The Effect of Neutron Irradiation on Cryogenic Temperature Strength of High-Mn Steels and Their Electron Beam Welded Joint†

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Abstract

The effect of neutron irradiation on the mechanical properties of High-Mn Steels and their electron beam welded joints have been studied using a miniature tensile testing method.

In the present study, High-Mn steels, A-T and B-T, for cryogenic structures were selected as the test materials, and their base metals and electron beam welded joints were tested at cryogenic temperatures.

Ductility in both materials decreases with increasing neutron flux, but it is larger in B-T than A-T.

KEY WORDS: (Neutron irradiation)(High-Mn steels)(Cryogenic temperature)(Electron beam) (Ductility)

1. Introduction

High-Mn steels are selected as candidate materials for fusion reactors because of their ductility. They are intended to be used as the material for the first wall of nuclear fusion reactors.

So, in this investigation, these materials are welded by the electron beam process irradiated in the research reactor, tensile tests are conducted at cryogenic temperatures.

2. Testing Method
2.1 Test materials

Chemical compositions are shown in **Table.1**. Both materials were hot rolled at 1473K and treated by water toughening for 1 hr at 1323K.

2.2 Processing of the materials

The test materials were welded by the electron beam welder shown schematically in **Fig.1**. Preheating and post welding heat treatment were not employed. Welding conditions are shown in **Table.2**. Hardness distributions in the welded joints of both materials are shown in **Fig.2** and **Fig.3**.

After electron beam welding tensile specimens were cut in the direction of rolling. The dimensions of the specimen are shown in **Fig.4(a)**. A small specimen size is used to suit the capacity of the testing machine and minimize He.

Test specimen were exposed to neutron irradiation in the reactor core in KUR (Kyoto University Research Reactor Institute), Neutron irradiation conditions are shown in **Table.3**.

2.3 Tensile tests at cryogenic temperatures[1-5)]

Tensile tests were conducted by Autograph (AG-500A type, Capacity 500kgf). The load-displacement curve was recorded. Testing temperatures were room temperature (293K), liquid nitrogen temperature (77K) and liquid helium temperature (4.2K). Crosshead speed was controlled in 0.1 mm/min.

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Table.1 Chemical composition of materials used.

Materials	Chemical compositions (wt%)											
	Fe	Mn	Cr	Si	C	P	S	Ni	Mo	V	Nb	N
A-T	Bal.	17.8	6.83	4.70	0.032	0.0016	0.0067	–	–	–	–	–
B-T	Bal.	21.6	6.39	4.42	0.029	0.0014	0.0074	–	–	–	–	0.182

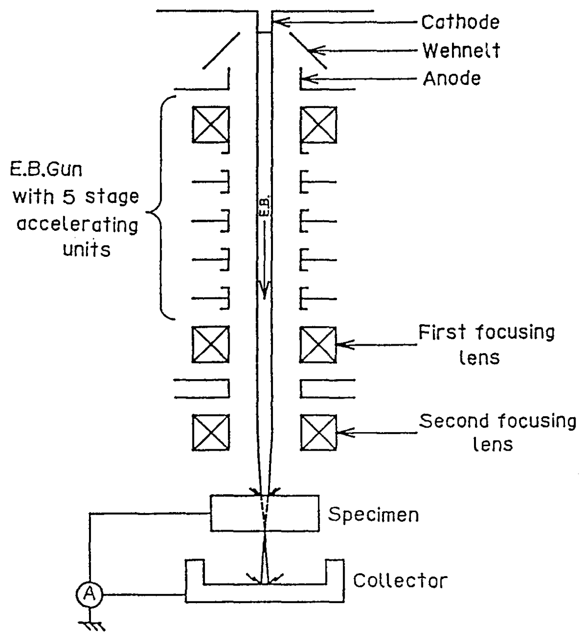

Fig.1 Schematic diagram of electron beam welding method in the position.

