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Effect of Neutron Irradiation on Cryogenic Temperature Strength of Aluminum Alloys and Their Electron Beam Welded Joints

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Abstract

Effects of neutron irradiation on mechanical properties of aluminum alloys have been studied using a miniature tensile testing method.

In the present study, aluminum alloys (A7N01, A5083 and A6061) for cryogenic structural materials were selected as the testing materials, and their base metals and electron beam welded joints were tested at cryogenic temperatures.

Decreasing of ductility at cryogenic temperature by irradiation was larger for the base metal than the welded joint. Both the base metal and welded joint became sensitive to existence of notch with increasing of neutron fluence.

KEY WORDS: (Cryogenic Temperature) (Structural Material) (Aluminum Alloy) (Welded Joint) (Tensile Test) (Neutron Irradiation)

1. Introduction

Aluminum alloys (A7NO1, A5083 and A6061) are selected as testing materials in this study. Aluminum alloys are expected as structural material at cryogenic temperature, because they do not exhibit low temperature brittleness and are excellent in processing ability, weldability, decrement characteristic of induction radioactivity, although they are not suitable to be used where the stress is high[1]. They are investigated to use as the materials for the first wall and super conductivity stabilization material of nuclear fusion reactor[2,8].

So, in this investigation, these materials are welded by electron-beam welding and the strength of base metal and welded joint is examined at cryogenic temperature.

2. Testing Method

2.1 Testing materials

Chemical compositions and heat treatment condition are shown in **Table 1.**

2.2 Processing of the materials

The test materials were welded by the electron beam

Table 1 Chemical compositions of Al alloys.

Alloys	Chemical compositions (wt%)									
	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
A7N01-T6	BAL.	0.05	0.11	0.16	0.30	1.12	0.06	4.73	0.01	0.15
A5083-O	BAL.	0.05	0.11	0.01	0.68	4.61	0.13	0.03	0.01	-
A6061-T6	BAL.	0.72	0.12	0.18	0.01	0.50	0.00	0.04	0.005	-

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welder shown in **Fig. 1**. The electron beam used was the second beam inclined with 25 degrees against the vertical line for the protection of the elctron gun to metal vapor and spatter. Welding conditions are shown in **Table 2**.

After electron beam welding, the smooth specimen and notched specimen are sampled in the direction of rolling. Size of the specimens is shown in **Fig. 2**. Small size of specimens are used under the consideration of evaporation of helium and capacity of testing machine. It has volume ratio of 1/360 compared with that of JIS No. 4 specimen. The location of notch agrees with the center of weld metal in welded specimen of aluminum alloys.

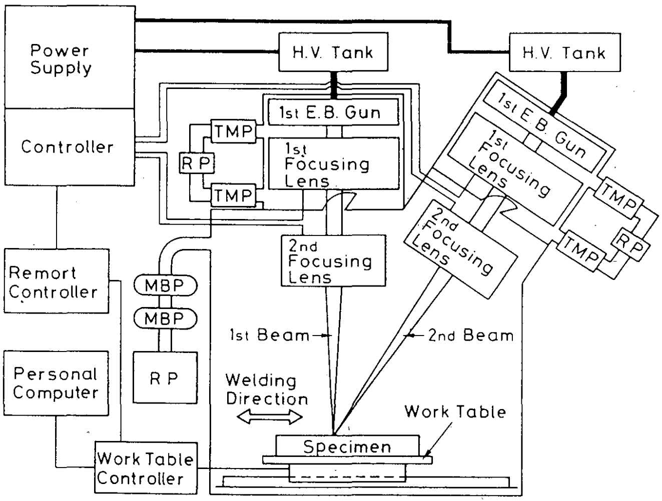

Fig. 1 30 kW class Tandem Electron Beam welder.

Test specimens were exposed to neutron irradiation in KUR reactor core. Neutron irradiation conditions are shown in **Table 3**.

2.3 Tensile test at cryogenic temperature

Tensile test is conducted by Autograph (AG-500A type: Capacity 500 Kg). The load-displacement curve is recorded. Testing temperatures are room temperature (293K), liquid nitrogen temperature (77K) and liquid helium temperature (4.2K).

