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Neutron Irradiation Effects of V–Ti Binary Alloys

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Synopsis

Mechanical Properties and microstructures of four kinds of V–Ti binary alloys were examined before and after neutron irradiation. The neutron irradiation was done in JMTR (Japan Material Testing Reactor) at an ambient temperature up to 1.5 x 10^{23} n/m^2 (E>0.1MeV) and in RTNS–II (Rotating Target Neutron Source–II) at room temperature up to 5 x 10^{22}n/m^2 (14MeV).

The tensile yield strength of unirradiated V–Ti alloys increased with Ti contents, it indicated a maximum value at near V–40Ti and slightly decreased at V–60Ti. The yield strength of high Ti contents V alloys were slightly affected by neutron irradiations. JMTR irradiation gave many effects on the tensile property, while RTNS–II irradiation affected only the elongation.

I. Introduction

The base metal vanadium has many attractive properties for the use of nuclear materials, that is a high melting point, low density and low induced radioactivity which is due to the neutron irradiation. However, this metal is very sensitive to oxygen or the other interstitial type impurities such as hydrogen, carbon and many others. Therefore, it is not fit alone for use as high temperature structural materials and so it needs alloying. An alloy consisting of vanadium and titanium has a homogeneous solid solution of bcc structure, over a wide composition range and a good oxidation resistance. Titanium contents above 2.5% in the alloy improves strength and maintains ductility [1–3]. Then, V–Ti alloys can be a candidate material for the fuel cladding of a fast breeder reactor or the first wall

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materials of a fusion reactor.

The objective of this experiment is to determine the composition of V-Ti alloy with good mechanical properties and to provide basic information on the irradiation resistance.

II. Experimental

1. Samples

V-Ti alloys were prepared with V metal tips and Ti metal sponge by a direct melting method using a plasma jet melting furnace.
The compositions of the test samples expressed as atomic percentage were pure V, V-20Ti, V-40Ti and V-60Ti alloys. The button shaped ingots were sliced into about 5 mm thickness and were annealed at 900 C for 3 hrs in vacuum (1 x 10^{-4}Pa). Then they were rolled again into foils of 0.1mm and 0.3mm thickness. The 0.1mm thickness foils were punched to miniature size test pieces with 1.5mm wide by 5 mm long (mini-size) for RTNS-II irradiation. The 0.3 mm thickness pieces were cut off to length 20 mm by 5 mm wide (midi-size) for use of JMTR irradiation. Finally these testing specimens were annealed at 900° C for 2 hrs in a vacuum of about 1x10^{-4} Pa to eliminate the strain. The results of composition analysis and the grain size were listed in table 1.

2. Neutron irradiation

The midi-size specimens were irradiated at an ambient temperature (below 150° C) with JMTR. The neutron fluence (E>0.1 MeV) was 1.5 x 10^{23}n/m^2, about 0.03dpa. The other mini-size specimens were irradiated at room temperature with fusion neutron (14MeV) in the range of 1 x 10^{21} - 3.5 x 10^{22} n/m2 (5 x 10^{-4} - 1 x 10^{-2} dpa) with RTNS-II.

3. Mechanical property tests

The tensile and the bend tests before and after irradiation were carried out on miniature and medium size test pieces using a Instron type universal testing machine. The cross-head speed was 3.3 x 10^{-4} mm/s and 8.4 x 10^{-4}mm/s for the midi- and mini-size specimens, respectively.

The vickers and the knoop hardness tests were done by a micro-hardness tester. The applied load weight and loading time were 200-300g and 20 seconds, respectively. In addition to the post irradiation tests above mentioned, structure change observations by a transmission electron microscope were also done.

Ⅲ. Results

1. Irradiation effects on tensile strength

The effects of irradiation hardening in pure V and V-Ti alloys have previously been studied by several investigators[3-8] whose data are compared to the present result in fig. 1. The data in this figure shows that the increase of the yield strength in V-Ti alloys depends on neutron fluence and titanium content. The yield strength of V-Ti alloys clearly increased by the irradiation above 10^{23}n/m^2 and the results of Bohm et al. [7] and this work showing the strong effect of titanium content in irradiated V-Ti alloys.

