論 文

Studies on Solidification Microstructure and Mechanical Properties of Vanadium-Aluminum Alloys

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V-A1 합금의 응고조직 및 기계적 성질에 관한 연구

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초 록

Vanadium은 비중이 6.09로써 비교적 무거운 금속에 속하나 A1을 30wt% 이내로 첨가하여 Ni_3Al 및 TiAl와 유사한 비강도가 크며 내열성을 지니는 V-A1합금을 얻을 가능성을 지니고 있다. 본 연구에서는 V-A1합금에 Si, Y, Ti, B등 제3원소를 첨가함에 따르는 미세 응고조직의 거동과 기계적 성질을 조사하였다. 알곤 분위기에서 제조된 V-30%A1합금은 상온에서 고용체와 취성이 큰 금속간 화합물인 $VA1_3$등 2상으로 존재하므로 용체화 처리 과정이 요구되며 24시간 이상 장시간 열처리에 의하여 단일 고용상을 이룰 수 있었다. 규소의 첨가는 금속간 화합물의 형성과 아울러 합금의 경도를 크게 증가시키는 경향을 나타내며 B을 0.3%정도가지 첨가할 때 경도가 낮아지는 현상이 관찰되었다. 캔칭된 V-30%A1 합금은 입계면을 따라 decohesive rupture 현상을 나타내며 입자간 파괴 현상도 일부 관찰되었다.

1. Introduction

The solidification structure and mechanical properties of V-(25%-30wt%)A1 alloy and V-A1-X(=Si,Y,Ti,Zr,B)alloys have been investigated in this study. The density of vanadium is 6.09 which is higher than that of Ti. However, by adding A1 less than 30wt% it potentially compete with Ti-base alloy in density. Therefore, the odjective if this study is to investigate the possibility of the development of light-weight, heat-resistance V-base alloy.

The price of pure vanadium is expensive so that it has been used as an additive of alloy steel to improve heat and oxidation resistance. In the early 50', Rostoker et al [1,2] at Argonne National Lab. U.S.A. initiated the investigation of vanadium alloys for cladding materials of fuel element in fast-breeder reactors. In eary 60', the high temperature strength of vanadium alloys temperature between 650 and 1300°C were examined by the Bureau of Naval Weapons[3,4]. The Westinghouse sponsed by the Atomic Energy Commission also studied V-alloys for breed reactor applications[5,6]. Until now, there have been virtually little research efforts on vanadium alloys. However, the application of V-alloys in the so called "first wall" of Fusion reactors becomes current interest.

Systematic investigation of solididication structure and mechanical properties of arc-melted V-A1 and V-A1-X alloys has been condected to develop low density, high temperature materials. Vanadium shows mod-

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erate density high temperature materials. Vamadium shows moderate density, high melting point(m. p. 1910°C). Therefore, the final target of this study is not only substitution of Ti and Ni base alloys but development of aero－space materials which has heat and oxidation resistance.

2. Experimental

All alloys were melted in an argon arc melting furnace. Nonconsumable tungsten electrode is used with water－cooled copper crucible. The schematic construction of furnace has been shown in Fig.1. The purity of vanadium used on this study is 99.98%. The following alloying elements were used for this study : aluminum(99.99%), titanium(99.8%), boron(99.8%), silicon(99.99%) and yttrium(99%). In several cases where weight loss were appreciable, deviations from nominal analyses were checked and corrected by weight losses.

The arc melted ingots were solutionized and annealed to evaluate the effect of heat treatment on their micro－structure and mechanical properties, Photo 1. shows the electrical furnace used for solution heat treatment. The chemical analysis of mother alloys and casted alloys listed in Table 1 have been carried out by EPMA.

