



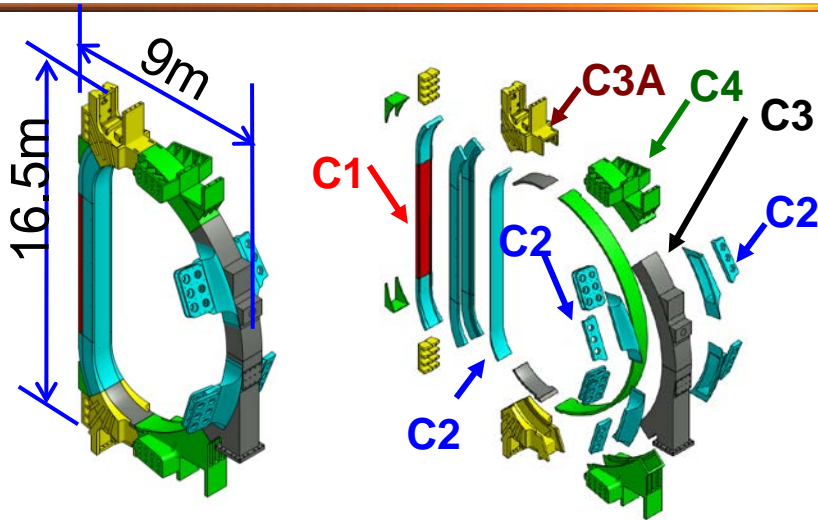
Evaluation of accuracy about prediction method of cryogenic tensile strength for austenitic stainless steels in ITER Toroidal Field Coil Structure procurement activity

Takeru SAKURAI, Masahide IGUCHI, Masatake NAKAHIRA, Toru SAITO,
Masaaki MORIMOTO, Takashi INAGAKI, Yunseok HONG, Kunihiro
MATSUI, Tsutomu HEMMI, Hideki KAJITANI, Norikiyo KOIZUMI
Japan Atomic Energy Agency (JAEA)

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Background



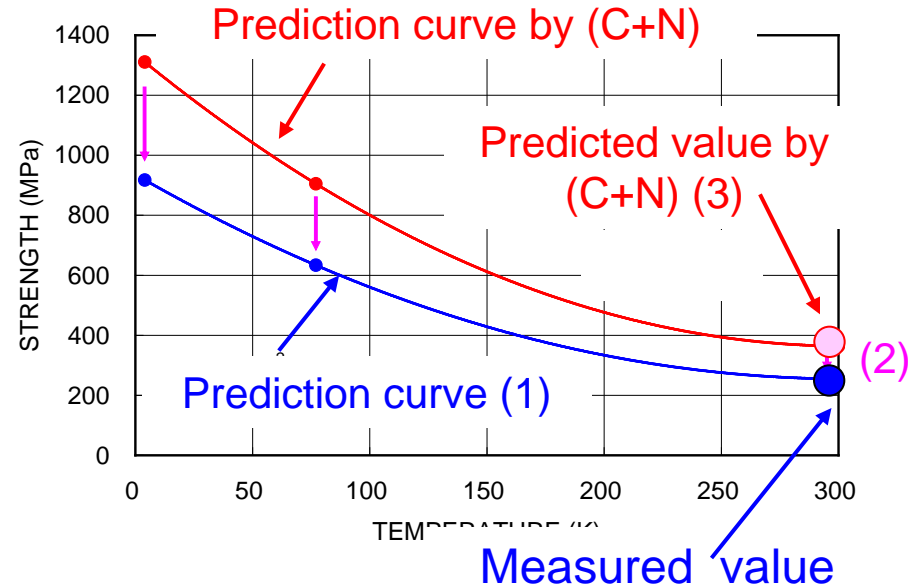
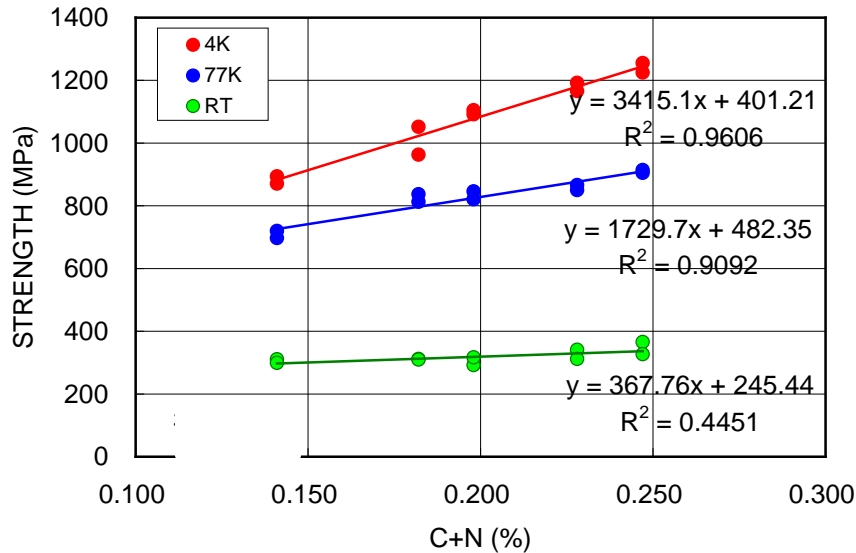
Class	YS @4K	Material
C1	>1000MPa	FMJJ1
C2	>900MPa	FM316LNH (C+N≥0.18%)
C3	>700MPa	FM316LNM (C+N≥0.13%)
C3A	>700MPa >280MPa @RT	FM316LNH (C+N≥0.18%)
C4	>500MPa	FM316LNL (C+N≥0.08%)

