Effect of Neutron Irradiation on Strength of Electron Beam Welded Joint of JFMS Steel for Fusion Reactor†

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Abstract

JFMS steel is a candidate material for nuclear fusion reactor in Japan. It is a material for high temperature use. Structural materials of fusion reactor will be exposed in neutron irradiation. In order to research the basic property of the material under irradiation, low temperature strength of JFMS steel and its electron beam welded joint is investigated under various irradiated conditions in this experiment.

It was shown, as testing results, that decreasing of strength and elongation at low temperature of base metal and electron beam welded joint of JFMS steel increases with increasing of neutron fluence.

KEY WORDS : (Nuclear Fusion Reactor) (Neutron Irradiation) (Ferritic Special Steel) (Tensile Test) (Notch Brittleness) (Welded Joint)

1. Introduction

Ferritic special steel (JFMS) is selected as testing materials in this study from the candidate materials for nuclear fusion reactor in Japan[1)]. JFMS (Japanese Ferritic and Martensitic Steel)is selected as candidate material for nuclear fusion reactor in 9Cr - 2Mo ferritic steel[2)]. 9Cr - 2Mo steel is a heat proof material but it is superior than austenitic stainless steel in resisitance to swelling by neutron irradiation and resisitance to helium embrittlement[3),4)].

So, in this investigation, the material are welded by electron beam welding and the strength of base metal and welded joint is examined at cryogenic temperature. JFMS is a material for high temperature use but test is conducted at only low temperature, in this investigation.

2. Testing Method

2.1 Testing materials

Chemical composition is shown in **Table 1.**

2.2 Processing of the materials

After the materials are welded by electron beam welding method in the condition shown in **Table 2**, the smooth specimen and notched specimen are sampled in the direction of rolling shown in Fig. 1. Horizontal position welding method is used to prevent the meltiing down of weld metal. Schematic diagram of horizontal position welding method is shown in **Fig. 2.** C$\mathcal{J}$ value is 10% in this experiment. In full penetration welding, the important factor is the value of C$\mathcal{J}$, the beam pass rate of the beam current. (C$\mathcal{J}$= I_c / I_b : I_b indicates the incident beam current, I_c indicates the collected beam current shown in Fig. 2.) Size of the specimens is shown in **Fig. 3.** 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. After processing the specimens, they are

Table 1 Chemical compositions of JFMS

Material	Chemical compositions (wt%)										
	Fe	Si	Mn	Cr	Ni	C	P	S	Mo	V	Nb
JFMS	BAL.	0.67	0.58	9.58	0.94	0.05	0.009	0.006	2.31	0.12	0.06

Table 2 Welding conditions of materials used (6.7×10^{-2}Pa)

Material	Welding position	Beam voltage (kV)	Beam current (mA)	Welding speed (m/min)
JFMS*	Horizontal	100	60	0.6

* Beam oscillation :fx=30(Hz) , dx=3(mm)

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Table 3 Neutron irradiation conditions of JFMS (E ＜ 0.1MeV)

Irradiation apparatus	Irradiation time (hr)	Fast neutron flux density (n/m²·s)	Neutron fluence (n/m²)	Irradiation temperature (K)
KUR	76.30	7.3×10^{16}	2.0×10^{22}	363
Reactor core	313.66		8.2×10^{22}	