Crosshead speed is controlled in 0.1 mm/min for smooth specimen and 0.05 mm/min for notched

Table 2 Welding conditions of material used. (6.7 Pa)

Materials	Welding position	Beam voltage (kV)	Beam current (mA)	Welding speed (mm/min)
A7N01-T6	Flat	60	80	600
A5083-0	Flat	60	80	600
A6061-T6	Flat	60	90	300

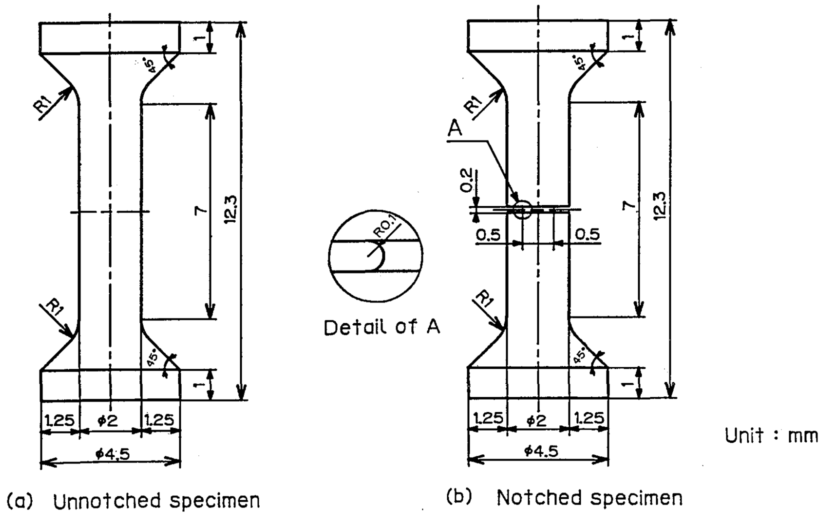

Fig. 2 Test specimen of Al alloys.

Table 3 Neutron irradiation conditions of Al alloys. (E>0.1 MeV)

Irradiation apparatus	Irradiation time (hr)	Fast neutron flux density ($n/m^2 \cdot s$)	Neutron fluence (n/m^2)	Irradiation temperature (K)
KUR Reactor core	76.90	7.3×10^{16}	2.0×10^{22}	358
	345.98		9.1×10^{22}	
	646.88		1.7×10^{23}	

specimen.

3. Results and Consideration

3.1 Nominal stress-nominal strain curve

Testing results for base metal and welded joint of aluminum alloys with neutron fluence: 1.7×10^{23} n/m^2 are shown in **Fig. 3** and **Fig. 4**, respectively. The serration is observed in the result at 4.2K of every materials. The serration is also observed at room temperature for A5083. This phenomenon is due to strain aging which observed in the temperature range in which the speed of dislocation is larger than that of solute atom[4,5,6]. Results of tensile test show same tendency as results of tensile test on the non-irradiated materials which is shown in former report[7]. The serration is observed in stress-strain curve at the testing temperature 4.2K of every materials. These phenomena are same as the case of non-irradiated material.

3.2 Effect of neutron irradiation on the strength of materials

Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of every material are shown in **Fig. 5**, **Fig. 6** and **Fig. 7**, respectively.Tensile strength and 0.2% proof stress of A7N01 material increase with increasing of neutron fluence as shown in Fig. 5. Increasing of ultimate tensile strength of welded joint is larger than that of base metal. It is considered that this is because of aging of welded joint

