ELSEVIER

Journal of Nuclear Materials 258–263 (1998) 1153–1157

journal of nuclear materials

Influence of tantalum and nitrogen contents, normalizing condition and TMCP process on the mechanical properties of low-activation 9Cr–2W–0.2V–Ta steels for fusion application

T. Hasegawa [a,*], Y. Tomita [a], A. Kohyama [b]

[a] *Steel Research Laboratories, Nippon Steel Corporation, 20-1 Shintomi, Futtsu, Chiba 293, Japan*
[b] *Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611, Japan*

Abstract

For clarifying the reason of good creep and mechanical properties and improving the mechanical properties of the low-activation 9Cr–2W–0.2V–Ta steels (JLF-1 steels), the influence of Ta, N contents, normalizing condition and thermo-mechanical controlled processes (TMCP) on the mechanical properties of the 9Cr–2W–0.2V–Ta steels was investigated in contrast with conventional 9Cr–1Mo–0.2V–Nb steels. The creep strength of the 9Cr–2W–0.2V–Ta steels increases with increasing amount of Ta and N contents irrespective of the manufacturing processes. An increase in the normalizing temperature or the application of TMCP processes can also improve creep strength. It is hypothesized that the increase in creep strength due to an increase in normalizing temperature or the application of TMCP processes is attributed to the uniform distribution of fine (Ta,V)(C,N) precipitates. Furthermore, the 9Cr–2W–0.2V–Ta steels demonstrate good toughness mainly due to a fine austenite grain size. The 9Cr–2W–0.2V–Ta steels have equivalent or better creep strength and better toughness compared with 9Cr–1Mo–0.2V–Nb steels.

1. Introduction

Ferritic and martensitic steels have better void swelling resistance, low thermal expansion coefficient, and high thermal conductivity compared with austenitic steels as structural materials for the first wall and blanket components of a fusion reactor. Irradiation-induced embrittlement and irradiation creep/relaxation have been recognized as the most important R&D issues for these materials.

Candidate low-activation ferritic and martensitic steels have been developed based on the conventional high-Cr heat-resistant steels with Mo replaced by W and Nb by Ta in order to reduce induced radioactivity. Several of the candidate steels such like the Japanese F82H and JLF-1, the US 9Cr–2WVTa steel, and the European EUROFER have similar alloy compositions [1]. Among the candidate steels, 9Cr–2W–0.2V–0.07Ta steels, developed in the Japanese Universities fusion program and designated as JLF-1 steels [2], have been considered the most promising because of their good irradiation-creep resistance and low irradiation embrittlement as well as good baseline properties.

In order to clarify the reason for the good creep properties and to improve the mechanical properties of the JLF-1 steels, the influences of Ta and N contents, normalizing conditions and the thermo-mechanical controlled processes (TMCP) [3] on the mechanical properties of the 9Cr–2W–0.2V–Ta steels were investigated in comparison with conventional heat-resistant steels.

2. Experimental procedure

All steels were melted in a vacuum-induction melting furnace. Ta and N contents were varied in 9Cr–2W–0.2V–Ta steels, and Nb and N contents were varied in 9Cr–1Mo–0.2V–Nb steels. The chemical compositions are listed in Table 1. The ingots were hot-rolled to

---

[*] Corresponding author.

0022-3115/98/$19.00 © 1998 Elsevier Science B.V. All rights reserved.
PII: S0022-3115(98)00138-X

Table 1
Chemical compositions of steels studied (mass%)

Steel	C	Si	Mn	P	S	Cr	V	W	Mo	Ta	Nb	N	Notes
W-1	0.10	0.24	0.48	0.002	0.003	8.87	0.19	1.9	–	0.084	–	0.0244	JLF-1
W-2	0.10	0.24	0.48	0.002	0.003	8.87	0.19	1.9	–	0.176	–	0.0245	
W-3	0.10	0.24	0.50	0.004	0.003	9.03	0.20	2.0	–	0.160	–	0.0564	
M-1	0.10	0.25	0.49	0.003	0.003	9.05	0.21	–	1.0	–	0.040	0.0259	
M-2	0.10	0.25	0.49	0.003	0.003	9.05	0.21	–	1.0	–	0.085	0.0262	
M-3	0.10	0.24	0.49	0.004	0.003	9.13	0.12	–	1.0	–	0.081	0.0535	

20-mm thick plates by applying two types of TMCP processes. One was a non-accelerated cooling type (Type A), and the other was controlled rolling followed by accelerated cooling (Type B). Using plates rolled by the "Type A" process, the influence of normalizing temperature was investigated. The plates were normalized by austenitizing for 3.6 ks at a constant temperature between 1333 and 1523 K.

