pre- and post metallography or fractography?

Choice	Remarks	Participants:
All	The methods for measuring variables is different For each partner	[3], [4], [5], [6], [9], [10], [13], [15], [16], [17], [18], [21]
	Perform pre test metallography to assure test material is the same as component and post test Fractography for features to compare with component features	[1]
	destructive metallography	[11]
	qualitative metallography	[12]
	pre-test and post-test metallography	[21]
	post-test Fractography	[2]
	sectioning, polishing + etching	[7]
None of them	-	[8], [14]

6.2 How do you estimate/measure/quantify damage?

Method	Remarks	Participants:
-	Damage is usually the formation of crack	[1]
Visual estimation of fracture mode	-	[2]
SEM	-To determine density and size distribution of cavities	[3], [15], [16]
SANS (Small Angle Neutron Scattering)	being investigated for sub-surface damage measurement	[16]
TEM, AFM	-	[3], [15]
damage mapping in terms of cavities/mm2	-	[4]
optical microscope	-Optically up to 1000x mag.	[15], [5]
AC-PD	-	[6]
Load at strain controlled tests	-	[6]
High temperature strain measurements	Capacitive gauges	[6]
Energy/unit volume consumed in gauge section partitioned	According to creep/fatigue components	[7]
Crack length	-	[8]
Cavitation	-	[8]
in house damage criteria	-	[10]
Cavity density and appearance	For creep	[11]
Presence of cavities at the crack tip on specimen section	-	[12]
Replication and optical manual cavity counting	-	[16]
Examination of the side surface of a sectioned specimen	-	[17]
life fraction based on rate acceleration	-	[18]
Visual assessment/metallography Scanning microscope	-	[21]
Carbide growth approach	Under consideration	[5]

6.3 What hardness measurements do you undertake?

Type	Remark	Participants:
-	Usually before test, Before and after test remote from damage zone Either on cylindrical surface or polished & etched section	[1], [4], [7]
Vickers hardness	-	[9], [10], [21]
Micro-Vickers	- Across HAZ	[3], [5], [9], [12] [11], [18]
Nano-hardness	-	[13]
Micro-hardness	-	[13], [17]
HV	HV1, HV5, HV10, HV30	[6]
HB	-	[6]
hardness	Perpendicular to crack for CMn	[21]
none	-	[2]

6.4 What method do you use to measure crack length measurements?

Method	Remarks	Participants:
AC/DC Potential Drop	During test	[18], [21], [6]
DC-PD (Potential Drop)	Reversed method	[11], [12]
DC electrical potential methods	-	[9]
Optical and back calibrate with PD results	Post test measure	[21]

6.5 What method do you use for creep displacement measurements?

Method	Participants:
On line measured by capacitive gauges	[6]
LVDT	[9], [11], [12], [18], [21]
Diametral strain with a non-contacting capacitive gauge	[11], [21]

6.6 Identify any other measurements you take.

Type	Remarks	Participants:
Initial & final crack size	- For crack initiation samples	[1]
Initial & final crack length	-Multi-point average per E1457 -ultrasonic at test interruptions or PD, destructive examination	[12], [17, [2], [21], [4], [5], [9], [13], [18], [16], [21]
Fractography	-Qualitatively	[11], [18], [21]
Hardness, oxidation	-	[5]
Crack mouth opening	-By capacitive gauges	[6]
Breaking open the notch after testing	To validate the on line AC-PD measurements	[6], [21]
Average crack depth (bowing)	-According to ASTM E1457	[7], [21]
Beach marks, striation	From stress, environment, Dwell	[7]
Crack growth	PD metallography	[14]
Crack mouth opening/displacement	With laser interferometers	[14]
In-situ observational method	By optical microscope	[15]
Creep deformation	Strain gauge/creep pips	[16]
Residual stresses	Deep hole, neutron diffraction	[16]
9pt average crack depth/length	-	[10]
Optical	-	[21]
Back calibration of PD	-	[21]

6.7 Please give a list of the relevant standards used.

Standards	Remarks	Participants:
E1457	-	[2], [4], [9], [12], [13], [15]
ASTM - other	-	[3], [17], [21]
ASTM E399, E647		[21]
JSPS	-	[3], [9], [15]
DIN EN 10003 –1	for hardness measurement	[6]
DIN EN ISO 6507-1	for hardness measurement	[6]
VdTUV – Mbl. 451-83/6	for metallography	[6]
DIN 54150	for metallography	[6]

