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IRRADIATION EXPERIMENTS OF LOW COPPER A533B STEELS FOR REACTOR PRESSURE VESSEL TESTED IN JMTR

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Irradiation Experiments of Low Copper A533B Steels for Reactor Pressure Vessel Tested in JMTR

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(Received August 18, 1994)

Irradiation embrittlement of A533B steels with low copper contents was investigated from the point of dose rate and irradiation temperature effects. Changes of neutron flux in the range from $\sim 10^{12}$ to $\sim 10^{13}$ n/cm²/s (E>1MeV) did not have a significant effect on the embrittlement. Irradiation temperature change of 1℃ resulted in the transition temperature shift (ΔT_{41J}) of about 1℃ and yield stress change ($\Delta \sigma_y$) of about 0.8MPa. Factors that might affect the embrittlement of low copper steels are also discussed.

Keywords: Irradiation Embrittlement, Pressure Vessel Steels, Dose Rate Effect, Charpy Shift, Hardening, JMTR

+ Department of Hot Laboratories

JAERI-Research 94-015

ＪＭＴＲによる低銅軽水炉圧力容器鋼材の照射試験

日本原子力研究所東海研究所原子炉安全工学部
鈴木　雅秀・鬼沢　邦雄・木崎　　実$^{+}$

（1994年８月18日受理）

不純物の銅含有量が低いA533B鋼の照射脆化特性を、照射速度ならびに照射温度依存性の観点から調べ、以下のことがわかった。

10^{12}から10^{13} n/cm^{3}(E>1MeV)の範囲では、中性子束の効果は余り大きくない。照射温度の低下に伴い照射による遷移温度の上昇量、降伏応力の増加量は大きくなり、その割合はそれぞれ１℃／℃、0.8MPa／℃となる。

このほか低銅圧力容器鋼材の脆化に及ぼす影響因子について議論した。

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＋ ホット試験室

Contents

目　次

1. INTRODUCTION

Irradiation embrittlement of pressure vessel steels is governed by various factors, such as chemical compositions, heat treatment conditions, irradiation temperature and neutron flux. Moreover, some of these factors are interactive. When a steel contains high impurity copper (Cu), embrittlement behavior is strongly dependent on the formation of Cu-rich precipitates[1-3], including the dose rate dependence. Japanese modern pressure vessel steels contain very low concentration Cu and other detrimental impurity atoms like phosphorus (P), and hence have very low susceptibility to irradiation embrittlement. In the material with very low Cu contents, effects of other metallurgical factors or irradiation variables should become discernible[4]. However, irradiation characteristics of low Cu steels (or highly purified materials in a level of industrial product) is not well established.

In the present experiment, embrittlement characteristics of two low Cu steels of A533B with different phosphorus (P) and sulfur (S) contents were evaluated in terms of effects of dose, dose rate and irradiation temperature.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Materials mainly used in the present irradiation experiments are two kinds of MnMoNi steels (A533B), which are hereinafter referred to as L and M. Both materials were produced as thick plates (thickness: 200 mm). The alloy L is of a very low impurity material for an industrial product (P:0.003, Cu:0.02, S:0.003 in wt%). The alloy M is of slight-

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2.2 Irradiation

Neutron irradiations were conducted in Japan Materials Testing Reactor (JMTR) to fluences to ~$2x10^{18}$ and ~$2x10^{19}$n/cm^2 (E>1MeV) at temperatures of 260, 275 and 290°C. Two different dose rates were adopted at 290°C irradiation : one at ~$1x10^{12}$n/cm^2/s (E>1MeV), which irradiation was conducted at a second aluminum reflector region, and the other at ~0.5-$1x10^{13}$n/cm^2/s (E>1MeV), which irradiation was conducted at a second beryllium reflector region of JMTR core. Irradiation at positions of different neutron flux inevitably induced the change of neutron spectrum. However, the spectrum difference in the present experiment was not considered to be large to cause significant spectral effect. Both of neutron spectra in position A (higher dose rate) and B (lower dose rate) are shown in Fig.1. Parameters relating to the neutron energy spectral are as follows:

parameter	Position A (higher flux)	Position B (lower flux)
thermal/fast neutron flux ratio	~8	~18
dpa/fast fluence ratio, cm^2	$2.16x10^{-21}$	$2.46x10^{-21}$

2.3 Mechanical property tests

After irradiation, Charpy impact, tensile and hardness tests were performed. Specimens were machined from the quarter thickness portion (1/4T) of the plate. The notch orientation of Charpy specimens were T-L in the ASTM designation. Procedures for Charpy test and specimen preparation were in accordance with JIS B7722 and JIS Z2202 (standard 10x10x55 mm^3 size), respectively. Tensile specimens had dimensions of 4 mm in diameter and 22 mm in gauge length. Vickers hardness (DPH) measurements were conducted using the brittle fractured Charpy specimens.

3. RESULTS AND DISCUSSION

3.1 Dose and dose rate effects on Charpy impact properties

Both of the alloy L and M are low copper steels, and also contents of impurity atoms which are detrimental to radiation embrittlement are small. Therefore, irradiation embrittlement is expected to be very small. For example, predicted shift of transition temperature (ΔT_{41J}) after irradiation to $2x10^{19}n/cm^2$ (E>1MeV) by prediction equations [5,6] are as follows:

	Predicted shift US R.G.1.99 Rev.2 [5]	JEAC 4201[6]
Alloy L:	13.2°C	14.2°C
Alloy M:	13.2°C	20.7°C

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In the upper shelf region, The alloy M shows lower toughness owing to the increased number density of MnS.

Fig.2 shows the absorbed energy transition curves after irradiation to ~$1x10^{18}$ and ~$2x10^{19}n/cm^2$ (E>1MeV) at 290°C.(*) Fig.3 shows the Charpy shift (ΔT_{41J}) as a function of dpa (displacement per atom). At lower dose, the alloy M shows larger shift than L. However, the shift of L becomes larger after irradiation to ~$2x10^{19}n/cm^2$ (E>1MeV). Shift itself is much larger than expected.

For dose rate dependence, almost no effect is observed for the alloy L. By contrast, M seems to be more embrittled by lower dose rate irradiation (by about 12°C shift by one order change of dose rate).

Hardness test results shows almost the same tendency with the Charpy test results, i.e. only the alloy M shows the slight difference of irradiation induced hardening by changing the dose rate (see Fig.4). However, the difference is small as compared to the magnitude of scatter band. So, one can conclude from the hardness measurements that dose rate dependence is weak in the dose rate range tested for both materials.

3.2 Irradiation temperature dependence

Fig.5 (a) and (b) shows temperature dependence of irradiation effects. Fig.5(a) shows the transition temperature shift caused by irradiation to ~$2x10^{19}$ n/cm^2 (E>1MeV) as a function of irradiation temperature. In the temperature

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(*) Data on Charpy impact tests as well as other mechanical tests are attached to Appendices of this report.

range from 260°C to 290°C, as the irradiation temperature decreases by 1°C, transition temperature shift increases by 1°C for both alloys L and M.

Fig.5(b) shows the irradiation induced yield stress increase as a function of irradiation temperature. Irradiation temperature change of 1°C results in a yield stress change of about 0.8MPa. Almost the same temperature dependence is observed for both alloys.

3.3 Anomalousness of embrittlement characteristics

The present experiment showed the anomalous embrittlement characteristics of the alloy L, which was caused in spite of the low impurity content material. Key observation for this anomalousness may be the very high ratio of transition temperature shift versus irradiation hardening. Usually the shift of transition temperature is proportional to the degree of hardening:

$$\Delta T_{41J} = \alpha * \Delta\sigma_y .$$

Here, the coefficient α lies in the range from ~0.45 to ~0.85 [7].

Fig.6 shows the ratio of $\Delta T_{41J}/\Delta DPH$ (=β) together with various IAEA steels (IAEA coordinated research program Phase III, JAERI contribution [8]) as a function of initial transition temperature. Most of the steels have β value of 1.7±0.7, while that of L is about 6. It is clear that high β value of the alloy L makes the transition temperature shift larger than that of M, in spite of the smaller increase in yield stress or hardness than M. In addition, unexpected embrittlement sometimes observed for high purity steels seems to be related with high β value. Fig.7 compares the measured shift (ΔT_{41J}) with the predicted value by JEAC 4201 for the IAEA low copper materials. Although chemical compositions of these materials are similar, measured shifts are widely scattered. Microstructures are also almost identical,i.e., both steels have a bainitic structure with carbides of M_3C and M_2C. Reason for producing difference in irradiation characteristics is not clear, but would be related with the fine scale microstructural difference. For example, morphology and density of M_2C carbides are different among these materials. Fig.8 shows the carbides extracted onto the carbon replica films. Fine needle-like particles of M_2C are observed in high density for the alloy JPI. By contrast, high β materials (L and JPJ) contain larger M_2C in less density. This tendency is more distinct for the alloy L. The reason for producing high β value is unknown at the present stage. We can say at least that this embrittlement is not related with intergranular brittleness, nor with some strain rate dependent phenomena. The former was confirmed by SEM observation of fracture surface, and the latter was examined by the analysis of instrumented Charpy test data. It may be related with the nano-scale microstructural change which is related with the strengthening mechanism of low alloy steels like "interaction solid solution hardening" [9]. Re-distribution of portions of various strengthening factors during irradiation may have caused the anomalous mechanical property correlations of the alloys L and JPJ. Microstructural variables (factors) are considered to be more important for the purified steels for the accurate embrittlement prediction.

4. CONCLUSIONS

Irradiation embrittlement of A533B steels with low copper contents was investigated from the point of dose rate and irradiation temperature effects. Conclusions obtained are:

1. Change of neutron flux in the range from $\sim 10^{12}$ to $\sim 10^{13}$ $n/cm^2/s$ (E>1MeV) did not have a significant effect on the embrittlement.

2. Irradiation temperature change of 1°C resulted in the transition temperature shift (ΔT_{41J}) of about 1°C and yield stress change ($\Delta\sigma_Y$) of about 0.8MPa.

3. High ratio of transition temperature shift versus irradiation hardening was observed for the very low Cu impurity alloy L. Microstructural variables become more important to give an accurate prediction of irradiation embrittlement for low Cu steels.

ACKNOWLEDGEMENTS

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Table 1 Chemical composition of the materials used. (wt%)

Alloy	C	Si	Mn	P	S	Ni	Cr	Cu	Co	Mo	V	N
L	0.17	0.24	1.39	0.003	0.003	0.60	0.07	0.02	0.009	0.46	<0.01	0.0082
M	0.21	0.29	1.44	0.006	0.014	0.65	0.03	0.03	0.009	0.51	<0.01	0.0096

Table 2 Material specification used for the irradiation experiment.

1) Material
A533 Gr. B cl. 1, Production form: plate 200 mm^t

2) Heat treatment

Alloy L:		Alloy M:	
Normalizing	970℃ x 7.0h (AC)	Normalizing	920℃ x 7.0h (AC)
Tempering	660℃ x 7.0h (AC)	Tempering	660℃ x 7.0h (AC)
Quenching	900℃ x 7.0h (WQ)	Quenching	900℃ x 7.0h (WQ)
Tempering	660℃ x 5.0h (AC)	Tempering	660℃ x 5.0h (AC)
SR	600℃ x 25h (*)	SR	600℃ x 25h (*)

(*) Heating and cooling rate 50℃/h max.

3) Microstructure
bainite

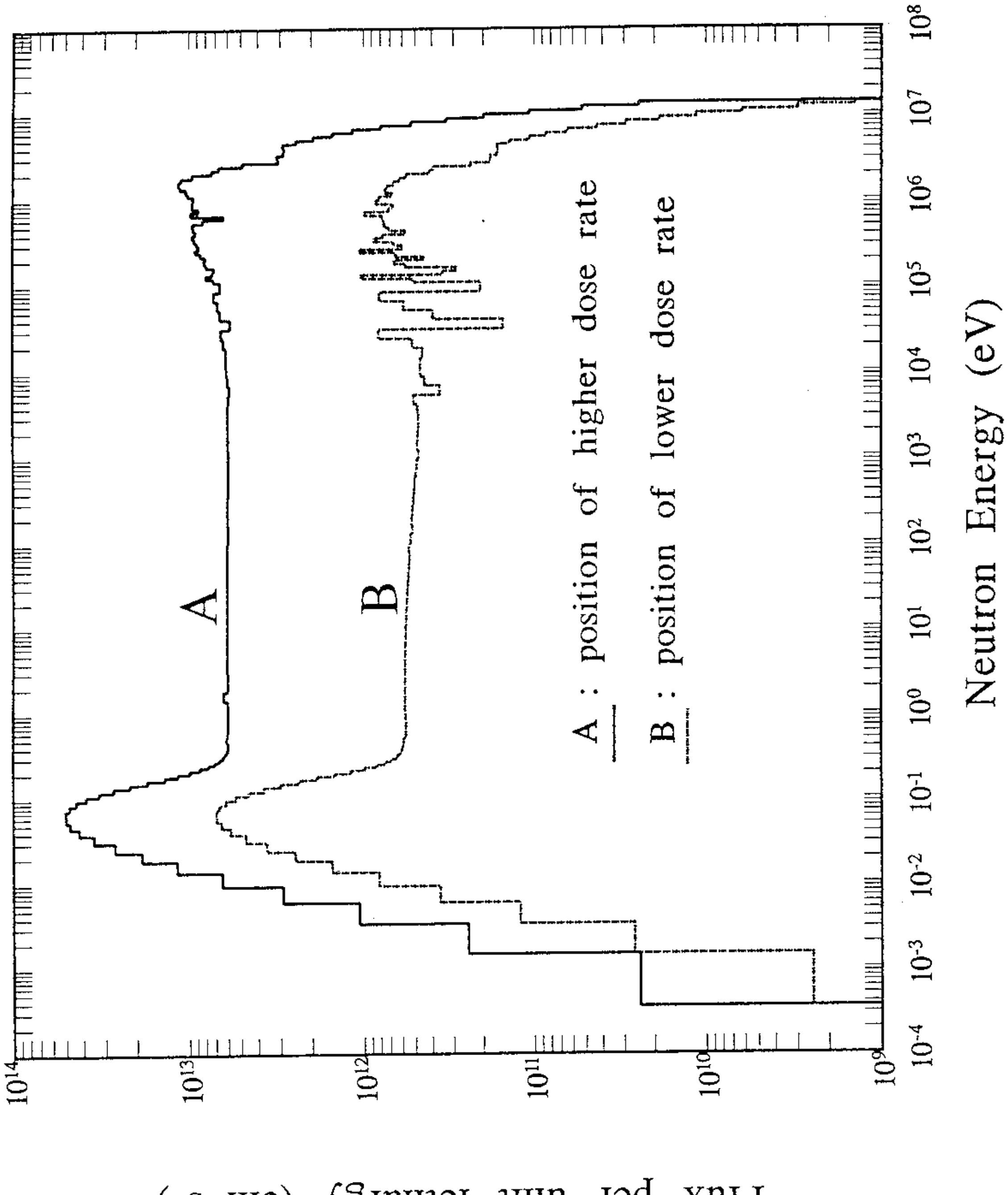
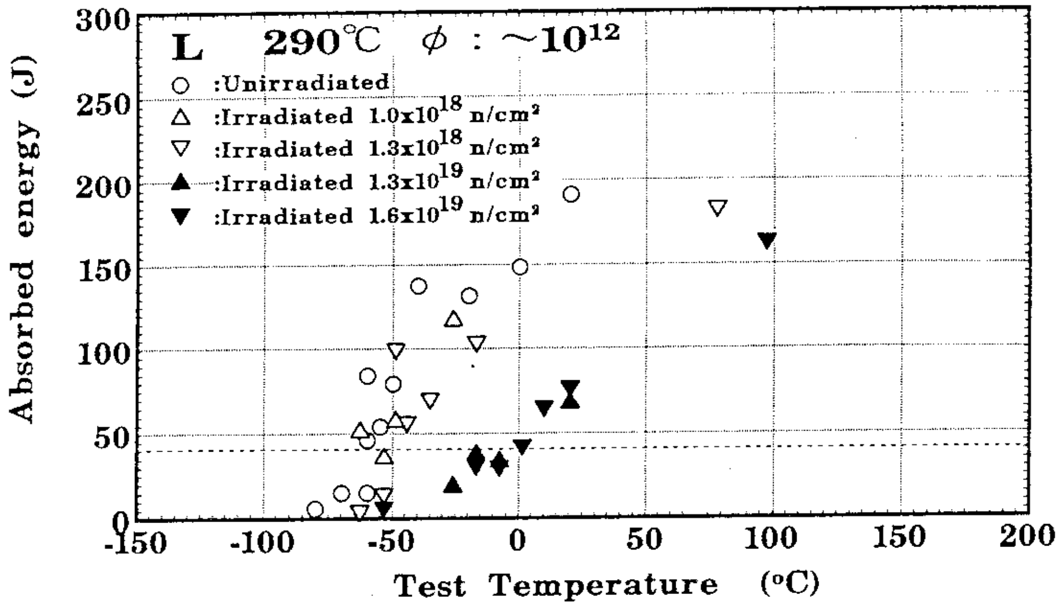


Fig. 1 Neutron energy spectra for positions A (higher dose rate) and B (lower dose rate).



