ORNL/M-3777

Proceedings of the IEA Working Group Meeting on Ferritic/Martensitic Steels

Sun Valley, Idaho, USA
June 24, 1994

Prepared by: R. L. Klueh

IEA WORKING GROUP - TASK ANNEX II

Implementing Agreement
for a program of research
and development on fusion materials

Oak Ridge National Laboratory
Oak Ridge, Tennessee, USA

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*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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IEA WORKING GROUP MEETING ON FERRITIC STEELS
SUN VALLEY, IDAHO

Friday, June 24, 1994 (8:15 a.m. - 4:00 p.m.)
Sun Valley Lodge, Ram Bar Room

Chairman: R. L. Klueh

A. Introduction

8:15 a.m. Opening remarks

B. Steels for Test Program

8:30 a.m. Information on 5-ton heat -- A. Hishinuma

Information on other heats -- A. Kohyama

C. Test Program Proposals

9:00 a.m. European Union proposed test program -- D. R. Harries

10:00 a.m. Japan proposed test program -- A. Hishinuma

11:00 a.m. U.S. proposed test program -- R. G. Odette

12:00 p.m. General Discussion

12:30 p.m. Lunch

D. Development of a Coordinated Test Plan

1:30 p.m. Discussion and formulation of coordinated test programs

2:30 p.m. Agreements -- schedule and future coordination

4:00 p.m. Adjourn

REPORT OF THE IEA WORKING GROUP MEETING ON FERRITIC/MARTENSITIC STEELS

Sun Valley, Idaho, June 24, 1994

Executive Summary

An IEA working group consisting of researchers from Japan, the European Union, and the United States, met at Sun Valley, Idaho, USA, June 24, 1994, to plan a collaborative test program on reduced-activation ferritic/martensitic steels for fusion applications. A 5-ton, a 1-ton, and three 150 kg heats of reduced-activation martensitic steels have been melted and processed to plates in Japan. This material is presently being distributed to the three parties that will participate in the test program. At the meeting, a collaborative program was outlined, but the details still need to be finalized. A meeting is planned for February 1995 in the United States to complete the planning for the test program.

Background

An international collaborative test program on reduced-activation ferritic/martensitic steels for fusion is in progress under the auspices of the International Energy Agency (IEA) Executive Committee for the Implementing Agreement on Fusion Materials. This program grew out of an IEA Workshop on Ferritic/Martensitic Steels in Tokyo, October 26-28, 1992. At the workshop, the Japanese delegation offered to purchase two large heats of reduced-activation steel that would be tested in the Japanese, European Union (EU), and U.S. programs. The Japanese delegation proposed that the compositions for the steels be similar to the Japanese F82H steel, an 8Cr-2WVTaB steel developed by the Japan Atomic Energy Research Institute (JAERI), and to the JLF-1 steel, a 9Cr-2WVTa steel developed in the Japanese Universities fusion program under Monbusho. The objective of the combined test program on the steels is a determination of the feasibility of using ferritic/martensitic steels for fusion by developing a comprehensive data base on representative reduced-activation steels.

At a working group meeting at Oak Ridge, May 20-21, 1993, specifications for the first IEA steel, a modified F82H composition, were developed, and a tentative test program for this steel was identified. At this meeting, it was tentatively decided that instead of obtaining a large heat of the JLF-1 composition as the second heat, several smaller heats would be obtained to study the effect of elemental variations on properties. The Oak Ridge meeting was followed by a working group meeting in Stresa, Italy, September 29, 1993, where details on processing the first IEA reduced-activation steel, a 5-ton heat of a modified F82H composition, were finalized. At Stresa, Prof. Kohyama reported that a second large IEA heat (1 ton) would be produced with the JLF-1 composition. Three smaller (150 kg) heats with boron and manganese variations would also be obtained.

A 5-ton heat of nominally 8Cr-2W-0.2V-0.04Ta-0.1C steel has been produced and processed into plate material. Plates are presently being distributed to the participating parties.

Objective of Meeting

Representatives from the fusion materials programs in the European Union (10), Japan (4), and the United States (4) participated in the IEA Working Group Meeting on Ferritic Steels for Fusion at Sun Valley, Idaho, June 24, 1994. The meeting was a follow up to the Stresa meeting. In Stresa it was agreed that the objective of the Sun Valley meeting would be the development of a coordinated program and task-sharing plan for testing the 5-ton IEA heat of reduced-activation ferritic steel then being processed in Japan. It was also agreed that the Japanese, the EU, and the U.S. delegations would prepare a summary proposal to inform each other of the tasks they proposed to carry out on the IEA heat of steel. These proposals were subsequently forwarded by each of the parties to the other parties at the beginning of 1994.

Other objectives for the Sun Valley meeting included: (1) a report on the 5-ton heat of steel melted and processed in Japan that is now ready for testing, and (2) a report on the other heats of reduced-activation steel being produced in Japan under the MONBUSHO program.

This report summarizes the Working Group Meeting. The first part presents an overview of the proceedings, the conclusions, recommendations, and a list of action items. Copies of handouts of the viewgraphs used for the presentations are appended to the summary. Working Group members who participated in the meeting and the meeting agenda are shown in the front of this report.

Steels for Test Program

Dr. A. Hishinuma of JAERI reported on the procurement of the IEA 5-ton heat of reduced-activation martensitic steel, a modification of the Japanese F82H composition. This heat was melted, cast, and processed into 7.5- and 15-mm plates by NKK Corporation. The chemical composition of the plate material fell within the composition specifications that were developed at the Working Group meeting in Oak Ridge. NKK normalized and tempered the steel: the heat treatment consisted of a 38 min austenitization treatment at 1040°C and a tempering treatment of 1 h at 750°C. After the heat treatment, the steel microstructure was entirely tempered martensite (no delta-ferrite), with a prior austenite grain size of about 100 μm. Details on the chemical composition and the melting and processing procedures are shown in Dr. Hishinuma's handout. Quantities of 7.5 x 320 x 420 mm and 15 x 320 x 420 mm plates have been shipped to Europe and the United States according to the requests received by Hishinuma.

In the original plan for the IEA 5-ton heat, 25-mm-thick plates and welds were also scheduled to be produced. However, because of the needs of the participants for 7.5- and 15-mm plate, it was decided that another heat would be required to obtain the 25-mm plates. A second 5-ton heat has been ordered, and plates are expected to be available in September, 1994.

Dr. Hishinuma reported that welds for the IEA collaboration will be made by Kobe Steel Ltd. on 15-mm plates obtained from the second 5-ton heat. Both EB and TIG welds will be made. Specifications for weld filler metal will be developed by the Japanese and circulated to all members of the IEA collaboration by August 1, 1994. Filler metal composition, welding conditions, and post-weld heat treatment procedures used previously by JAERI, Kobe Steel, and NKK for F82H have been published (Journal of Nuclear Materials vol. 179-181, p. 693, 1991); a copy of that publication is attached to Hishinuma's handout. Dr. Hishinuma is to be informed about the length of weld material required by each research program by September 1, 1994.

In the discussion that followed Hishinuma's presentation, concern was expressed that more details on the melting, casting, and processing procedures should be obtained from NKK so that future heats can be processed in accordance with this heat or that future changes in the procedure can be evaluated. Dr. Hishinuma agreed to obtain this information and supply it to the other parties.

Professor A. Kohyama of the University of Tokyo reported on the additional heats of steel that are being obtained by Monbusho/Japan for use in the IEA program. Nippon Steel Corporation produced a 1-ton heat with the JLF-1 composition, a nominal 9Cr-2W-0.2V-0.08Ta-0.1C steel. Plates 250 mm by 500 mm were produced in 7- and 15-mm thicknesses. Details on the melting, casting, and processing, along with the chemical composition, information on ambient and 500°C tensile properties, and 600°C creep-rupture strengths are given in Kohyama's attached handout material.

In addition to the 1-ton heat, three 150 kg heats are to be obtained with the same chemical composition as the 1-ton heat, except that one will contain 20 ppm B (compared to 2 ppm B for the 1-ton heat), one will contain 1% Mn, and one will contain 2% Mn (compared to 0.45% Mn for the 1-ton heat). These will only be available in 7-mm thick plate.

For future reference, Kohyama agreed to obtain further details from Nippon Steel on the processing. The plate is in the normalized-and-tempered condition. Normalization was: 1050°C/1h/AC; tempering was 780°C/1h/AC. Although it has not been finalized how much plate can be provided to the collaborative program, the U.S. and EU programs can request material from Prof. Kohyama.

Test Program Proposals

The proposed test programs of the EU, Japan, and the U.S. delegations were presented by Drs. D. R. Harries, A. Hishinuma, and G. R. Odette, respectively. An outline for each of these programs had previously been submitted to the other members of the collaboration. Table 1 is a summary of the proposals. It indicates that a wide-ranging program for testing both unirradiated and irradiated specimens has been proposed by each party.

In the discussion that followed the presentations, the Working Group attempted to assess whether the three proposals constituted a comprehensive program that minimized redundancy while maximizing the use of available

Table 1. Summary of Proposed Studies on Modified F82H and JLF-1 Steels

1.	**Unirradiated Studies**	Japan	EC	USA
(a)	Metallurgical and mechanical characterization	√	√	√
(b)	Thermal stabilities of steels [and welds]	√	√	√
(c)	Composition optimization	√	[√]	√
(d)	Dynamic and static fracture toughness tests	√	√	√
(e)	Micromechanics of fracture			√
(f)	Size effects, crack geometry effects, advanced fracture mechanics	√	[√]	√
(g)	Low-cycle fatigue and creep-fatigue		√	√
(h)	Fatigue crack growth	√	√	√
(i)	Thermo-mechanical, uni-axial, and bi-axial thermal fatigue		√	
(j)	Hydrogen embrittlement studies of steels and welds	√	√	
(k)	Welding technologies and susceptibility to weld cracking	√	[√]	
(l)	Environmental effects:			
	(i) Compatibility with Li and He			√
	(ii) Aqueous corrosion & SCC		√	√
	(iii) Vacuum property	√		
	(iv) Magnet mechanical properties	√		
(m)	Physical properties	√		

2.	**Irradiation Studies**	Japan	EC	USA
(a)	Charged particle irradiation effects	√	√	
(b)	Mixed spectrum reactor irradiations of steels and welds	[?]	√*	√**
	Tensile	√	√	√
	Charpy and fracture toughness	√	√	√
	Creep-rupture	√	√	
	Low-cycle fatigue		√	√
	Fatigue crack growth		√	
	Irradiation creep			√
	Swelling	√	[√]	√
	Microstructural evolution	√	√	√
	Helium effects	√		√
	Hydrogen embrittlement	√		
(c)	Fast reactor irradiations of steels and welds [properties as for (b)]	[?]	[√]†	√††
(d)	Mechanisms of radiation hardening and embrittlement [microstructure-hardening-fracture correlation]		√	√

*HFR: 200 to 400°C
**HFIR: 50 to 400°C
†PHENIX?: 300 to 400°C; 380 to 400°C
††EBR II?: >370°C

resources to achieve the program objective in the shortest time possible. Several things prevented such an assessment at the present meeting. In particular, more detailed information on each program would be needed before such an evaluation could be undertaken. Also, both the EU and the U.S. ferritic\martensitic steel programs are presently being reviewed, and the outline of their overall programs should be clearer later in the year.