Tempering (1033 K × 3.6 ks; air cooling) and additional heat treatment corresponding to post-weld heat treatment (PWHT; 1013 K × 30.2 ks/furnace cooling) were carried out for all TMCP plates and normalized plates.

Tensile tests, creep-rupture tests and Charpy impact tests were carried out for specimens oriented parallel to the transverse direction of the plates. Optical and electron metallography was also investigated.

3. Results and discussion

Figs. 1 and 2 show creep-rupture strength at 873 K for 3.6×10^8 s (600°C × 10^5 h) estimated from the relation between measured creep-rupture strength and Larson–Miller parameter for accelerated creep tests. The creep strength of the 9Cr–2W–0.2V–Ta steels and 9Cr–1Mo–0.2V–Nb steels tends to increase with increasing normalizing temperature or the application of TMCP processes. For most of the manufacturing conditions, the creep-rupture strength of the 9Cr–2W–0.2V–Ta steels is higher than that of the 9Cr–1Mo–0.2V–Nb steels for the same atomic percentage of Ta and Nb as well as for N. The creep strength increases with increasing Ta, Nb and N contents irrespective of manufacturing processes. It should be noted that increasing Ta contents from 0.08% to 0.16% is effective to improve creep-rupture strengths for the steels containing 0.025% of N. N is considered an element that leads to long term radioactivity. However, it may be too early to put the limit of N and it is still necessary to take into consideration in using N for optimization of the materials.

A good correlation between tensile strength (0.2% proof stress at 873 K) and creep rupture strength is indicated in Fig. 3. It demonstrates that a higher creep-rupture strength is attained for 9Cr–2W–0.2V–Ta steels at the same tensile strength. Thus, it is suggested that the

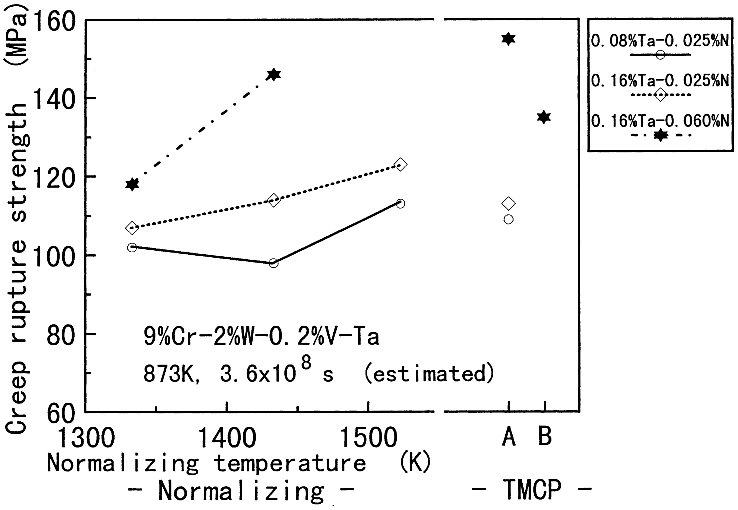

Fig. 1. Influence of manufacturing process on estimated creep-rupture strength of the 9Cr–2W–0.2V–Ta steels after tempering and PWHT.

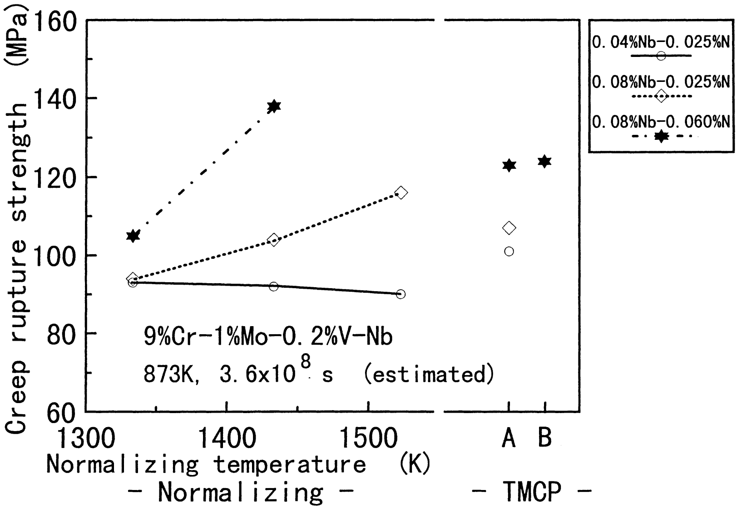

Fig. 2. Influence of manufacturing process on estimated creep-rupture strength of the 9Cr–1Mo–0.2V–Nb steels after tempering and PWHT.