Fig. 2 shows the yield strength and the maximum elongation before and after irradiation with JMTR. Irradiation fluences were all 1.5 x 10^{23}n/m^2 and the highest irradiation temperature was 150°C. The yield strength of unirradiated V-Ti alloys increases with increasing Ti content. The highest value 650 MPa is found for V-40Ti and the yield strength decreased slightly to 580 Mpa for V-60Ti alloy. The elongation is not different greatly among the compositions.

After irradiation, the yield strength and the maximum elongation are changed depending on the alloy composition. The yield strength increases in each alloy composition by the neutron irradiation. The change in the maximum elongation by alloying is more remarkable. It is found that the total elongation change of pure V is an one order of magnitude larger than that of V-40Ti. Fig.3 shows the Knoop hardness number before and after the irradiation versus Ti contents. The variation in the hardness number is also different among the different compositions as in the strength and the elongation. The highest changed value is for pure V metal and the smallest is for V-60Ti alloy. This tendency agrees well with the variation of the yield strength. The reason for this may be the difference of atom size of V and Ti and we enter into details in a next chapter.

2. RTNS-II irradiation

Figs. 4, 5 and 6 show the tensile strength, the elongation, the bend strength and the Vickers hardness of the RTNS-II irradiated V-Ti alloys at room temperature, respectively. The data at left end indicate, primary points of the unirradiated state. At the fluence of

$3 \times 10^{22} n/m^2$, though the yield strength of V-20Ti starts to increase, the yield strength of V-40Ti and V-60Ti decrease still more. This is softening phenomenon which is not observed in the JMTR irradiation. The maximum elongations are different among the different Ti composition alloys. The value of V-20Ti at $3 \times 10^{22} n/m^2$ irradiation decreases on large scale, but the value of V-60Ti changes a little, rather increasing from the value before the irradiation.

Ⅳ.Discussion

1. Alloy composition dependence of yield strength

As already mentioned above, the irradiation effects on several mechanical properties with the irradiation fluence in figs. 4,5 and 6 were rearranged in figs. 7.8 and 9 to show the variation of tensile strength, the maximum elongation, the bend strength and the Vickers hardness, with alloying compositions at $3.5 \times 10^{22} n/m^2$ with RTNS- Ⅱ irradiations. Though the tensile strength was practically an affected by the Ti content, the other properties such as the elongation percentage and the hardness number varied widely depending on the alloy composition. The existence of the maximum strength on intermediate Ti content comes from the solid solution hardening. The atomic size of Ti is about 10% larger than that of V diameter [9], and the yield strength resulting from this difference is estimated to be about 200 MPa for V-20Ti alloy using the Mott-Nabarro equation[10]. Although this value is smaller than the present experimental value of 400 Mpa, we can suppose a maximum at around V-40Ti alloy.

2. Irradiation effects on the mechanical properties

The atomic displacement cross sections of V and Ti are not so much different. Therefore it seems that it may be a small diference between pure V and V-60Ti alloy in the number of displacement atoms by irradiation. However, the experimental data shows that minor difference in alloy composition can significantly affect the mechanical properties. This behavior may be due to the formation of induced clusters. The observation of induced clusrers in the irradiated specimens was carried out by using a transmission electron microscope, but the sufficient results to explain the mechanism of hardning were not derived from that.

On the other hand, the electron irradiation experiments for these V-Ti alloys were performed by using a HVEM at 1 MeV in the temperature range from 200°C to room temperature [11]. The results show that the induced cluster density of these V-Ti alloys by irradiation decreased as the Ti content increases. The variation of the cluster density with Ti content is thought to be due to the formation of nucleous which adheres to dislocation. Therefore the higher titanium content V-Ti alloys such as V-60Ti are more difficult to form the nucleous or those nuclei will be unstable. These nuclei are expected to be impurities such as hydrogen, carbon and oxygen etc. There is a trend toward lower oxygen contents with increasing Ti content.

3. Comparison between JMTR and RTNS-II irradiation

The energy of the neutron in RTNS-II 14 Mev is about 14 times as large as that in JMTR and so it is expected that there is a big difference of the irradiation damage. Fig. 10 shows the variation of mechanical properties concernedon some V-Ti alloys irradiated with JMTR and RTNS-II. The vertical axis indicated by arbitrary units aproximately correspons to the ratio of the change in mechanical properties. The zero point denotes the unirradiated level, the tensile and the bend strength of V-60Ti alloy with RTNS-II irradiation exhibits lowew values than the unirradiated level.