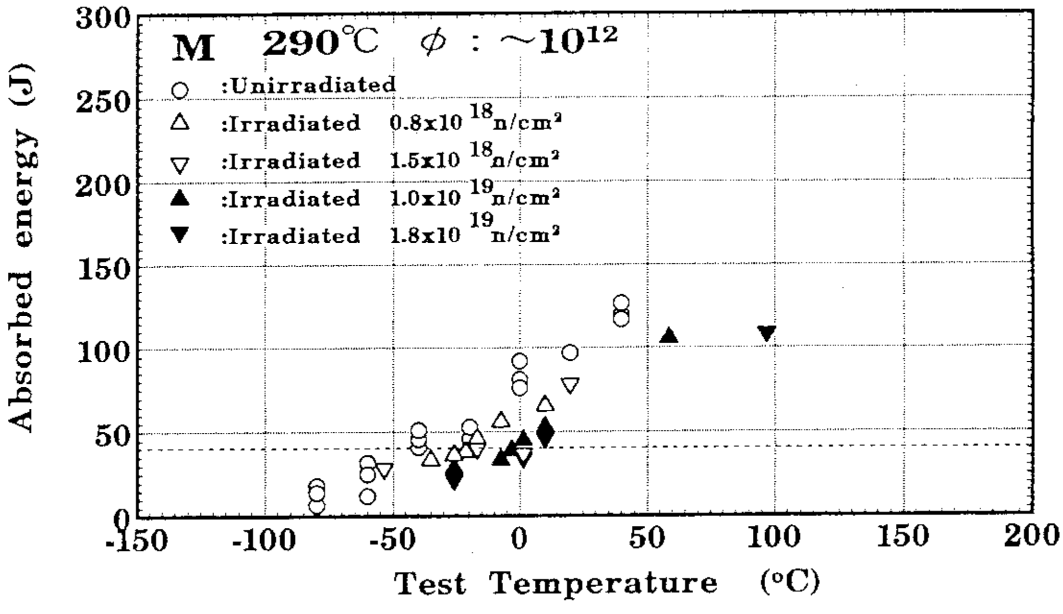


Fig. 2 Absorbed energy transition curves before and after irradiation to 1×10^{18} and 2×10^{19} n/cm² (E>1MeV) at 290℃ for the alloys L and M.

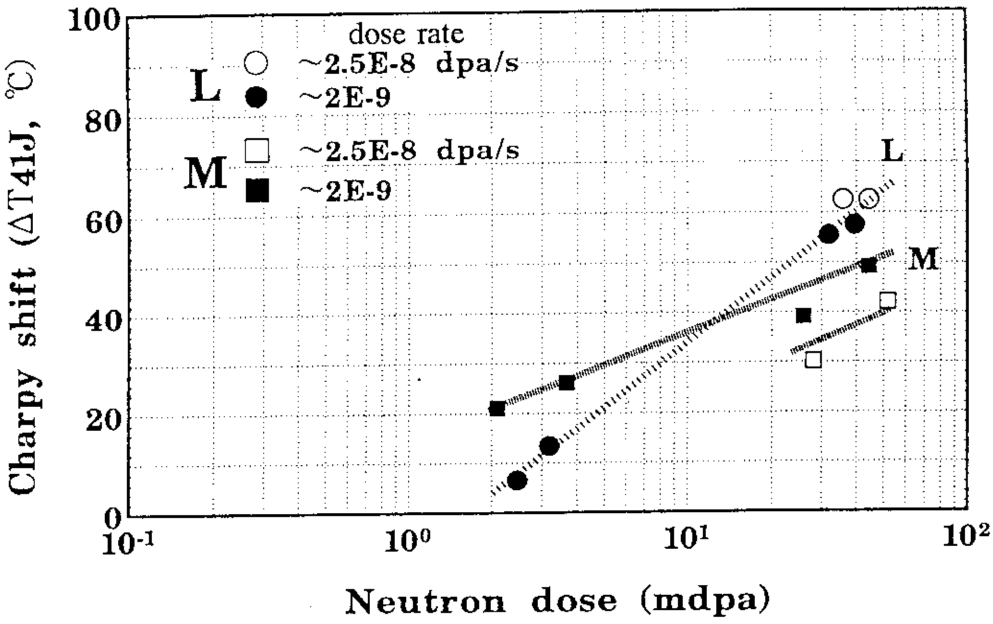


Fig. 3 Charpy shift (ΔT_{41J}) as a function of dose (dpa).

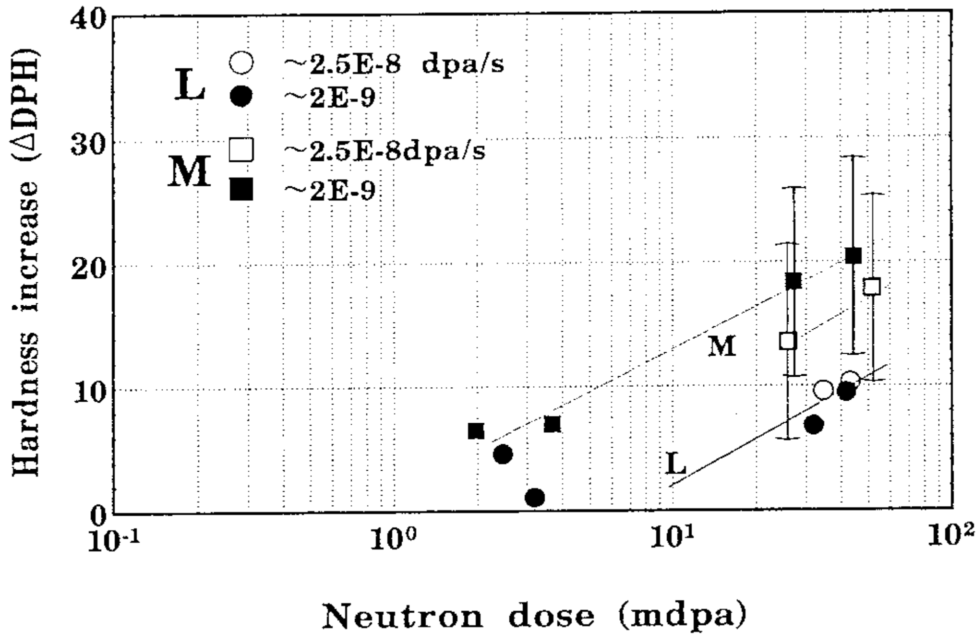


Fig. 4 Hardness increase (ΔDPH) as a function of dose (dpa).

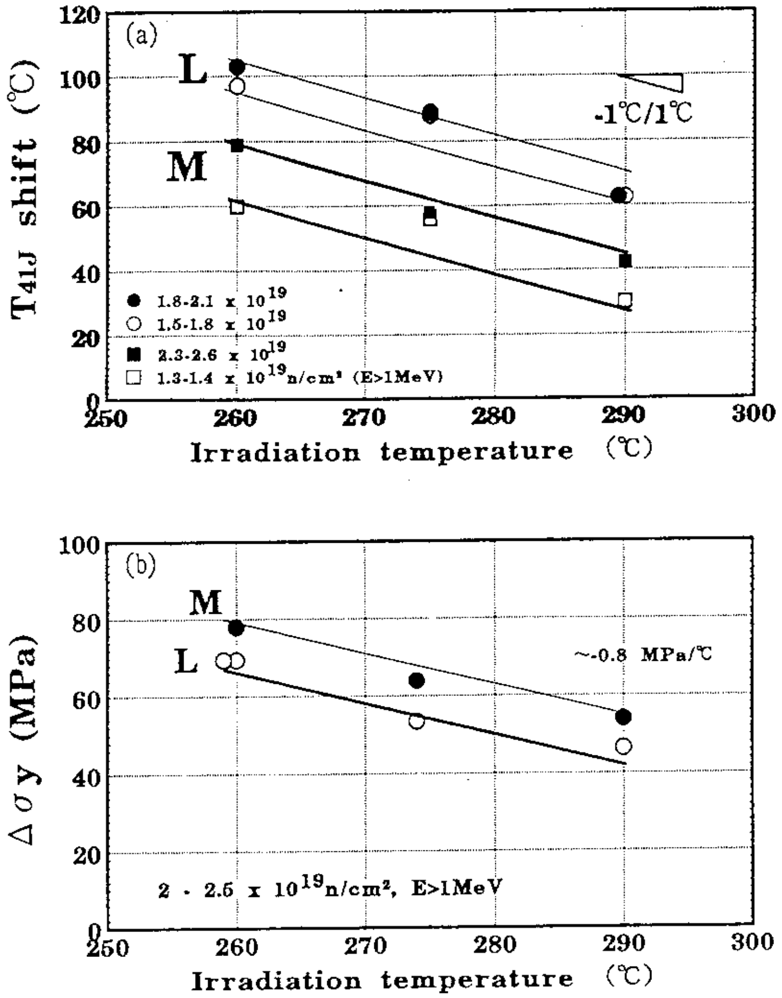


Fig. 5 Effects of irradiation temperature on (a) transition temperature shift and (b) yield stress increase, after irradiation to $\sim 2\times 10^{19}$ n/cm^2 (E>1MeV).

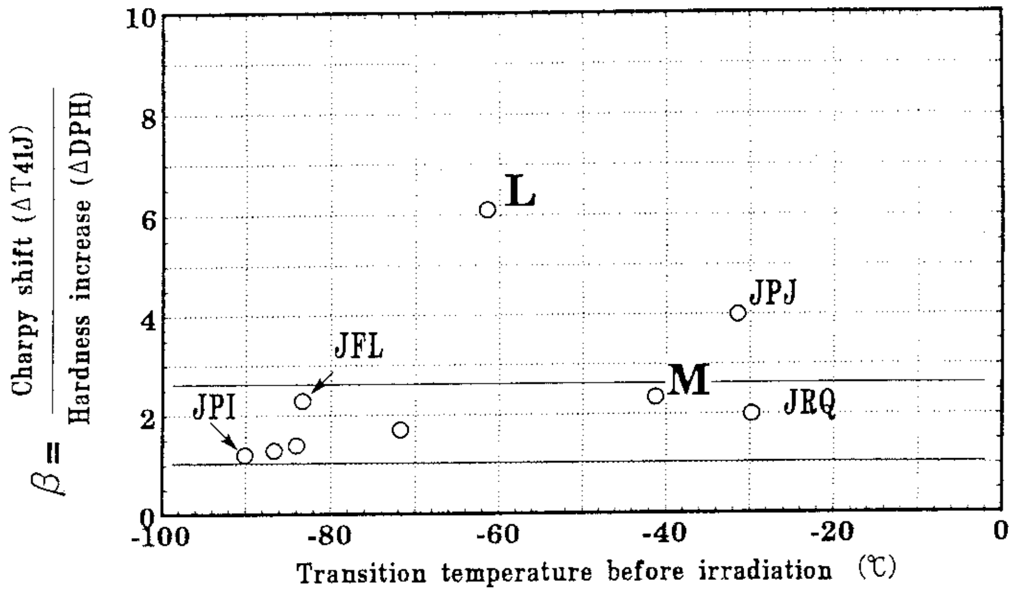


Fig. 6 Ratio of $\Delta T_{41J}/\Delta DPH$ (= β) for the alloys L, M and the IAEA heavy section steels.

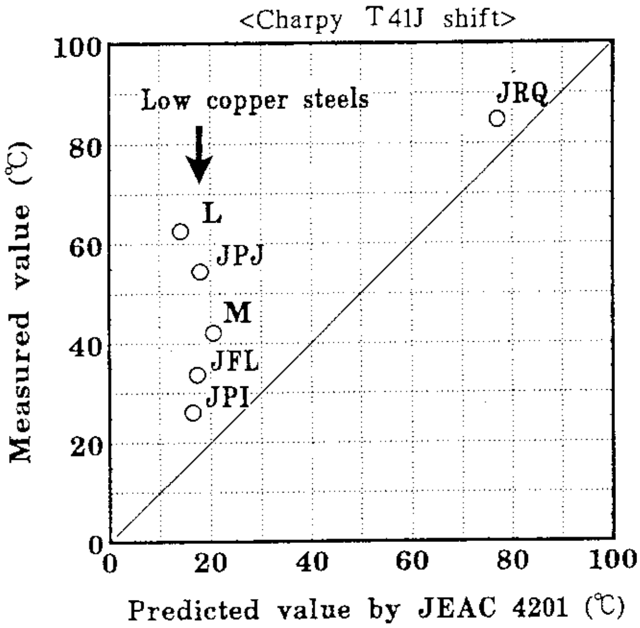


Fig. 7 Comparison of measured and predicted Charpy T_{41J} shift.