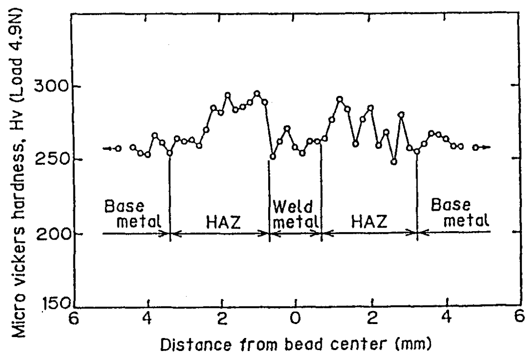

Fig.2 Hardness distribution in welded joint of A-T.

Table.2 Welding conditions of materials used.

Materials	Welding position	Beam voltage (kV)	Beam current (mA)	Welding speed (m/s)
A-T	Flat	60	80	0.005
B-T	Flat	60	80	0.005

Beam oscillation : 30Hz , 3mm
Vacuum : 4.0×10^{-2}Pa

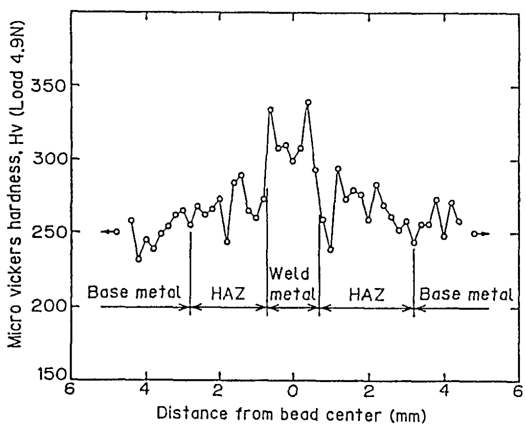

Fig.3 Hardness distribution in welded joint of B-T.

Table.3 Neutron irradiation conditions of high Mn steels.

Materials	Fast neutron flux density ($n/m^2 \cdot s$)	Irradiation time (hr)	Neutron flux (n/m^2)	Mark
Base material specimens	7.30×10^{16}	313.66	8.24×10^{22}	IR·B1
		989.35	2.60×10^{23}	IR·B2
Welded joint specimens	1.20×10^{17}	76.90	3.32×10^{22}	IR·W1
		377.31	1.63×10^{23}	IR·W2
		687.76	2.97×10^{23}	IR·W3

Irradation apparatus : KUR reactor core (E>0.1MeV)
Irradation temperature : 360K

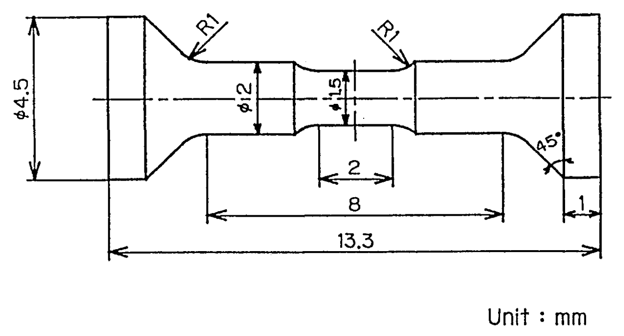

Fig.4(a) Test specimen of high Mn steels.

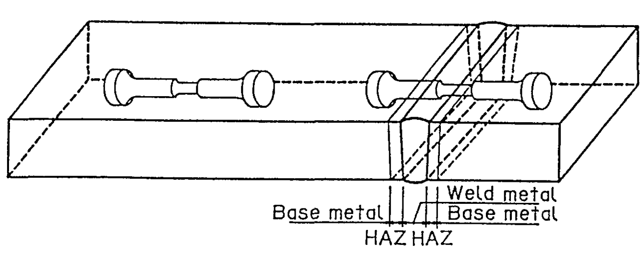

Fig.4(b) Sampling of specimens for tensile test.

3. Test Results and Discussion

3.1 Nominal stress - Nominal strain curve

Test results for base metal and welded joints of High-Mn steels irradiated at different neutron fluxes are shown in **Fig.5** - **Fig.8**, respectively. Serration is observed in the test at 4.2K of both materials at every neutron fluence.