3. Results and Discussion

The effects of alloying elements addition and heat treatment on the hardness of as-cast and annealed specimen were examined. Fig.2 shows the effect of various alloying elements addition on the hardness of as csat alloys. Also, all the data obtained on as cast, quenched and annealed ternary alloys are

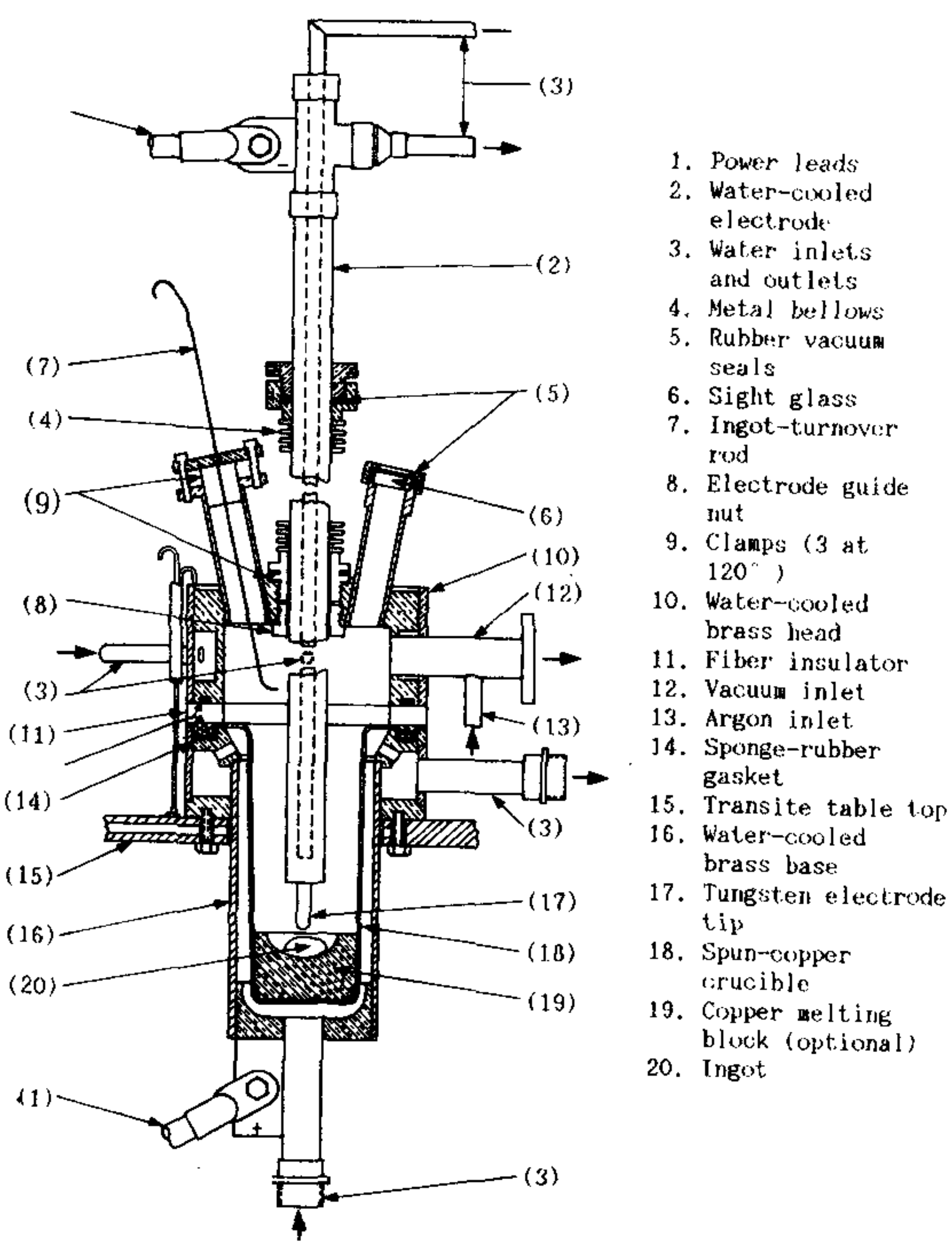

Fig. 1. Nonconsumable－electrode arc furnace.

