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Recent Design Improvements of Elevated Temperature Structural Design Guide for DFBR in Japan

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ABSTRACT

In Japan, DFBR Design Standard (DDS) consists of the Elevated Temperature Structural Design Guide (ETSDG) and the Material Strength. DDS (ETSDG) constitutes limits as follows, primary stress limits, strain limits (progressive deformation limits), creep-fatigue damage limits and buckling prevention. DDS usually adopts a design based on elastic analysis, in which inelastic behaviors of structures are estimated by simplified methods using stresses by elastic analysis. To design components reasonably, DDS applies inelastic analysis. Preparation of practical guidelines for inelastic analysis is in progress at the present time.

This paper presents the summary of recent improvements of DDS, for example, welded joint evaluation method, ratcheting evaluation method and other relative activities. In welded joint evaluation, a fatigue strength reduction factor is introduced and a creep damage factor is raised. In ratcheting evaluation, saturation effect is considered.

1. Contents of DDS documents in JFY 1998

In Japan, Demonstration Fast Breeder Reactor (DFBR) Design Standard (DDS) consists of the Elevated Temperature Structural Design Guidelines (ETSDG) and the Material Strength Standard for Type304SS, Type316SS, Type321SS, 316FR stainless steel, 21/4Cr-1Mo steel and Mod.9Cr-1Mo steel. DDS (ETSDG) constitutes limits as follows, primary stress limits, strain limits (progressive deformation limits), creep-fatigue damage limits, buckling prevention and some appendices shown in Fig.1.

DDS usually adopts a design based on elastic analysis, in which inelastic behaviors of structures are estimated by simplified methods using stresses by elastic analysis. To design components reasonably, DDS applies inelastic analysis. Preparation of practical guidelines for inelastic analysis is in progress at the present time.

2.Recent Developments

2.1 Ratcheting evaluation method

Eliminating over-flow systems of reactor vessel, thermal ratcheting produced by moves of the sodium surface level should be taken into account in addition to the conventional Bree type ratcheting.

Since elastic analysis route evaluation of ratcheting may be more complicated than straightforward inelastic analysis route evaluation. Benchmark analyses concerning ratchet strain evaluations have been performed in the Japan Society of Materials Science (JSMSS), employing thermally loaded cylinder tests in the previous papers and uniaxial specimen tests as analytical model.

2.2 Improvement of evaluation applied inelastic analysis

Most design standards have been developed based on elastic analysis. The standards take simplified estimation schemes to predict inelastic strain behavior from elastic analysis result. DDS employs a elastic follow-up factor "q" to predict total strain range in creep-fatigue evaluation. Most inelasitc analysis show that actual elastic follow-up factor "q=3" is too conservative for most cases. But there are many difficulties to inelastic analysis method for design because of uncertainty caused by different strain prediction for each constitive equation.

Some paper describes a trial use of so-called "partial inelastic analysis" route design where elastic follow-up factor and ratchet strain are evaluated by inelastic analysis based on simple classical constitutive equations and conventional elastic route design for DFBR. Validity of the "partial inelastic analysis" route design is evaluated by comparing the results with "fully inelasitc analysis" based on advanced constitutive equations.

More detailed explanations have been made in another related paper [8].

2.3 Improvement piping design procedure

Newly developed piping design procedures have been incorporated into DDS. The proposal eliminates the conventional Se limitation, where thermal expansion load was limited within shakedown region. A simplified inelastic analysis using elastic analysis with changing the stiffness of piping elements (elbows, etc) is used to predict plastic and creep behaviors. Ratcheting strains and local strain ranges in pipe components are estimated by formulae using the results of the simplified inelastic analyses. Experiments and large deformation inelastic analyses have been carried out for elbows and straight pipes to generate the formulae. Comparison of the piping behavior between the predictions and experiments is also introduced to validate the proposal.

2.4 Improvement core support structure design procedure

The basic design of the DFBR assumes that conditions to hold the core support structure at elevated temperatures to cause creep damage during its service life. In order to evaluate the strength of full penetrated T- and L- welded joints at elevated temperatures in conservative manner, fatigue and creep-fatigue tests at 600℃ are conducted. As a result, it was found that the relationship between the nominal strain range and the crack initiation life is presented by nearly the same trend curve, independent of the shape of the joint and test temperature. The study results gives background of fatigue strength reduction factor (Kf=5) for welded joints in DDS to estimate the fatigue life based on nominal and welded toe strain ranges.

More detailed explanations have been made in another related paper [14].

2.5 Creep-fatigue evaluation of 316FR stainless steel and Mod.9Cr-1Mo welded joints

From results of low-cycle fatigue, creep and creep-fatigue tests conducted for 316FR and Mod.9Cr-1Mo welded joint specimens, fatigue strength reduction of welded joint was evaluated considering strain concentration due to the difference in the cycle response of each portion in welded joint specimens. Strain concentration and failure were occurred in the base metal away from fusion line. These test results could be estimated by simple tri-metal model consisting of base metal, heat-affected zone (HAZ), and weld metal. Evaluation method of welded joints is shown in Appendix F on DDS. For example, tentative proposal for creep-fatigue evaluation of 316FR welded joints is shown in Table1.

More detailed explanations have been made in another related paper about 316FR welded joint [21] and Mod.9Cr-1Mo steel [22].