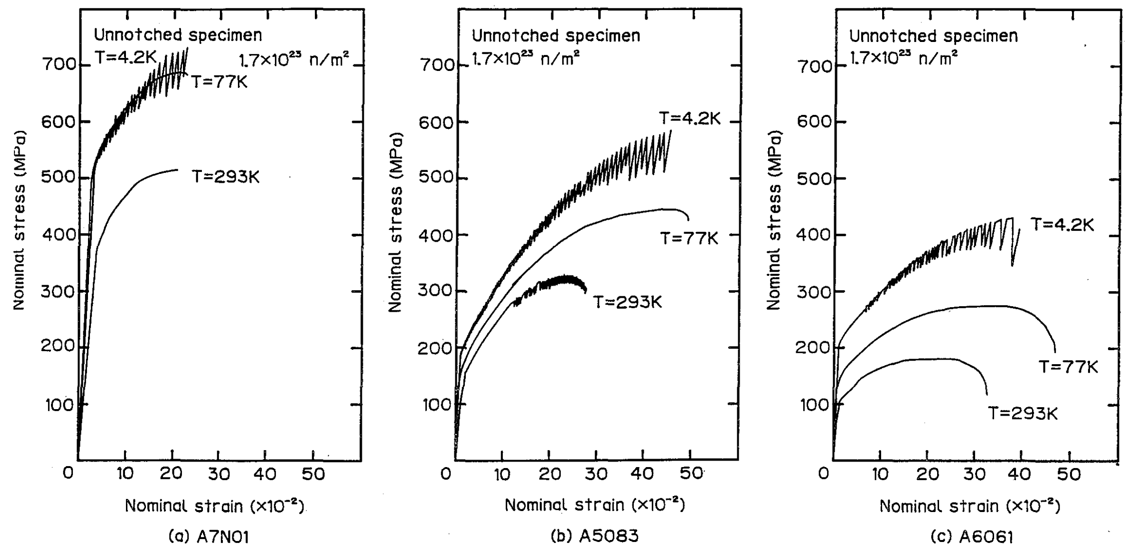

Fig. 3 Nominal stress-strain curves of irradiated Al alloy base metals at various test temperatures. (Neutron fluence: 1.7×10^{23} n/m^2)

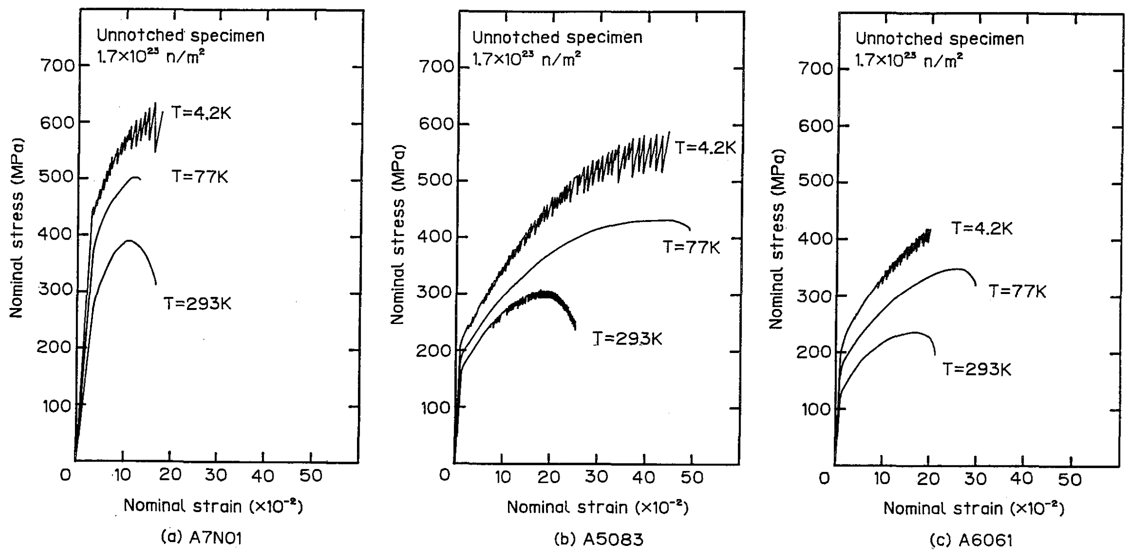

Fig. 4 Nominal stress-strain curves of irradiated Al alloy weld joints at various test temperatures. (Neutron fluence: 1.7×10^{23} n/m^2)