As this figure shown clearly in fig. 10, the higher Ti content V-Ti alloys have a small variation of mechanical propertis for both irradiations. The degree of apparent irradiation effects differs between each properties. Since there is the no standerd of comparison, we have compared with the relative values against the hardness number. The change of tensile strength with JMTR irradiation is more evident than that of RTNS-II irradiation, while the maximum elongation is in reverse order. The remarkable elongation changes in RTNS-II irradiation reflects that the dislocation motion is much hindered by cascade damage. The mechanical properties also depend on irradiation temperaturue and fuluences of course, so the dose dependency and the influence of irradiation temperature are not mesured and therefore more investigation is necessary.

V. Conclusions

The mechanical properties of V-Ti binary alloys were examined before and after neutron irradiation and led to the following conclusions:

(1) The tensile yield strength of unirradiated V-Ti alloys (Ti

contents up to 60 atomic percents) increases with Ti content.

(2) The tends are clearly upward for yield strength and downward for total elongation with increasing fluence in V-Ti binary alloys.

(3) The irradiation effects of several mechanical properties of various V-Ti alloys are affected in the alloying constituents.

(4) The high Ti contents V-Ti alloys have the small variation of mechanical properties with JMTR and RTNS-II irradiations.

(5) JMTR irradiation gives much effect on the tensile property while RTNS-II irradiation is affected the elongation.

Acknowledgement

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Table 1. Composition and grain size of testing materials

	V	V-20Ti	V-40Ti	V-60Ti
V (at%)	99.7	80.0	60.8	40.6
Ti(at%)	0	19.8	38.9	59.2
O (ppm)	300	150	130	100
C (ppm)	40	30	50	40
N (ppm)	---	30	80	110
Grain size(μ)	10	12	20	90

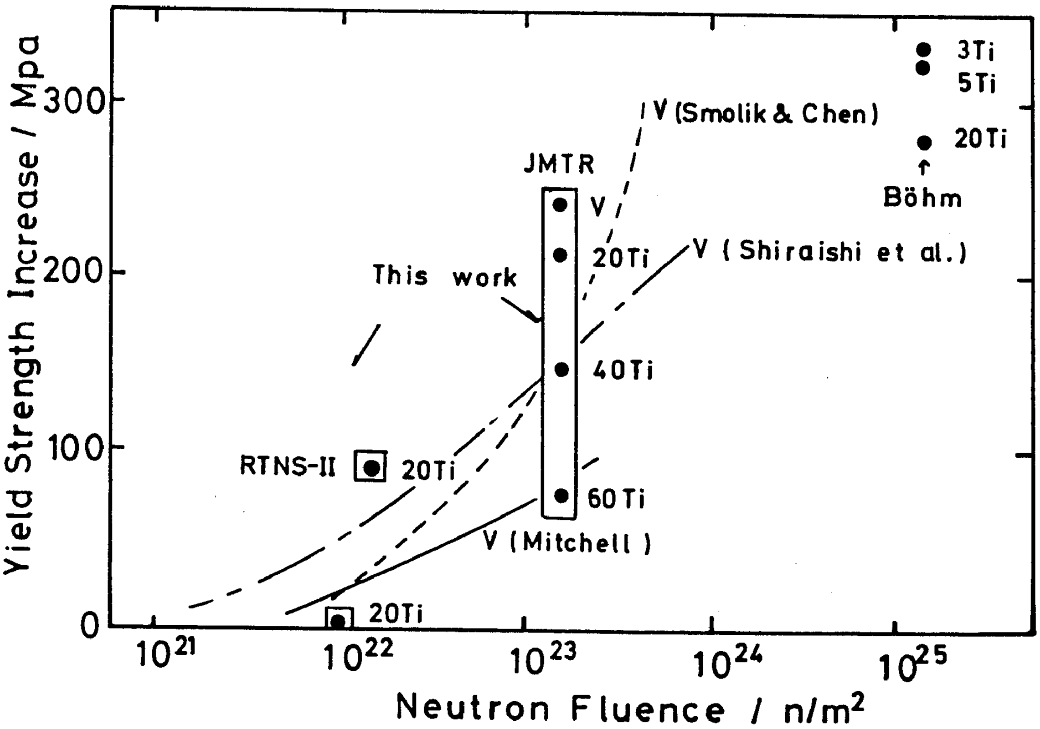

Fig. 1 Yield strength increase versus neutron fluence for V metal and V-Ti binary alloys.