Although it was recognized that the detailed assessment of the programs would have to be delayed, it was concluded that preliminary work on the steels could proceed. Of critical importance for the program to ultimately succeed is the availability of irradiation facilities. It would be most useful if any scheduled irradiation experiments could include appropriate specimens of the new heat. To aid this possibility, each party was asked to communicate to the other two parties their plans for near-term radiation experiments.

In order to be able to assess how the three individual programs fit together and ultimately tailor them to assure an efficient and comprehensive program to achieve the objectives of the collaboration, a set of tasks was set for the individual parties. First, each party will develop and circulate detailed plans for each of their proposed tasks outlined in Table 1. These plans will then be circulated to the other two parties for study and comment. This is to occur by November 1, 1994. Comments by each of the parties on the other two plans will be returned to the originating party by January 1, 1995. In February, 1995 (exact date to be determined), a working group meeting will be convened in the U.S. to agree on a combined matrix that will contain the outline for a program that will ultimately determine the feasibility of reduced-activation ferritic/martensitic steels for fusion.

Action Items

The following summarizes the action items developed during the meeting that are required to complete the evaluation of the combined program:

1. Communicate radiation schedules -- August - October.

2. Exchange detailed program plans -- November 1, 1994.

3. Exchange comments on program plans -- January 15, 1995.

4. Working Group meeting to finalize the combined program -- February 1995 (exact date and location to be determined).

Other action items that are required include:

5. Inform Professor Kohyama on needs of 1-ton heat -- as required.

6. Dr. Hishinuma will propose weld specifications and circulate the proposal -- August 1, 1994.

7. Dr. Hishinuma and Prof. Kohyama will obtain details on the melting, casting, and processing of the IEA 5-ton and 1-ton heats of reduced-activation steel, respectively, and circulate this information to other parties -- when information is obtained.

8. Communicate to Dr. Hishinuma the program needs for weld material -- September 1, 1994.

9. Communicate to Dr. Hishinuma the program needs for 25-mm plate -- September 1, 1994.

Presentation on Steels for Test Program

Information on five-ton heat

by

A. Hishinuma
JAERI

IEA Modified F82H Steel

Proposed specification of IEA heat
IEA workshop, May 20-21, 1993, Oak Ridge, USA
IEA workshop, September 29,1993, Stresa, Italy

Compositions(Revision 3, September 30, 1993)

Elements	Compositions, wt.%	
	Typical	Range
Cr	8.0	7.5 - 8.5
C	0.10	0.08 - 0.12
Mn	0.10	0.05 - 0.20
P	0.005	<0.01
S	0.002	<0.01
V	0.20	0.15 - 0.25
B	0.0003	<0.001
N	0.005	<0.02
W	2.0	1.8 - 2.2
Ta	0.04	0.01 - 0.06
Si	0.10	0.05 - 0.20
Cu	0.01	Lap*.<0.05
Ni	0.03	Lap.<0.10
Mo	0.001	Lap.<0.05
Ti	0.005	0.004 - 0.012
Nb	0.00005	Lap.<0.0002
Sol.Al	0.01	Lap.< 0.1
Fe	Bal	Bal
Co	0.005	Lap.<0.01
Ag	0.002	Lap.<0.05
Sn	0.001	Lap.<0.004
As	0.002	Lap.<0.005
Sb	0.0005	Lap.<0.004
O	0.005	Lap.<0.01

* Low as possible

Other elements needed:Tb, Ho, Zr, Bi, Eu

Data sheets of IEA modified F82H

A. HISHINUMA (JAERI)
Y. TAKAGI(JAERI/NKK)

IEA Group Meeting on Ferritic Steels
June 24, 1994
Sun Valley, Idaho

F82H fabrication data

Melting	5 ton VIF	
Casting	ingot case size	top 350 x 1410, bottom 250 x 1350 height 2000 mm
Blooming	Temp. slab size	1250℃ 115t x 1310 x 3820 mm
Grinding	slab size	107t x 1310 x 3820 mm
Slab cutting	powder cutting slab size	 107t x 1310 x 2000 mm 107t x 1310 x 1650 mm
Rolling	Temp. machine	1250℃ reversible rolling mill
Normalizing	Temp. time	1040℃ 7.5t 37 min 15t 38 min
Tempering	Temp. time	750℃ 7.5t , 15t 60 min
Plate cutting	plasma cutting plate size	 7.5t x 1000 x 3000 mm 15t x 1000 x 3000 mm

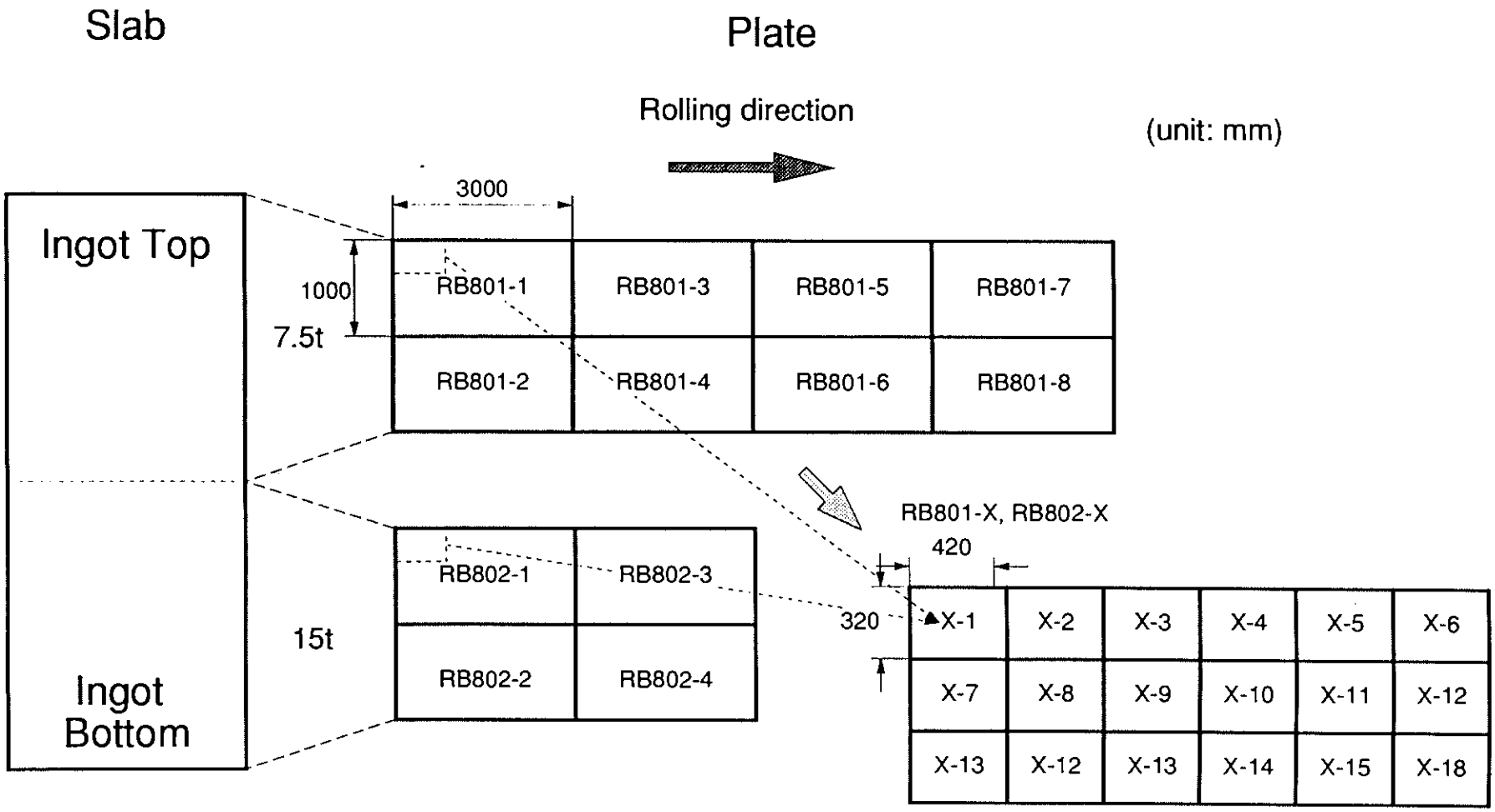


Fig. Plate position

Table Chemical composition (wt%)

Heat No.	Roll No.		C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	B	T. N	Sol. Al	Co	Ti	Ta	W
9741		Ladle	0.09	0.11	0.16	0.002	0.002	<0.01	0.02	7.66	<0.01	0.16	<0.01	0.0002	0.005	0.001	<0.01	0.01	0.02	2.00
9741	RB801-1 7.5t ingot top	check	0.09	0.11	0.16	0.002	0.002	0.01	0.02	7.70	0.003	0.16	0.0001	0.0002	0.006	0.003	0.005	0.01	0.02	1.94
9741	RB801-8 7.5t ingot middle	check	0.09	0.11	0.16	0.002	0.001	0.01	0.02	7.64	0.003	0.16	0.0001	0.0002	0.008	0.003	0.005	0.01	0.02	1.97
9741	RB802-1 15t ingot middle	check	0.09	0.11	0.16	0.002	0.002	0.01	0.02	7.71	0.003	0.16	0.0001	0.0002	0.006	0.003	0.005	0.01	0.02	1.95
9741	RB802-4 15t ingot bottom	check	0.09	0.11	0.16	0.002	0.002	0.01	0.02	7.70	0.003	0.16	0.0001	0.0002	0.008	0.003	0.005	0.01	0.02	1.95

Ag, Sn, As, Sb, O, Tb, Ho, Zr, Bi, Eu : under evaluating

Table Tensile test result

Heat No.	Roll No.	Ingot position	RT			500℃		
			YS(MPa)	UTS(MPa)	El.(%)	YS(MPa)	UTS(MPa)	El.(%)
9741	RB801-1(7.5t)	top	556	661	22	432	479	26
	RB802-1(15t)	middle	530	654	26	423	471	26
	RB802-2(15t)	bottom	535	668	25	430	471	26