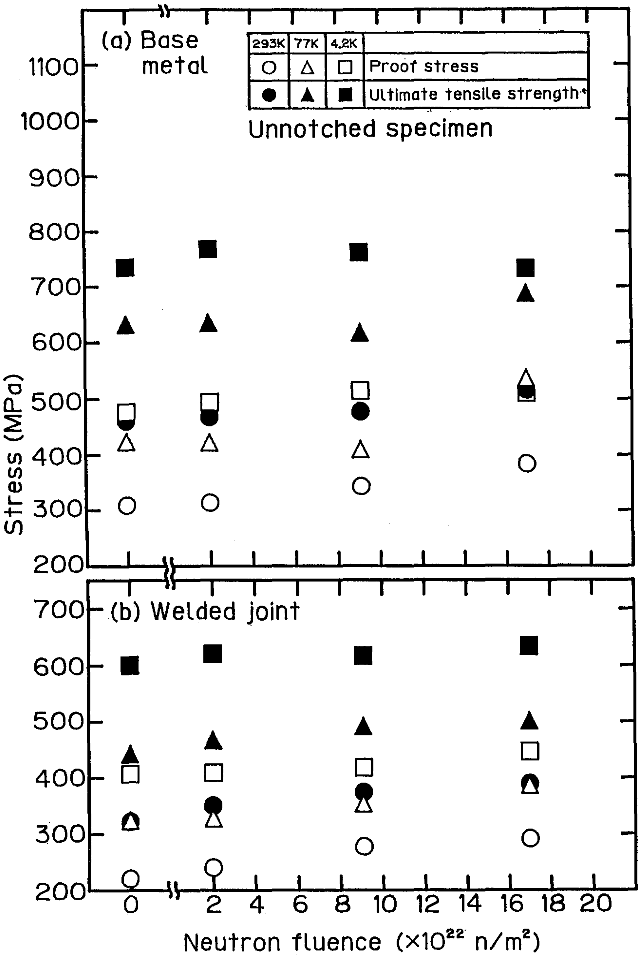

Fig. 5 Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of A7NO1 against various test temperatures.

during the neutron irradiation.

Strength of A5083 material little increases with increasing of neutron fluence as shown in Fig. 6. Strength of welded joint of A6061 material increases with increasing of neutron fluence as shown in Fig. 7.

3.3 Effect of neutron irradiation on the ductility of material

Neutron fluence dependences of elongation of the material are shown in **Fig. 8**, **Fig. 9** and **Fig. 10**, respectively. Elongation of the A7N01 material increases with the neutron fluence up to 2×10^{22} n/m^2 and decreases with increasing neutron fluence as shown in Fig. 8. Elongation of A5083 material exhibits same dependency as the A7N01 as shown in Fig. 9. Elongation of A6061 material exhibits some scattering and effect of neutron fluence can not be observed.

3.4 Effect of neutron irradiation on the sensitivity to notch of the materials

Effect of neutron irradiation on the sensitivity to

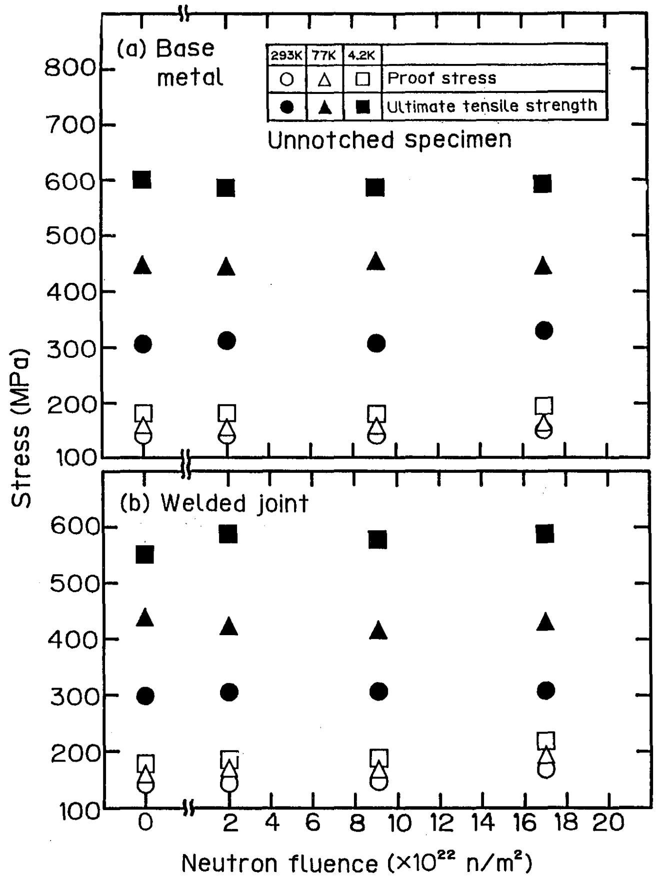

Fig. 6 Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of A5083 against various test temperatures.