- Toroidal Field Coil Structure(TFCS) was required high tensile strength at liquid helium temperature(4K) to withstand huge magnetic force.
- JAEA has responsibility to procure 19sets TFCS. Large amount of **stainless steels** required for TFCS: 3,800tons.
- To establish efficient quality control method to avoid expensive and time consuming tests at 4K.
- Material for actual TFCS will be qualified to show correlation with mechanical properties of 4K(Prediction method).
- JAEA has also developed prediction curves to estimate 4K strengths not only qualification.

Prediction method

JSME code

1. Strengths of material is determined by only (C+N) contents.
2. Temperature dependence of strength is expressed by a quadratic curve.
3. Correction factor (ratio of measured strength and predicted one) does not depend on temperate.



$$ST_{296P} = (A_1(C+N) + A_2) \times 296^2 + (A_3(C+N) + A_4) \times 296 + (A_5(C+N) + A_6)$$

$$\alpha = (\text{Measured strength at RT}) / ST_{296P}$$

$$ST_P = \alpha [(A_1(C+N) + A_2)T^2 + (A_3(C+N) + A_4)T + (A_5(C+N) + A_6)]$$

Objective

1. *To estimate strength at 4K of actual materials.*

- Accuracy of applying this prediction method to three-dimensional complex shaped forgings and round bar forgings have not been confirmed.
- Tensile test at 4K these materials (B3 Wing, B4 Side Plate and A1 Side Plates) were conducted.

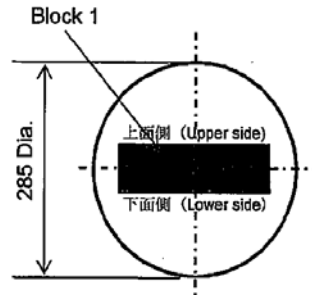
2. *To estimate the accuracy of prediction method when it is applied to actual shaped materials.*

This estimation was conducted by following step;

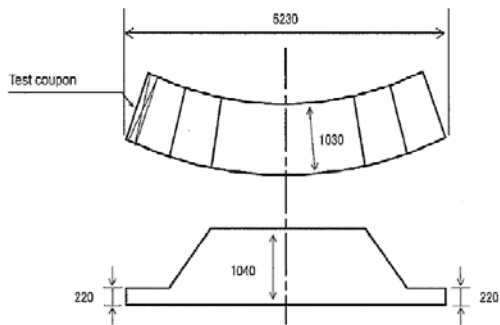
- ① Prediction of 4K strength using prediction method are conducted.
- ② 4K tests at same sampling positions are conducted.
- ③ Comparisons prediction and tested 4K results are conducted.
- ④ These estimations for round bar forgings and complex shape forgings were also conducted in order to compare these results.

Materials for test

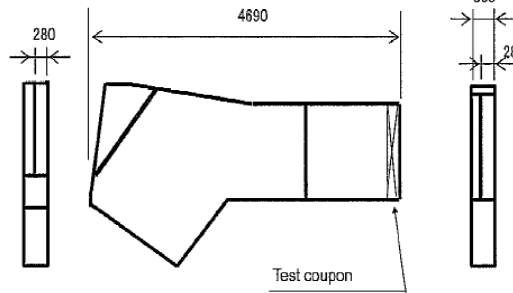
Round bar forgings



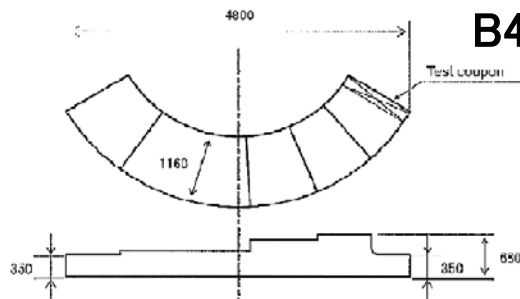
Complex shape forgings



B3 Wing



B4 Side Plate



A1 Side Plate

- Argon Oxygen Decarburization (AOD) process
- Solution treatment at 1050 degree C
- Oil hydraulic press or high speed radial forging machine
- Forging Ratio is around 7 -10 (depend on diameter)

- Vacuum Oxygen Decarburization (VOD) process
- solution treatment at 1010-1150 degree C
- Formed at similar configuration of final dimension by 8000ton press or/and 13000ton press.
- Forging Ratio is around 13.