50 μm

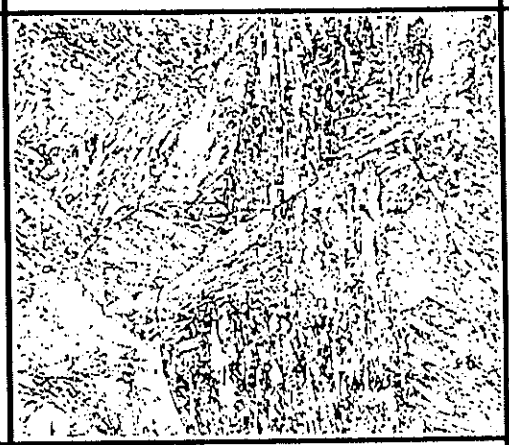
	1/2t	1/4t
RB801-8 7.5t		
RB802-4 15t		

Photo. Micro-structure (X400)

Journal of Nuclear Materials 179–181 (1991) 693–696
North-Holland

Mechanical properties of welded joints of the reduced-activation ferritic steel: 8% Cr–2% W–0.2% V–0.04% Ta–Fe

H. Hayakawa [1], A. Yoshitake [1], M. Tamura [1], S. Natsume [2], A. Gotoh [2] and A. Hishinuma [3]

[1] *Steel Research Center, NKK Corporation, 1-1 Minami-watarida, Kawasaki-ku, Kawasaki 210, Japan*
[2] *Welding Division, Kobe Steel, Ltd., 100 Urakouchi, Miyamae, Fujisawa, Kanagawa 251, Japan*
[3] *Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki 319-11, Japan*

A reduced-activation ferritic steel, 8Cr–2W–0.2V–0.04Ta–Fe (F-82H) has been developed by JAERI and NKK to improve creep properties and toughness as compared with HT9. The mechanical properties and phase stability of the steel were reported at the previous conferences, ICFRM-2 and 3.

This paper is concerned with the mechanical properties of weld metal and welded joints using a newly-developed filler wire of F-82H which contains less C and Ta than the base metal. The design concept of chemical composition of the filler wire was based on as much reduction of activity after irradiation as possible and considerations of the hardenability and toughness of the weld metal. Mechanical properties, such as tensile strength and toughness, of the weld metal and welded joints produced by GTAW after stress-relieving heat treatment were investigated. The results showed that this welding material has almost the same properties as the base metal.

1. Introduction

As the material for the first wall of the Tokamak reactor, we have developed a 0.1C–8Cr–2W–0.2V–0.04Ta steel (referred to as F-82H hereafter) consisting of the so-called reduced-activation elements after high energy neutron irradiation [1,2]. Recently, reduced-activation ferritic steels based on Cr–W–(V) type steel have also been studied in several institutions [3–5]. These studies have confirmed that the strength and toughness of Cr–W–(V) steels are comparable to those of the conventional Cr–Mo steels. As a next step, we have developed a matching filler wire for F-82H steel in consideration of the actual application of this steel to the first wall of the fusion reactor. This paper is concerned with the development of the filler wire for F-82H and the data on the mechanical properties of welded joints obtained so far.

2. Experimental procedure

Seven kinds of wire (1.6 mm diameter) were prepared and their contents of C, Ta and B were varied from the base metal to investigate their effect on the strength and toughness. The edge of the 16 mm thick plate was machined for single-V welds with steel backing, fitted-up with 0.79 rad in groove angle and 6 mm root opening. The welding method used in this study

Table 1
Welding condition

Thickness (mm)	Polarity	Current (A)	Voltage (V)	Travel speed (m/s)	Preheat temp. (°C)	Position	Layer	Pass
16	DC-SP	280	11	1.67×10^{-3}	200–250	flat	7	11

Table 2
Chemical compositions of weld metals and base metal (wt%) (Other elements: P < 0.005, S < 0.004, N < 0.005)

	C	Si	Mn	Cr	W	V	Ta	B	Comparison with base metal		
									C	Ta	B
AD	0.08	0.10	0.48	7.53	2.0	0.19	0.031	0.0035	–	–	–
BD	0.07	0.10	0.47	7.47	2.0	0.18	0.038	0.0025	low	–	–
CD	0.10	0.09	0.46	7.21	1.9	0.18	0.024	0.0029	–	low	–
DD	0.08	0.10	0.55	7.54	2.0	0.18	< 0.005	0.0034	–	free	–
ED	0.10	0.09	0.50	7.53	2.0	0.17	< 0.005	0.0018	–	free	free
FD	0.07	0.10	0.49	7.48	2.0	0.19	0.035	0.0011	low	–	free
GD	0.06	0.09	0.50	7.50	2.0	0.18	0.013	0.0011	low	low	free
Base metal	0.09	0.09	0.49	7.65	2.0	0.18	0.038	0.0034			

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was inert gas shield tungsten arc welding (GTAW), which was in conformity with the procedure described by the Japanese Industrial Standard (JIS Z 3316–1983). Welding was conducted using an automatic TIG welding machine and details of the welding conditions are given in table 1. After welding, stress relieving heat treatment on the weldment was conducted at 720 °C for 3.6 ks. This temperature was 20 °C lower than the tempering temperature of the base metal.

3. Results and discussion

3.1. Welding material

3.1.1. Chemical analysis of weld metal

Results of a chemical analysis of the weld metal are given in table 2 and levels of C, Ta and B contents in the filler wire as compared with the base metal are also indicated by terms such as "low", "free" and – in table 2. The chemical composition of each weld metal was almost the same as that of the filler wire. However, a small amount of B was detected in the three weld metals, ED, FD and GD as a result of dilution by the base metal in spite of using B-free wires. The microstructure of each weld metal was fully martensitic.

3.1.2. Tensile test and Charpy impact test of weld metal

Results of tensile tests at room temperature (25 °C) and 600 °C are given in table 3. Weld metal containing almost the same level of C and B as the base metal had about 750 MPa of ultimate tensile strength (referred to as UTS hereafter) at room temperature which were higher than 686 MPa of the base metal. On the other hand, weld metal containing lower C or less B (B-free) than the base metal showed the same level of UTS as the base metal. In the case of the tensile test at 600 °C, weld metal containing almost the same level of Ta as the base metal had higher UTS than those containing lower Ta or without Ta. However, the remarkable effects of C and B on UTS observed at room temperature were not observed at 600 °C.

Table 3
Tensile properties of weld metal

Weld metal	Temp. (°C)	0.2% PS (MPa)	UTS (MPa)	El. (%)	R.A. (%)
AD	25	643	751	28	84
	600	391	403	22	85
BD	25	655	720	27	80
	600	371	394	23	89
CD	25	675	760	27	78
	600	374	385	22	89
DD	25	590	708	27	78
	600	338	357	22	85
ED	25	521	667	26	73
	600	304	347	28	90
FD	25	592	699	28	78
	600	383	405	21	89
GD	25	585	688	28	85
	600	352	375	24	89
F-82H	25	568	686	24	80
	600	294	372	21	91

Table 4
Results of Charpy impact tests at 0 °C on weld metal

Weld metal	Absorbed energy at 0 °C (J)			
	1	2	3	Average
AD	217	22	143	127
BD	187	326	32	183
CB	345	333	340	340
DD	292	298	269	286
DD	274	270	296	280
FD	201	138	123	155
GD	342	336	344	340
F-82H				294 <

Table 4 gives the results of Charpy impact tests on weld metal at 0 °C. In the case of weld metal containing less Ta than the base metal or without Ta, the values of absorbed energy were higher compared with those of the weld metal containing the same level of Ta as the base metal. It is clear that the Ta content of less than 0.025% relates to the higher and less-scattered absorbed energy values than the higher Ta content. Large scatter was observed for three weld metals, AD, BD and FD with Ta content of more than 0.03%. It seems that the test temperature (0 °C) was close to the ductile-brittle transition temperature (referred to as DBTT hereafter) of these weld metals.

3.1.3. Proper composition of filler wire

To decide the proper composition of the filler wire, changes in 0.2% proof stress at 600 °C and absorbed energy at 0 °C of each weld metal due to Ta content are shown in fig. 1.

Fig. 1 shows that weld metal containing above 0.03% Ta, the same level as the base metal, had a high proof stress of above 370 MPa, while individual values of the absorbed energy were widely scattered and the average value was much smaller as compared with those of weld metal containing less Ta. Because a possible shift of DBTT after high energy neutron irradiation is a current major concern in the case of ferritic materials for fusion reactor application, the weld metal with high and less-scattered values of absorbed energy is more desirable than that with high strength. Because of this, the proper content of Ta was selected as 0.02 wt%. The effect of C content was not clear because of the very small difference in the C content of AD and BD as shown in table 2. However it seems that a less C content than the base metal is desirable in the case of a weld metal, since the UTS of weld metal tends to be higher than that of

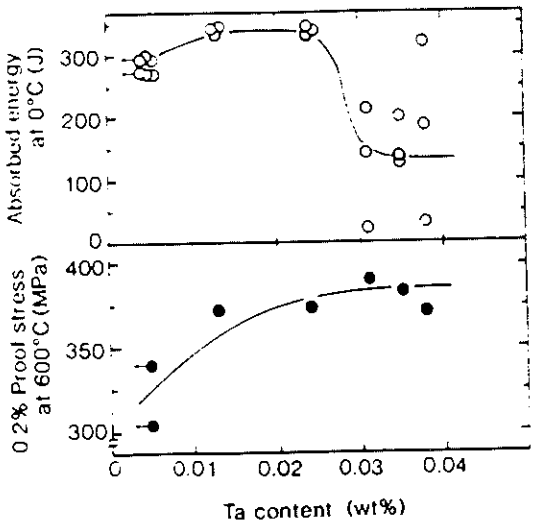


Fig. 1. Changes in 0.2% proof stress at 600°C and absorbed energy at 0°C due to Ta content in weld metal.

the base metal because of the rapid solidification in the welding process. Addition of B into the filler wire is not necessary because its effect on high temperature strength and toughness was not distinguishable from a comparison of the weld metals BD and FD, and also of the weld metals DD and ED as shown in tables 3 and 4.

Based on these results, optimization of the filler wire was made as follows: C: 0.08, Si: 0.10, Mn: 0.50, Cr: 7.50, W: 2.0, V: 0.18, Ta: 0.020, B: as little as possible (wt%).