6.8 List relevant references for more detailed information

Participants: [15] :	A.T Yokobori Jr and T. Yokobori: « Engng Fract Mech », vol. 31, 6, pages 931-945, 1998 A.T Yokobori Jr: « Engng Fract Mech », vol. 62, pages 61-78, 1999 A.T Yokobori Jr , A. Fiuji, M. Yoshida, T. Yamaoku: «Engng Fract Mech », vol. 47 3, pages 423-429, 1993

7. Data Analysis

7.1 What correlating parameters do you use to interpret crack initiation?

Parameters	Remarks	Participants:
Observation of crack and comparison with a critical local strain value and the applied strain or stress value	-	[1]
K –stress intensity factor	-	[2], [5], [6], [10], [17], [18], [21]
K_{cmat}	Creep toughness	[16]
C*	-	[2], [6], [10], [14], [16], [17], [21], [4]
Relative Notch Opening Displ.	-	[15], [3]
δI,x		[4]
σref		[4], [10], [14], [18], [21]
Q*	Needs tests at different temps.	[3], [14]
Energy expenditure Total/plastic strain range	-	[7]
J	-	[10]
J_{cmat}	Creep toughness	[16]
σ_D	-	[10], [14], [16]
C(t)	-	[12]
CTOD	-	[16], [17]

7.2 What correlating parameters do you use to interpret crack growth test?

Parameters	Remark	Participants:
Total strain range	-	[7]
K	-	[1], [2], [3], [6], [9], [10], [13], [15], [17], [18], [21]
	in thermal fatigue	[11]
K_{cmat}	Creep toughness	[16]
K_{IO}	Initial KI for brittle materials	[9]
ΔK_{eq}	for FCG depending on a	[4]
ΔK (=ΔJ)	-	[7]
C(t)	-	[13]
C*	-	[2], [3], [5], [6], [8], [9], [10], [12], [13], [14], [15], [16], [17], [18], [21], [4], [11]
Q*	-	[3], [9], [14]
σ_{ref}	-	[6], [10], [14], [18], [21], [8]
σ_{net}	Remaining ligament criterion	[7]
σ_D	-	[10]
$\Delta\varepsilon$	For FCG depending on a	[4]
J	-	[10]
J_{cmat}	Creep toughness	[16]
CTOD	-	[17]

7.3 Which standard, code of practice or in-house document do you use to select the relevant parameter?

Standards	Remarks	Participants:
Customer preference	-	[2], [10]
in-house	For parameter selection , Data reduction package	[4], [13], [21]
ETM	-	[17]
ASTM	-	[17]
	ASTM E1457	[5], [16], [21]
HIDA procedure	-	[6]
R5	Short (for $a/w \leq 0.25$) and deep crack growth sections	[8], [16,][7]
A16	-	[14]
API 579	-	[18]
Software	PREFIS, OMEGALIFE, ZRATE	[18], [17], [21]

7.4 Which parameter do you recommend to use for particular applications?

Parameters	Remark	Participants:
K	For creep brittle	[2], [13], [17], [18]
C*	For creep ductile CCG, only	[2], [17], [16, [7]
C*0	For CCI – initiation	[4]
ΔK_{eff}, ΔKeq	Two separate formulae for short & deep crack	[7], [21]
	For FCG depending on a	[7]
R5	Short (a/w ≤ 0.25) and deep crack growth sections	[8], [7]
J	-	[10]
$\Delta\varepsilon$,	For FCG	[4]
C(t)	For creep ductile	[13]
CTOD	For creep brittle and ductile	[17]
size effects	-	[21]
δI,x	For CCI - initiation	[4]
σref		[4], [18], [21]