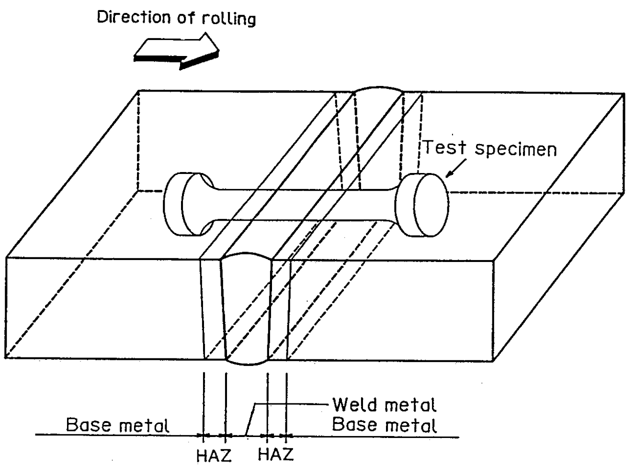

Fig. 1 Sampling of test specimen from welded joint

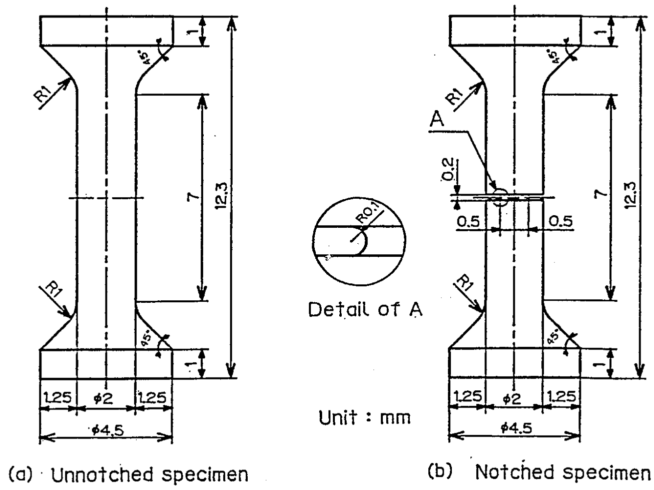

Fig. 3 Test specimen of JFMS

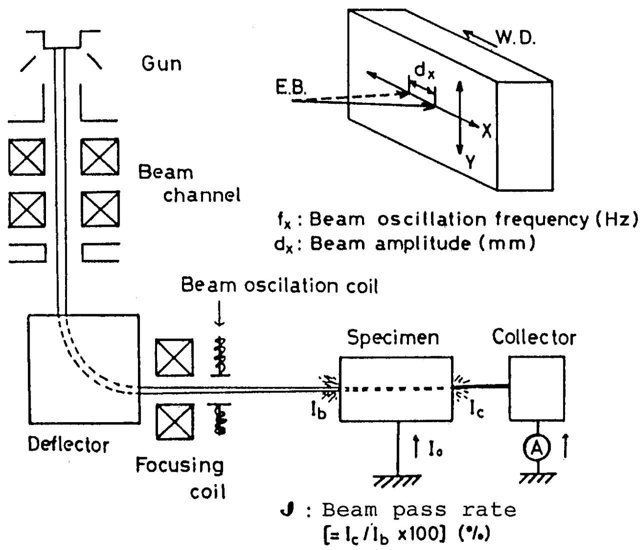

Fig. 2 Schematic diagram of horizontal position welding method

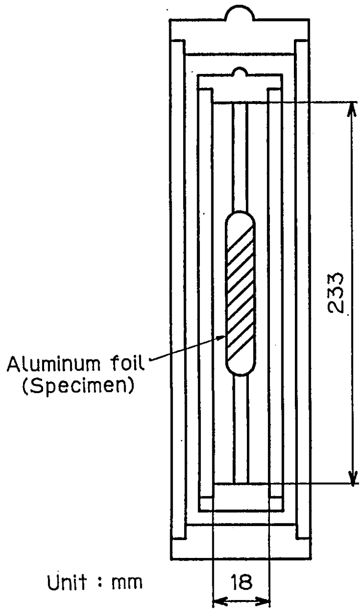

Fig. 4 Capsule for neutron irradiation

exposed to neutron irradiation in KUR reactor core by using the capsule for neutron irradiation shown in **Fig. 4**. Neutron irradiation conditions of the material are shown in Table 3.

2.3 Tensile test

Testing apparatus used in this experiment is shown in **Fig. 5**. Cryostat is used in experiment at liquid helium temperature. Autograph (AG-500A, capacity 4900N) is used as tensile apparatus. Testing temperatures are room temperature (293K), liquid nitrogen temperature (77K) and liquid helium temperature (4.2K), and initial strain rate is 2.38×10^{-4} s^{-1}.