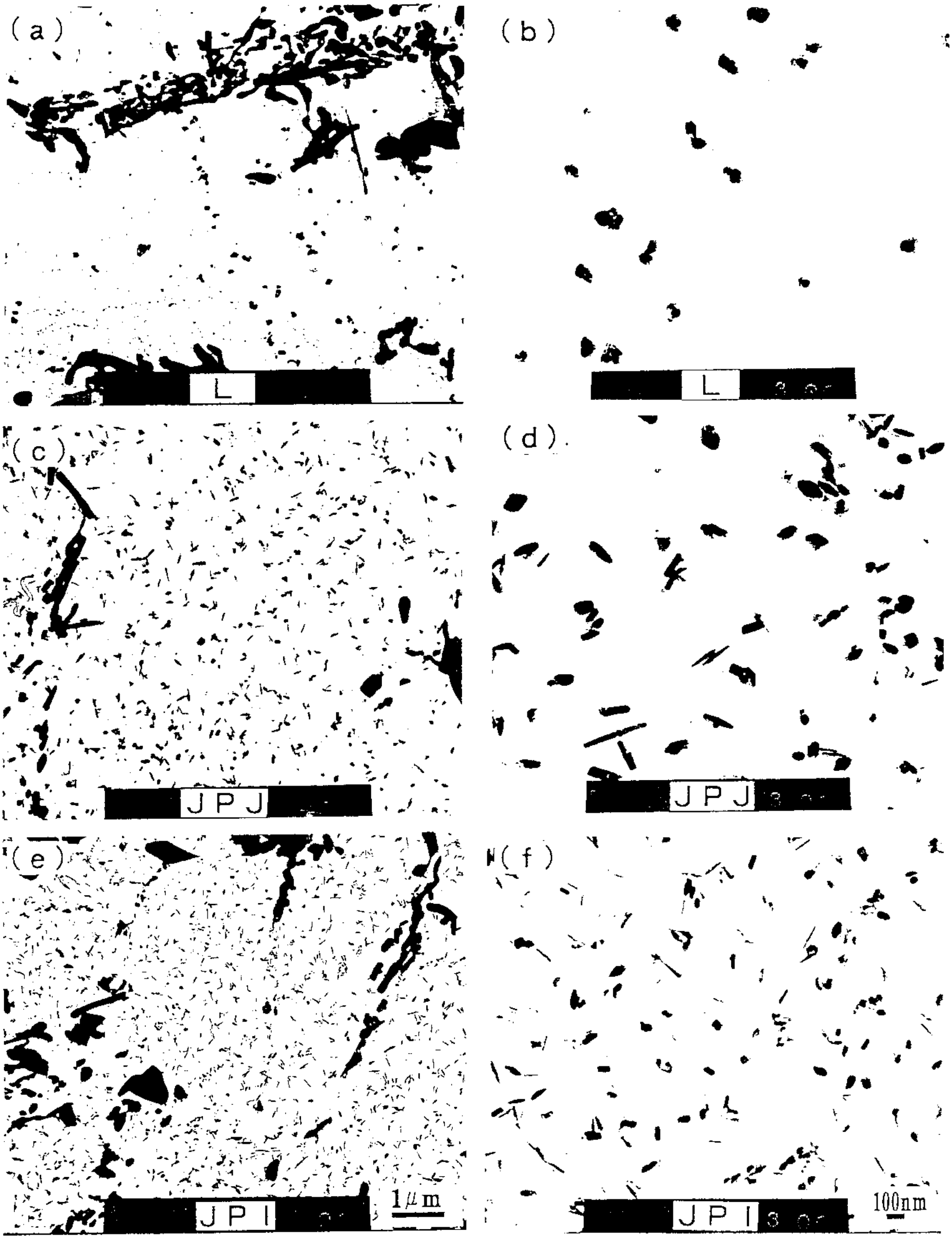


Fig. 8 Carbide distribution for the alloy L (a, b), JPJ (c, d) and JPI (e, f) observed by TEM for carbon extraction replicas. Large ones are M_3C and others M_2C.

Appendices

-Mechanical Property Test Data Relating to the Present Report-

Contents (List of Figures and Tables, and pages)

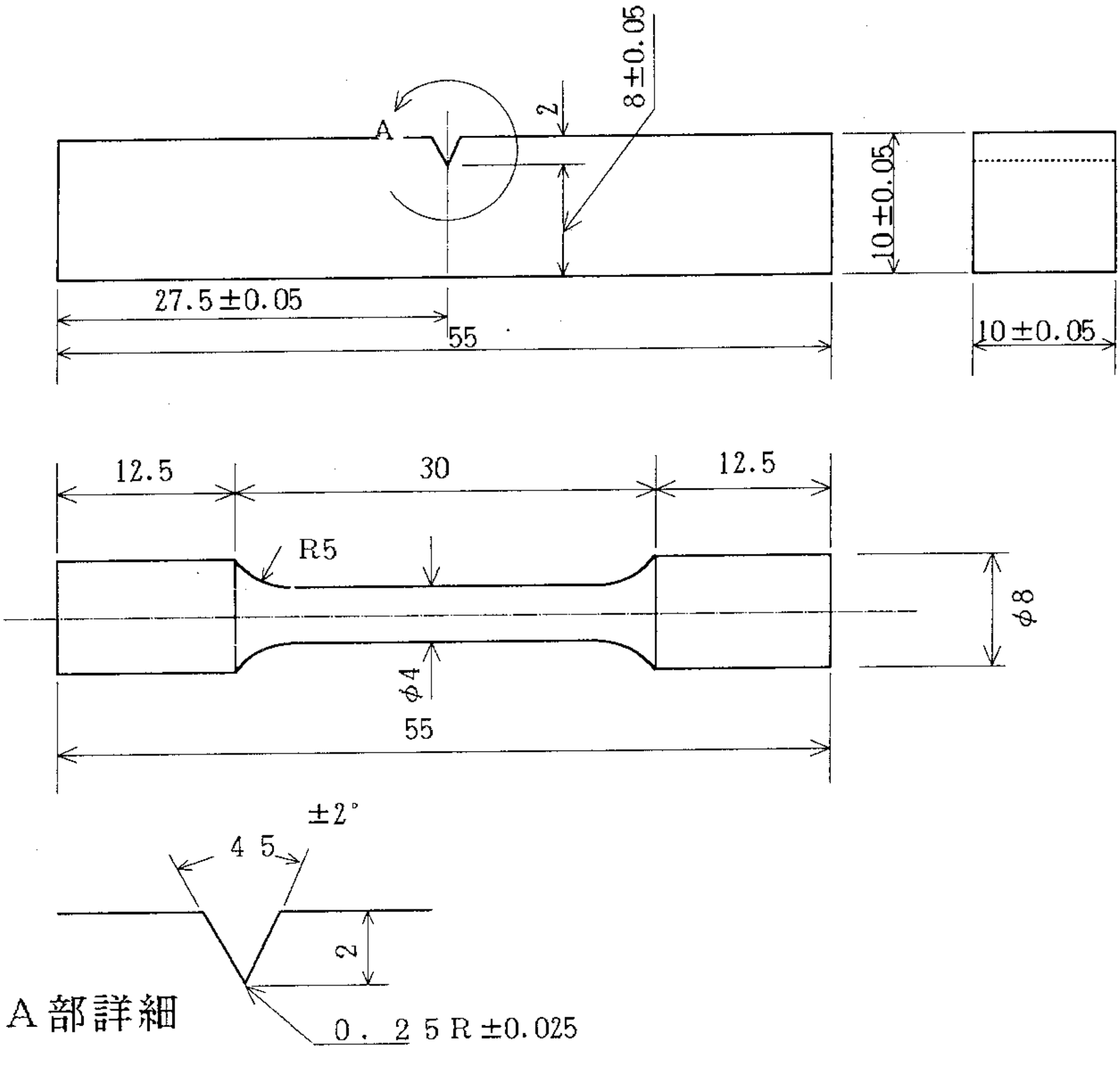


Fig. A-1 Configurations of Charpy and tensile test specimens

Table A-1 Charpy impact test results-1

533 Gr. B Cl. 1, Material L

Material condition	Irradiation Condition			41J Transition temperature ℃
	Irradiation Temperature ℃	Estimated fluence n/cm^2 E>1MeV	Estimated flux $n/cm^2/s$ E>1MeV	
as received	—	—	—	-61.5
irradiated (534h)	290±2	1.0×10^{18}	5.2×10^{11}	-55
irradiated (534h)	290±2	$1.2\text{-}1.4 \times 10^{18}$	$6.2\text{-}7.3 \times 10^{11}$	-48
irradiated (5301h)	290±2	1.3×10^{19}	6.8×10^{11}	-6
irradiated (5301h)	290±2	$1.5\text{-}1.7 \times 10^{19}$	$7.9\text{-}8.9 \times 10^{11}$	-4
irradiated (525h)	290±8	1.6×10^{19}	8.5×10^{12}	1
irradiated (525h)	290±10	$1.9\text{-}2.2 \times 10^{19}$	$1.0\text{-}1.2 \times 10^{13}$	1

Table A-2 Charpy impact test results-2

533 Gr. B Cl. 1, Material M

Material condition	Irradiation Condition			41J Transition temperature ℃
	Irradiation Temperature ℃	Estimated fluence n/cm² E>1MeV	Estimated flux n/cm²/s E>1MeV	
as received	—	—	—	-41.2
irradiated (534h)	290	0.8-0.9X10^{18}	4.2-4.7 x10^{11}	-20
irradiated (534h)	290	1.5 x 10^{18}	7.8x10^{11}	-15
irradiated (5301h)	290±2	1.0-1.1x10^{19}	5.2-5.8 x10^{11}	-2
irradiated (5301h)	290±2	1.8 x 10^{19}	9.4x10^{11}	8
irradiated (525h)	294±4	1.2-1.4X10^{19}	6.3-7.4 x10^{12}	-11
irradiated (525h)	290±7	2.4 X 10^{19}	1.3x10^{13}	1

Table A-3 Charpy impact test results-3
(Temperature effect)
533 Gr.B Cl.1, Material L

Material condition	Irradiation Condition			41J Transition temperature ℃
	Irradiation Temperature ℃	Estimated fluence n/cm^2 E>1MeV	Estimated flux n/cm^2/s E>1MeV	
as received	—	—	—	-68
irradiated (529h)	275±5	1.5-1.6x10^{19}	7.9 - 8.4 x10^{12}	20
irradiated (529h)	275±5	1.8-1.9x10^{19}	9.5- 10.0 x10^{12}	21
irradiated (530h)	260±5	1.7-1.8x10^{19}	8.9- 9.4 x10^{12}	29
irradiated (530h)	260±10	2.0-2.2x10^{19}	10.5-11.5 x10^{12}	35

533 Gr.B Cl.1, Material M

Material condition	Irradiation Condition			41J Transition temperature ℃
	Irradiation Temperature ℃	Estimated fluence n/cm^2 E>1MeV	Estimated flux n/cm^2/s E>1MeV	
as received	—	—	—	-40
irradiated (529h)	275±3	1.25 - 1.4 x10^{19}	6.6 - 7.4 x10^{12}	16
irradiated (529h)	275±5	2.25 x10^{19}	11.8 x10^{12}	18
irradiated (530h)	260±3	1.35 - 1.45 x10^{19}	7.1 - 7.6 x10^{12}	20
irradiated (530h)	260±10	2.6 x 10^{19}	13.6 x10^{12}	39

Table A-4 Charpy tests data sheet-1

Material	:	533 Gr. B Cl. 1
Heat	:	L
Material condition	:	as received
comments	:	V-notch was made by wire cut
Tests performed by	:	Kobe Material Testing Laboratory ('94.2)

Specimen number	Test Temperature (℃)	Absorbed energy (J)	Lateral exapnsion (mm)	Fibrosity (%)
L49	0	148	1.87	70
L50	20	191	2.17	100
L51	-20	131	1.68	55
L52	-40	137	1.79	45
L53	-60	15	0.12	10
L54	-80	6	0.03	0
L55	-60	46	0.53	15
L56	-50	103	1.39	35
L57	-70	15	0.40	10
L58	-50	79	1.03	30
L59	-55	54	0.69	15
L60	-60	84	1.11	30

Table A-5 Charpy tests data sheet-2

Material	:	533 Gr. B Cl. 1
Heat	:	L
Material condition	:	as received
comments	:	V-notch was made by flice / projecter grinding
Tests performed by	:	Kobe Material Testing Laboratory ('94. 2)

Specimen number	Test Temperature (℃)	Absorbed energy (J)	Lateral exapnsion (mm)	Fibrosity (%)
L99	0	134	1. 84	60
L100	20	196	2. 35	100
L101	-20	112	1. 48	50
L102	-40	103	1. 41	35
L103	-60	59	0. 78	20
L104	-80	11	0. 02	0
L105	-70	42	0. 50	15
L106	-50	90	1. 21	30
L107	-80	21	0. 16	0
L108	-60	54	0. 69	30
L109	-70	56	0. 71	20
L110	-65	39	0. 47	10

Table A-6 Charpy tests data sheet-3

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 90M-3A $\phi \sim 10^{12}$
Tests performed by :	Tokai Hot Laboratory ('92. Hot Labo #319)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}$ n/cm² E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
L23	290	0.10	-55/ -49.0	56.8	0.80	10
L24	290	0.10	-70/ -62.7	51.0	0.78	5
L25	289	0.10	-30/ -26.1	116.6	1.61	40
L26	289	0.12	-60/ -53.5	14.7	0.220	0
L27	290	0.13	-70/ -62.7	4.9	0.005	0
L28	290	0.13	-20/ -16.9	103.9	1.555	30
L29	289	0.12	-40/ -35.2	70.6	1.015	15
L30	289	0.14	-55/ -49.0	100.0	1.405	30
L31	289	0.14	80/ 77.8	183.3	2.335	100
L32	290	0.10	-60/-53.5	35.3	0.505	5
L33	290	0.12	-50/ -44.4	56.8	0.845	10

Table A-7 Charpy tests data sheet-4

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
Tests performed by:	Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
L12	289+	1.3	20/ 20	67.6	1.09	20
L13	289+	1.3	-10/ -7.7	33.3	0.555	10
L14	292-α	1.3	-30/ -26.1	18.6	0.300	5
L15	292	1.5	-10/ -7.7	30.4	0.480	10
L16	290-α	1.6	-60/ -53.5	6.9	0.085	0
L17	289-	1.6	-20/ -16.9	31.4	0.500	5
L18	290-	1.5	10/ 10	65.7	0.895	20
L19	290	1.7	0/ 1.4	43.1	0.680	10
L20	290	1.7	100/ 97.0	163.7	2.240	100
L21	290.5	1.3	-20/-16.9	37.2	0.595	10
L22	290.5+	1.5	20/ 20	77.4	1.210	20

Table A-8 Charpy tests data sheet-5

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
Tests performed by:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
L1	298	1.6	20/ 20	70.4	1.06	20
L2	298	1.6	-10/ -7.7	29.2	0.545	5
L3	279-α	1.6	0/ 1.4	41.8	0.53	10
L4	279	1.9	0/ 1.4	40.5	0.645	10
L5	295-α	2.0	-60/ -53.5	5.3	0.01	0
L6	283	2.0	-20/ -16.9	13.7	0.23	5
L7	298	1.9	10/ 10	56.6	0.735	15
L8	298+α	2.2	60/ 58.7	138.5	1.86	80
L9	298+α	2.2	100/ 97.0	164.0	2.175	100
L10	281	1.6	-20/-16.9	30.9	0.465	5
L11	281+α	1.9	20/ 20	65.1	1.07	20

Table A-9 Charpy tests data sheet-6

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	as received
comments :	V-notch was made by wire cut
Tests performed by :	Kobe Material Testing Laboratory (' .)