3.2 Effect of neutron irradiation on the strength of materials

Neutron flux dependencies of ultimate tensile strength and 0.2% proof stress of both materials are shown in **Fig.9** - **Fig.12**, respectively. The increase of 0.2% proof stress at 4.2K following irradiation is larger than of the ultimate tensile strength at 4.2K in both materials[6-8].

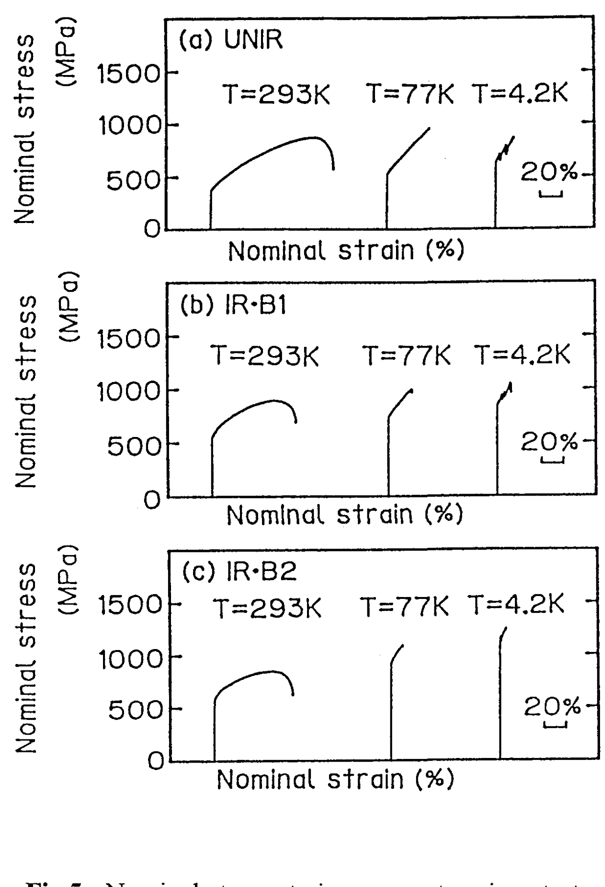

Fig.5 Nominal stress-strain curves at various test temperatures of A-T base metal irradiated to different neutron fluxes.