3. Results of experiment and consideration

3.1 Nominal stress-nominal strain curve

Load-displacement curves obtained in this test of base metal and welded joint are shown in **Fig. 6** and **Fig. 7**,

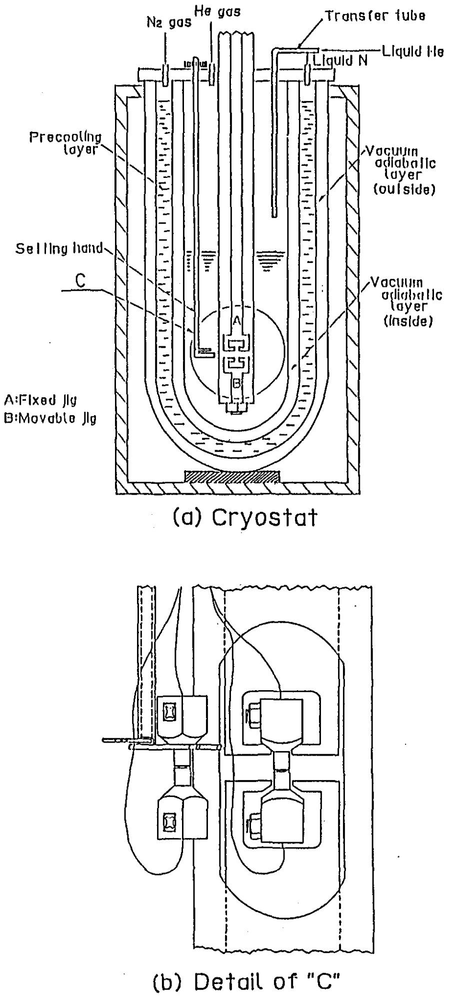

Fig. 5 Apparatus for cryogenic test

respectively.

3.2 Neutron fluence dependences of strength of the material

Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of base metal and welded joint of JFMS are shown in **Fig. 8** and **Fig. 9**, respectively.

Proof stress and ultimate tensile strength at 293K and 77K of base metal of JFMS increase with increasing of neutron fluence.

Proof stress and ultimate tensile strength at 293K of welded joint of JFMS also increase with increasing of neutron fluence. However, proof stress and ultimate tensile strength at 4.2K of base metal and welded joint of JFMS much decrease at high neutron fluence of 8.2 × 10^{22}n / m^2.

3.3 Neutron fluence dependences of elongation of the material

Neutron fluence dependences of elogation of JFMS against various test temperatures are shown in **Fig. 10**. Elongation of base metal and welded joint of JFMS at various test temperature decrease with increasing of neutron fluence.

3.4 Tensile property of notched specimen

3.4.1 Notch tensile strength

Neutron fluence dependence of notch tensile strength of JFMS against various temperatures are shown in **Fig. 11**. Notch tensile strength of welded joint of JFMS at