Specimen number	Test Temperature (℃)	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
MW10	-80	7	0.07	0
MW11	-80	18	0.25	5
MW12	-80	14	0.22	0
MW7	-60	12	0.20	10
MW8	-60	32	0.54	10
MW9	-60	25	0.39	10
MW19	-40	41	0.63	25
MW20	-40	46	0.72	20
MW21	-40	51	0.79	25
MW16	-20	46	0.80	35
MW17	-20	53	0.94	35
MW18	-20	53	0.83	35
MW13	0	81	1.37	60
MW14	0	76	1.33	55
MW15	0	92	1.36	60
MW1	20	97	1.64	80
MW2	20	97	1.59	75
MW3	20	97	1.47	75
MW4	40	120	1.95	95
MW5	40	117	1.82	100
MW6	40	127	1.97	100

Table A-10 Charpy tests data sheet-7

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	as received
comments :	V-notch was made by flice projector grinding
Tests performed by :	Kobe Material Testing Laboratory (' .)

Specimen number	Test Temperature (℃)	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
MP10	-80	22	0.32	10
MP11	-80	22	0.34	10
MP12	-80	16	0.24	5
MP7	-60	25	0.41	15
MP8	-60	32	0.48	15
MP9	-60	22	0.35	15
MP19	-40	36	0.58	25
MP20	-40	46	0.71	25
MP21	-40	36	0.63	25
MP16	-20	46	0.78	40
MP17	-20	48	0.91	35
MP18	-20	61	1.07	40
MP13	0	83	1.32	55
MP14	0	51	0.92	45
MP15	0	71	1.17	50
MP1	20	103	1.63	80
MP2	20	120	1.85	95
MP3	20	106	1.58	80
MP4	40	125	1.83	100
MP5	40	123	1.82	100
MP6	40	125	1.89	100

Table A-11 Charpy tests data sheet-8

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 90M-3A $\phi \sim 10^{12}$
Tests performed by :	Tokai Hot Laboratory ('92. Hot Labo #319)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
M22	290	0.08	-40/ -35.2	33.3	0.525	5
M23	290	0.15	-20/ -16.9	40.2	0.68	10
M24	290	0.15	-60/ -53.5	28.4	0.44	5
M25	290	0.15	0/ 1.4	37.2	0.735	20
M27	290	0.08	-25/ -21.5	38.2	0.73	10
M28	290	0.09	-30/ -26.1	36.3	0.615	5
M30	290	0.09	10/ 10	65.7	1.1	30
M42	290	0.08	-20/ -16.9	46.1	0.79	10
M43	290	0.15	20/ 20	78.4	1.325	50
M44	290	0.08	-10/ -7.7	55.9	0.96	20

Table A-12 Charpy tests data sheet-9

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
Tests performed by:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
M1	298-	1.4	-50/ -44.4	6.9	0.09	0
M2	298-	1.4	-35/ -30.6	26.5	0.44	5
M3	295	2.4	0/ 1.4	44.1	0.705	10
M4	295	2.4	-40/ -35.2	20.6	0.4	5
M5	283+ α	2.4	-10/ -7.7	27.4	0.54	5
M6	283+	2.4	100/ 97	112.7	1.92	100
M7	290	1.2	-10/ -7.7	31.4	0.535	10
M8	290+ α	1.4	-30/ -26.1	42.1	0.66	5
M9	290	1.2	-10/ -7.7	48.0	0.845	10
M10	290+	1.4	10/ 10	55.9	0.91	20

Table A-13 Charpy tests data sheet-10

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	Irradiated
comments :	V-notch was made by wire cut
:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
Tests performed by:	Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
M11	289	1.1	-10/ -7.7	33.3	0.58	10
M12	289	1.1	0/ 1.4	45.1	0.79	15
M13	290	1.8	10/ 10	46.1	0.705	15
M14	290	1.8	-30/ -26.1	21.6	0.345	5
M15	289	1.8	0/ 1.4	34.3	0.585	5
M16	289	1.8	100/ 97.0	108.8	1.76	100
M17	290	1.0	-5/ -3.2	39.2	0.655	15
M18	290-	1.1	-30/ -26.1	28.4	0.435	5
M19	290	1.0	60/ 58.7	105.8	1.7	95
M20	290-	1.1	10/ 10	52.9	0.875	10

Table A-14 Charpy tests data sheet-11

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiated
comments :	V-notch was made by flice projecter grinding
:	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
Tests performed by :	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm² E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lareral expansion (mm)	Fibrosity (%)
L65	259±2	1.70	0/ 1.4	24.5	0.345	5
L66	262±2	1.71	30/ 30	41.2	0.6	10
L68	262±2	2.02	-60/ -53.5	3.9	0.02	0
L69	253±2	2.19	0/ 1.4	10.8	0.13	0
L71	267±3	2.17	30/ 30	38.2	0.585	10
L72	267±3	2.57	-15/ -12.3	13.7	0.11	5
L73	261±3	2.03	100/ 97	131.3	1.975	100
L74	261±3	2.40	120/ 116.2	128.4	1.87	100
L75	258±2	1.79	40/ 39.5	47.0	0.73	15
L76	258±2	2.12	40/ 39.5	44.1	0.615	15

Table A-15 Charpy tests data sheet-12

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiated
comments :	V-notch was made by flice projecter grinding
:	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
Tests performed by:	Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm^2 E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
L77	278	1.48	20/ 20	40.2	0.57	15
L78	273	1.49	-60/ -53.5	4.9	0.04	0
L79	273	1.76	0/ 1.4	18.6	0.22	5
L80	270	1.91	-10/ -7.7	17.6	0.23	5
L81	280±2	1.89	120/ 116.2	159.7	2.27	100
L82	280±2	2.24	-60/ -53.5	4.9	0.04	0
L83	272	1.77	30/ 30	47.0	0.7	15
L84	272	2.09	100/ 97	134.3	1.95	100
L85	279	1.56	60/ 58.7	94.1	1.48	30
L86	279	1.85	20/ 20	40.2	0.625	15

Table A-16 Charpy tests data sheet-13

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	Irradiated
comments :	V-notch was made by flice projecter grinding
:	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
Tests performed by :	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm² E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
M62	259±2	1.44	0/ 1.4	36.3	0.6	10
M63	259±2	1.44	-40/ -35.2	24.5	0.25	5
M64	253±2	2.59	0/ 1.4	24.5	0.24	5
M65	253±2	2.59	20/ 20	31.4	0.37	10
M66	267±3	2.57	40/ 39.5	43.1	0.665	15
M67	260±1	1.36	20/ 20	48.0	0.79	20
M68	260±1	1.36	30/ 30	46.1	0.76	20
M69	260±1	1.61	100/ 97	90.2	1.6	100
M70	260±1	1.61	-60/ -53.5	4.9	0.045	0

Table A-17 Charpy tests data sheet-14

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	Irradiated
comments :	V-notch was made by flice projecter grinding
:	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
Tests performed by :	Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen			Charpy Test			
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Temperature (℃) /Corrected	Absorbed energy (J)	Lateral expansion (mm)	Fibrosity (%)
M71	278	1.25	0/ 1.4	31.4	0.43	10
M72	278	1.25	-40/ -35.2	21.6	0.385	5
M73	270	2.26	0/ 1.4	33.3	0.56	10
M74	270	2.26	20/ 20	45.1	0.66	20
M75	280±2	2.24	40/ 39.5	52.9	0.81	30
M76	275	1.19	-60/ -53.5	9.8	0.15	0
M77	275	1.19	120/ 116.2	99.0	1.72	100
M78	275	1.40	20/ 20	41.2	0.69	20
M79	275	1.40	40/ 39.5	70.6	1.215	50