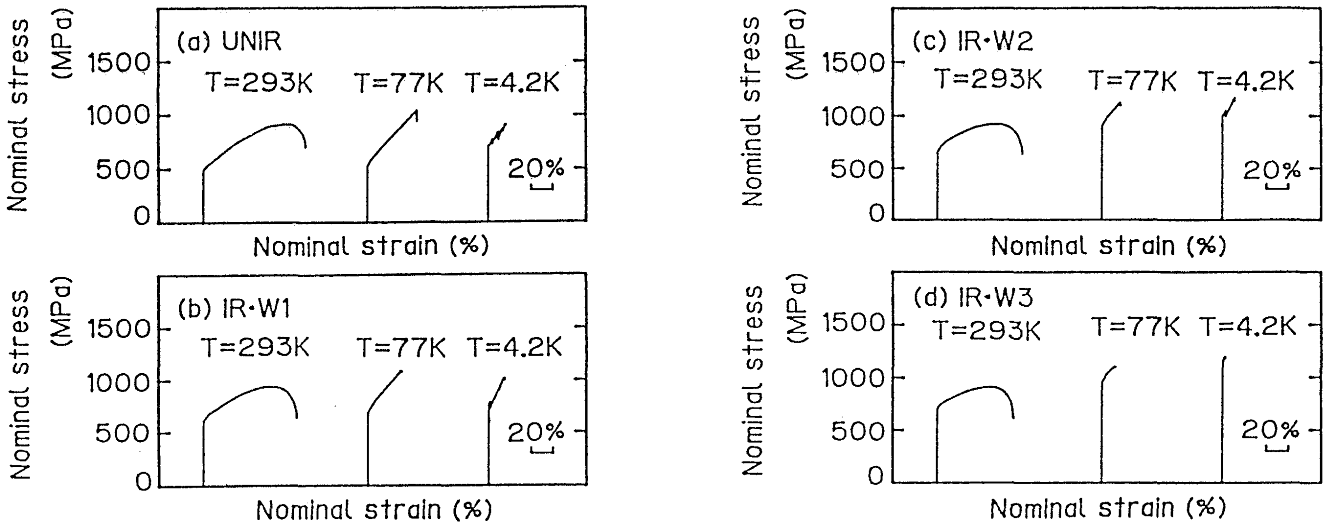

Fig.6 Nominal stress-strain curves at various test temperatures of A-T weld metal irradiated to different neutron fluxes.

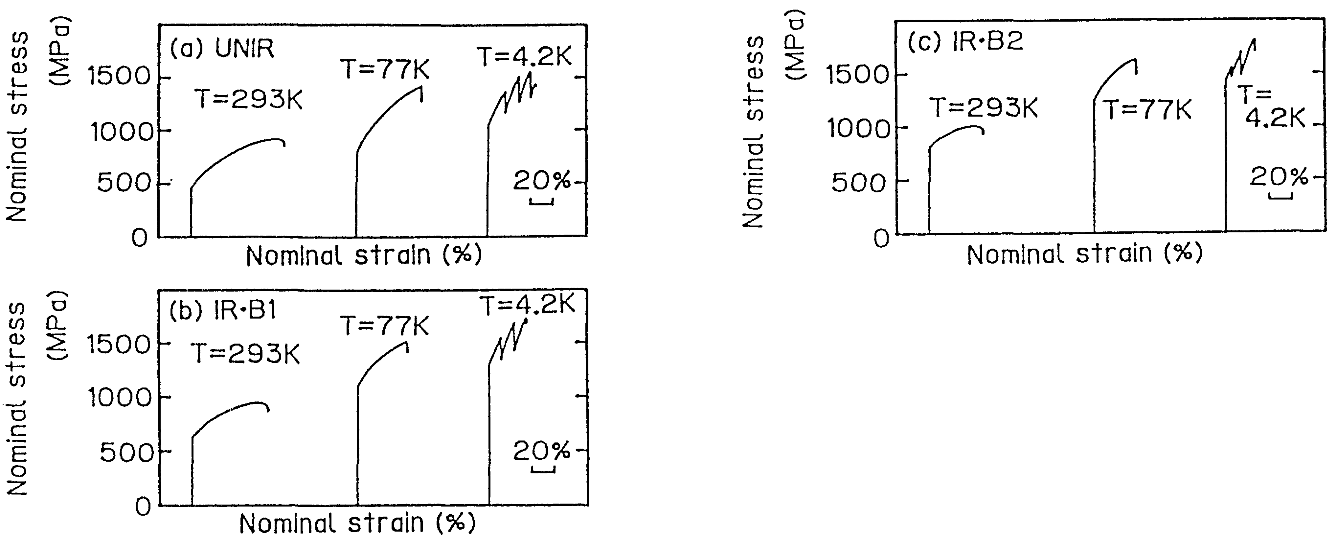

Fig.7 Nominal stress-strain curves at various test temperatures of B-T base metal irradiated to different neutron fluxes.