notch of the materials is examined by using of notch proof stress ratio (notch tensile strength/unnotched 0.2% proof stress). Neutron fluence dependences of notch proof strength ratio between notched and unnotched specimen of the materials are shown in **Fig. 11**, **Fig.12** and **Fig. 13**, respectively. Values of notch proof stress ratio of these material are larger than 1 at every testing temperature and every neutron fluence. It can be seen that every materials fracture with sufficient plastic deformation after yielding. Notch proof strength ratio of every materials decreases with increasing of neutron fluence as shown in the figures. Dropping the values at neutron fluence of 1.7×10^{23} n/m^2 is larger in the value of welded joint than that of base metal. It is considered that increasing of sensitivity to the existence of notch is larger in the case of welded joint than that of base metal.

4. Conclusion

(1) Serration is observed in the test 4.2K of every material at every neutron fluence.

(2) Welded joint of A7N01 exhibits larger increasing of stress than base metal by the effect of neutron ir-

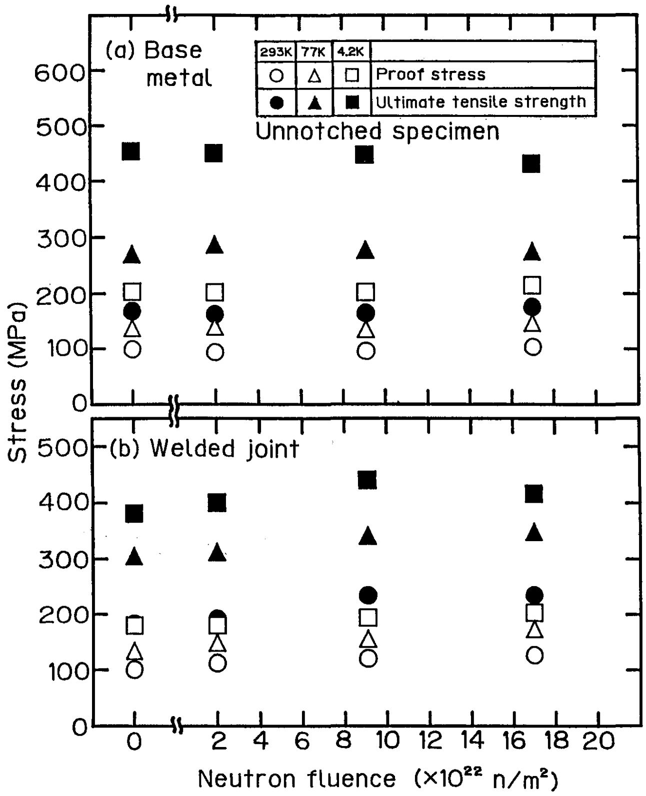

Fig. 7 Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of A6061 against various test temperatures.

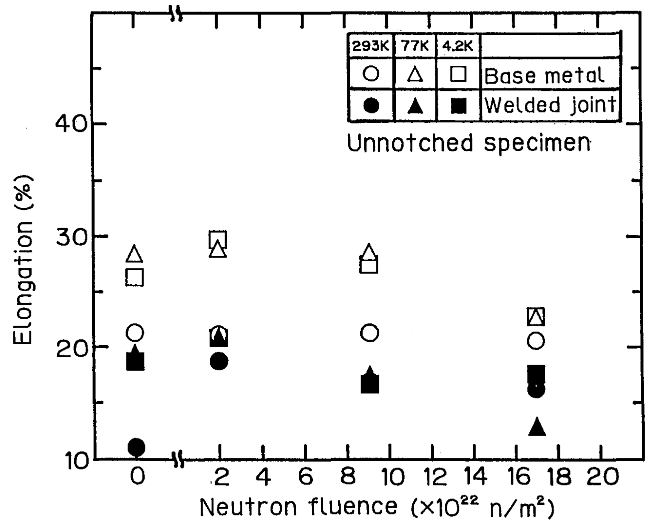

Fig. 8 Neutron fluence dependences of elongation of A7NO1 against various test temperatures.