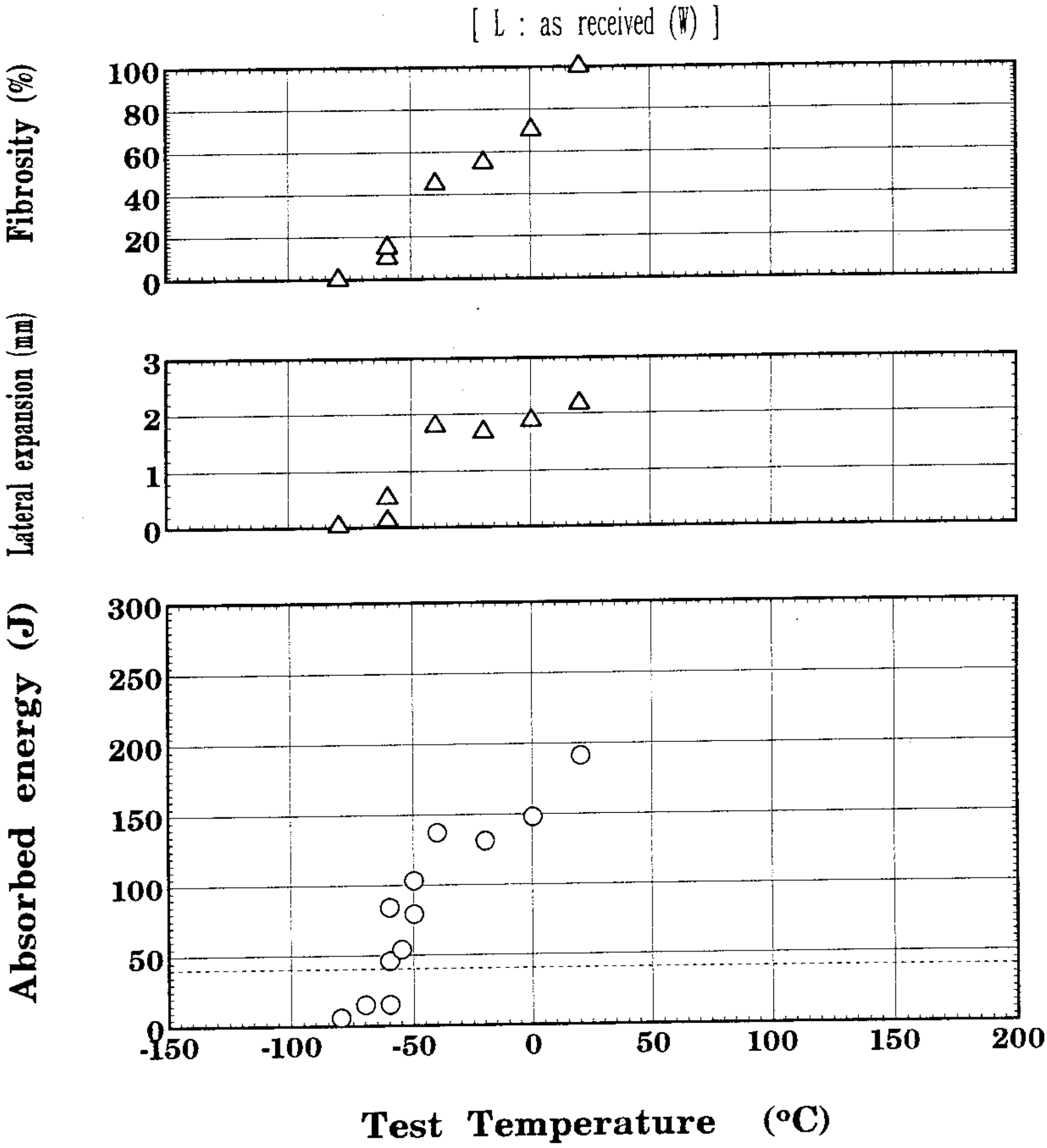


Fig. A-2 Charpy transition curves-1

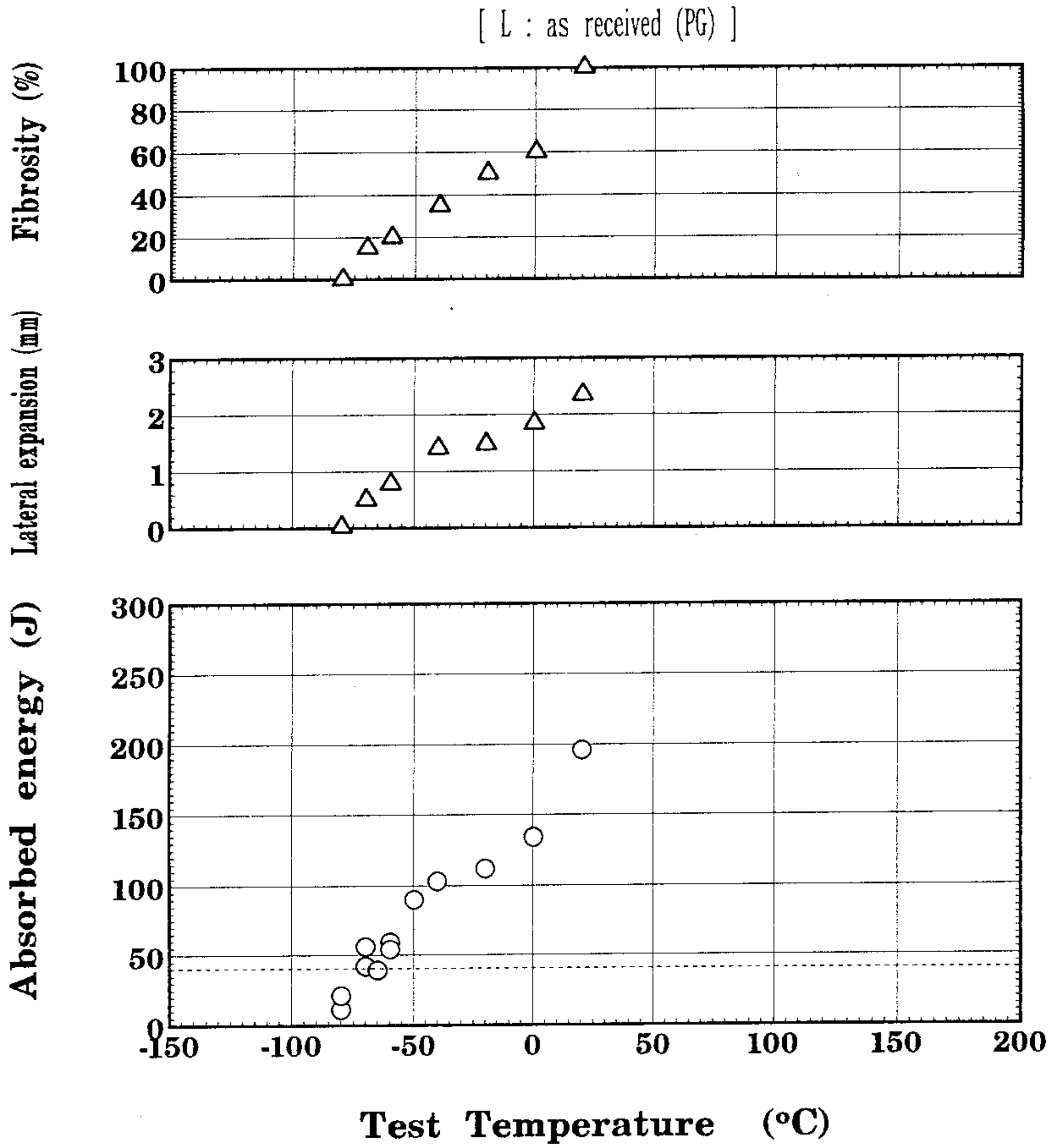


Fig. A-3 Charpy transition curves-2

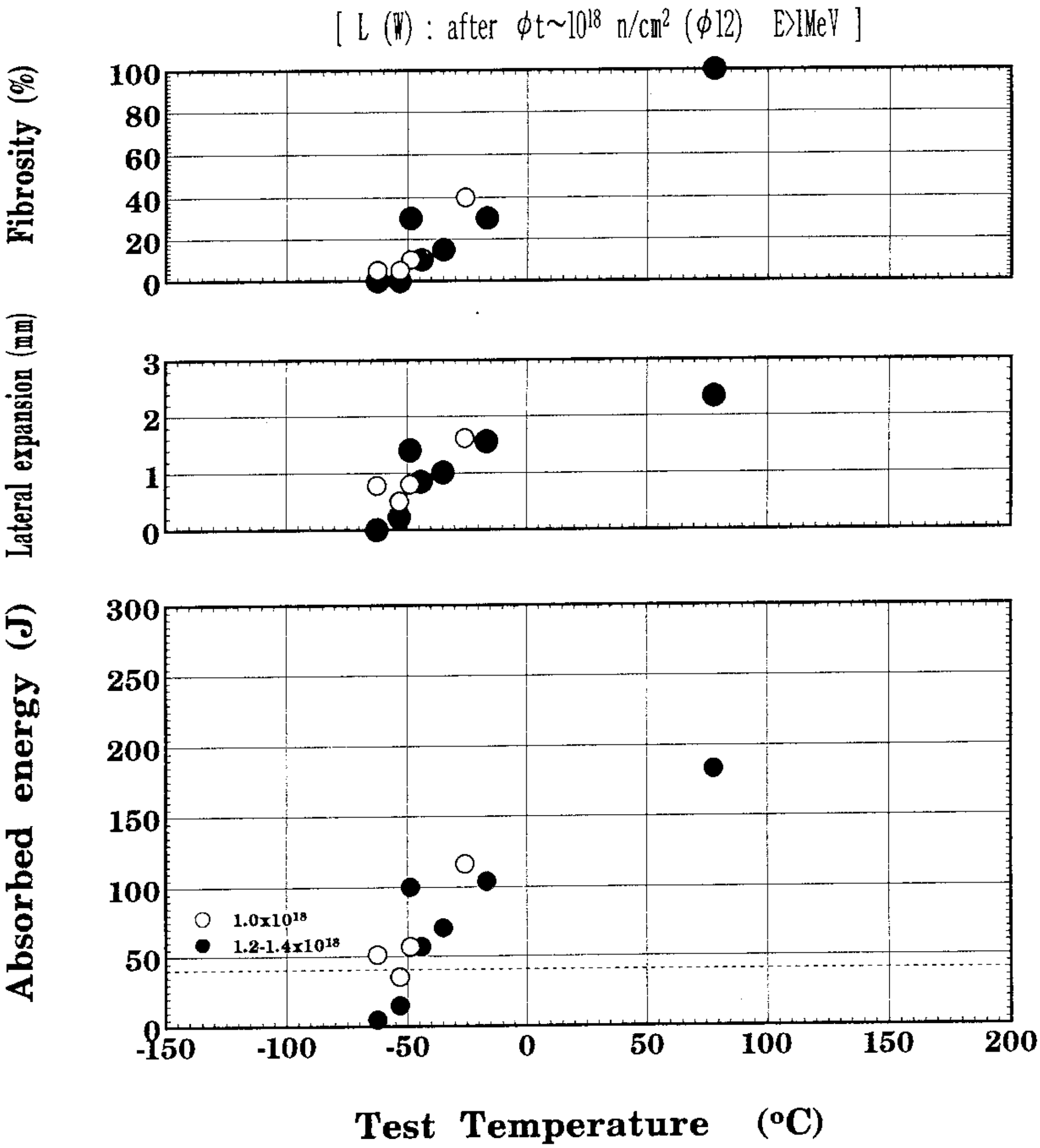


Fig. A-4 Charpy transition curves-3

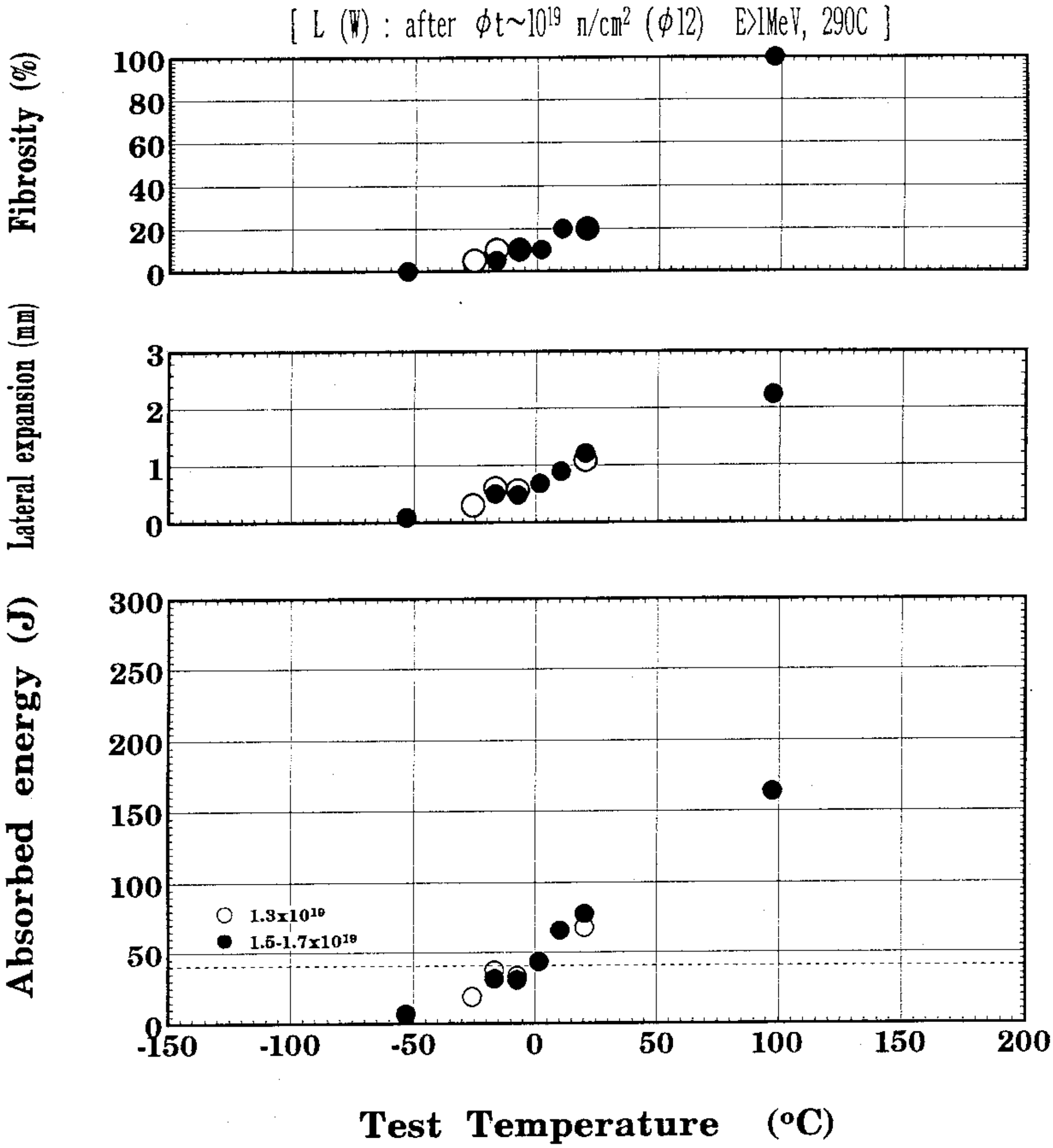


Fig. A-5 Charpy transition curves-4

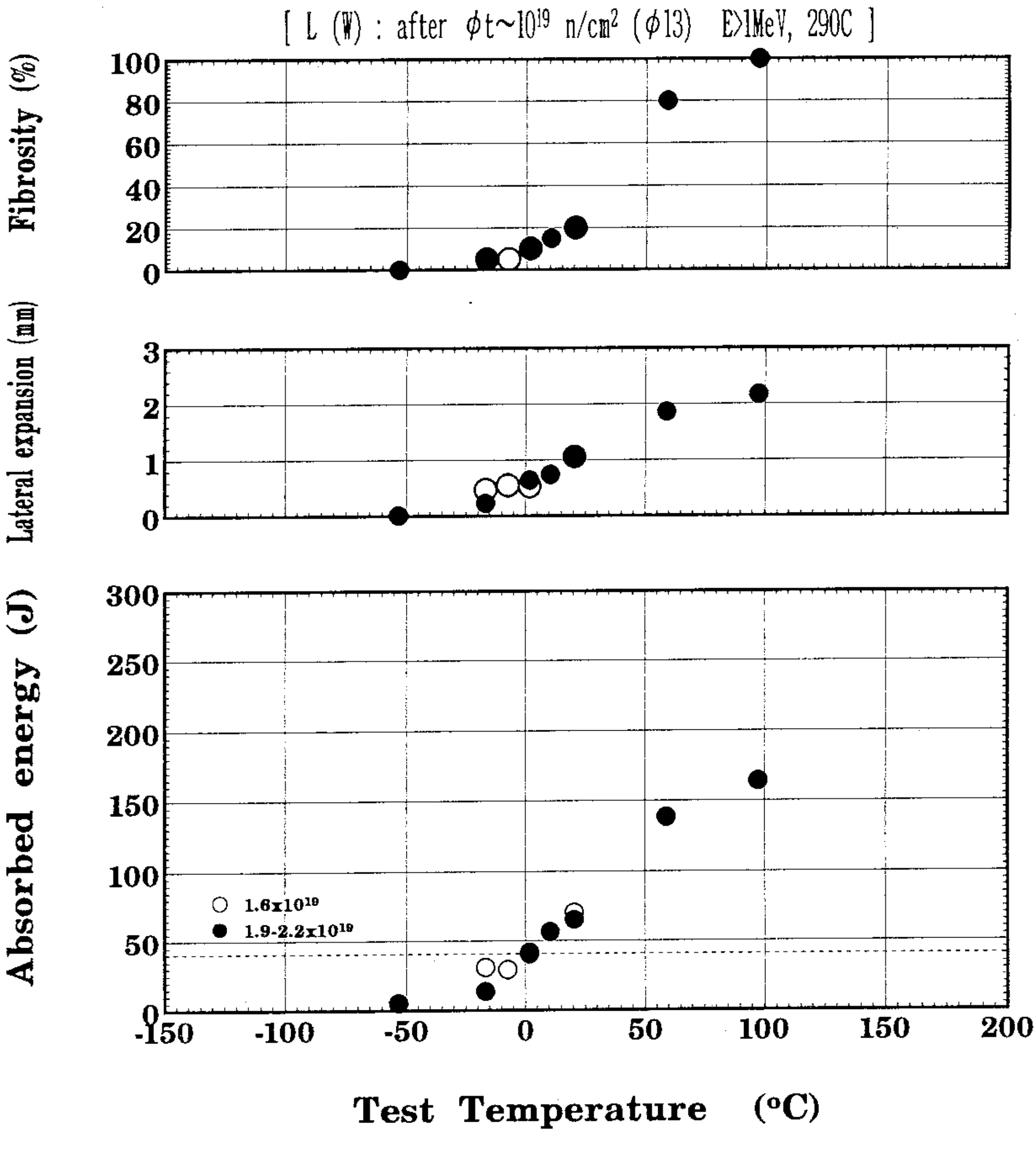


Fig. A-6 Charpy transition curves-5

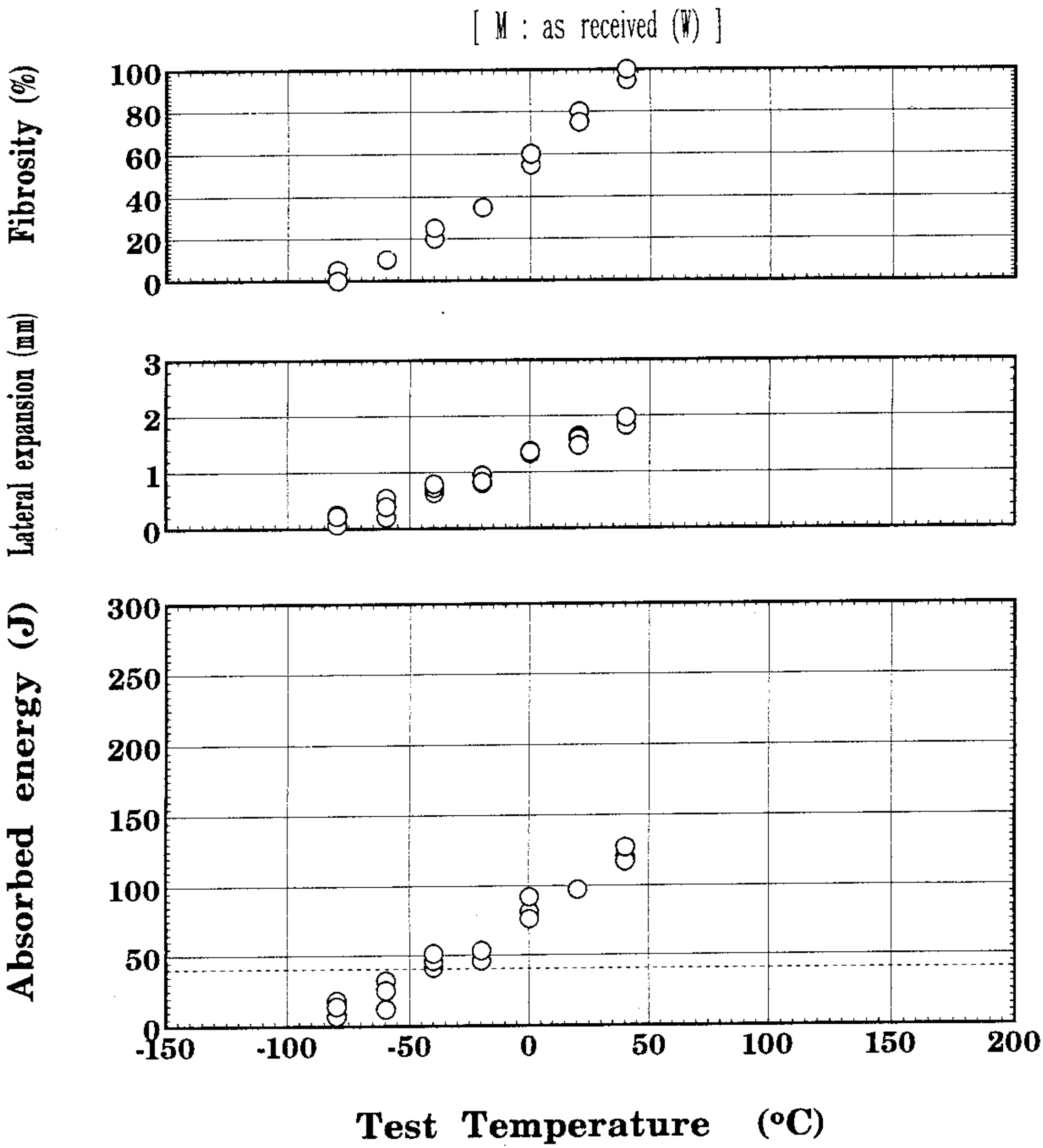


Fig. A-7 Charpy transition curves-6