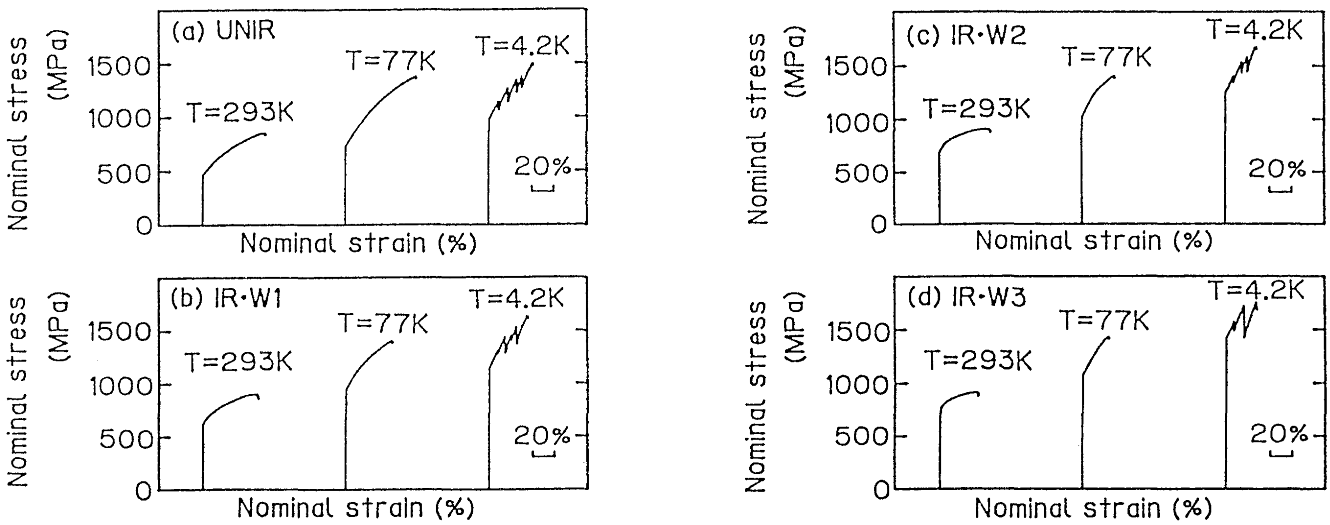

Fig.8 Nominal stress-strain curves at various test temperatures of B-T weld metal irradiated to different neutron fluxes.

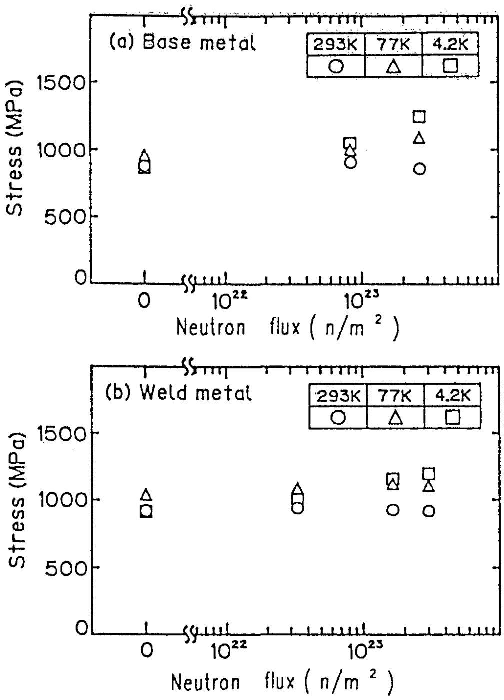

Fig.9 Neutron flux dependences of ultimate tensile strength of A-T at various test temperatures.

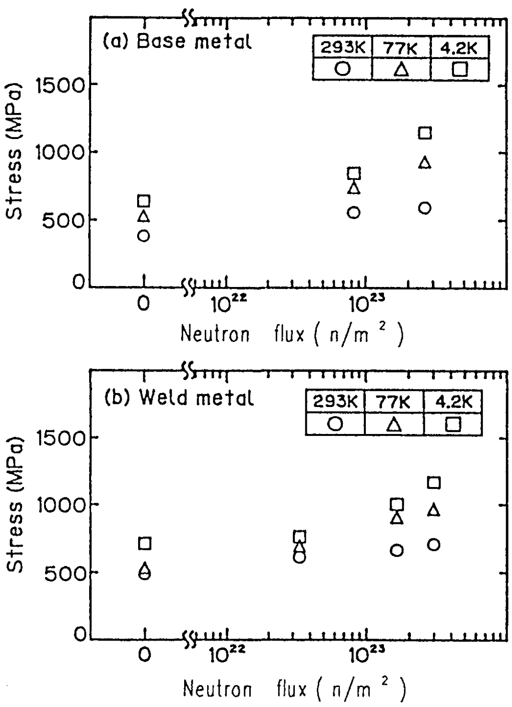

Fig.10 Neutron flux dependences of 0.2% proof stress of A-T at various test temperatures.