CC=Crack Growth –Initiation, CCG=Creep Crack Growth, FCG= Fatigue Crack Growth

7.5 What material properties do you use to calculate the parameters?

Materials properties	Remark	Participants:
Tensile properties generally developed in-house		[2]
Handbook data		[2]
Cyclic stress-strain		[7]
Plastic strain range (short)		[7]
Reversible displacement range (deep)		[7]
Crack opening range		[7]
Error! Objects cannot be created from editing field codes.	Creep strain rate	[8], [21], [18]
ε_f	Fracture/failure strain	[8], [21]
NF	Fatigue failure	[8]
IVF		[8]
HOT tensile and creep properties		[15], [17]
Problem arises in case of CCG in welds: we follow the SOTA recommendation		[11]
Creep deformation, secondary and primary creep constants	**Error! Objects cannot be created from editing field codes.**	[13], [15], [21]
Cyclic curve, stress-strain curve, primary and secondary creep laws		[14]

7.6 General Remark

Participants:	Parameters for:
[4]:	Ramberg-Osgood, static and cyclic (E,A’, β) Norton (B’, n) or Norton-Bailey (D’, n, p) Creep rupture tu (T, σ_o)
[6] :	Crack initiation by two criteria diagram: KIA, which is the K-value at creep crack initiation experimentally determined and R_u/t/T Creep law for C* evaluation **Error! Objects cannot be created from editing field codes.**
[16] :	C* evaluated using experimental load line displacement rate Creep toughness evaluated using area (elastic+plastic+creep) under experimental load displacement curve CTOD evaluated using experimental displacements The **Error! Objects cannot be created from editing field codes.** approach uses an analytical estimate of the stress 50 m ahead of the crack tip together with uniaxial rupture data to predict initiation. The crack growth tests are then used as validation of this approach.
[21]	Information to be collected to analyse: Da/dt, dΔ/dt, limit load, reference stress, $\dot{\varepsilon} = A\sigma^n$, $\dot{a} = DC^{*\phi}$, $da/dN = C\Lambda K^m$, initiation times for initial crack extension,

7.7 Where is this data obtained; -in house tests or from generic data-base?

Choice	Remarks	Participants:
Both	-	[3], [4], [6], [10], [11], [14], [15]
In house test	-	[1], [7], [9], [16], [17], [18], [21]
	For tensile properties	[2]
	Only few cases	[12]
From generic data-base	-	[2], [12], [21]

7.8 What procedure/code or validation do you use prior analysis of data?

Standards	Remarks	Participants:
HIDA procedures	-	[6]
In-house quality system	-	[12]
R5	-	[16]
ASTM E 1457	- Carry out C* analysis and validity	[16], [17] [18], [21]
EFAM	-	[17]
Check specimen for evidence of CCG	-	[18]

7.9 Can you make available relevant crack growth initiation data for specimens and components for a VAMAS TWA 25 Round Robin analysis?

Yes	No	If yes, what will be provide	Participants:
	x	-	[1]
	x	-	[2]
x		Floppy disk or paper sheet	[3], [15], [21]
x		Depending on ground rules for activity, cyclic/hold cycles to initiation for large SENB feature specimen tests, with details of loading conditions	[4]
x		One data set from HIDA which needs to be specified (either one pipe bend test or one four point bending test of straight seam welded pipe)	[6]
	x	-	[7]
	x	Initiation data	[9]
x		Growth data (many data with CT specimen available / creep crack growth data; 2,25 Cr-1Mo, 1CrMoV, IN100	[9]
x		Crack initiation data generated on notched round bars under cyclic creep-fatigue loading 1CrMoV at 550C with hold periods to 16 hours	[10]
	x	-	[13]
x		Some pressure vessel initiation data can be released. More recent tests can only be released following internal agreement within British Energy, which is likely to be dependent on the extent to which other data are made available within VAMAS TWA 25.	[16]

7.10 List relevant references for more information.

Participants: [6] :	Please see appropriate paper on the HIDA Conference, Stuttgart, October 2000: U. Gampe, P. Seliger : « Creep crack growth testing of P91 and P22 pipe bends »
[15] :	Yokobori T., Yokobori T., and Kuriyama T.: « Life of crack initiation, propagation, and final fracture under high-temperature creep, fatigue, and creep- fatigue multiplication conditions » Am. Soc. Test Materials STP 942, pages. 236-256, 1988. Yokobori T., Yokobori T., Kuriyama T., and Kako T: « Relative notch opening displacement concept for crack initiation in high temperature time dependent fracture », Advance in Fracture Research, pages 2181-2190, 1984 Yokobori T. : « High temperature creep, fatigue and creep-fatigue interaction in engineering materials », second international HIDA conference Keynote paper, 2000