metallurgical factors governing creep rupture strength for the 9Cr–2W–0.2V–Ta steels are not identical to those for the 9Cr–1Mo–0.2V–Nb steels.

Figs. 4 and 5 show absorbed energy at 273 K for a Charpy impact tests as a function of manufacturing processes. The increase in normalizing temperature causes deterioration in toughness regardless of chemical composition. Toughness can be improved by applying TMCP processes. Besides the creep-rupture strength, the toughness for the 9Cr–2W–0.2V–Ta steels is higher than that for the 9Cr–1Mo–0.2V–Nb steels for the same manufacturing processes and same atomic concentrations of Ta, Nb and N.

Metallographical analysis was carried out in order to clarify the metallurgical factors governing the creep strengths and toughness of the steels. Better toughness for the 9Cr–2W–0.2V–Ta steels compared with the 9Cr–1Mo–0.2V–Nb steels is mainly attributed to the finer prior austenite grain size due to the finer dispersion of Ta(C,N) in the 9Cr–2W–0.2V–Ta steels than that of Nb(C,N) in 9Cr–1Mo–0.2V–Nb steels. For example, the austenite grain diameter is 18 μm in the 9Cr–2W–0.16Ta–0.060N steel and 25 μm in the 9Cr–1Mo–0.08Nb–0.060N steel following normalization at 1333 K.

Tensile strength and creep-rupture strength are generally considered to be affected by the distribution of

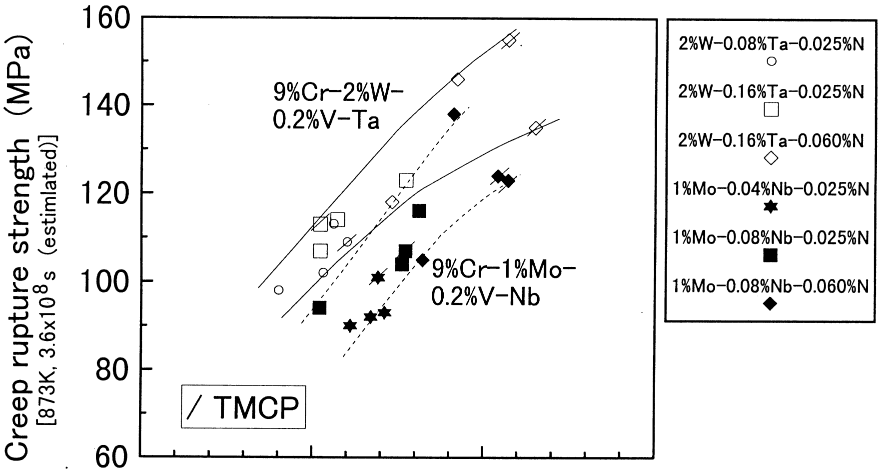

Fig. 3. Relation between tensile strength at 923 K and creep-rupture strength.

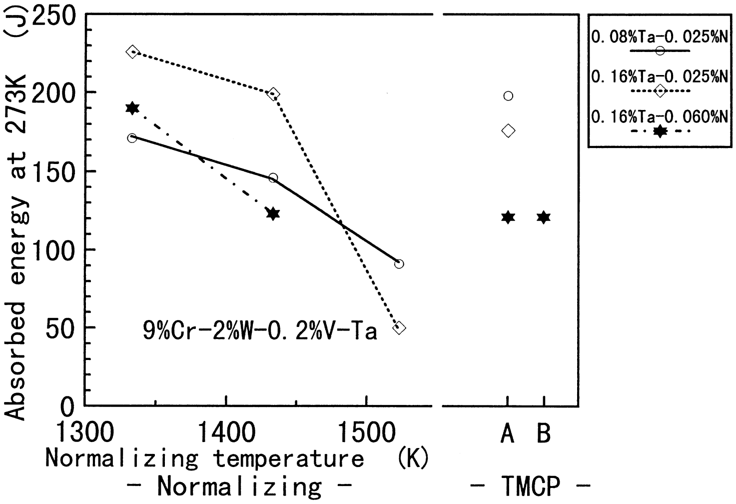

Fig. 4. Influence of manufacturing process on the toughness of the 9Cr–2W–0.2V–Ta steels after tempering and PWHT.

