Structural Material Innovation for Advanced Blanket Design
--Current status and future prospect of ODS steels R&D--

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Abstract. Materials development is essential for realization of fusion DEMO reactor and beyond. High performance materials R&D has been conducted for the last several decades, and there have been made some remarkable technology innovations of fusion blanket structural material including first wall material. In this report, current status of blanket structural materials R&D is summarized and the impacts of some material innovations on blanket design are introduced.

1. Introduction

Among the several candidate blanket structural materials, oxide dispersion strengthened (ODS) steels, which have been produced by means of mechanical alloying, are considered to be promising for advanced nuclear systems with high thermal efficiency, because the ODS steels have high-strength at elevated temperatures and good resistance to corrosion and irradiation degradation. The operation temperature can be elevated up to 700 °C. Radiation tolerance was considerably improved by a dispersion of nano-scaled oxide particles.

There are several types of ODS steels with different Cr contents: (9-12)Cr-ODS ferritic/martensitic steels and (14-16)Cr-ODS ferritic steels with and without Al addition [1]. The former two groups of ODS steels were developed for application to sodium cooled fast reactors and fusion reactors, and the last group of ODS steels were for so-called Generation IV fission nuclear reactors. More recently, accident tolerant fuel R&D is progressing to apply high Cr/high Al ferritic ODS steels to fuel cladding of light water reactors because of “Fukushima Incident”. It has been considered that the replacement of Zirconium alloys cladding with high-performance ferritic steels cladding may retard the hydrogen generation at a severer accident (SA) of nuclear reactors, resulting in a large time lag up to hydrogen explosion.

2. Objectives

In this presentation, current status of ODS steels R&D is summarized and the impacts of some material innovations on the safety issue of nuclear technologies are addressed. Radiation tolerance mechanism of ODS ferritic steels is introduced in terms of trapping capacity for radiation defects caused by nano-scaled ultra-fine oxide particles dispersion. Furthermore, the recent experimental results on mechanical properties at elevated temperatures, aging effects, corrosion behavior in super critical pressurized water and liquid lead alloy eutectics and phase stability under ion-irradiation of ODS steels are shown to demonstrate that the ODS steels with nano-scaled oxide particles in high number density are promising for radiation tolerant nuclear material.

3. High Performances of ODS Steels

3.1. Strength at Elevated Temperatures

Fig. 1 shows the Larson-Miller diagram of the ODS steels with a value of 25 as the coefficient parameter to gather creep data measured between 600 and 900 °C. The data of the F/M steel, F82H, and SUS316L are also plotted in the figure for comparison. Although the data of the ODS steels are widely distributed in a band because the data was obtained from various sorts of ODS steels, it is clear that the creep stress of the ODS steels is much higher than those of F82H. Fig. 1 indicates that the creep strength of 200 MPa is available for ODS steels at 780 °C with 10,000 h of rapture time, while the corresponding test temperature and rapture time of F82H is 550 °C and 5,000 h, respectively.