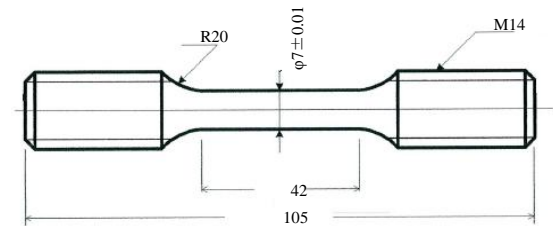
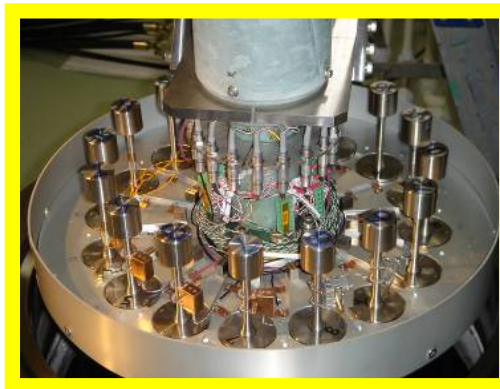
Cryogenic Mechanical Test Facility

Screw-driven Tensile test machine



JAEA has own cryogenic material test facilities for mechanical test of structural materials, which is mechanical screw-driven machine for 4K tensile test.

<Following Standard>
The Japanese Industrial Standards
JIS Z 2277 for 4K test.
JIS Z 2241 for RT test.



Turret disk :
16 specimens

Results of evaluation (Round bar)

Material name	Measured at 4K		C+N contents [mass%]	Measured at RT		Predicted 4K value		Accuracy of Prediction from Measured	
	YS [MPa]	UTS [MPa]		YS [MPa]	UTS [MPa]	YS [MPa]	UTS [MPa]	Accuracy (4K YS) [%]	Accuracy (4K UTS) [%]
410-1T-1	1000	1642	0.225	298	657	1068	1619	6.8	-1.4
410-1T-2	959	1652						11.4	-2.0
410-1T-3	943	1661						13.3	-2.5
410-1L-1	1056	1665	0.225	323	659	1158	1624	9.7	-2.4
410-1L-2	1049	1681						10.3	-3.4
285-2L-1	948	1692	0.208	306	664	1062	1646	12.1	-2.7
285-2L-2	966	1685						9.9	-2.3
190-1T	1088	1694	0.213	321	664	1125	1643	3.4	-3.0
190-2T	963	1685	0.226	309	665	1108	1639	15.0	-2.7
Average	997	1673	0.219	311	662	1003	1635	10.2	-2.5

- All minimum YS at RT and 4K satisfied ITER requirement (>900MPa)
- The accuracy for round bar forgings was estimated about **10.2%** (4K YS), **2.5%** (4K UTS)



Results of evaluation (Complex shape)

Material name	Measured at 4K		C+N contents [mass%]	Measured at RT		Predicted 4K value		Accuracy of Prediction from Measured	
	YS [MPa]	UTS [MPa]		YS [MPa]	UTS [MPa]	YS [MPa]	UTS [MPa]	Accuracy (4K YS) [%]	Accuracy (4K UTS) [%]
B3 Wing-1T	1078	1616	0.223	294	644	1050	1588	-2.7	-1.8
B3 Wing-2T	1081	1627	0.228	303	653	1093	1607	1.1	-1.2
B4 side plate-1T	1082	1626	0.222	308	661	1096	1631	1.3	0.3
B4 side plate-2T	1097	1647	0.229	327	676	1181	1663	7.7	0.9
A1 side plate-1T	1063	1642	0.213	294	648	1032	1604	-2.9	-2.3
A1 side plate-2T	1039	1631	0.231	304	657	1102	1615	6.1	-1.0
Average	1073	1632	0.224	305	656	1091	1617	1.8	-0.8

- All minimum YS at RT and 4K satisfied ITER requirement (>900MPa)
- The accuracy for complex shape forgings was estimated about **1.8%** (4K YS), **-0.8%** (4K UTS).

Discussion

- The chemical component and tensile RT YS of complex shape and round bar were almost same.
→ There should be no difference at predicted value between complex shape and round bar.



- However, measured 4K YS value of complex shape is 76MPa higher than round bar's one.
→ It is assumed that less accuracy caused of manufacturing process. Manufacturing round bar forging tend to less Forging Ratio than other forgings to make round form.



To more improve accuracy, a coefficient calculated for each manufacturing conditions (form, process) .

Conclusion

Accuracy of prediction method developed by JAEA, which predicts strengths at 4K from strengths at RT and C+N content of products, has been estimated. The following conclusions are obtained in this study.

- (1) The accuracy for round bar forgings was estimated about 10.2% (4K YS), 2.5% (4K UTS), and the accuracy for complex shape forgings was estimated 1.8 % (4K YS), -0.8% (4K UTS).
- (2) Measured C+N and RT YS of complex shape and round bar were not so different. Accuracy of 4K YS for round bar is less than complex shape's one, it is assumed that less accuracy caused of manufacturing process.
- (3) Prediction method can presume the tendency of tensile strength. A coefficient calculated for each manufacturing conditions (form, process), it can also be predicted with sufficient accuracy by taking in the coefficient to prediction relation.

Thank you for your attention