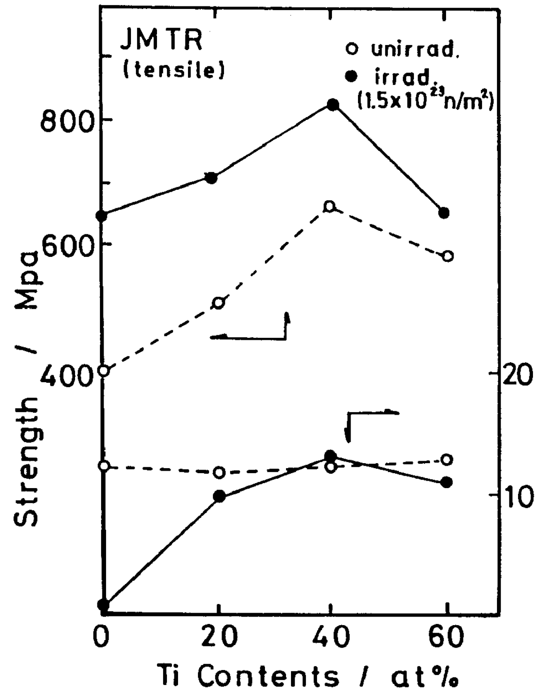

Fig. 2 The composition dependence of tensile properties for V-Ti alloys irradiated by JMTR.

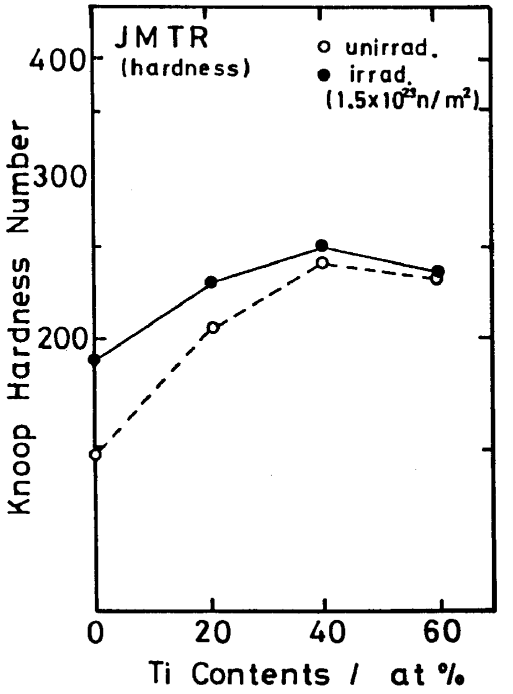

Fig. 3 The composition dependence of Koop hardness for V-Ti alloys irradiated by JMTR.

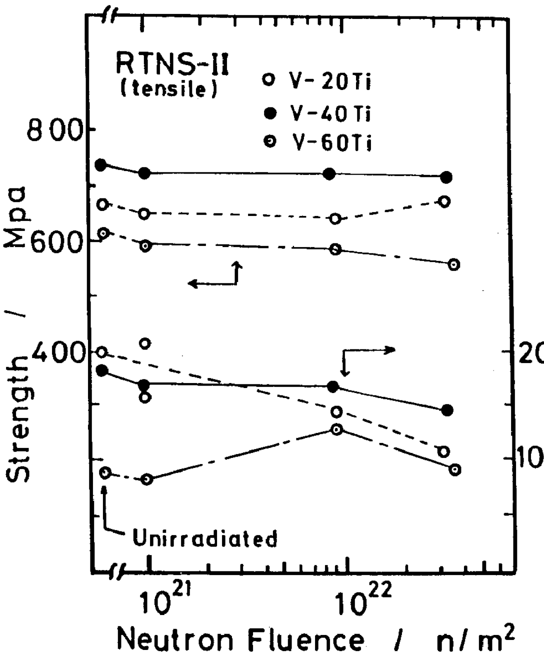

Fig. 4 The fluence dependence of the tensile properties for V-Ti alloys irradiated by RTNS-II at room temperature.