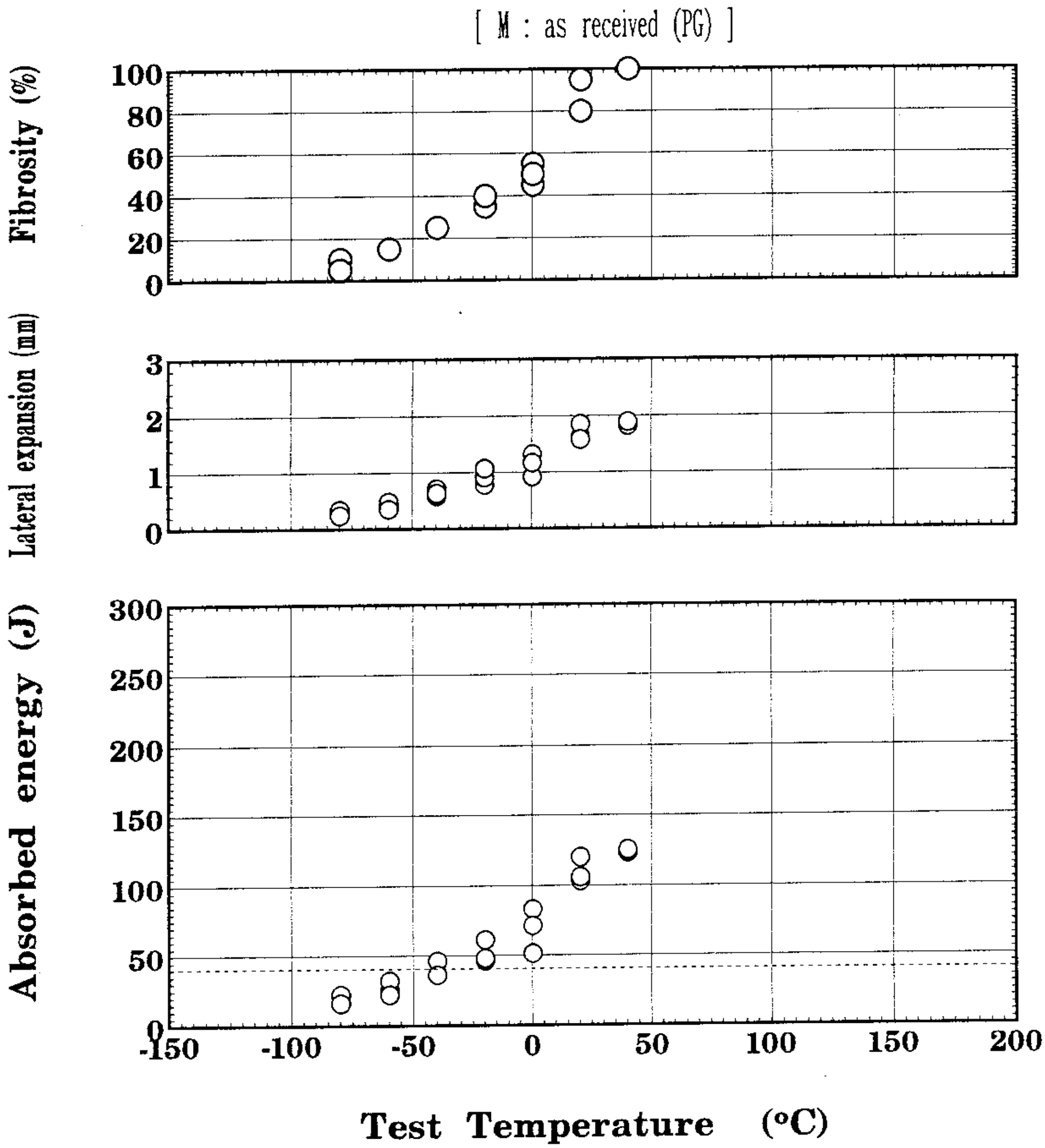


Fig. A-8 Charpy transition curves-7

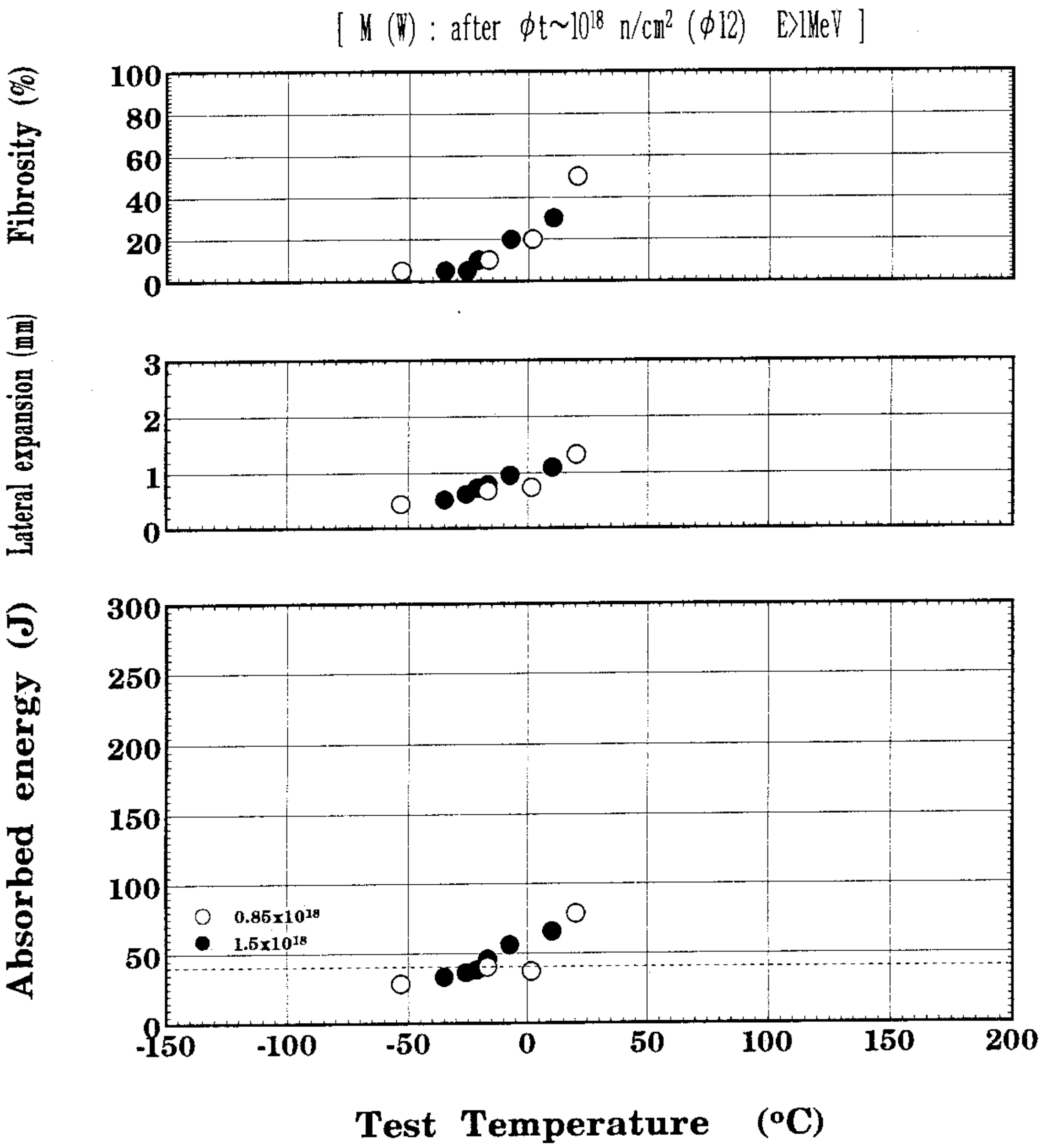


Fig. A-9 Charpy transition curves-8

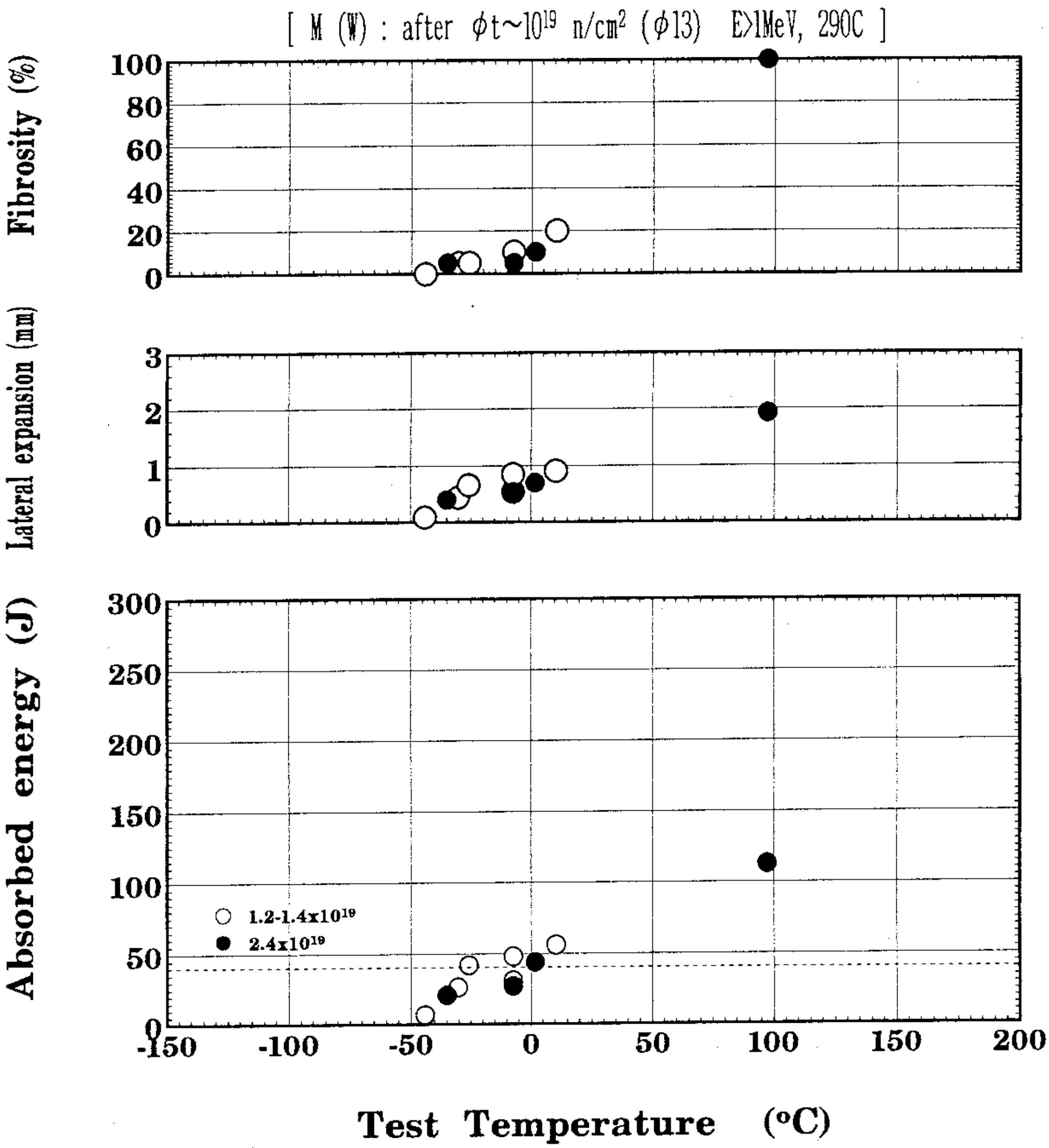


Fig. A-10 Charpy transition curves-9

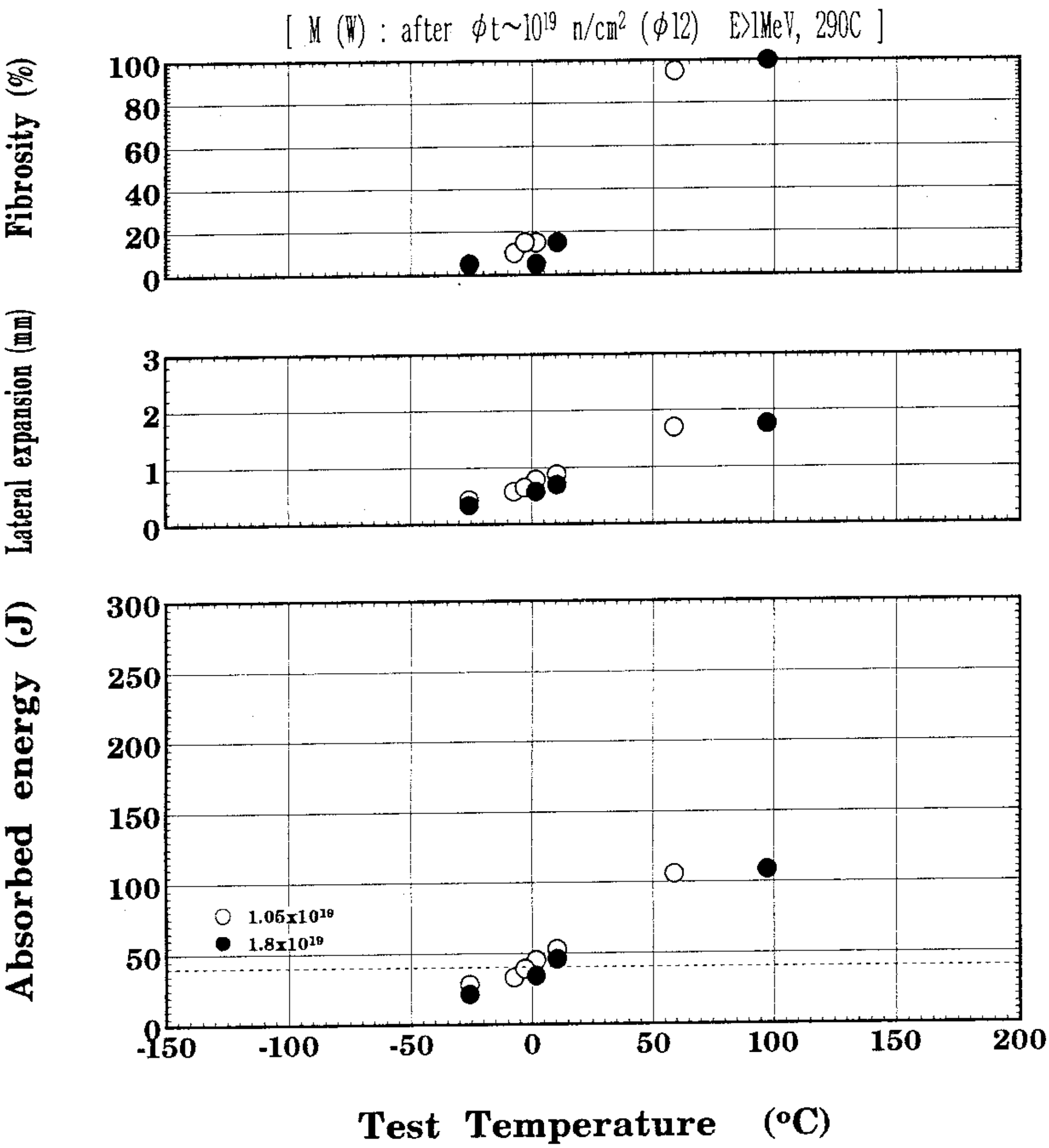


Fig. A-11 Charpy transition curves-10

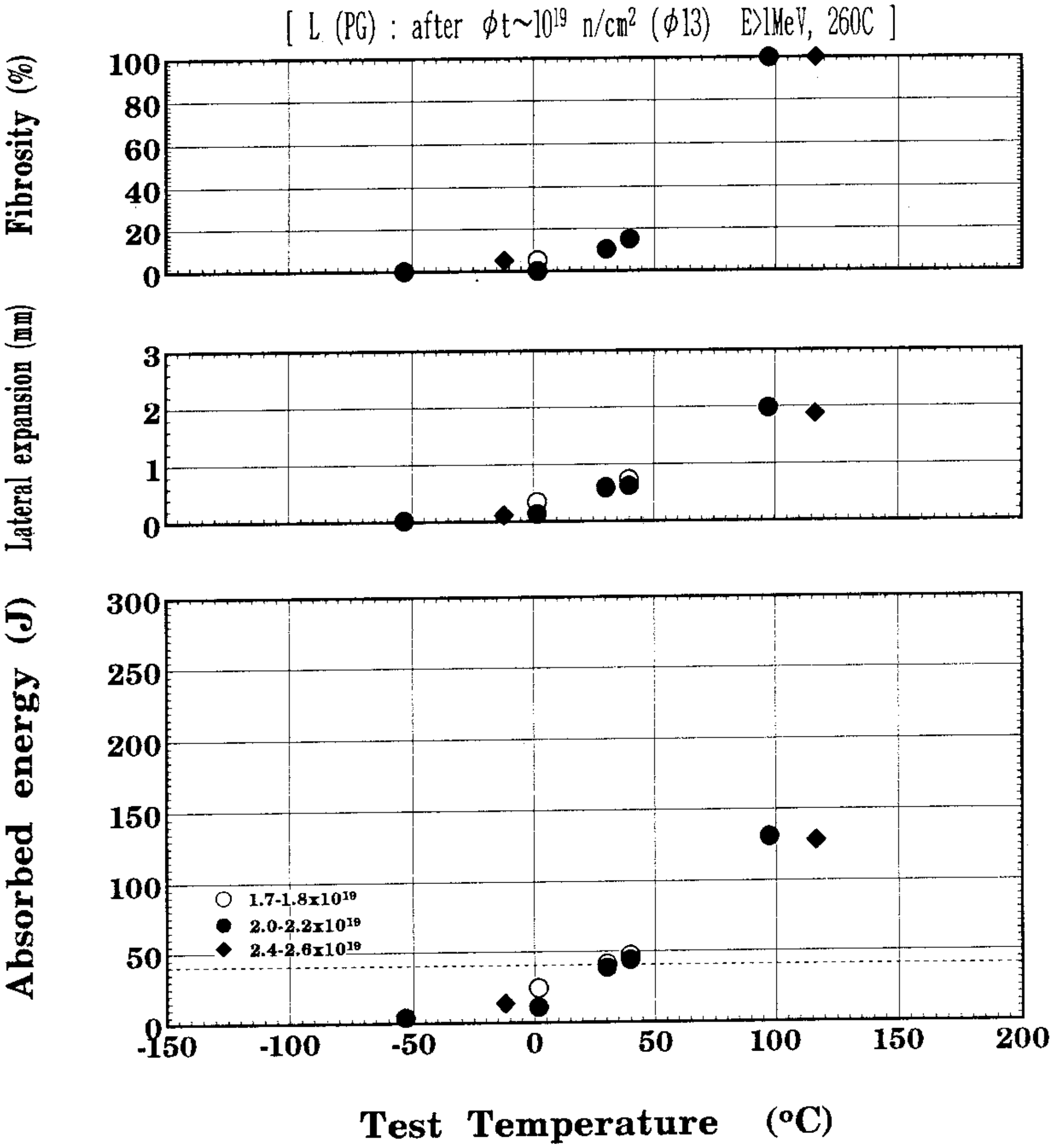


Fig. A-12 Charpy transition curves-11

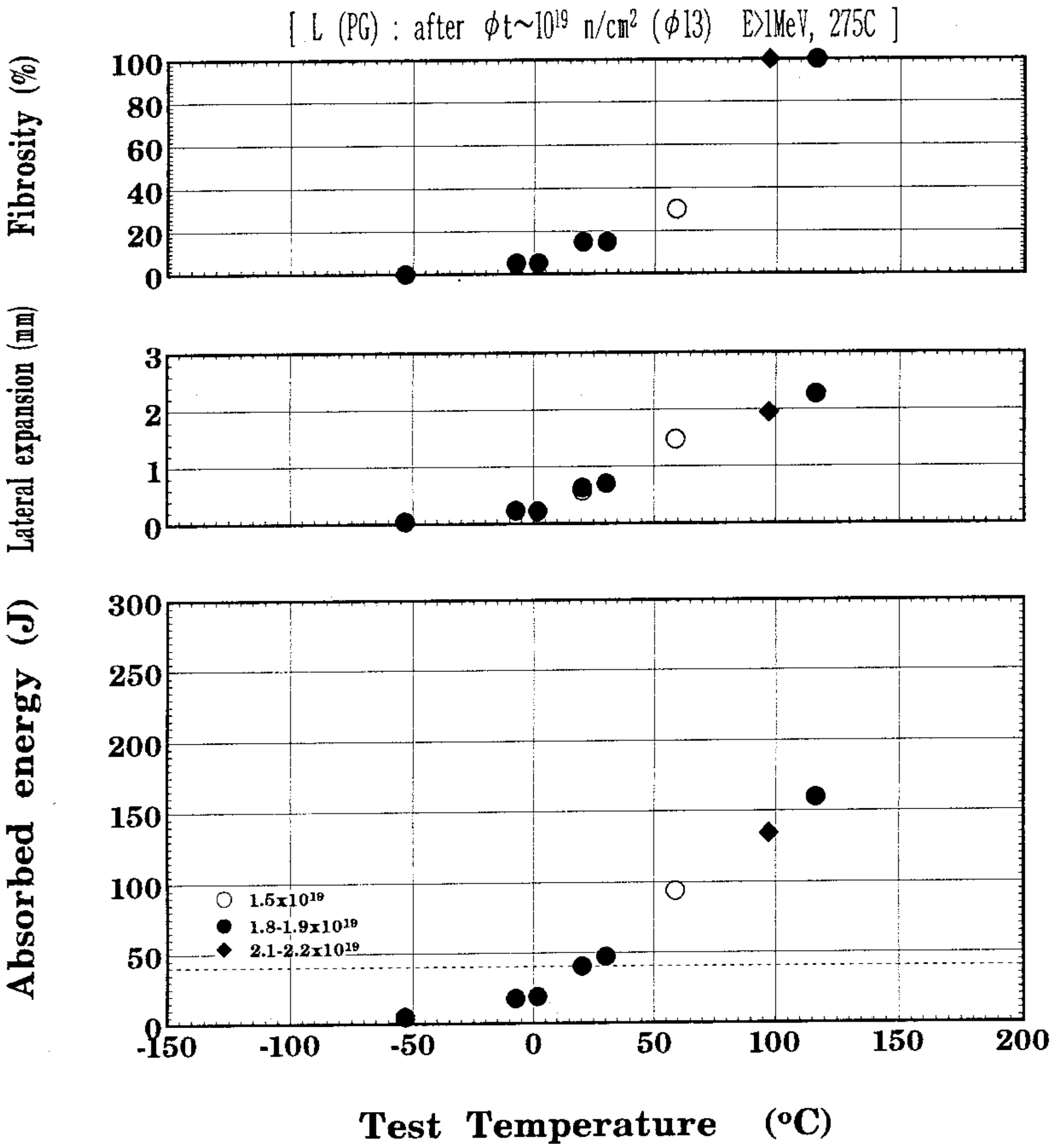