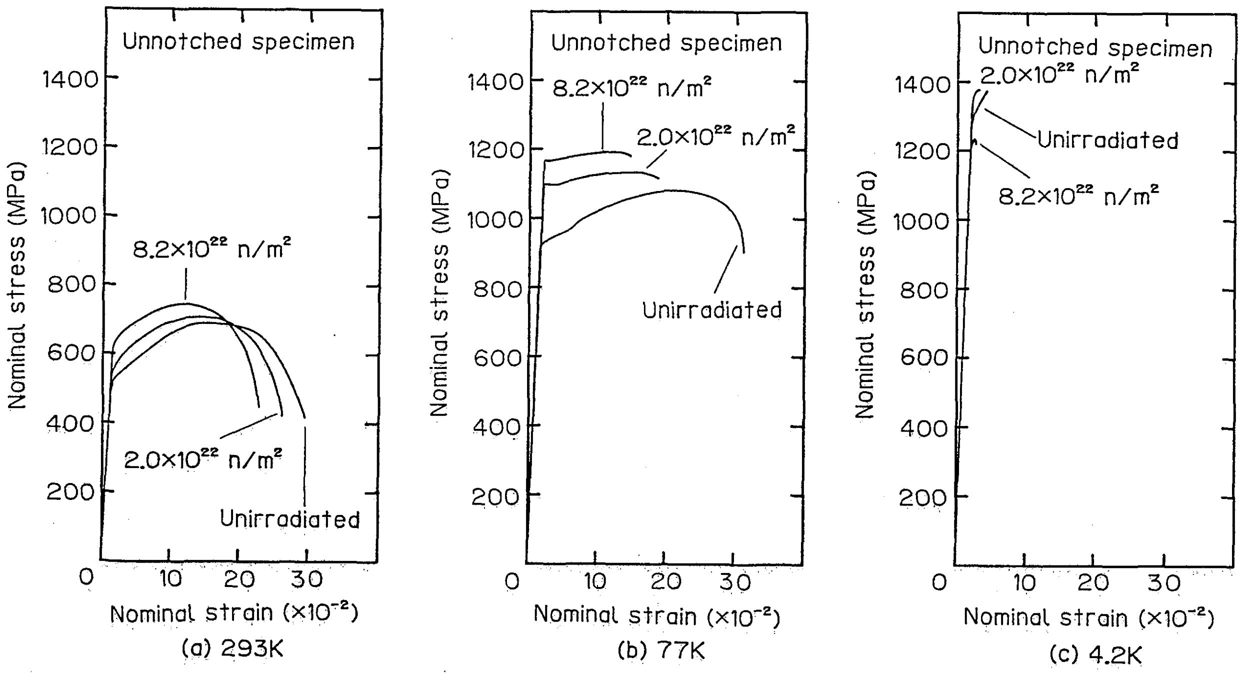

Fig. 6 Nominal stress-strain curves at various test temperatures of JFMS base metals irradiated at different neutron fluence

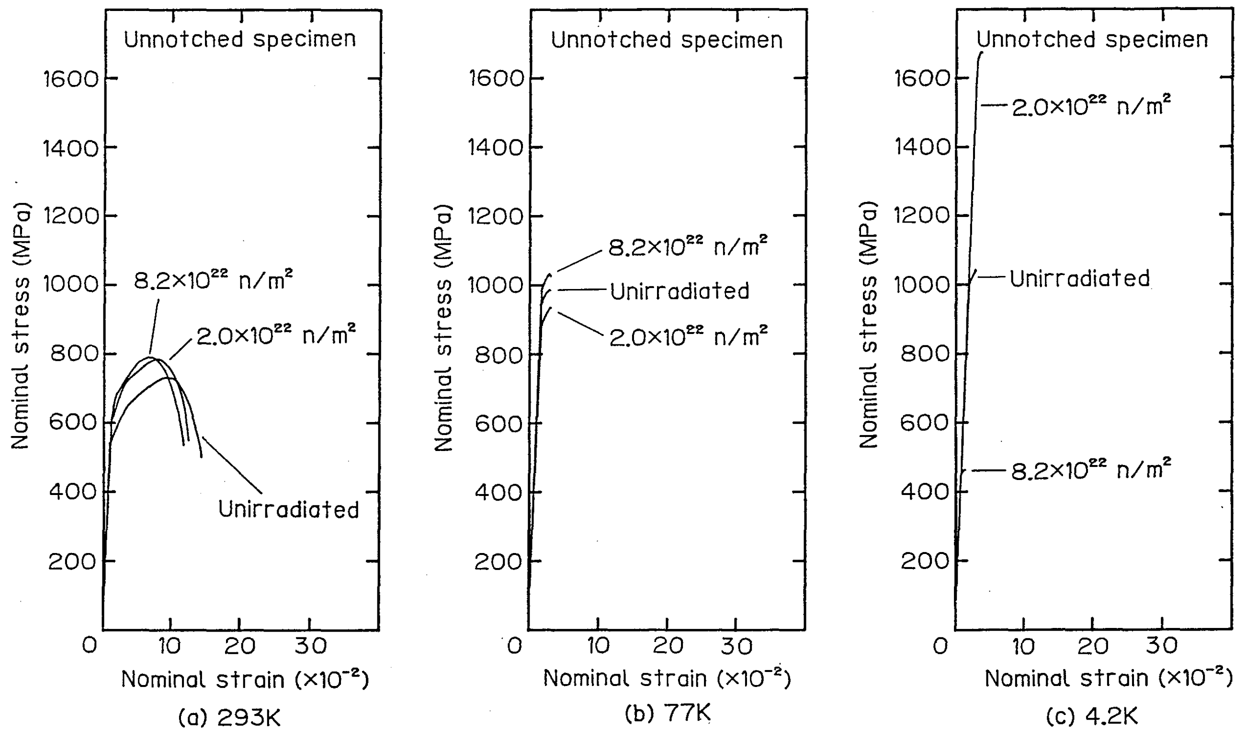

Fig. 7 Nominal stress-strain curves at various test temperatures of JFMS welded joints irradiated at different neutron fluence

