The Impression Creep
Monkman Grant Relationship

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Scoop sampling and impression creep

On-site sampling is used to produce a 10x10x2.5mm or 8x8x2mm specimen to be impression creep tested at high temperature. Impression creep is a versatile testing method which can be extended to stepped stress/temperature tests on the same specimen.

SSAM2 Sampler (Rolls-Royce)
Photo: Paul Hutchinson (Wood)
Conversion of impression data to uniaxial rupture life

• The impression test does not produce a specimen failure. In order to make impression creep data useful for plant application, a method of converting impression creep strain data into the equivalent uniaxial rupture life is required.

• The first attempt at this utilised the Monkman Grant relationship between uniaxial minimum creep strain rate and rupture life in conventional uniaxial tests.

• The use of the conventional Monkman Grant relationship is valid provided:
  1. Impression creep strain rate and uniaxial minimum creep rate are interchangeable
  2. The correct Monkman Grant relationship is used
This approach was demonstrated using three different grade 91 casts:

• **Bar 257** – as-received, but relatively weak F91 forged bar with low N:Al ratio, intensively studied in a number of collaborations.

• **2328** – as-received normal P91 pipe.

• **RWE Simulated** – a different P91 pipe re-heat treated to produce an aberrant 100% Ferrite (ie completely non martensitic) microstructure.
Aberrant grade 91 Mis-heat treatment

• If, during the tempering (or PWHT) of P91, the temperature overshoots into the Austenite range for long enough to remove the Martensite, cooling back to the correct tempering temperature will not reform the Martensite.

• The structure will be Ferrite (much weaker) and this will be retained on final cooling to ambient.

• Such weak material, if it fails in service, will be likely to do so by axial splitting along the pipe and the probability of leak before break is poor.
Examples of normal and aberrant grade 91 microstructure (Electron microscope images)

Normal 100% Martensite (Typically 200-240HV)
*Image - Juan Sanchez-Hanton*

Aberrant 100% Ferrite (Typically 140-160HV)
*Image - Alex Bridges (Modified)*
Why is aberrant grade 91 of interest?

- In this presenter’s experience of 12 CCGT power stations with P91 piping systems in the UK, 5 have been found to have 100% Ferrite present.

- This situation is not confined to the UK.

- Although not every power station operator will have this problem, it is sufficiently widespread that all operators should be on the lookout for it and should be prepared to deal with it if encountered.
Predicted vs actual rupture life using conventional Monkman Grant

(Published in the 7th EPRI Advanced Materials Conference, 2013).

The Parker MG relationship was used: \( MCR = 0.1 \ t_f^{-1.16} \) - equation (1)

Rupture life predicted vs actual

Average strength relative to mean (using Cipolla 2005)
• MCR is measured by linear intercept over a time range corresponding to ~0.1-0.3 life.
• For higher ductility material there is a significant reduction in cross section at this point and a correspondingly higher stress.
Use of the Monkman Grant relationship

While the impression test does not produce a failure, rupture life can be estimated from the impression creep strain rate via the Monkman Grant relationship provided (a) the impression creep strain rate and the minimum creep strain rate in the corresponding uniaxial creep test are interchangeable and (b) the appropriate Monkman Grant relationship is used.

Unfortunately aberrant grade 91 presents problems for either requirement:

- Aberrant material is very ductile and strain rates diverge (effective stress is higher in fixed load uniaxial tests)
- Normal and aberrant grade 91 have different Monkman Grant relationships
Alternative Monkman Grant, relating Impression SR to the corresponding uniaxial rupture life (Schematic)
Impression Monkman Grant relationship

This is the relationship between the impression creep strain rate (ICR) and the corresponding uniaxial rupture life at the same stress and temperature. The first version of this relationship was derived from Bar 257 (martensitic) data using interpolated values of rupture life and measured ICR. (Impression tests carried out at Nottingham University for RWE).

\[ \text{ICR} = 0.004575 \ t_f^{-0.7391} \quad \text{- equation (2)} \]

Rupture life predicted vs actual
Impression Monkman Grant relationship

A second version of this relationship has been derived from “paired” values of measured rupture life and measured ICR for aberrant material. The two relationships are almost (but not quite) identical.

*(Impression tests carried out at Nottingham University for RWE and at Wood for a Centrica/SSE/Engie/RWE collaborative project)*

ICR = 0.004575 $t_f^{-0.7391}$ - equation (2)

ICR = 0.0057597 $t_f^{-0.7265}$ - equation (3)
Use of ImpMG to predict rupture life

Rupture life predicted from impression creep rate via the two Impression Monkman Grant Relationship relationships (using mean rupture life obtained from the Cipolla 2005 equation) compared to measured rupture life for four grade 91 materials (two 100% Martensite, two 100% Ferrite).

Via ICR = 0.004575 $t_f^{-0.7391}$ – equation (2)

Via ICR = 0.0057597 $t_f^{-0.7265}$ – equation (3)
Use of ImpMG to predict relative strength

Average creep strength predicted from impression creep rate via the two Impression Monkman Grant Relationship relationships (using mean rupture life obtained from the Cipolla 2005 equation) compared to measured average creep strength for four grade 91 materials (two 100% Martensite, two 100% Ferrite). The earlier Bar 257 based ImpMG remains valid as a general equation, giving slightly conservative rupture lives for aberrant material, while the more recent aberrant ImpMG is arguably more appropriate for aberrant material.

Via ICR = 0.004575 \( t_f^{-0.7391} \) – Eq. (2)

Via ICR = 0.0057597 \( t_f^{-0.7265} \) – Eq. (3)
Current grade 91 impression data

All grade 91 impression creep strain rates compared to predicted via the aberrant paired values ImpMG

100% Ferrite data only compared to predicted using both ImpMG relationships

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Example of an application to plant
Four bends were scoop sampled, three identified as 100% Ferrite and one identified as over-tempered Martensite by on-site replication. *(Work carried out by Wood for Scottish Power published in Brennan et al, ECCC Conference 2017).*

Impression creep strain rates measured compared to predicted

Impression rates converted to estimated creep rupture life
Extrapolation to service operation

At the station hot reheat operating conditions of 41MPa hoop stress and 562°C (measured over a representative 12kHrs operation) the aberrant strength encountered in this exercise (Mean-43%) would have a life of >1000kHrs.

At the hot reheat design conditions of 52MPa hoop stress and 595°C this drops to ~100kHrs. The weakest aberrant material encountered (Mean-50%) would have a life of ~40kHrs under these conditions.
Conclusions

• The Impression Monkman Grant relationship, links the impression creep strain rate to the uniaxial rupture life obtained at the same stress and temperature.

• This relationship can be used to predict rupture life from impression creep data obtained from small scale on-site scoop samples, providing a method of evaluating the creep strength of materials on plant and allowing decisions to be made about replacement or continued operation.

• It is particularly useful in the case of grade 91 in the aberrant 100% Ferrite condition encountered on plant, where the creep strength may be substantially lower than normal.