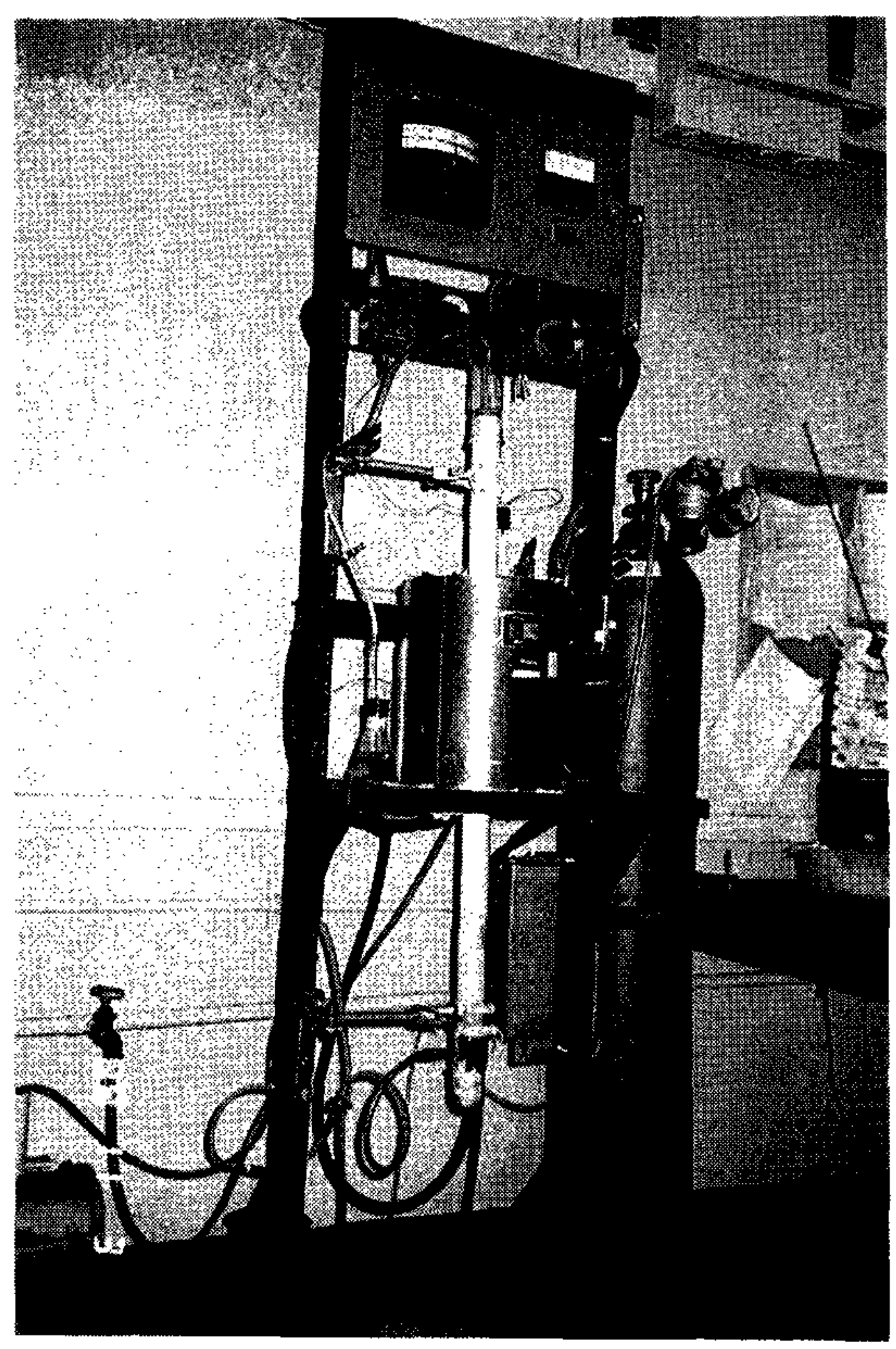

Photo 1. Photography of furnace for solution heat－treatment.