3. Future perspectives

(1) Methodologies necessary to perform design activities of the DFBR have already been developed. The emphasis of DDS development is moving toward promoting futher licensability of DDS methodologies and materials strength standards.
(2) Long-term creep (up to 100,000 hr) and creep-fatigue tests (up to 50,000 hr) are on going.
(3) Comparison works between European and Japanese codes are desired to continue, focusing especially on methods peculiar to DDS, e.g. piping design method and ratcheting evaluation.
(4) International benchmarks, taking up thermal transient tests, are desired to be made.
(5) More detailed descriptions on inelastic route design will be introduced in DDS.
(6) Modifications in stress classifications will be made to enable 3D stress analysis in design.

CONCLUDING REMARKS

The current status of DDS have been introduced, the elevated temperature structural design guide for the Demonstration Fast Breeder Reactor in Japan. DDS will introduce improved evaluation methods of limits of creep-fatigue damage of base metal and weldment, thermal ratcheting, piping design and support structure design procedure. DDS would be established by reflecting the results of R&D based on the future perspectives.

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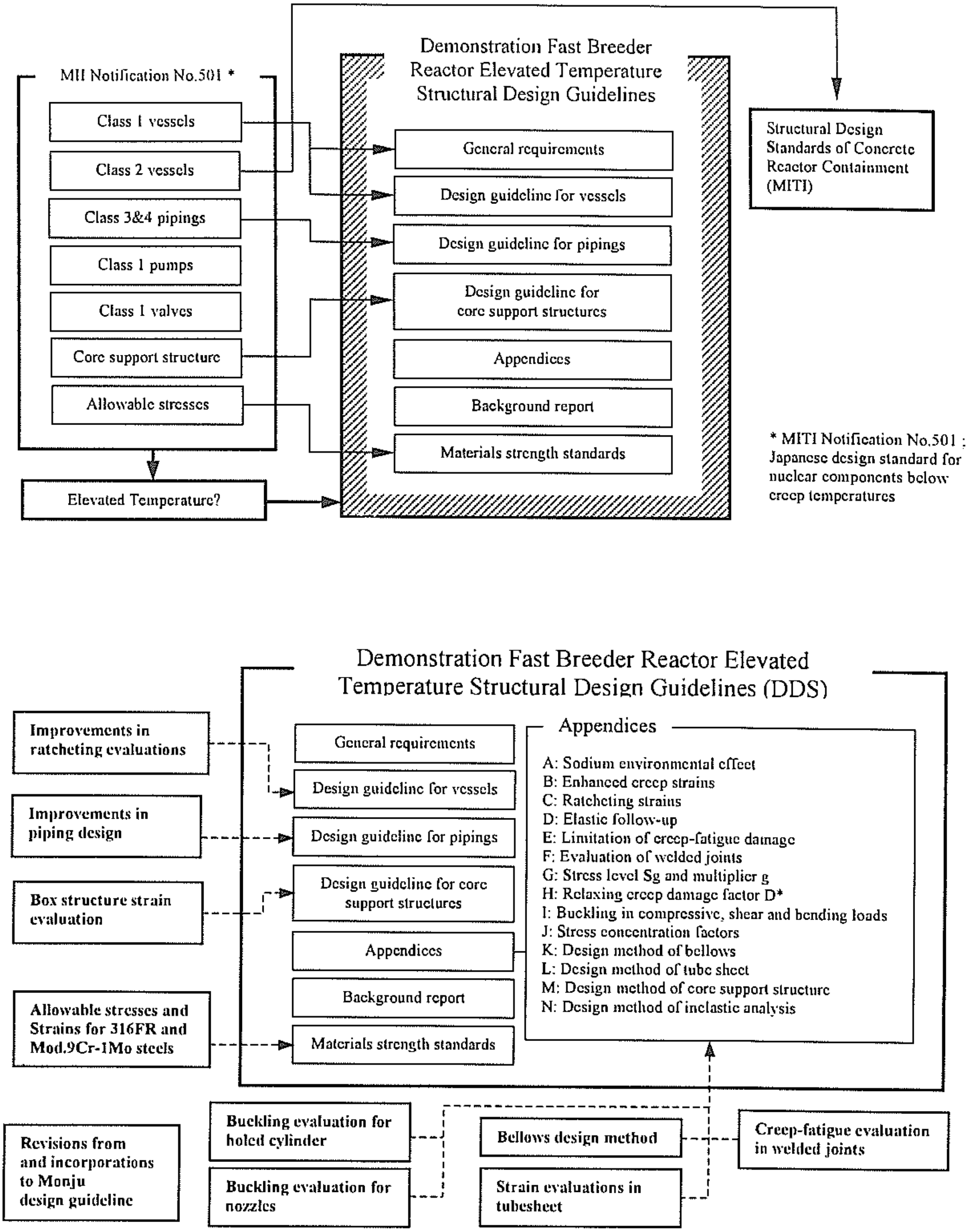

Fig.1 Contents of DDS documents

Table.1 Tentative proposal for creep-fatigue evaluation of 316FR welded joints

Fatigue strength	Fatigue strength reduction factor, Kf=1.4	Determined from the round bar specimen fatigue tests
Creep rupture strength	Equivalent to parent metal	Determined from the round bar specimen creep tests
Initial stresses for creep damage calculation	1.2 times of parent metal evaluation	Determined from the round bar specimen fatigue tests
Elastic follow-up factor	Equivalent to parent metal	Determined from the inelastic analysis of typical components
Creep damage multiplier	3.0 times of the estimated creep damage using the above increased initial stress	Slower creep strain rate of weldment may increase the creep damage