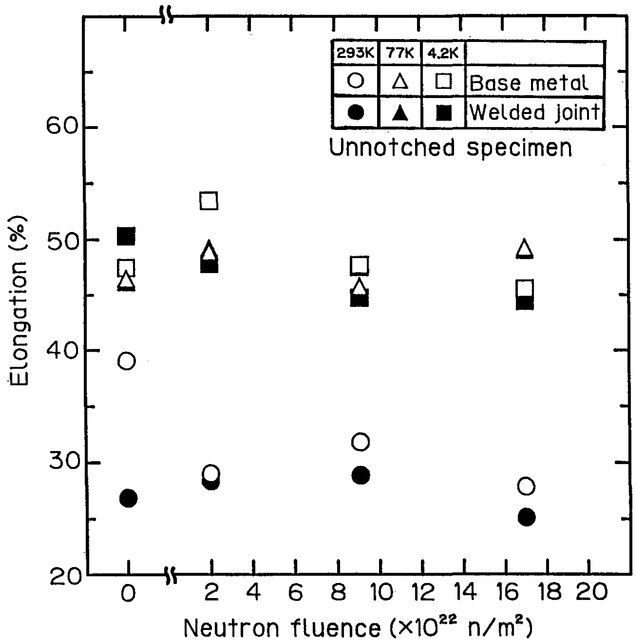

Fig. 9 Neutron fluence dependences of elongation of A5083 against various test temperatures.

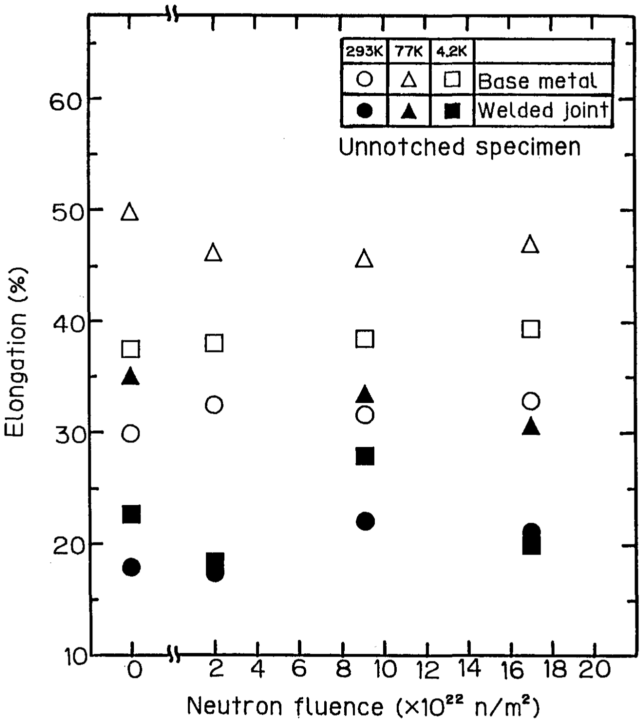

Fig. 10 Neutron fluence dependences of elongation of A6061 against various test temperatures.

radiation. Ductility increases slightly by the neutron fluence of 2.0×10^{22} n/m^2 and after that decreases with the increasing of neutron fluence.

(3) A5083 material shows same characteristics of strength and ductility as A7N01 material. Notch proof stress ratio decreases with increasing of neutron fluence. Dropping of the value of welded joint at higher neutron fluence is larger than that of base metal.

(4) Strength of welded joint of A6061 material increases by neutron fluence. Sensitivity to notch of base metal and welded joint of the material much increases at the neutron fluence of 1.7×10^{23} n/m^2.