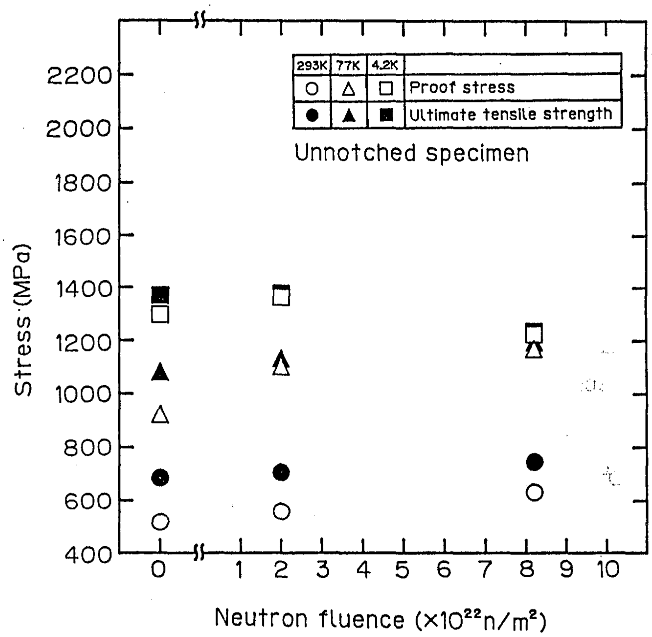

Fig. 8 Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of JFMS base metals against various test temperatures

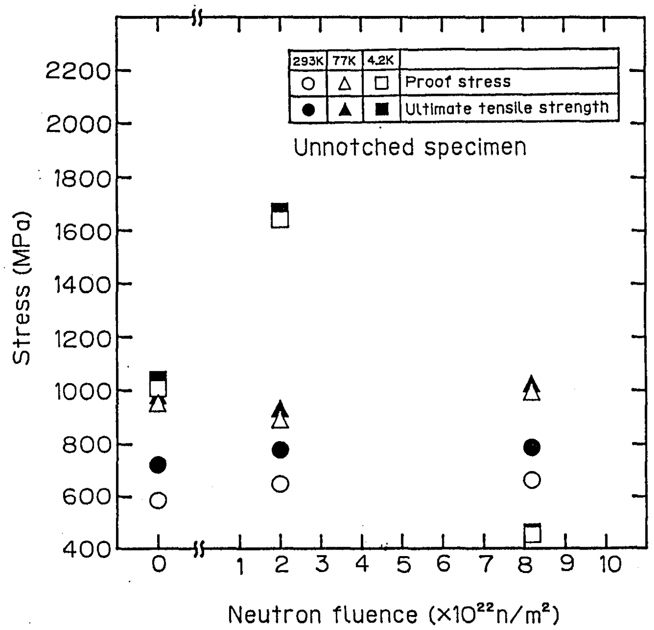

Fig. 9 Neutron fluence dependences of ultimate tensile strength and 0.2% proof stress of JFMS welded joints against various test temperatures

293K increases with increasing neutron fluence and notch tensile strength of welded joint of JFMS at 4.2K decrease with increasing of neutron fluence. Effect of neutron irradiation on the notch tensile strength of welded joint is more evident than effect of neutron irradiation on the notch tensile strength of base metal.

3.4.2 Notch proof stress ratio

Neutron fluende dependences of notch proof stress ratio (notch tensile strength / unnotched proof stress) between notched and unnotched specimen of JFMS against various temperatures are shown in **Fig. 12**. Notch proof ratio has good correlation to fracture toughness and is used as evaluating method of toughness. Notch proof stress ratio decreases at low neutron fluence and increases again at high neutron fluence as shown in Fig. 12.