3.2. Evaluations of weld metal and welded joints

Tensile tests at high temperatures and Charpy impact tests on the weld metal and welded joints were

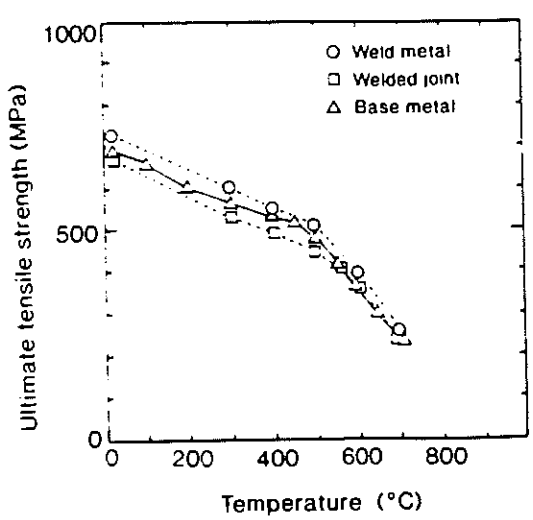


Fig. 2. Ultimate tensile strength of weld metal, welded joint and base metal as a function of temperature.

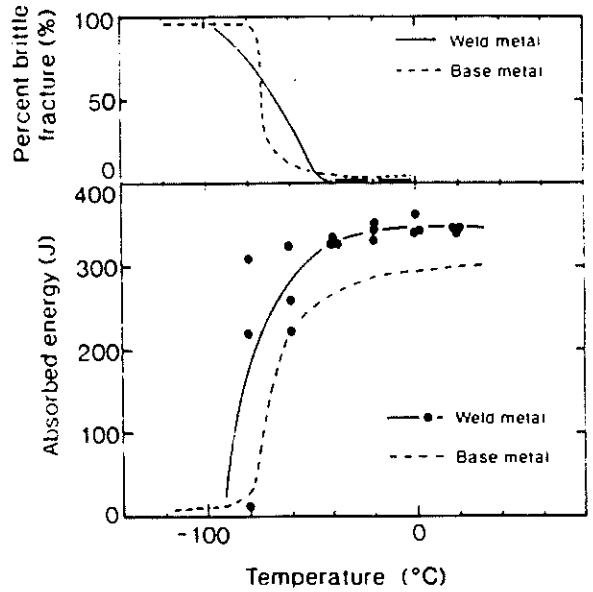


Fig. 3. Changes in absorbed energy and percentage brittle fracture of weld metal and base metal as a function of temperature.

performed using the filler wire whose chemical composition was determined as described previously.

Fig. 2 shows the results of high temperature tensile tests on weld metal and welded joints. High temperature tensile properties on the base metal are also indicated. UTS of the weld metal was a little higher than that of the base metal. However, the difference is small and it can be said that the UTS's of the weld metal and the base metal were almost equivalent over the temperature range tested. On the other hand, the UTS of welded joints was a little less than that of the base metal at temperatures up to 500°C and at above 500°C, both UTS's were almost the same. The rupture position of welded joints after the tensile testing was always in the base metal.

Charpy impacts tests of the weld metal at various temperatures were performed and fig. 3 shows the results along with the full curve of the base metal. The DBTT of the weld metal was −66°C and was almost the same as −72°C of the base metal, and the values of the absorbed energy of the weld metal were higher at all testing temperatures than that of the base metal. From these results, it can be said that the DBTT of this weld metal is very low as a weld metal of ferritic steel.

4. Conclusions

(1) A matching filler wire for the reduced-activation 0.1C–8Cr–2W–0.2V–0.04Ta steel (F-82H) was developed. The chemical composition of the wire is 0.08C–7.5Cr–2W–0.2V–0.02Ta–B (as little B

as possible) containing less C and Ta than that of F–82H.

(2) In terms of the strength and the toughness, the most effective element in the filler wire was Ta: and it was confirmed that a small addition of Ta of about 0.02% enhanced the high temperature strength but an addition of Ta to the same level of the base metal, 0.04%, decreased toughness greatly. From this result, the proper content of Ta was determined as 0.02%.

(3) It was confirmed that the weld metal produced by the use of the filler wire has equivalent strength at high temperatures and toughness to the base metal.

References

[1] M. Tamura, H. Hayakawa, M. Tanimura, A. Hishinuma and T. Kondo, J. Nucl. Mater. 141–143 (1986) 1067.

[2] M. Tamura, H. Hayakawa, A. Yoshitake, A. Hishinuma and T. Kondo, J. Nucl. Mater. 155–157 (1988) 620.

[3] R.L. Klueh and P.J. Maziasz, J. Nucl. Mater. 155–157 (1988) 602.

[4] K.W. Tupholme, D. Dulieu and G.J. Butterworth, J. Nucl. Mater. 155–157 (1988) 650.

[5] F. Abe, H. Araki, T. Noda and M. Okada, J. Nucl. Mater. 155–157 (1988) 656.

Information on one-ton and 150-kg heats

by

A. Kohyama
University of Tokyo

IEA Working Group on Ferritic/Martensitic Steels
Sun Valley, Idaho, U.S.A., June 24th, 1994

Data Sheets of JLF-1 and Other Small Heat Steels for IEA Working Group[1*]

A. Kohyam, Y. Kohno and K. Asakura
(Univ. of Tokyo)

1 ton heat of JLF-1 steel and three 150 kg heats
with 20ppmB, 1%Mn and 2%Mn additions to JLF-1

JLF-1 Fabrication Data

Melting	1 ton VIF
Casting	300 kg Ingot (240t x 240w x 640h) x 3 (JLF-1-2,3,4) 150 kg Ingot (195t x 195w x 500h) x 1 (JLF-1-1)
Grinding	ingot size (230t x 240w x 640h) x 3 (190t x 195w x 500h) x 1
Rolling (1st)	Homogenizing: 1250 C x 3hrs Reduction to 50mmt
Cutting	Shearing at 800C
Rolling (Finishing)	Reheating to 1100 C Reduction to 15mmt (JLF-1-1) and 7mmt (others) Finishing Temperature: 900-1000 C
Plate Cutting	Saw Cut: 15t x 220w x 500l, 7t x 270w x 500l
Normalizing	1050 C x 1hr / A.C.
Tempering	780 C x 1hf / A.C.

1* : work conducted as a part of the Japan/US Collaboration utilizing FFTF/MOTA

** : produced by Nippon Steel Corporation (NSC)

Table1: Chemical Compositions of JLF-1 Steel

(wt.%)

Elements	Targeted Value	JLF-1-1	JLF-1-2	JLF-1-3	JLF-1-4
C	0.09/0.10	0.10	0.10	0.10	0.10
Si	≦0.20	0.05	0.05	0.05	0.05
Mn	0.45/0.50	0.45	0.48	0.46	0.47
P	≦0.005	<0.005	<0.005	<0.005	<0.005
S	≦0.005	0.0026	0.0029	0.0024	0.0027
Cr	8.5/9.3	8.88	8.93	8.95	8.83
W	1.8/2.2	1.95	1.96	1.95	1.94
V	0.18/0.22	0.20	0.19	0.19	0.20
Ta	0.06/0.10	0.090	0.089	0.091	0.093
T-N*	200/250	215	239	229	238
T-B*	≦10	2	2	2	2
Ni	ALAP	0.01	0.02	0.01	<0.01
Cu	ALAP	<0.01	<0.01	<0.01	<0.01
Co	ALAP	<0.01	<0.01	<0.01	<0.01
Mo	ALAP	<0.005	0.001	0.001	0.001
T-Nb	ALAP	<0.01	<0.01	<0.01	<0.01
T-Al	ALAP	0.005	0.004	0.007	0.007
T-Ti	ALAP	0.002	<0.005	<0.005	<0.005

+: sampling position; bottom of the ingot

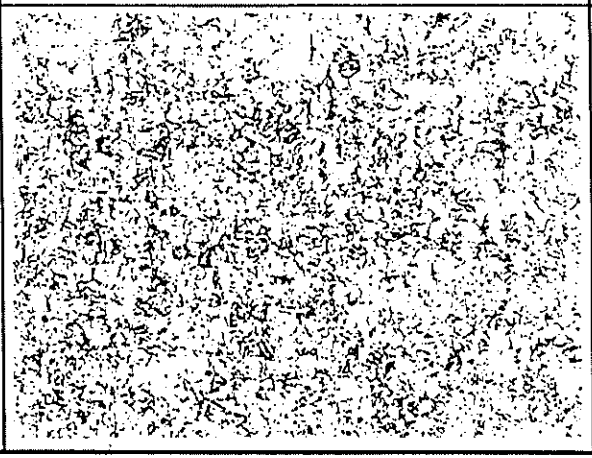
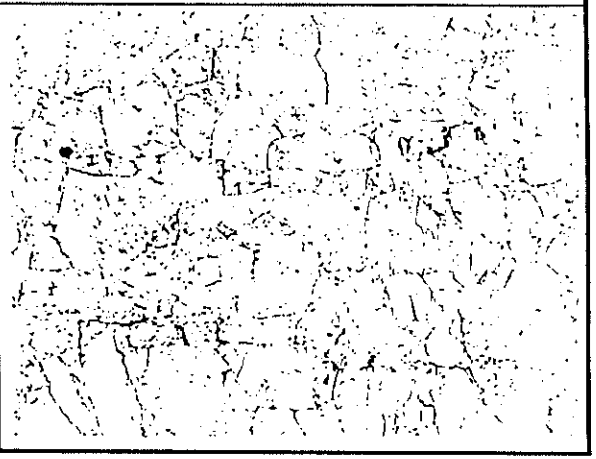
*: in wt.ppm

Table2: Tensile Properties of JLF-1

Heat No.	Plate No.	Ingot Position	R T			500℃		
317089			YS(MPa)	TS(MPa)	El(%)	YS(MPa)	TS(MPa)	El(%)
		top						
		Middle						
	JLF-1	Bottom	525	677	27.8	402	481	26
	-3-4-7		513	670	27.2	407	476	25

Note: Blank positions will be filled out soon.