Acknowledgment

Tensile test was conducted by using the Autograph

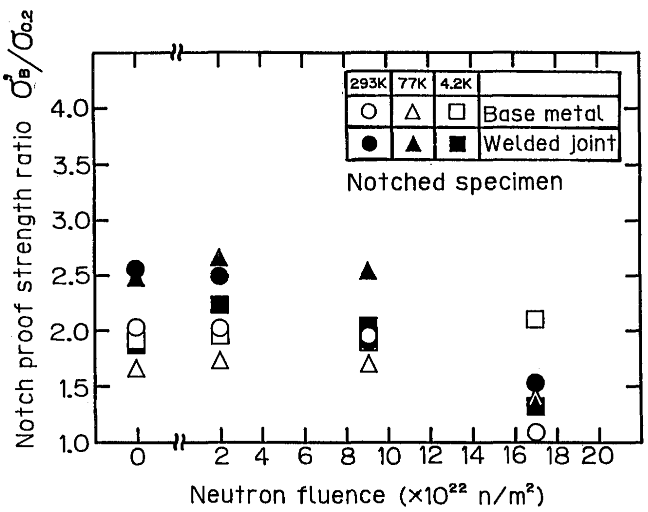

Fig. 11 Neutron fluence dependences of notch proof strength ratio between notched and unnotched specimen of A7NO1 against various test temperatures.

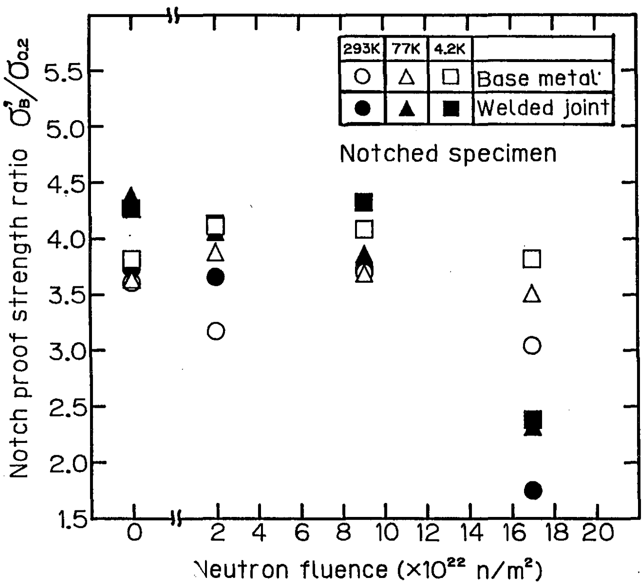

Fig. 12 Neutron fluence dependences of notch proof strength ratio between notched and unnotched specimen of A5083 against various test temperatures.

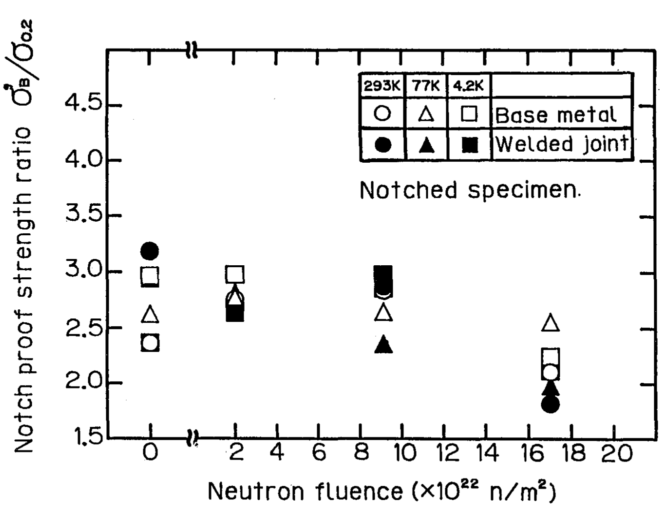

Fig. 13 Neutron fluence dependences of notch proof strength ratio between notched and unnotched specimen of A6061 against various test temperatures.

and cryostat of the Third Research Section, Research Reactor Institute, Kyoto University. We thank for the leading and advice to the experiment by Dr. Hiroyuki Yoshisa, associate professor and Mr. Kiyomi Miyata, technical assistant, the Third Research Section, Research Reactor Institute, Kyoto University.

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