Fig. A-13 Charpy transition curves-12

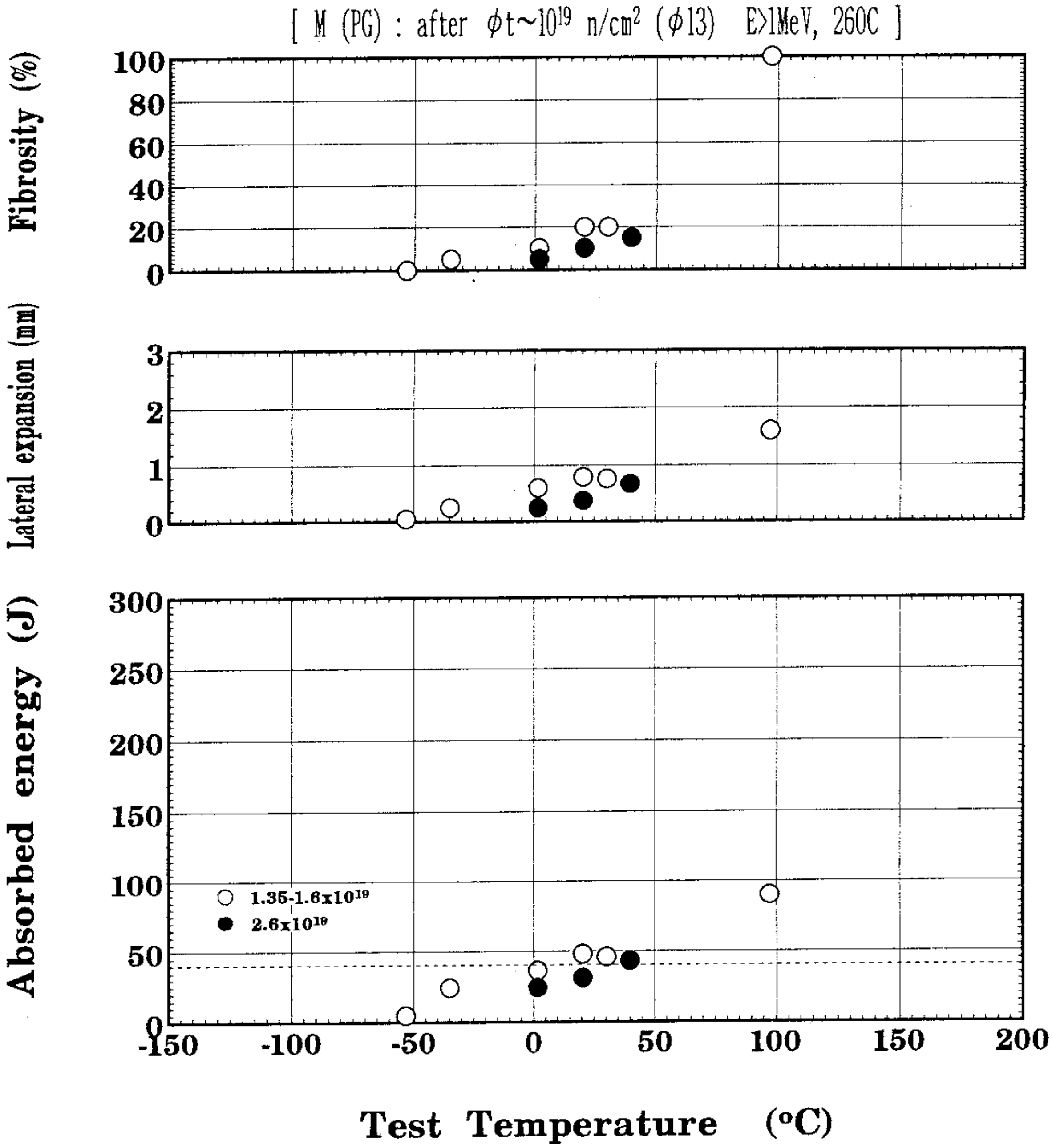


Fig. A-14 Charpy transition curves-13

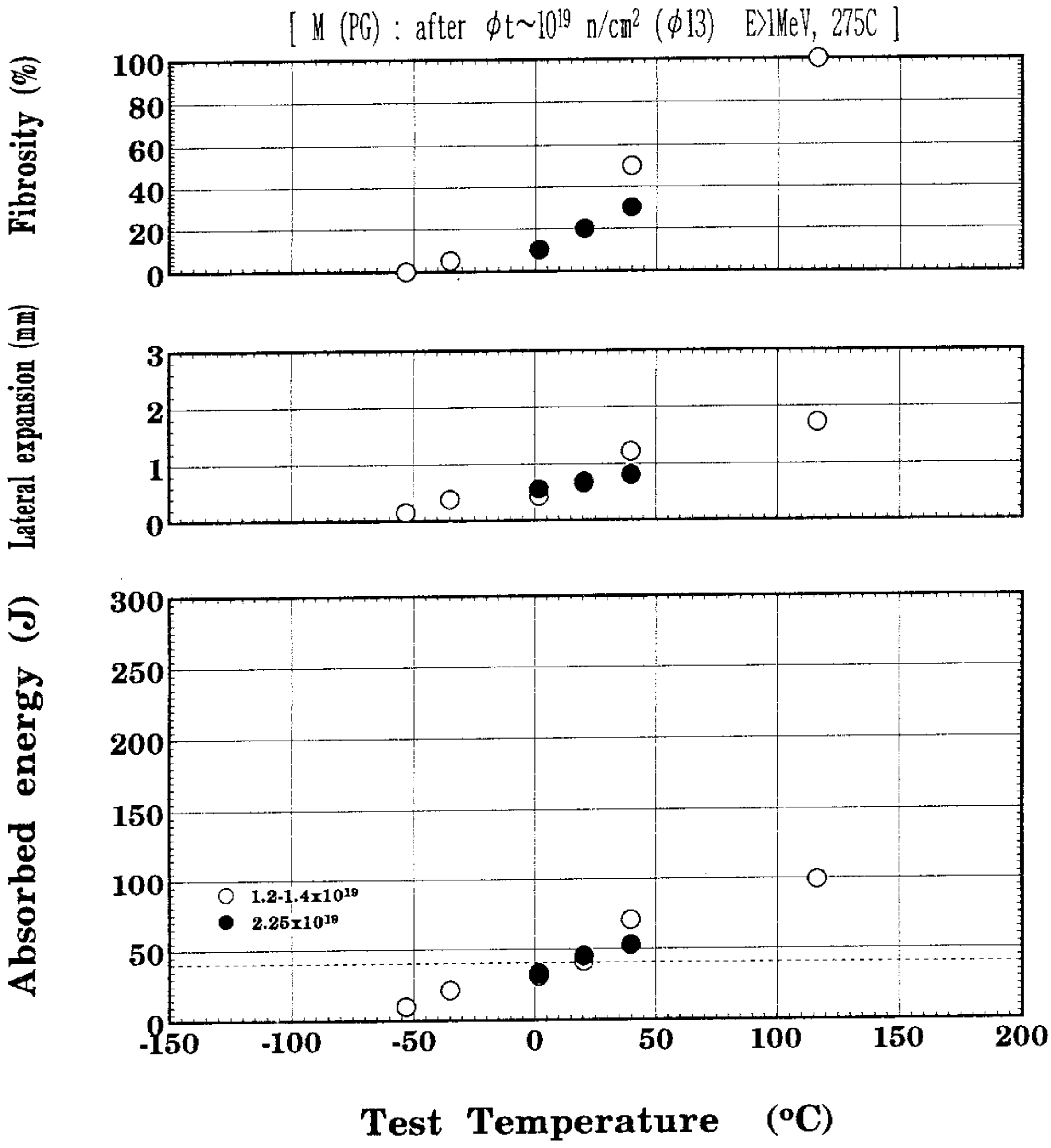


Fig. A-15 Charpy transition curves-14

Table A-18 Tensile test data sheet-1

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	as received
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red.area
L21	—	—	RT	607	465	11.8	24.1	72.8
L22	—	—	RT	599	456	11.3	25.5	74.0
L23	—	—	290	608	412 *	12.0	24.3	73.7