Optical Micro Structure

Plate No. JLF 1-3-4-7		
	X100	X500
1/2t		

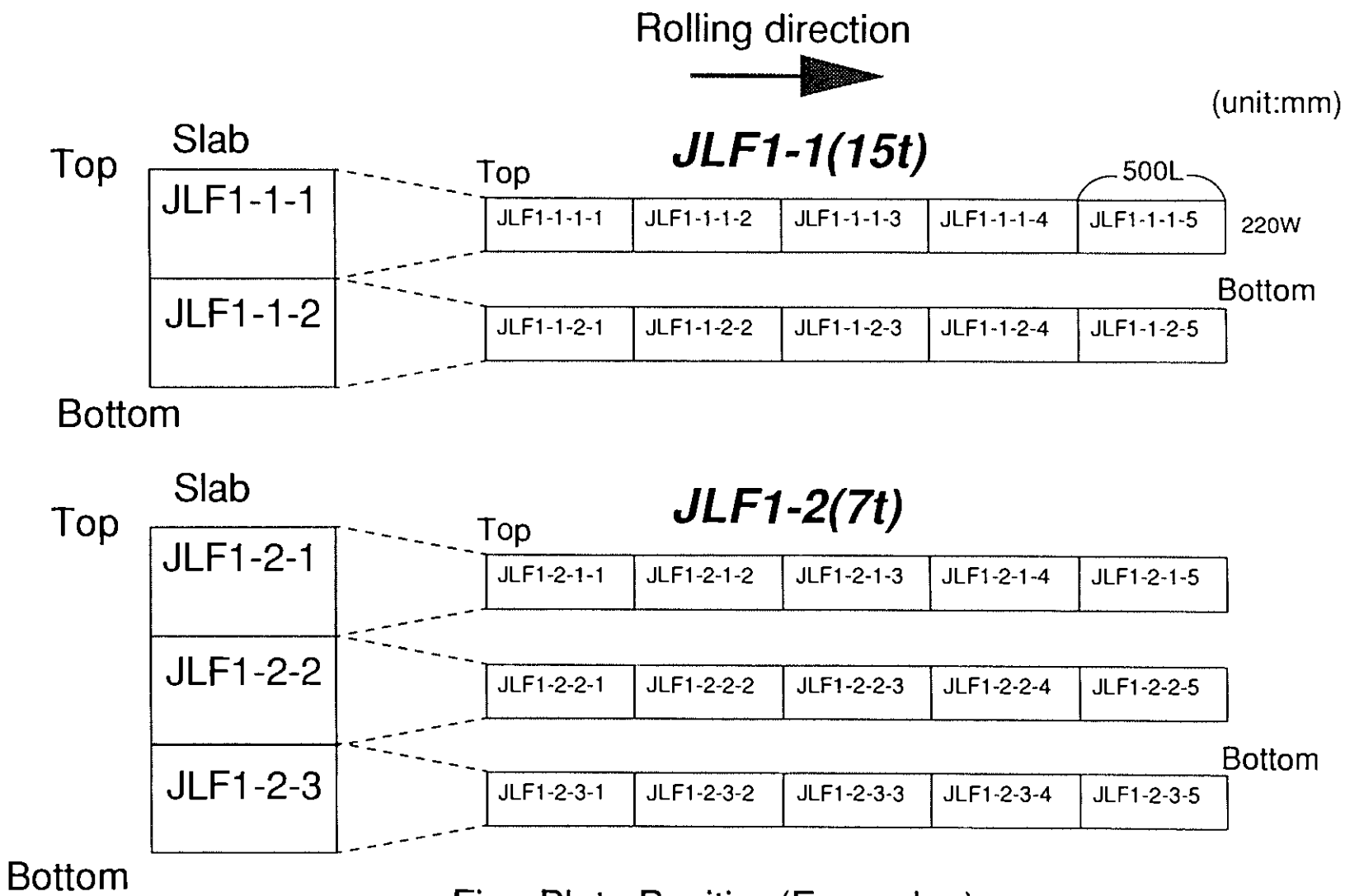


Fig. Plate Position(Examples)

Japanese Universities' Program of LAFS Development

Basic Principle:

Mo replacement by W in conventional Fe-Cr-Mo heat resistant steels

Composition Optimization:

(Cr, W, C, V, Ta, ...)

<-- Creep rupture strength

<-- Charpy impact property

Fe-(7-10)Cr-2W-0.1C-0.2V-0.07Ta-N

Proposed Leading Candidate LAFS:

JLF (Japanese Low-activation Ferritic steel) series steels

Fe-(2.25-12)Cr-2W-0.1C-0.2V-0.07Ta-0.05N

Proposed Low Activation Ferritic/Martensitic Steels Steels (Fe-Cr-W Steels) in Japan

Universities Fe-XCr-2W-V-Ta (JLF series steels)

Fe-2.25Cr-2W-0.2V-0.07Ta-0.1C-0.005N	(JLF-4)
Fe- 7Cr-2W-0.2V-0.07Ta-0.1C-0.05N	(JLF-3)
Fe- 9Cr-2W-0.2V-0.07Ta-0.1C-0.05N	(JLF-1)
Fe- 9Cr-2W-0.2V-0.07Ta-0.1C-0.05N-0.015Ti	(JLF-2)
Fe- 12Cr-2W-0.2V-0.07Ta-0.1C-0.05N	(JLF-5)
Fe- 12Cr-2W-0.2V-0.07Ta-0.1C-0.05N-0.015Ti	(JLF-6)

NRIM Fe-9Cr-XW-V-Ta-B

Fe- 9Cr-1W-0.2V-0.1Ta-0.005B-0.1C	(9Cr-1WVTa)
Fe- 9Cr-3W-0.2V-0.1Ta-0.005B-0.15C	(9Cr-3WVTa)

JAERI Fe-8Cr-2W-V-Ta-B

Fe- 8Cr-2W-0.2V-0.04Ta-0.003B-0.1C	(F82H)

Remarks:

NRIM and JAERI programs focus on (8,9)Cr steels
University program covers wide range of Cr concentration
NRIM program dose not include include 2W version steel
Intensional addition of nitrogen in university JLF-series steels

Composition Optimization of Low Activation Fe-Cr-W Ferritic/Martensitic Steel

(K.Asakura; U.Tokyo, F.Abe; NRIM)

Optimum C concentration: 0.1%
- Less C: Tends to form delta-ferrite
- Excess C: Tends to cause carbides coarsening at higher temperature

Optimum V concentration: 0.2%
- Improves creep strength
- Excess V addition tends to cause carbide coarsening
  --> Degradation of creep strength and toughness

Optimum Ta concentration: 0.07-0.1%
- Potentially same effect as V
- Ta addition improves toughness
- Excess Ta causes coarsening of Ta(C,N) --> Degradation of toughness
- No significant change in creep strength with Ta

Ti addition:
- Improves high temperature creep strength
- Serious degradation of toughness and DBTT after long-time heating

N addition:
- Improves high temperature creep strength
- 0.05% N maximum N including level in steel making process
- Less desirable from low activation consideration

University Program of Mechanical Property Examination on Low Activation Ferritic/Martensitic Steels

Neutron irradiation in FFTF/Fusion-MOTA (Hanford)
(Part of Monbusho/US-DOE collaborative experiment)

FFTF Cycle-11,12: MOTA-2A,2B
- Neutron exposure: MOTA-2A: 8.6E22 n/cm2 (35dpa)
  MOTA-2B: 5.8E22 n/cm2 (25dpa)
- Temperature: 650K - 870K

MOTA specimens for mechanical property examinations

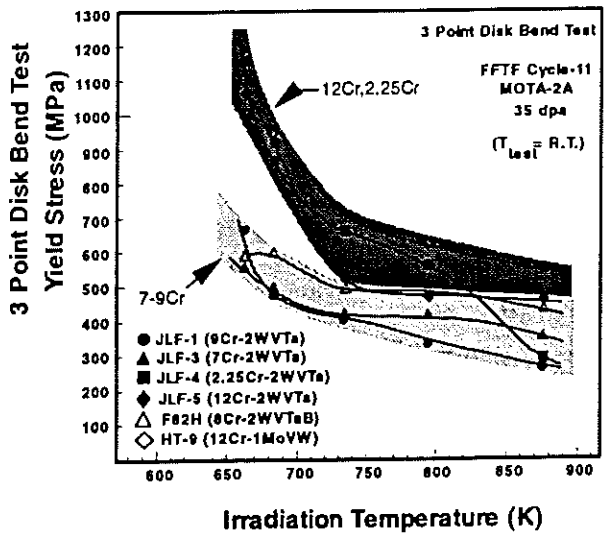
Tensile spec.	Charpy Impact spec.	Disk Bend spec.
S size	1.5mm size	3mm dia. disk
W size	1/3 size	
SS3 size		

Creep spec.
(Pressurized tube type)

Mechanical property testing apparatus

- MATRON (Installed at PNL)
- Instrumented Impact Testing Machine (IMR/Tohoku Univ.)
- Disk Bend Testing Machine (IMR/Tohoku U.)

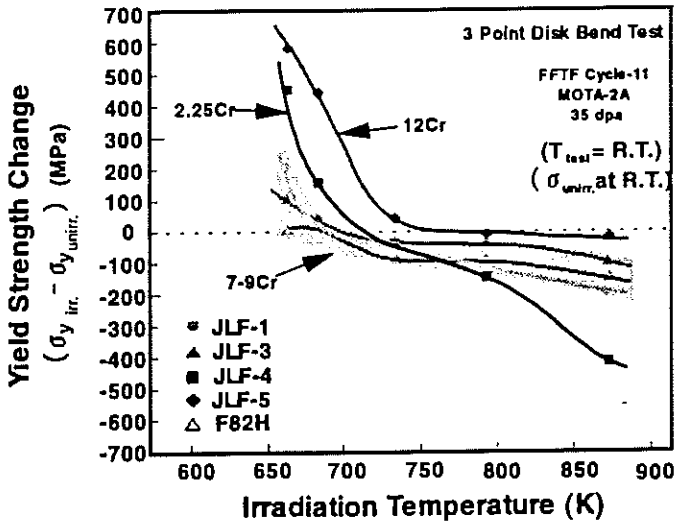
Temperature dependence of flexural yield strength following irradiation to 35dpa in the FFTF/MOTA (Kohno, Kohyama, Asakura)



7-9Cr steels (JLF-1, JLF-3, F82H) indicate lower yield strength than 12Cr, 2.25Cr steels, especially at lower irradiation temperature (below about 720K)

Yield strength of 2.25Cr steel decreases to the same strength level of 7-9Cr steel at higher irradiation temperature

Temperature dependence of flexural yield strength change following irradiation to 35dpa in the FFTF/MOTA. (Kohno, Kohyama, Asakura)