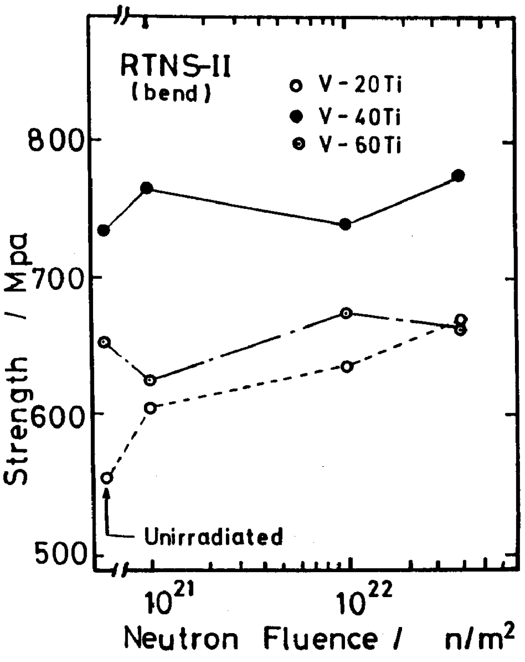

Fig. 5 The fluence dependence of the bend strength for V-Ti alloys irradiated by RTNS-II at room temperature.

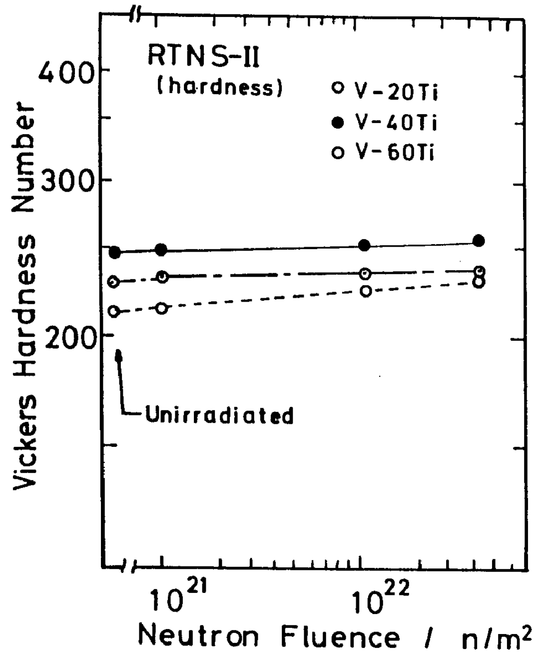

Fig. 6 The fluence dependence of the Vickers hardness for the V-Ti alloys irradiated by RTNS-II at room temperature.

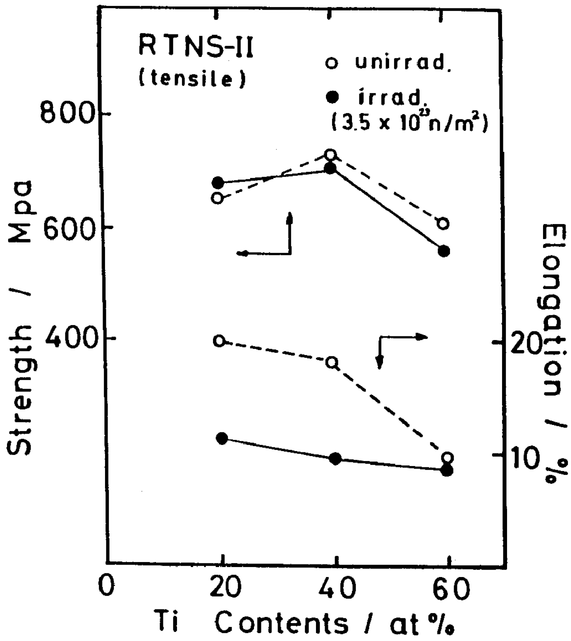

Fig. 7 The composition dependence of the tensile properties for V-Ti alloys irradiated by RTNS-II at room temperature.