8. Finite element analysis

8.1 What FE package do you use?

Program	Remarks	Participants:
ANSI	-	[1]
ANSYS	-	[6]
ABAQUS PATRAN	-Non-linear -Pre processing	[5], [8], [10], [11], [13], [16], [18], [21], [7], [12]
SAFER (EPRI)	-	[12]
MARK	-	[15]
EPIC	Modified	[15]
FEMAP	Pre/post processor	[11]
CASTEM2000	-	[14]
Own package developed in-house	-	[18], [21], [12]
None	-	[2]

8.2 What parameters do you calculate with the packages?

Parameters	Participants:
C*	[5], [8], [12], [14], [16], [21]
C(t)	[16], [21]
h (constraint parameter)	[5], [21]
creep strain	[5], [21], [8]
creep strain rate	[5], [18], [21]
K	[12], [16], [18]
J	[12], [16]
σref	[14], [16], [18], [21]
Stress/temperature/displacement/displacement rate/Damage	[21]

8.3 What capabilities do you have for 2D and 3D calculations?

2D	3D	both	Remarks	Participants:
		x		[1], [5], [7], [13], [14], [15], [16], [21]
x			With limitations	[10]
			HP series 9000, 0.5 GB RAM, 8 GB hard disk, practically unlimited number of nodes and elements	[12]
		x	PC based packages	[18]
		x	Full and implicit	[21]

8.4 List the type of loading conditions you would consider in the model.

Elastic	Plastic	Creep	Remarks	Participants:
x	x	x	Constitutive model for plastic &creep Cyclic and monitoring loading	[1], [6], [8], [12], [16], [21] [10], [21] [14]
x	x		-	[7], [15]
x x	 x	x x	- Elastic-primary-secondary creep	[2], [11], [16] [13], [21]
	x		Damaging plastic	[18]

8.5 What restrictions do you have in choice of stress/strain and creep laws?

Participants	
:[1] :	in most cases it is the availability of materials data that restrict them
[6] :	Creep law: approximation of primary and secondary creep by firm multi parameter equation. These firm parameters have to be quantified on the basis of the actual creep law, which gives always a more or less satisfactory approximation
[10] :	Use a non-unified constitutive model which has primary and secondary creep law + cyclic/monotonic hardening/softening rules.
[11] :	FE package; ABAQUS standard + CMD model
[12] :	Any type of law (user subroutines)
[18] :	Few due to the FE package ; the package allow our laws or alternative descriptions (note : they have their own FE package)
[21] :	Limited by ABAQUS programmability and computing power – especially in 3D

8.6 Can you make available relevant solutions for a VAMAS TWA 25 Round Robin?

Yes	No	If yes, what will be provided	Participants:
	x		[1], [2]
	x	Results of flat specimens with central hole with interaction of creep and cyclic thermal fatigue are existing but they are not available for reasons of confidentiality.	[6]
x		Uncertain	[13]
x		Floppy disk and sheets	[15]
x		Some 2D specimen analyses for C(t) can be released	[16]
x		Substantial	[21]

8.7 References

Participants: [6] :	G. Sörgel, M. Raddatz: « Experimentally supported examination and development of creep-ratchetting stress analyses methods for plant components made of cast steel G-X 20 CrMoWVNbN 10 1 1. », Proc. of HIDA Conference, Saclay, Paris, 1998

9. Prediction of component behaviour

9.1 Do you have interest in component crack initiation and growth predictions?

Yes	No	Participants:
x		[1], [3], [4], [5], [6], [7], [8], [9], [10],[11], [12], [14], [15, [16], [17], [18], [21]
	x	[2],

9.2 What procedures, codes or in-house documents do you use to predict component failures?

Procedure	Remarks	Participants:
R5	-	[4], [5], [7], [8], [10], [12], [16], [17], [18], [21]
R6	-	[8], [10], [21]
NASCRAC	-	[1]
RNOD	For crack initiation (also under fatigue condition)	[3], [15]
BS 7910	-	[6], [21]
two criteria diagram	-	[6]
PD 6539 (BSI)	-	[7]
ASME	N-47	[7], [10]
A16	-	[14], [21]
RCC-MR	-	[10]
EFAM	-	[17]
in house code	-	[18]
SN curves	-	[18]
API 579	-	[18]