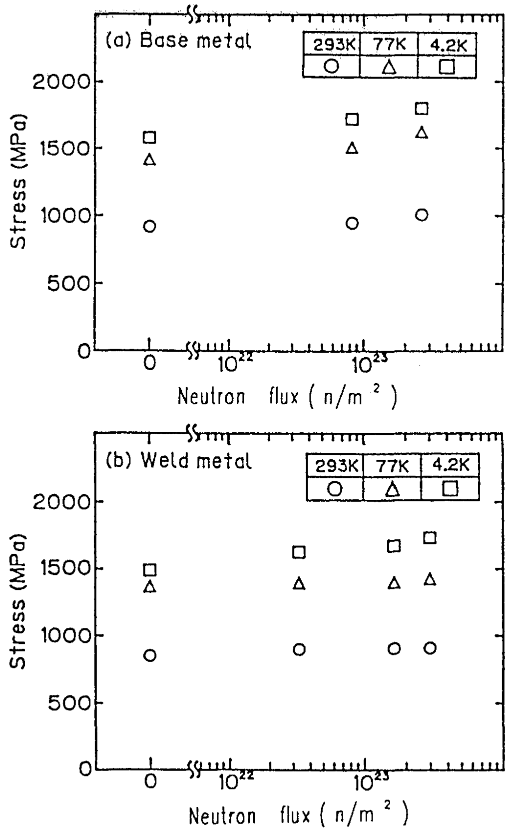

Fig.11 Neutron flux dependences of ultimate tensile strength of B-T at various test temperatures.

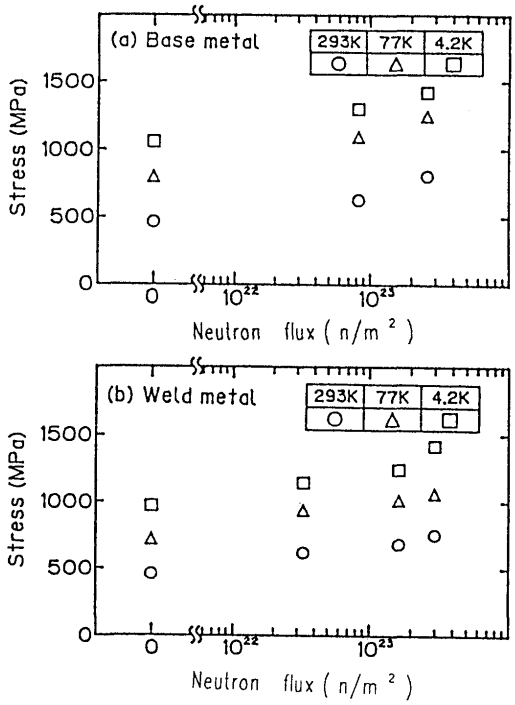

Fig.12 Neutron flux dependences of 0.2% proof stress of B-T at various test temperatures.

3.3 Effect of neutron irradiation on the ductility of materials

The neutron flux dependencies of elongation of the materials are shown in **Fig.13** and **Fig.14**. The elongation of base metal and the welded joint of materials A-T and B-T decreases with increase of neutron flux.