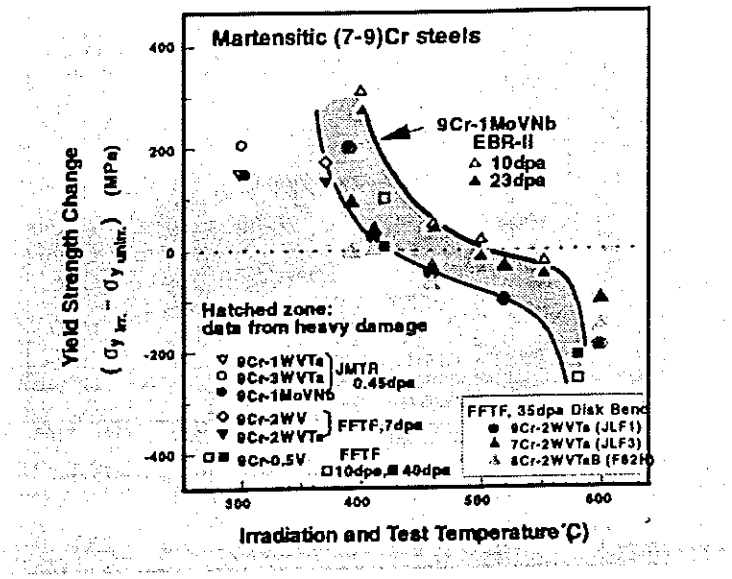


- **Irradiation hardening at lower temperature (below about 720K), Softening at above 720K**
- **Smaller irradiation hardening in 7-9Cr steels than 12Cr, 2.25Cr steels**
- **No hardening in F82H (8Cr)**
- **Significant softening in 2.25Cr steel at above 800K**

Irradiation Effect on Disk Bend Mechanical Property

Comparison of yield strength change with other data

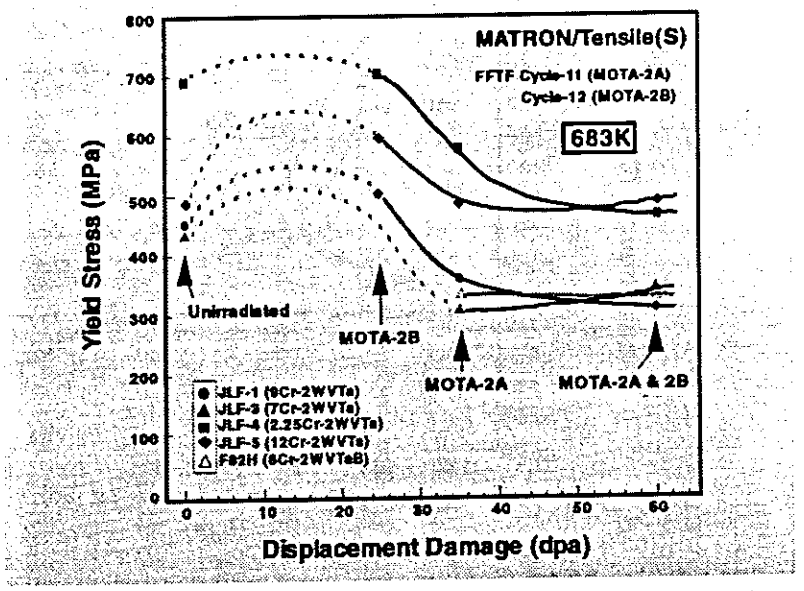
(Base data: compiled by F.Abe, NRIM)



- Disk bend results fit well in the data trend band from other heavy damage results

Tensile Test Results / MATRON / Tensile (S)

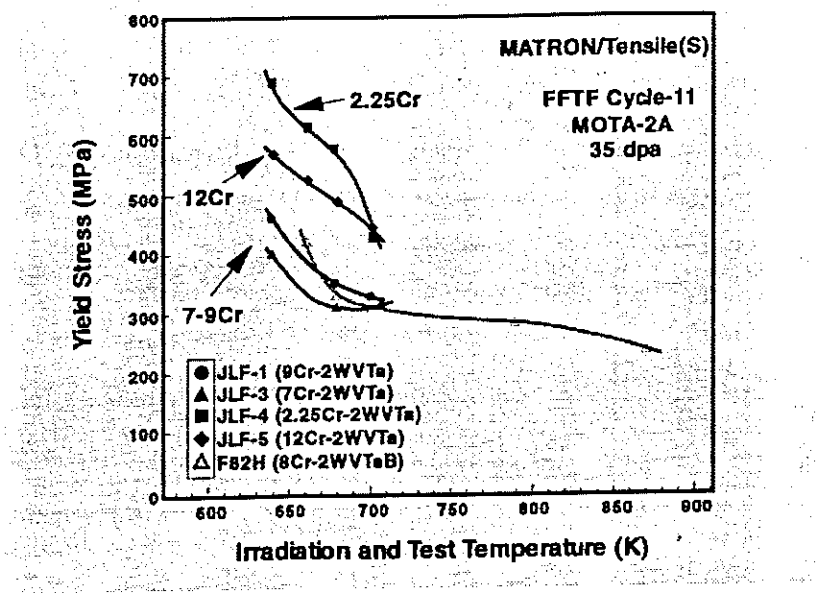
Dose dependence of yield strength following irradiation at 683K in the FFTF/MOTA



- Yield strength once increases with irradiation dose and then decreases to become saturation level over 35-40dpa. Peak hardening at around 10-15dpa (?)
- Lower saturation strength level in 7-9Cr steels than 2.25Cr, 12Cr steels

Tensile Test Results / MATRON / Tensile(S)

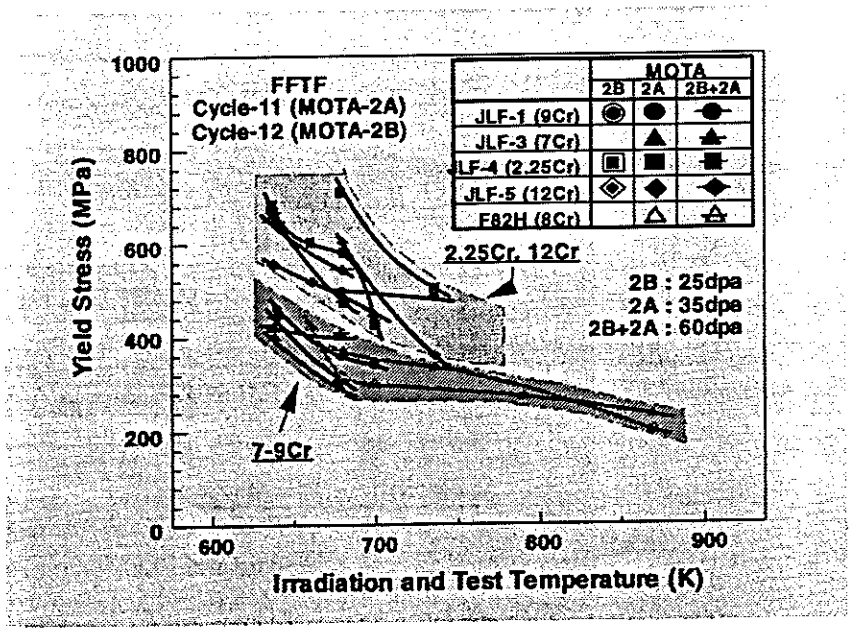
Temperature depecdence of yield strength following irradiationto 35dpa in the FFTF/MOTA



- Essentailly same temperature dependence and Cr level dependence of yield stress

Tensile Test Results / MATRON /Tensile (S)

Irradiation temperature and dose dependence of yield strength of JLF series steels and F82H irradiated in the FFTF/MOTA



- Possible to classify into two groups; 7-9Cr steels & 2.25Cr, 12Cr steels
- Yield strength range at 683K; 300-400MPa (7-9Cr steels), 450-700MPa (2.25Cr, 12Cr steels)

Tensile Test Results / MATRON / Tensile (S)

Dose dependence of uniform and total elongation in JLF series steels and F82H following irradiation at 683K in the FFTF/MOTA

- Relatively larger total and uniform elongation in 7-9Cr steels than in 2.25Cr, 12Cr steels
- Elongation seems to reach saturation over about 35dpa.

Charpy Impact Test Results / 1.5mm CVN

Charpy impact curves for JLF-1 (Fe-9Cr-2W) and F82H (Fe-8Cr-2W) following irradiation to 0.01-60dpa at 570-693K in JMTR or FFTF

- Excellent Charpy impact response in JLF-1 and F82H, DBTT still remains below R.T.
  - Superior DBTT property of JLF-1 than F82H
- DBTT decreases at high displacement damage level (in JLF-1)

Summary

- R&D program of low activation ferritic steel in Japanese universities proposed 6 kinds of Fe-Cr-W leading candidate steels (JLF series steels) with 2.25 - 12%Cr and 2%W.

- Mechanical property examinations of JLF series steels and JAERI's F82H after heavy neutron irradiation by means of FFTF/MOTA provided;
  - Three point disk bend test and tensile test results following irradiation to 35dpa show serious hardening in 2.25%Cr and 12%Cr steels below about 720K, while in 7-9%Cr steels hardening was small or negligible.
  - Dose dependence of yield strength after 683K irradiation seems to show peak hardening dose at around 10 or 15dpa followed by decrease and saturation over 35 or 40dpa. Saturated yield strength in 7-9%Cr steels are lower than 2.25%Cr and 12%Cr steels. Dose dependence of uniform and total elongation also seemed to saturate following irradiation over 35 or 40dpa, and uniform or total elongation in 7-9%Cr steels are relatively larger than in 2.25%Cr or 12%Cr steel.
  - Average creep deformation coefficient shows complicated temperature dependence with a peak temperature at around 700K which is likely to be caused by void swelling.
  - DBTT in JLF-1 (9%Cr) or F82H (8%Cr) still remains below room temperature even after heavy neutron irradiation of about 60dpa. DBTT in JLF-1 shifts to lower temperature after irradiation over about 35dpa.

Presentation on Test Program Proposals

IEA Working Group Meeting on ferritic steels
Sun Valley, Idaho, June 24, 1994

A. Hishinuma, JAERI

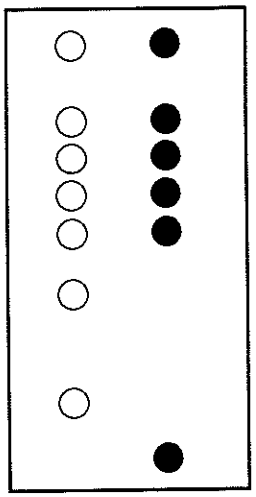
Proposed Japanese Test Program on IEA Heats of Modified F82H and the Others of Reduced-Activation Ferritic Steels

The purpose of Japanese program on the IEA heat of modified F82H and the others is to take basic data forcusing on irradiation behavior for evaluating them as structural material for fusion reactor system until 2000 year. The schedule is adjusted to the time when the module tests can be demonstrated in ITER and the 14 MeV neutron-irradiation test facility, IFMIF(International Fusion Material Irradiation-testing Facility) start to operate.

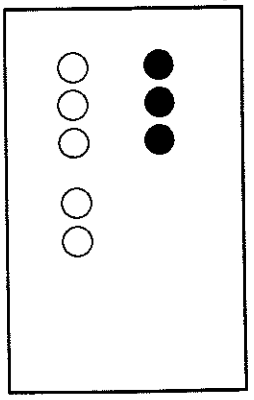
(Material properties needs for design and analysis)

○ Unirrad
● Irrad.