9.3 What input information do you use?

Input information	Participants:
δI, Initiation crack opening	[4], [9]
da/dt= f(C*)	[4], [5], [9], [7]
Reference stress	[5], [16], [9]
Minimum creep strain rate	[5], [9], [8], [21]
strain rate, primary, secondary, tertiary	[18], [9], [8], [21]
Damage	[18], [9], [21]
creep rupture strength	[5], 21]
Component geometry/effect geometry	[6], [16]
Service load- history	[6]
Fatigue endurance	[7]
Cyclic (da/dN) short and deep	[7]
C* data	[7], [9], [21]
K, K_{ic}	[8], [12]
σ_{ref}	[16], [9], [21]
σ_{net}	[8]
Hardening law/, Norton’s law	[8], [21], [14]
Poisson’s ratio/yield modulus/applied loads	[10]
Temperature	[12], [14], [16]
Defect scenario	[12]
Monotonic law	[14]
Cyclic law	[14]
Specified in R6	[18], [21]
Ramberg-Osgood, static and cyclic (E,A’, β)	[4]
Norton (B’, n) or Norton-Bailey (D’, n, p)	[4]
Creep rupture tu (T, σo)	[4]

9.4 How do you validate the calculations?

Validation method	Remarks	Participants:
Predict laboratory specimen results first	-	[1], [21]
Against benchmark test results	-	[4], [18], [9]
Sensitivity analysis	Material properties upper &lower bound, variation in service cycles	[7], [21]
Performed by experiments on features	-	[8]
Parallel alternative method	-	[10]
Using 2 codes or 2 methods	-	[12]
Validation of the R5 procedure	-	[16]
Plant experience	-	[16]
Numeric	-	[17]
Experimental test where possible	Tensile, creep temperature, component	[5], [21]

9.5 Are you involved or interested in probabilistic methods for life assessments?

Yes	No	Remarks	Participants:
x		Tentative in some cases	[6], [11], [12], [21], [18]

9.6 Can your experiences be shared for a VAMAS TWA 25 Round Robin?

Yes	No	Remarks	Participants:
x		-Teaching examples only Require customer clearance	[3], [6], [9], [15], [17], [21] [7], [8], [10]

9.7 References

<u>Participants</u>: [3] :	Yokobori T., Yokobori T., and Kuriyama T.: « Life of crack initiation, propagation, and final fracture under high-temperature creep, fatigue, and creep- fatigue multiplication conditions », Am. Soc. Test Materials STP 942, pages 236-256, 1988. Yokobori T., Yokobori T., Kuriyama T., and Kako T.: « Relative notch opening displacement concept for crack initiation in high temperature time dependent fracture », Advance in Fracture Research, pages 2181-2190, 1984. Yokobori T.: « High temperature creep, fatigue and creep-fatigue interaction in engineering materials », second international HIDA conference Keynote paper, 2000

10. Reporting procedures

10.1 What procedures, codes or in-house documents do you use to prepare a report on the test results?

Procedure	Remarks	Participants:
-	Provide all data that was collected from the test Software has report format	[1] [18]
In-house	-	[4], [10], [12] [11], [21]
Company operating procedure	-	[21]
DIN EN ISO/IEC 17025 DIN EN 45004	-	[6]
Tailor-Made report for client	-	[7]
R5	-	[8], [16]
R6	-	[8]
ASTM	-	[17]
EFAM	-	[17]