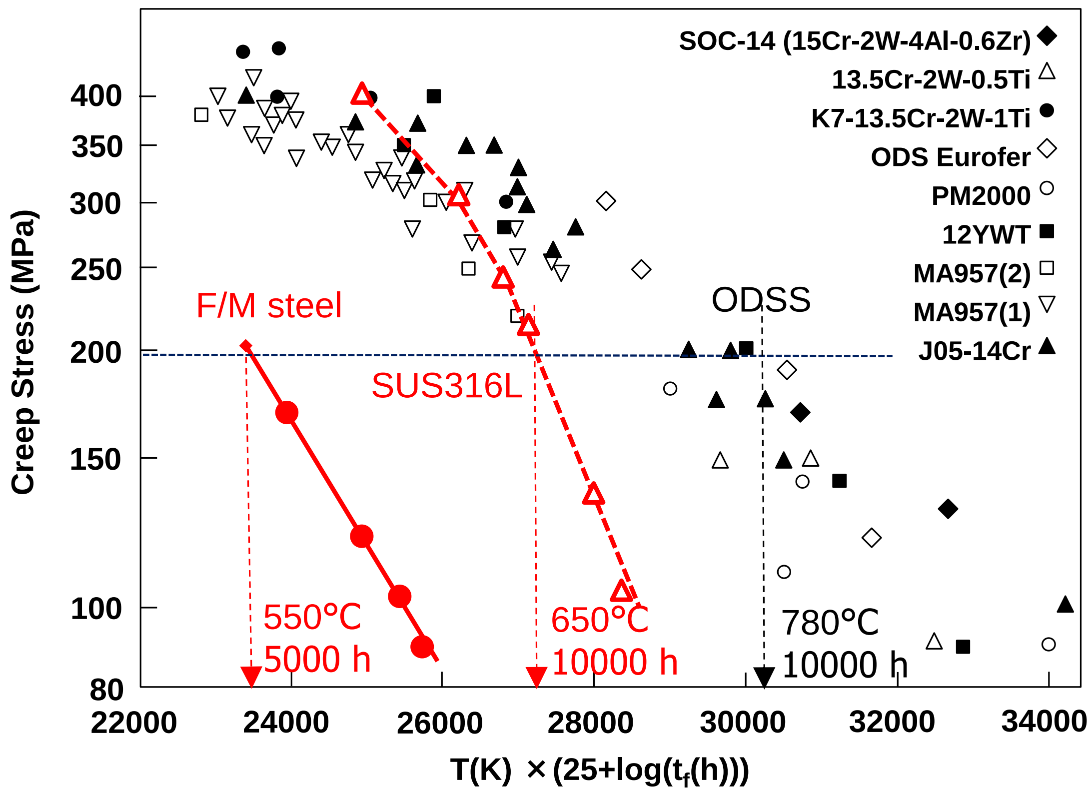

FIG. 1. Larson-Miller diagram of the ODS steels [1].

3.2. Swelling Resistance

As for radiation swelling, the ODS steel did show quite higher radiation tolerance than the other ferritic steels. Ferritic steels containing 9-12Cr are well known as swelling resistant steel in comparison to austenitic stainless steels. However, the swelling of ferritic steels abruptly increases over 130 dpa at a swelling rate of 0.2 %/dpa. Recent ion-irradiation experiments revealed that an ODS steel shows tremendous radiation tolerance indicating still very low swelling values (<2%) up to 500 dpa. The radiation tolerance is due to very fine grains as well as the high number density of oxide particles which provide a large number of trapping sites for vacancies and its clusters, consequently suppress the void swelling.

3.3. Joining/welding Technology

Thus, ODS steels possess rather high materials performance than F/M steels. However, it is difficult to fabricate massive products of ODS steel because of the limitation of the mechanical alloying process. It can be said that both F/M steels and ODS steels are used as a coupling component where ODS steels are used to face severer environment, and F/M steels are for production of huge structural container. Here, joining technology R&D is essential [2]. An example of the microstructure change by friction stir welding of ODS steel is shown in Fig. 2, indicating that the anisotropy in the microstructure of the ODS steel disappeared after the welding. Aging effects on and anisotropy in the mechanical properties are also addressed.

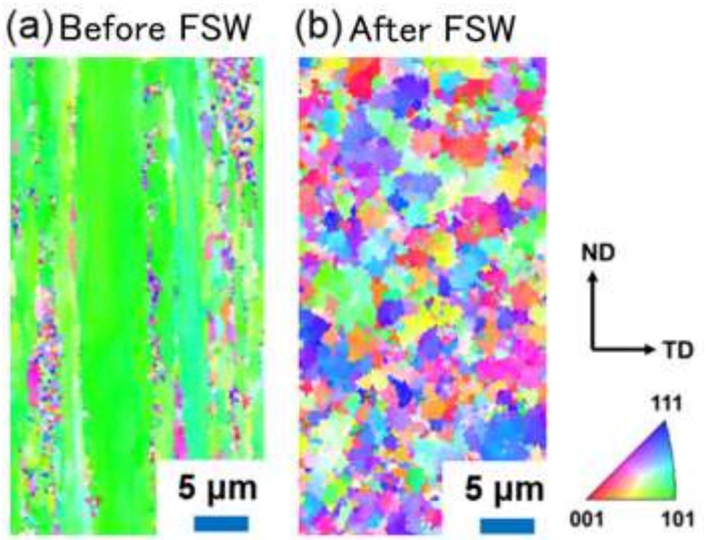

FIG. 2. The microstructure change in friction stir welded ODS steel.

4. Summary

It is recognized that early realization of the nuclear fusion energy is essential for acceleration of fusion reactor development. However, thermal efficiency of power plant is also important for the reduction of future energy consumption. For the progress in fusion science and technology, aiming high level of targets may push people forward to realization of fusion reactors.

References

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