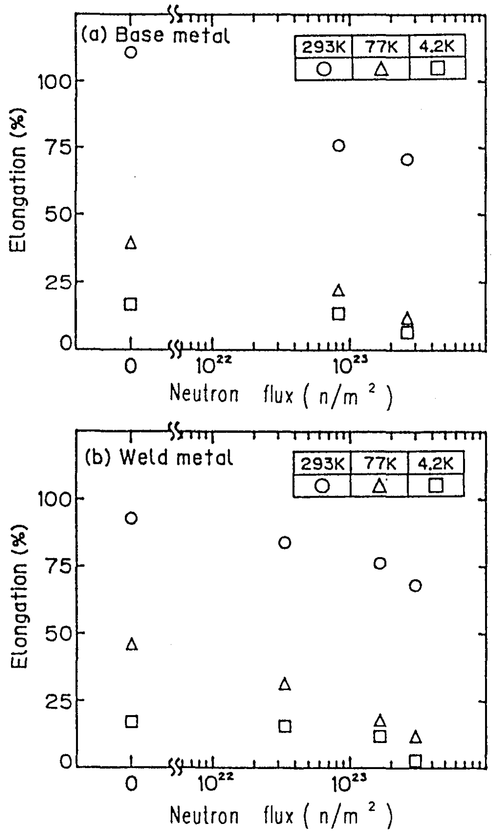

Fig.13 Neutron flux dependences of elongation of A-T at various test temperatures.

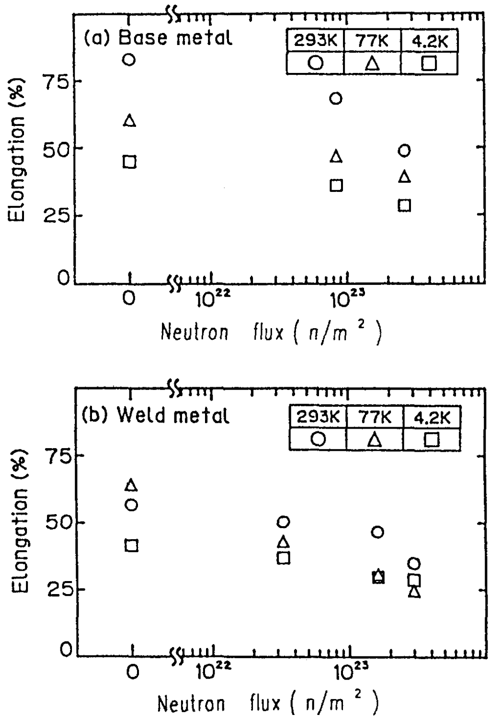

Fig.14 Neutron flux dependences of elongation of B-T at various test temperatures.

4. Conclusion

(1)Serration is observed in the test at 4.2K of both materials at every neutron flux.

(2)The increase of 0.2% proof stress with increasing neutron flux is larger than that of the ultimate strength in both materials.

(3)The reduction of elongation of material A-T with increasing neutron flux is larger the reduction of elongation material B-T.

Acknowledgment

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References

1) Kenzo Yamamoto and Tomitaro Ishimori : Nuclear Reactor Technology, Part 1, Baifukan, (1976)(in Japanese)
2) Ryukichi Hashiguchi : Irradiation Damage of Nuclear Fusion Reactor Metallic Materials, J. of Japanese Society of Metallurgy, 20(1981)5,339-346(in Japanese)
3) Hiroyuki Yoshida : Irradiation Damege of Materials in Application of Nuclear Energy Materials, 25 (1976)271, 323-335(in Japanese)
4) Hirofumi Yoshimura : Review of Research on Steels for Cryogenic Application, Iron and Steel, 67,(1981) 14, 2108-2116 (in Japanese)

5) Takefumi Horiuchi : Recent Trend on Metallic Materials for Cryogenic Application, J. of Japanese Society of Metallurgy, 21(1982)12, 965-972(in Japanese)
6) Jiro Obukata and Yoshihiro Konda : Low Temperature Ductility of Fe-Mn Alloy, J. of Society of Strength of Materials Japan, 22(1987),1, 965-972(in Japanese)
7) Toshimi Matsumoto, Hirishi Sato, Fumio Haritani, Kei Ogawa and Yoshinori Karatsu : Mechanical Property of Deposited Metal of Non Magnetic Materials for Cryogenic Temperature, Quarterly J. of Japan Welding Society, 4(1986)3, 621-627(in Japanese)
8) Review and Problem of Design and Development of Nuclear Fusion Reatctor, Society of Atomic Energy of Japan, (1983)(in Japanese)