10.2 What do you regard as the minimum information that should be report?

Participants: [4]:	Material pedigree (e.g. to ECCC requirements) Test piece / component geometry details Details of control parameters (load, displacement and/or pressure) Record of response parameters (load, remote and local displacement/strain, crack length Post-test inspection results (damage/type, cracking mechanism and extent, hardness)
[7]:	Minimum required in order that an independent assessment may be made. Thus applies to all materials properties datas.
[8]:	Crack initiation time Evaluation of cavitation (Pre-post and intermediate metallography) Materials properties/σnet versus time Strain rate as function of stress/σy, σuts, K1/initial stress
[10]:	Material manufacture route, source and composition/prior treatment Specimen manufacturing methods and dimensions/post treatment Test methods Calibration records/raw data, PD, COD, load etc Smoothed/filtered data Analysis methods/analysed data Discussion/conclusions/recommendations
[12]:	Time to failure/failure criterion utilised Code utilised An estimate of the uncertainty
[14]:	Experimental device description and loading conditions Global parameters variation (i.e. load, displacement,) Crack growth if propagation test CMOA variation
[16]:	Geometry Material information (spec., heat treatment, properties) Defect details (location, shape, size) Loading conditions (temperature & stress history) Details of creep strain monitoring Details of crack size monitoring Results (creep strain vs. time, crack size vs. time
[17]:	As in ASTM
[18]:	Reference stress/material damage state Crack growth rate at surface and deep point/remnant life Sensitivity or probability of failure plots/numerous definition σref/tr, El, R/A, initial stress +Tap
[21]:	All details of testing procedure and data where possible Best fit from 40 points data as in an in house programme ‘ZRATE’ As in ASTM standard

11. List of PARTICIPANTS

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12. Additional related list of References

1. Ainsworth, R. A, (1999), editor R5: Assessment procedure for the high temperature response of structures, British Energy Generation Ltd. Procedure R5 Issue 2.
2. British Standards- 7910: (1999), Guide to methods of assessing the acceptability of flaws in fusion welded structures, BSI, London.
3. AFCEN (1995), RCC-MR, Appendix A16, AFCEN, Paris.
4. K. Nikbin, A unified European approach to high temperature defect assessment code and its incorporation in a Knowledge Base System, In Proc. High Temperature Defect Assessment Conference, HIDA2', Stuttgart, Oct 2000.
5. ASTM E 1457-98, (1998), Standard Test Method for Measurement of Creep Crack Growth Rates in Metals, ASTM Standards 03.01.
6. Schwalbe, K.H., Ainsworth, R.H., Saxena, A. and Yokobori, T., (1999), Recommendations for Modifications of ASTM E1457 to Include Creep-Brittle Materials, Engineering Fracture Mechanics, Vol. 62, pp123-142.
7. A.Fuji, M.Tabuchi, A.T.Yokobori,Jr., and T.Yokobori, (1999), Engineering Fract. Mechanics vol. 62, pp. 23-32.
8. Nikbin, K. M., Smith, D. J. and Webster, G. A., J Eng. Mat. and Tech.,(1986), ASME, 108, 186-191.
9. Saxena, A., "Evaluation of Crack Tip Parameters for Characterizing Crack Growth: Results of the ASTM Round-Robin Program", Materials at High Temperatures, (1992), Vol.10, pp 79-91.
10. Webster, G. A., And Ainsworth, R. A., High temperature component life assessment, (1994) Chapman & Hall,
11. Miller A. G., Int. J. of Press Vess. And Piping (1988), 32, p 197-327.
12. ASME Boiler and Pressure Vessel Code (1991), Case N-47 (29), Class 1 components in elevated temperature service, Section III, Division I, ASME, New York.
13. RCC-MR (1985) Technical Appendix A3, Section 1, Subsection Z, Materials design and construction rules for mechanical components of FBR nuclear test islands, AFCEN, Paris.
14. Webster, G. A., Role of residual stress in engineering application, Mat. Science Forum, (2000), Vols, 347-349, pp1-9.
15. V. Prunier, U. Gampe, K. Nikbin, 'High temperature crack growth in P91 steel feature components', Journal of Materials at High Temperature, 15(3/4) 159-166, 1998.
16. Shibli, B Al Abed, K Nikbin, 'Scatter bands in creep and fatigue crack growth rates in high temperature plant materials data', Journal of Materials at High Temperature, 15(3/4) 143-149, 1998
17. A Webster, K. Nikbin, M. R Chorlton, N.J.C. Cellard, M. Ober, 'A comparison of High temperature defect assessment methods' , Journal of Materials at High Temperature, 1998
18. K Nikbin, 'Comparison between crack growth in fracture mechanics specimens and feature component tests carried out in a low alloy steel', ASME Pressure Vessels and Piping June 1998
19. Tabuchi M., Kubo K. & Yagi K., "Effect of Specimen Size on Creep Crack Growth Rate using Ultra-Large CT Specimens for 1CrMoV Steel", Eng. Frac. Mech., 40, No.2, pp. 311-321, 1991.