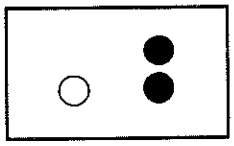
1. Mechanical properties
   - Basic mechanical properties of
     - tensile,
     - fatigue,
     - creep,
     - fracture toughness,
     - DBTT evaluation with Charpy tests,
     - crack growth
   - Thermal stability(aging effects)
   - Heat treatmen optimization
   - Composition optimization studies
   - Size effects on fracture behavior (testing methodology)



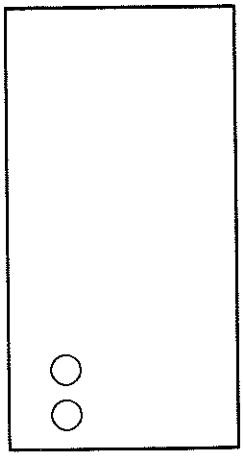
2. Welding technologies and properties
   - Mechanical properties
     - tensile,
     - fracture toughness
     - DBTT
   - Welding procedure development
   - Weld metal development
   - Dissimilar metal welds
   - Non-destructive testing



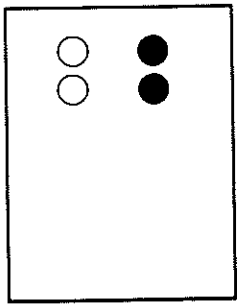
3. Dimensional and phase stability
   - Swelling
   - Micrstructual studies



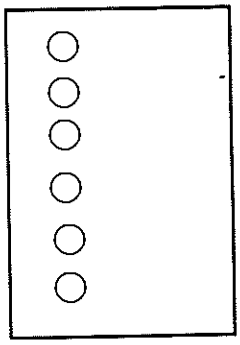
4. Environmental effects
   - Compatibility with water
   - Compatibility with liquid metal
   - High temperature oxidation
   - Corrosion
   - SCC
   - Mass transfer
   - Vacuum property
   - Magnetmechanical properties



5. Hydrogen and helium effects
   - H effects on mechanical properties and others
   - He effects on mechanical properties and others
   - Solubility of H
   - H transfer effect
   - Tritium inventory



6. Physical properties
   - Densityいえあ
   - Modulus of elasticity
   - Specific heat
   - Thermal conductivity
   - Thermal expansion constant
   - Electrical conductivity



Proposed titles and representatives

1. Mechanical properties
   1-1 Effects on neutron irradiation on the mechanical properties(tensile, creep, Charpy) of F82H
   (H. Kayano & H. Kurishita, Tohoku Uni.)
   1-2 Study of heavy neutron irradiation response of Fe-(7-9)Cr-2W low activation ferritic steels for fusion structural application(Tensile, PT creep, fracture toughness, Charpy, crack growth)
   (A. Kohyama & Y. Kohno, Uni. Tokyo)
   1-3 Neutron irradiation effects on mechanical properties(tensile, Charpy and fracture toughness) of low activation ferritic steels
   (K. Shiba & S. Jitsukawa, JAERI)
   1-4 Composition optimaization studies fron a view point of fracture toughness
   (F. Abe, NRIM)
   1-5 Strength and toughness evaluation of un-irradiated low activation ferritic steels
   (K. Hamada, Nippon Steel Co.)
   1-6 Basic properties(tensile, Charpy, etc.,) of un-irradiated IEA modified F82H
   (JAERI &NKK)

2. Welding technologies and properties
   2-1 Study of heavy neutron irradiation response of Fe-(7-9)Cr-2W low activation ferritic steels for fusion structural application(tensile, fracture toughness)
   (A. Kohyama & Y. Kohno, Uni. Tokyo)
   2-2 Neutron irradiation effects on mechanical properties(tensile, DBTT/SSTT) of low activation ferritic steels
   (K. Shiba & S. Jitsukawa, JAERI)
   2-3 Development of welding procedure and weld metal
   (NKK & Kobe Steel Co.)

3. Dimensional and phase stability
   3-1 Precipitation and swelling behavior of low activation ferritic steels neutron-irradiated.
   (A. Kohyama & Y. Kohno, Uni. Tokyo)
   3-2 Phase stability and microstructural evolution during neutron irradiation of low activation ferritic steels
   (K. Shiba & S. Jitsukawa, JAERI)

4. Environmental properties

4-1 Influence of static magnetic field on fatigue crack growth of low activation ferritic steels under reversed torsional and push-pull stress
(M. Misumi, Seikei Uni.)

4-2 Evaluation of magnetic stress due to magnetization in magnetic field and its effect on bending properties of ferritic steels.
(K. Miya, Uni. Tokyo)

4-3 Evaluation of eddy current and magnetic stress
(K. Miya, Uni. Tokyo)

4-4 Hydrogen retention and helium selective pumping properties of low activation steel
(T. Hino, Hokkaido Uni.)

5. Hydrogen and helium effects

5-1 Effect of hydrogen on irradiation embrittlement of low activation martensitic steels
(A. Kimura, Tohok Uni.)

5-2 Helium effect on mechanical properties of low activation ferritic steels
(K. Miyahara, Nagoya Uni.)

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6. Physical properties

6-1 High temperature elastic moduli of F82H
(F. Abe, NRIM)

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IEA Working Group on Ferritic/Martensitic Steels
Sun Valley, Idaho, U.S.A., June 24th. 1994.

Proposed European Programme on the Modified F82H and JLF-1 Steels

D. R. HARRIES

DRH.

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(a) Solidification cracking.
(b) Reheat cracking.
(c) Hydrogen cracking.

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Overview of Preliminary/Near Term Program on IEA Martensitic Steels

R. Odette, R. Klueh and D. Gelles

IEA Working Group Meeting
June 25, 1994
Sun Valley Idaho

General Objectives

- Key objective - to develop appropriate data bases and couple analytical methods to predict the integrity limits of IEA heat first wall and blanket structures

- US emphasis on fast fracture and temperature limits imposed by embrittlement

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- Primary focus - fracture toughness, shifts in fracture toughness and constitutive properties
- Secondary/complementary interests
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  - other properties (creep, LCF, subcritical crack growth/hydrogen effects)
  - TMT optimization and small heat studies
  - studies on similar 7-9 Cr helium alloys - helium effects, extended irradiations, composition effects and optimization
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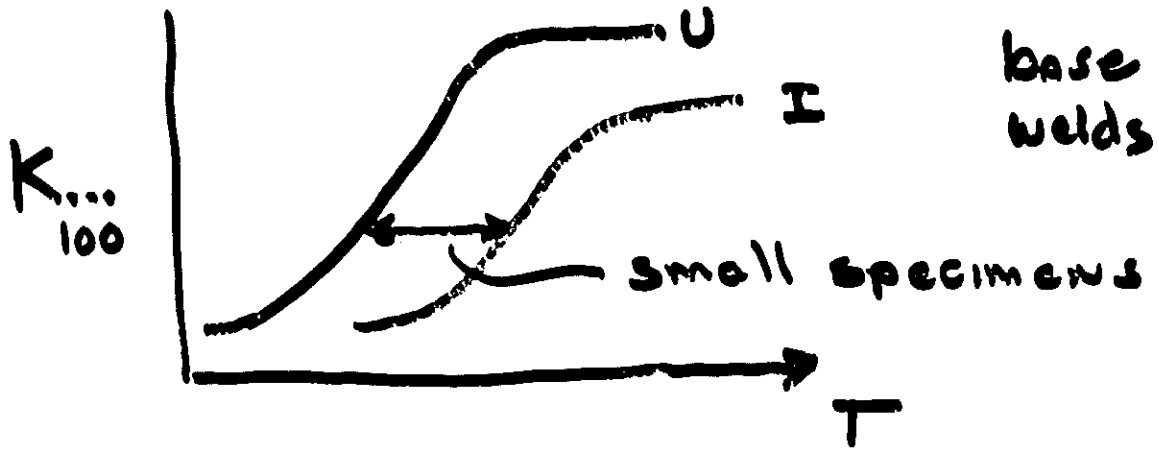
  limited irradiated verification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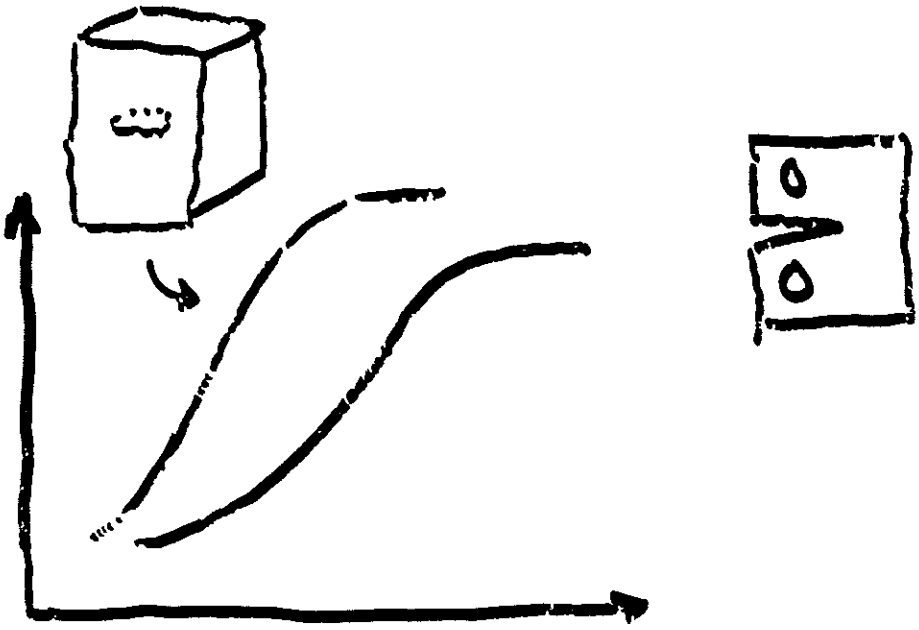