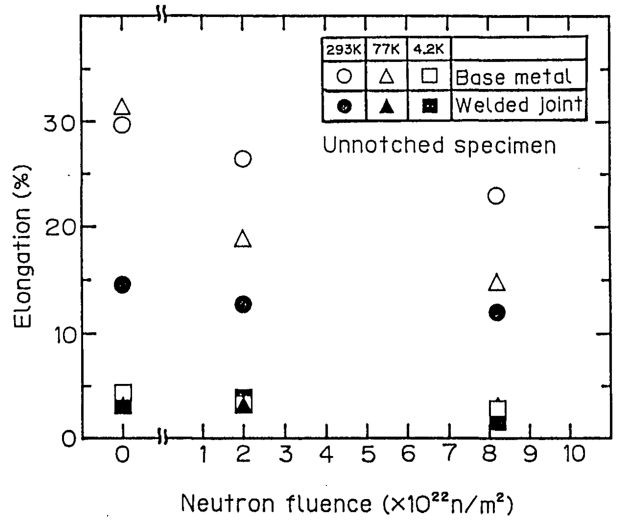

Fig. 10 Neutron fluence dependences of notch tensile strength of JFMS against various test temperatures

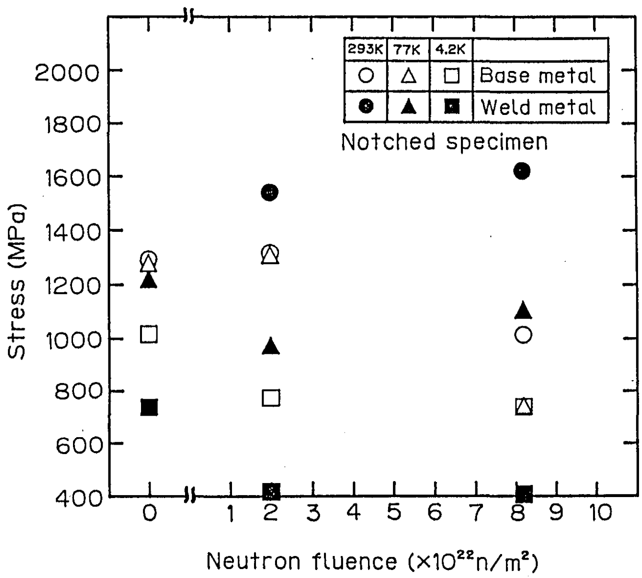

Fig. 11 Neutron fluence dependences of notch tensile strength JFMS against various test temperatures

4. Conclusion

(1) Strength of base metal and welded joint at 293K and 77K increases with increasing of neutron fluence. Strengh at 4.2K decreases with increasing of neutron fluence. Decreasing of the strength at 4.2K in high neutron fluence is larger in welded joint than in base metal.

(2) Elongation of base metal and welded joint of JFMS decreases with increasing of neutron fluence.

(3) Notch tensile strength of welded joint of JFMS at 293K increases with increasing of neutron fluence and notch tensile strength of welded joint of JFMS at 4.2K decreases with increasing of neutron fluence.

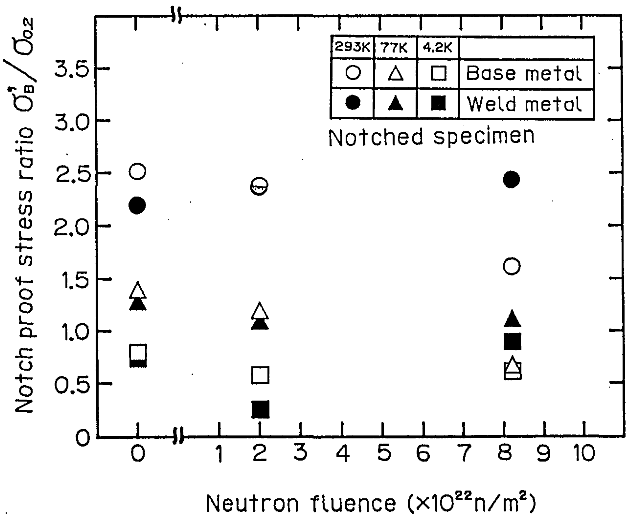

Fig. 12 Neutron fluence dependences of notch proof stress ratio between notched and unnotched specimen of JFMS against various test temperatures

(4) Notch proof stress ratio between notched and unnotched specimen of JFMS at various test temperatures decreases with low neutron fluence and increases again with high neutron fluence.

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