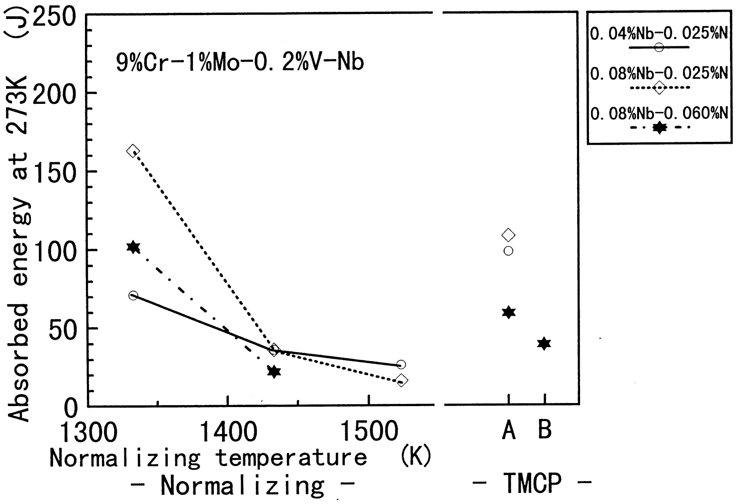

Fig. 5. Influence of manufacturing process on the toughness of the 9Cr–1Mo–0.2V–Nb steels after tempering and PWHT.

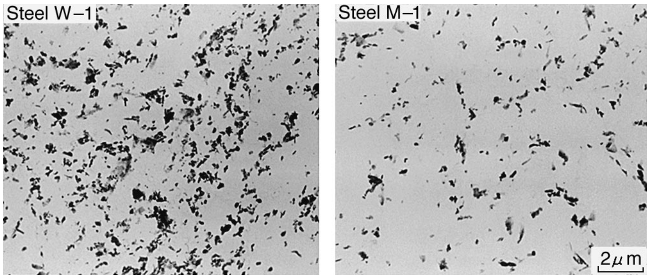

Fig. 6. $M_{23}C_6$ in the 9Cr–2W–0.2V–0.08Ta–0.025N steel (steel W-1) and the 9Cr–1Mo–0.2V–0.04Nb–0.025N steel (steel M-1).

$M_{23}C_6$ and complex carbo-nitride ((Ta,V)(C,N) or (Nb,V)(C,N)) [4]. Fig. 6 shows $M_{23}C_6$ distribution in the 9Cr–2W–0.08Ta–0.025N steel and the 9Cr–1Mo–0.04Nb–0.025N steel normalized at 1333 K. It is observed that $M_{23}C_6$ tends to be more finely and densely dispersed in the 9Cr–2W–0.08Ta–0.025N steel than in the 9Cr–1Mo–0.04Nb–0.025N steel. On the other hand, the increase of creep-rupture strength due to increasing normalizing temperature and applying TMCP is caused by refinement of (Ta,V)(C,N) and (Nb,V)(C,N) in all the steels tested.

4. Conclusions

1. The 9Cr–2W–0.2V–Ta steels (JLF-1 steels) have better creep strength and toughness than the 9Cr–1Mo–0.2V–Nb steels.
2. Improvement of the creep strength without deterioration in toughness is accomplished by applying TMCP process.
3. The creep strength can be related to the size and distribution of precipitates.

Acknowledgements

This work was partly supported by the Japan-USA collaborative program on Fusion Materials (JUPITER Program).

References

[1] A. Kohyama, A. Hishinuma, D.S. Gelles, R.L. Klueh, W. Dietz, K. Ehrlich, J. Nucl. Mater. 233–237 (1996) 138.

[2] A. Kohyama, Y. Kohno, K. Asakura, H. Kayanko, J. Nucl. Mater. 212–215 (1994) 684.

[3] Y. Tsuchida, K. Okamoto, Y. Tokunaga, ISIJ International 35 (1995) 309.

[4] K. Hamada, K. Tokuno, T. Takeda, Nucl. Eng. and Design 139 (1993) 277.