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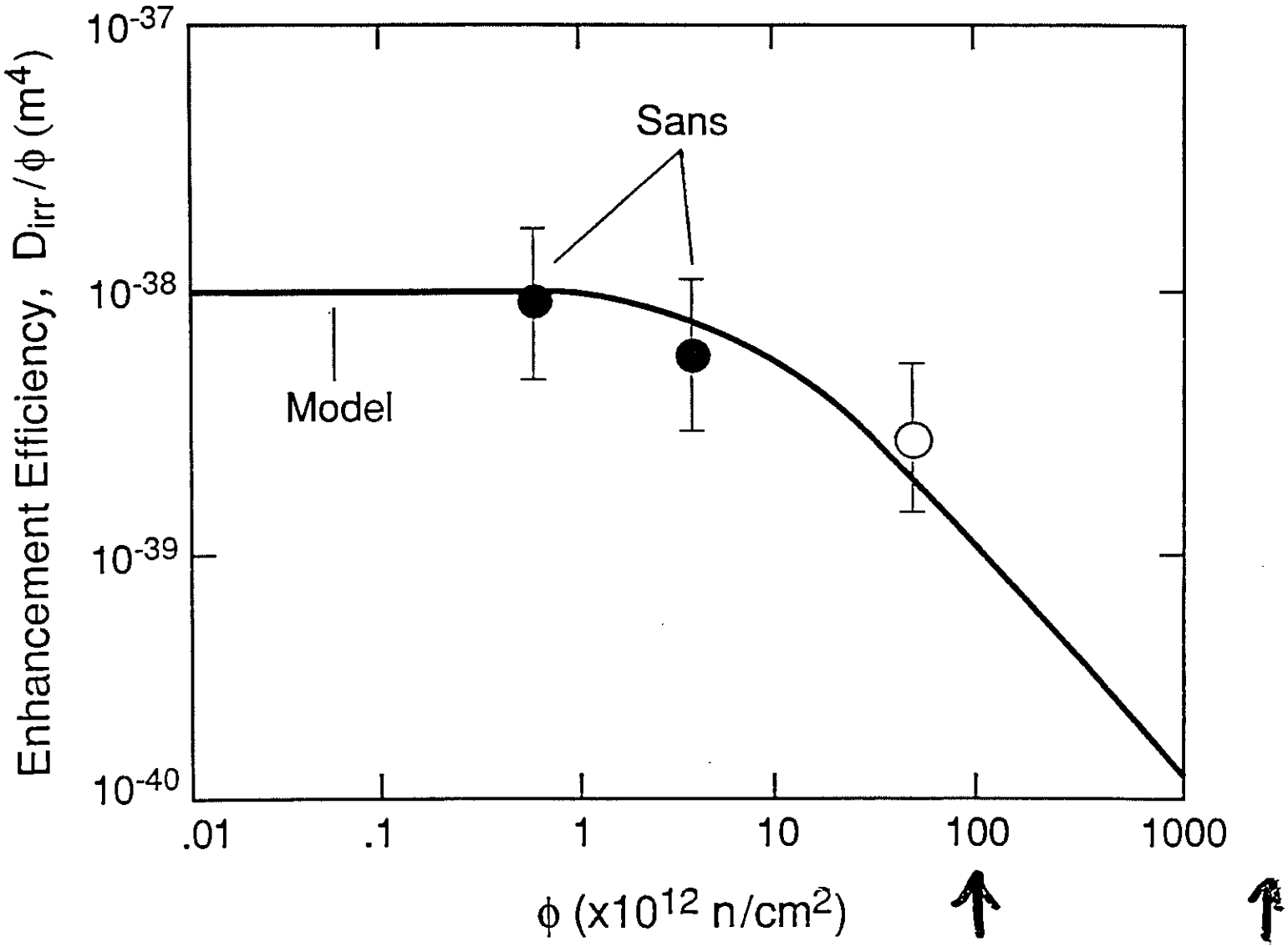

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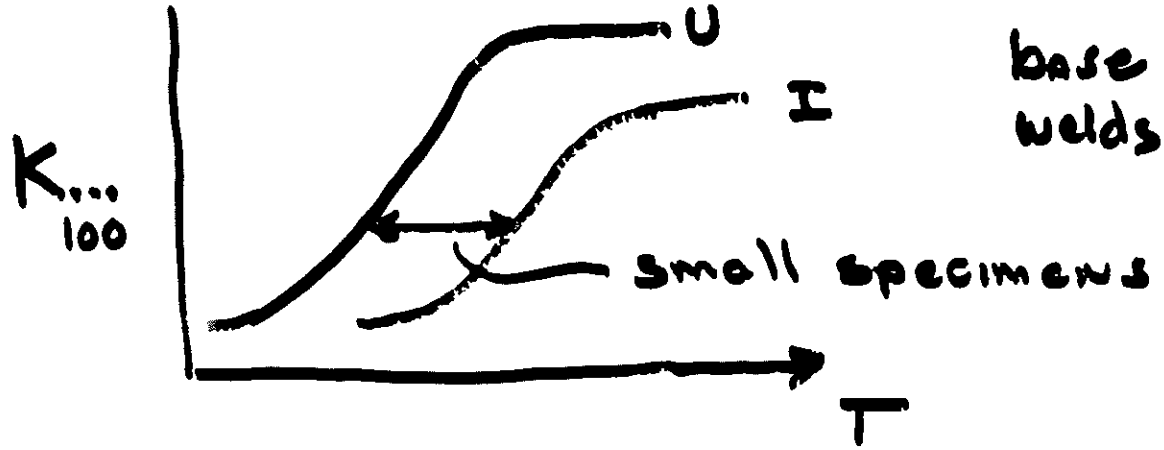
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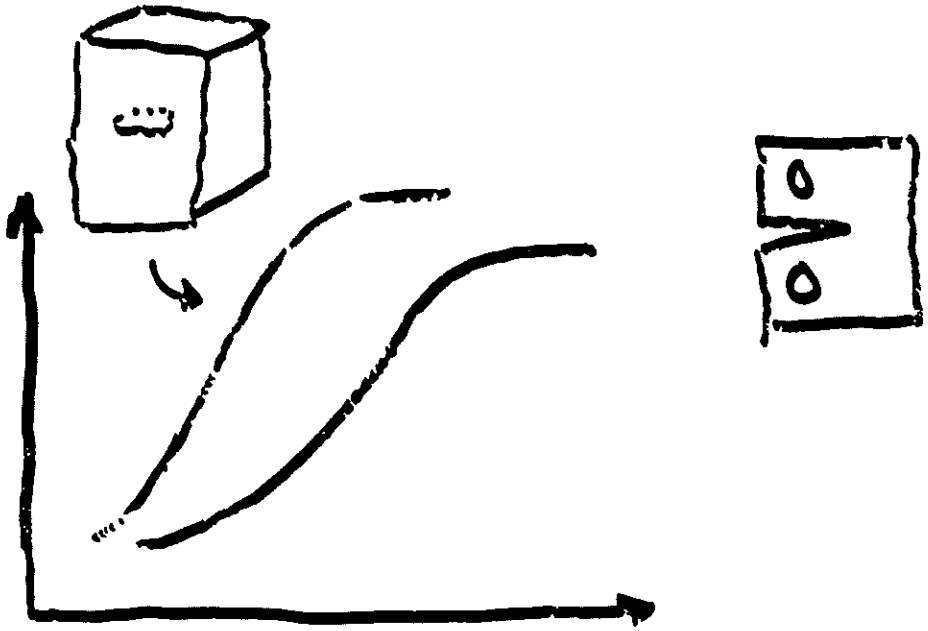

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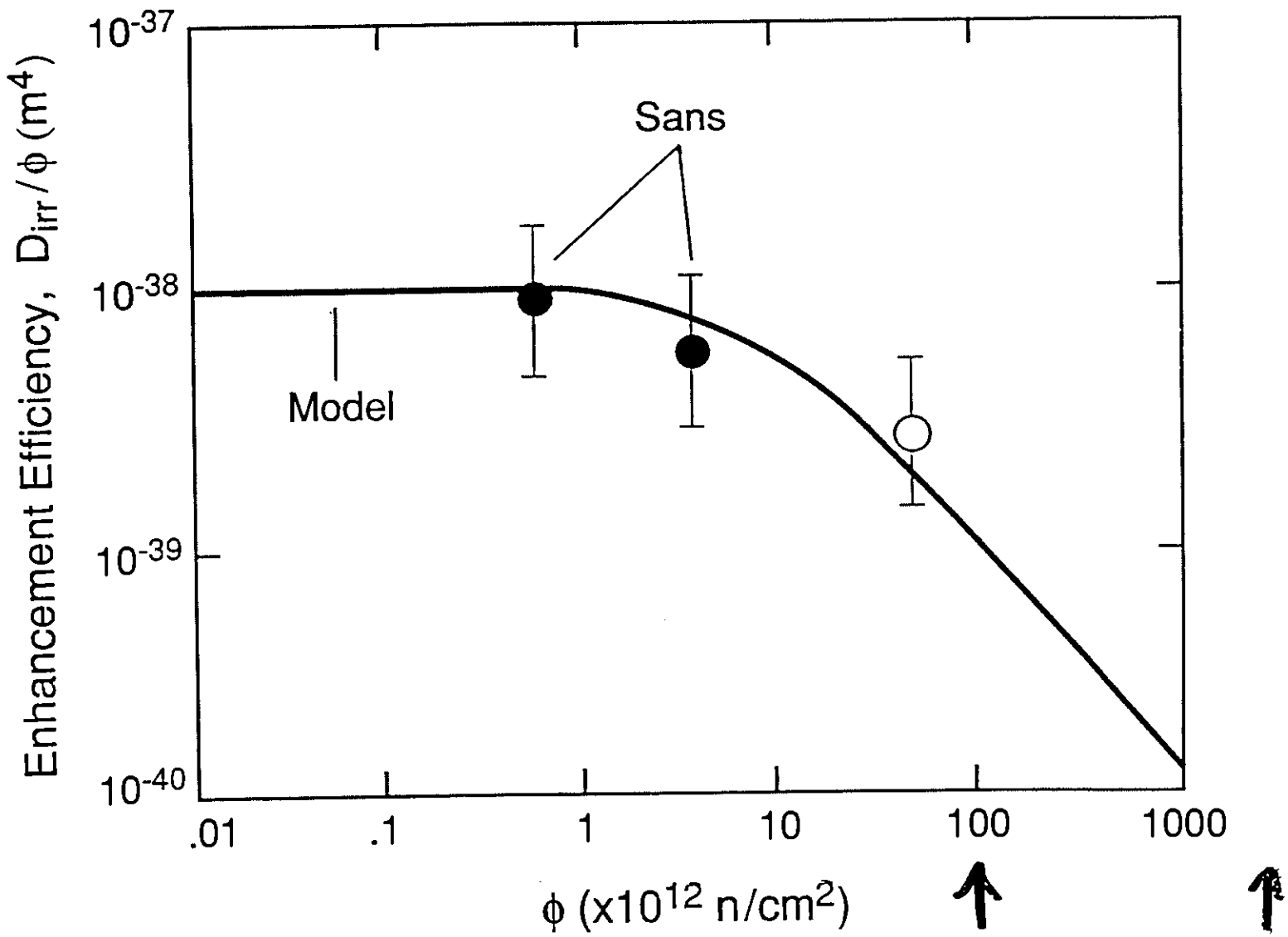

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