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens(=$(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-19 Tensile test data sheet-2

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiation Capsule JMTR 90M-3A $\phi \sim 10^{12}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #319)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red.area
L12	294	0.11×10^{19}	RT	620	483	12.2	26.3	72.7
L14	287	0.14×10^{19}	RT	613	476	11.9	25.0	72.2
L13	287	0.12×10^{19}	290	614	429 *	12.9	25.5	76.7
L15	287	0.14×10^{19}	290	610	421 *	12.1	23.6	73.6

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-20 Tensile test data sheet-3

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	fracture	red.area
L2	292-	1.8×10^{19}	RT	605	478	10.5	21.8	69.7
L4	287+	2.3×10^{19}	RT	634	507	11.3	21.4	73.3
L1	292	2.1×10^{19}	290	622	439 *	12.5	24.8	71.7
L5	287+	2.3×10^{19}	290	620	438 *	11.6	22.6	67.9

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens(=$(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-21 Tensile test data sheet-4

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	Elongation (%) fracture	red. area
L7	293.5-	1.5×10^{19}	RT	629	494	11.7	25.1	70.7
L9	287+	1.8×10^{19}	RT	632	499	11.5	22.6	71.6
L8	287	1.5×10^{19}	290	621	435 *	12.1	22.4	69.3
L5	287+	1.8×10^{19}	290	622	444 *	11.1	21.1	68.6

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red. area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-22 Tensile test data sheet-5

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	as received
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red. area
M21	—	—	RT	623	473	11.4	22.1	67.9
M22	—	—	RT	622	475	11.1	21.3	66.0
M23	—	—	290	625	428*	12.5	23.6	65.3

YS: Lower Yield Stress
    Marked with * means 0.2% off set stress
Elongation:
    fracture elongation was evaluated by load-displacement curve
    red. area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-22 Tensile test data sheet-5

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	as received
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	Elongation (%) fracture	Elongation (%) red. area
M21	—	—	RT	623	473	11.4	22.1	67.9
M22	—	—	RT	622	475	11.1	21.3	66.0
M23	—	—	290	625	428*	12.5	23.6	65.3

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red. area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-23 Tensile test data sheet-6

Material :	533 Gr.B Cl.1	
Heat :	M	
Material condition:	Irradiation Capsule JMTR 90M-3A	$\phi \sim 10^{12}$
comments :		
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)	
by:	Tokai Hot Laboratory ('92. Hot Labo #319)	

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red. area
M11	294	0.14×10^{19}	RT	643	501	11.3	20.9	59.9
M15	287	0.11×10^{19}	RT	642	498	10.8	20.7	64.5
M13	294	0.11×10^{19}	290	636	445 *	11.8	20.9	54.3
M14	287	0.15×10^{19}	290	629	445 *	10.3	19.6	64.7

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red. area ; reduction of area measured on fracured specimens(=$(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-24 Tensile test data sheet-7

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red.area
M1	292+	2.3×10^{19}	RT	662	528	10.9	20.7	63.0
M2	292-	1.7×10^{19}	RT	662	530	11.6	22.3	64.8
M5	287-	1.8×10^{19}	RT	663	531	11.0	21.4	66.7
M3	292-	1.8×10^{19}	290	648	465 *	10.6	19.1	59.1
M4	287+	2.5×10^{19}	290	650	468 *	10.7	20.1	60.8

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-25 Tensile test data sheet-8

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	fracture	red. area
M6	293.5+	1.8×10^{19}	RT	664	525	10.9	21.6	65.6
M7	293.5-	1.3×10^{19}	RT	653	517	11.1	22.1	66.7
M10	287-	1.4×10^{19}	RT	663	522	11.4	21.9	63.8
M8	293.5-	1.5×10^{19}	290	648	463 *	10.9	19.6	62.6
M9	287+	1.9×10^{19}	290	649	466 *	10.8	19.2	56.9

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-26 Tensile test data sheet-9

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd.(Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	fracture	red.area
L31	259±1	1.96×10^{19}	RT	661	543	9.8	20.1	69.4
L34	259±1	2.13×10^{19}	RT	648	530	7.5	16.4	69.9
L35	259±1	2.50×10^{19}	RT	648	530	8.6	17.9	68.0
L32	259±1	2.30×10^{19}	260	648	465 *	10.5	19.8	68.0
L33	259±1	1.97×10^{19}	260	630	451 *	9.5	18.9	69.4

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-27 Tensile test data sheet-10

Material :	533 Gr.B Cl.1
Heat :	L
Material condition:	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red.area
L36	274±1	1.71×10^{19}	RT	640	514	10.0	20.5	71.1
L39	274±1	1.85×10^{19}	RT	642	518	9.7	19.3	69.5
L40	274±1	2.17×10^{19}	RT	638	514	9.7	20.3	71.5
L37	274±1	2.01×10^{19}	275	633	447 *	10.2	19.4	64.7
L38	274±1	1.71×10^{19}	275	624	445 *	9.3	19.1	68.3

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens$(=(A_0-A_f)/A_0)$
Tensile speed- 0.2mm/min

Table A-28 Tensile test data sheet-11

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%) uniform	fracture	red. area
M31	259±1	1.81×10^{19}	RT	677	558	9.9	19.1	54.7
M33	259±1	2.70×10^{19}	RT	679	559	9.6	17.7	59.1
M34	259±1	2.50×10^{19}	RT	672	552	9.2	17.6	63.2
M32	259±1	1.96×10^{19}	260	658	480 *	10.5	17.9	57.1

YS: Lower Yield Stress
Marked with * means 0.2% off set stress
Elongation:
fracture elongation was evaluated by load-displacement curve
red.area ; reduction of area measured on fracured specimens($=(A_0-A_f)/A_0$)
Tensile speed- 0.2mm/min

Table A-29 Tensile test data sheet-12

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
comments :	
Tests performed in:	Model 1361, Instron Co. Ltd. (Electro-mechanical/10tf)
by:	Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen #	Irradiation Condition		Tensile tests					
	Irradiation temperature ℃	Estimated fluence n/cm^2, E>1MeV	Test temp. ℃	UTS MPa	YS MPa	Elongation (%)		
						uniform	fracture	red.area
M35	274±1	1.58 x 10^{19}	RT	660	531	9.4	18.6	65.5
M36	274±1	1.71 x 10^{19}	RT	667	535	10.2	19.1	60.1
M37	274±1	2.35 x 10^{19}	RT	665	538	9.1	18.0	64.1
M38	274±1	2.17 x 10^{19}	275	658	468 *	10.9	18.6	57.2

YS: Lower Yield Stress
  Marked with * means 0.2% off set stress
Elongation:
  fracture elongation was evaluated by load-displacement curve
  red.area ; reduction of area measured on fracured specimens $(=(A_0-A_f)/A_0)$
Tensile speed- 0.2mm/min

Table A-30 Vickers hardness test data sheet-1

Material	:	533 Gr. B Cl. 1
Heat	:	L
Material condition	:	as received
comments	:	
Tests performed at	:	Load 10kgf
by	:	Vickers Hardness Tester JAERI (JPDR Labo.) ('94. 2)

Measurement #	Vickers hardness	
1	183	
2	184	
3	181	
4	184	
5	186	
6	182	
7	185	Average 186
8	190	
9	185	σ 5
10	179	
11	192	
12	195	
13	188	
14	186	
15	185	
16	190	

Table A-31 Vickers hardness test data sheet-2

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 90M-3A $\phi\sim10^{12}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #319)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Measurement #	Hardness	
L24	290	0.10	1	186.1	
			2	194.3	average
			3	189.8	190.6
			4	193.9	σ
			5	188.7	3.1
L27	290	0.13	1	182.3	
			2	188.1	average
			3	182.7	187.1
			4	193.4	σ
			5	189.2	4.2

Table A-32 Vickers hardness test data sheet-3

Material	:	533 Gr. B Cl. 1
Heat	:	L
Material condition	:	Irradiated
comments	:	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
Tests performed at	:	Load 10kgf Vickers hardness tester
by	:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm² E>1MeV	Measurement #	Hardness	
L2	298	1.6	1	203.5	
			2	194.7	average
			3	189.4	195.6
			4	193.8	σ
			5	196.6	4.6
L5	295-α	2.0	1	194.7	
			2	199.0	average
			3	194.3	196.3
			4	194.3	σ
			5	199.4	2.3

Table A-33 Vickers hardness test data sheet-4

Material	:	533 Gr.B Cl.1
Heat	:	L
Material condition:		Irradiated
comments	:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
Tests performed at:		Load 10kgf Vickers hardness tester
by:		Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm² E>1MeV	Measurement #	Hardness	
L14	292-α	1.3	1	190.7	
			2	189.5	average
			3	197.3	192.8
			4	197.3	σ
			5	189.4	3.7
L19	290	1.7	1	197.4	
			2	191.7	average
			3	191.2	195.5
			4	201.7	σ
			5	195.7	3.9

Table A-34 Vickers hardness test data sheet-5

Material	:	533 Gr. B Cl. 1
Heat	:	M
Material condition:		as received
comments	:	
Tests performed at:		Load 10kgf
by:		Vickers Hardness Tester JAERI (JPDR Labo.) ('94. 2)

Measurement #	Vickers hardness	
1	183	
2	187	
3	205	
4	196	
5	190	
6	185	
7	203	Average 191
8	196	
9	201	σ 7.5
10	180	
11	185	
12	192	
13	188	
14	186	
15	184	
16	191	

Table A-35 Vickers hardness test data sheet-6

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 90M-3A $\phi \sim 10^{12}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #319)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times10^{19}$n/cm^2 E>1MeV	Measurement #	Hardness	
M22	290	0.08	1	193.2	
			2	199.1	average
			3	191.8	197.5
			4	200.3	σ
			5	203.2	4.3
M24	290	0.15	1	196.6	
			2	197.5	average
			3	196.2	198.0
			4	199.1	σ
			5	200.7	1.7

Table A-36 Vickers hardness test data sheet-7

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 89M-4A $\phi \sim 10^{13}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #220)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Measurement #	Hardness	
M7	290	1.2	1	202.4	
			2	202.5	average
			3	208.4	204.6
			4	206.7	σ
			5	202.8	2.5
M4	295	2.4	1	209.1	
			2	208.1	average
			3	205.8	208.9
			4	203.8	σ
			5	204.3	2.1

Table A-37 Vickers hardness test data sheet-8

Material	:	533 Gr. B Cl. 1
Heat	:	M
Material condition:		Irradiated
comments	:	Irradiation Capsule JMTR 89M-5A $\phi \sim 10^{12}$
Tests performed at:		Load 10kgf Vickers hardness tester
by:		Tokai Hot Laboratory ('92. Hot Labo #401)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Measurement #	Hardness	
M18	290-	1.1	1	210.6	
			2	206.0	average
			3	207.2	209.4
			4	212.0	σ
			5	211.0	2.3
M14	290	1.8	1	209.9	
			2	211.9	average
			3	208.9	211.4
			4	208.7	σ
			5	217.4	3.2

Table A-38 Vickers hardness test data sheet-9

Material :	533 Gr. B Cl. 1
Heat :	L
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm^2 E>1MeV	Measurement #	Hardness	
L65	259±2	1.70	1	201.1	
			2	201.7	average
			3	209.1	203.9
			4	199.0	σ
			5	208.5	4.1
L68	262±2	2.02	1	212.1	
			2	209.2	average
			3	208.1	209.8
			4	209.9	σ
			5	209.5	1.3
L72	267±3	2.57	1	207.1	
			2	208.8	average
			3	210.5	208.8
			4	207.7	σ
			5	209.7	1.2

Table A-39 Vickers hardness test data sheet-10

Material	:	533 Gr. B Cl. 1
Heat	:	L
Material condition:		Irradiated
comments	:	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
Tests performed at:		Load 10kgf Vickers hardness tester
by:		Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Measurement #	Hardness	
L78	273	1.49	1	202.7	
			2	202.3	average
			3	204.7	201.3
			4	198.2	σ
			5	198.6	2.5
L80	270	1.91	1	207.0	
			2	212.1	average
			3	205.8	209.4
			4	212.1	σ
			5	210.1	2.6
L82	280±2	2.24	1	215.9	
			2	230.4	average
			3	224.7	217.5
			4	211.5	σ
			5	205.2	9.0

Table A-40 Vickers hardness test data sheet-11

Material :	533 Gr.B Cl.1
Heat :	M
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 91M-3A $\phi \sim 10^{13}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #426)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $\times 10^{19}$ n/cm² E>1MeV	Measurement #	Hardness	
M63	259±2	1.44	1	218.2	
			2	216.0	average
			3	216.2	216.3
			4	217.3	σ
			5	214.0	1.4
M70	260±1	1.61	1	214.7	
			2	217.0	average
			3	214.7	215.5
			4	218.1	σ
			5	213.2	1.8
M64	253±2	2.59	1	225.6	
			2	221.0	average
			3	215.4	221.6
			4	225.8	σ
			5	220.2	3.9

Table A-41 Vickers hardness test data sheet-12

Material :	533 Gr. B Cl. 1
Heat :	M
Material condition:	Irradiated
comments :	Irradiation Capsule JMTR 91M-4A $\phi \sim 10^{13}$
Tests performed at:	Load 10kgf Vickers hardness tester
by:	Tokai Hot Laboratory ('92. Hot Labo #428)

Specimen			Hardness test		
Specimen number	Irradiation Temperature (℃)	Estimated fluence $x10^{19}n/cm^2$ E>1MeV	Measurement #	Hardness	
M76	275	1.19	1	217.3	
			2	211.1	average
			3	210.5	209.8
			4	212.7	σ
			5	197.4	6.6
M78	275	1.4	1	206.7	
			2	207.1	average
			3	206.0	208.9
			4	210.4	σ
			5	214.4	3.1
M73	270	2.26	1	211.2	
			2	216.6	average
			3	212.7	216.1
			4	222.5	σ
			5	217.5	4.0