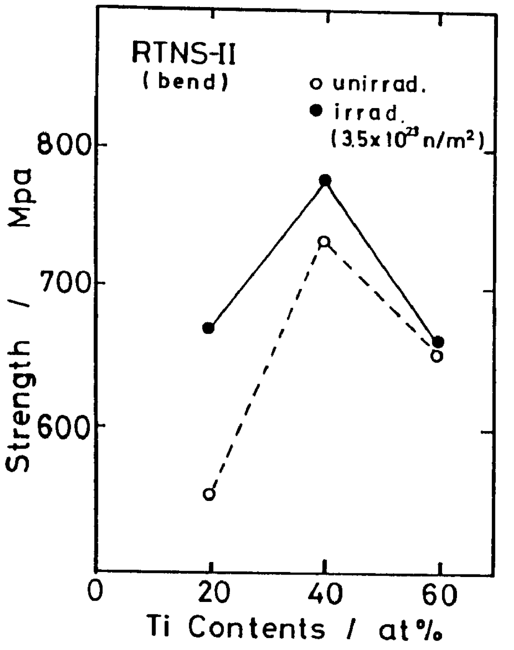

Fig. 8 The composition dependence of the bend strength for V-Ti alloys irradiated by RTNS-II at room temperature.

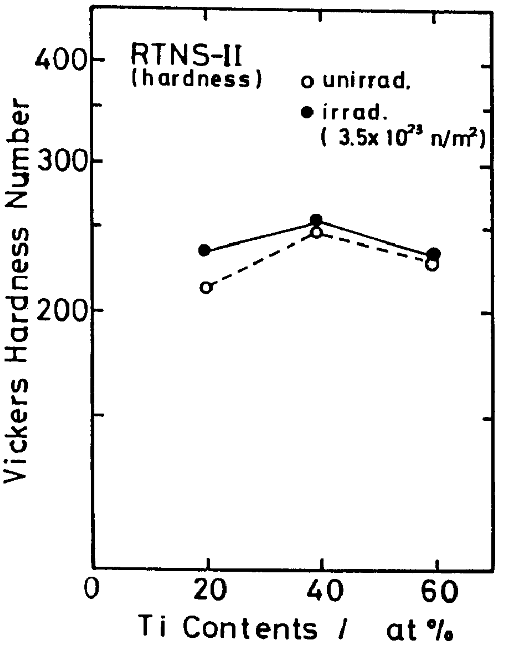

Fig. 9 The composition dependence of the hardness for V-Ti alloys irradiated by RTNS-II at room temperature.

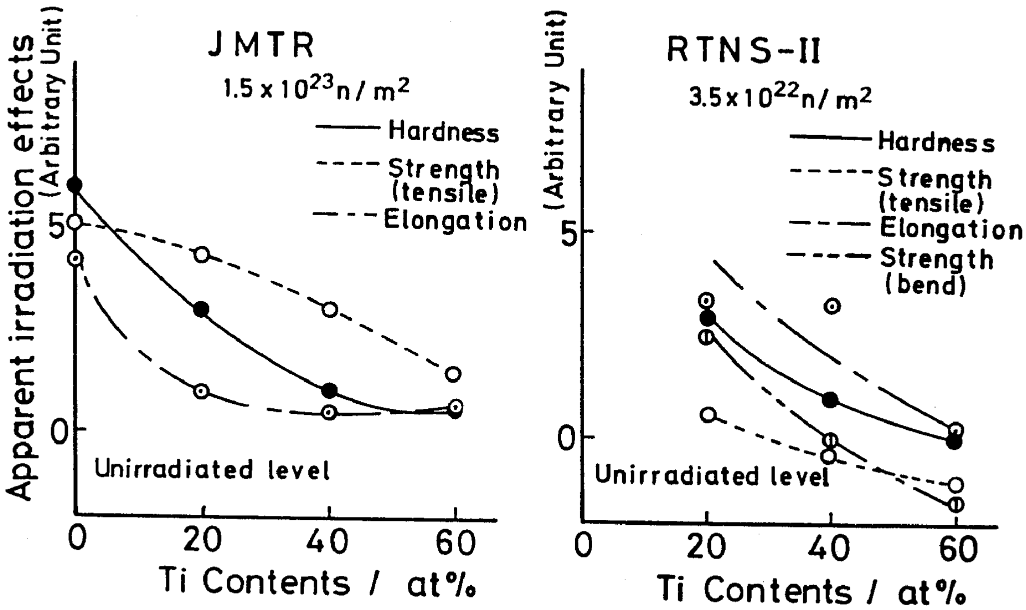

Fig. 10 The comparison of mechanical properties between JMTR and RTNS-II irradiation.