Table 1. Vickers hardness of V－Al alloys

Column 1	wt%	as cast	quenched	annealed	density
Si	0.5	468	443	417	
	1.0	470			
	1.5	555			
Y	0.6	515	382	377	
	1.06	414			
	2.91	434		384	
Ti	3.06	422	431	388	
	6.07	415		394	
	8.12	434		433	4.685
Zr	1.0	418		398	
	1.95	448		400	
	3.94	467	426	417	4.636
B (25%Al)	0.06	393	403	374	
	0.1	381			
B (30%Al)	0.2	425			
	0.3	333		405	
Zn	2.03	423			
	4.95	426			
	8.94	409			

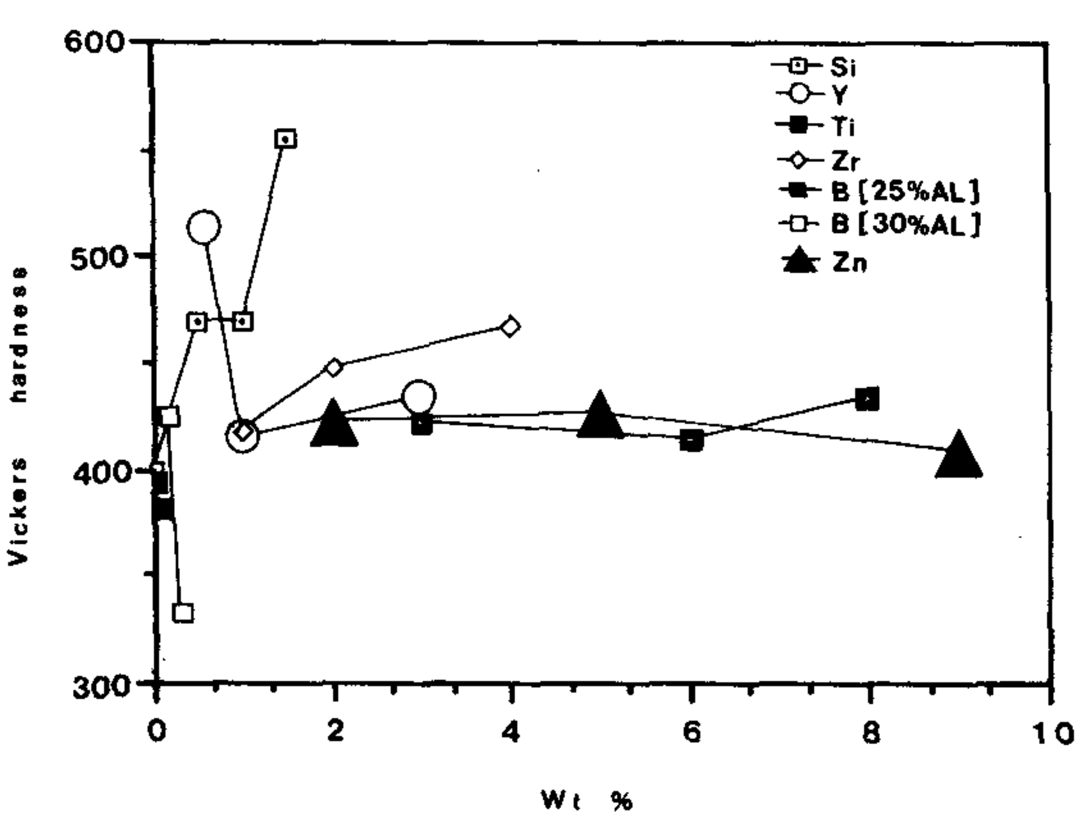

Fig. 2. Hardness of V－Al－X (X=Si, Y, Ti, Zr, B, Zn) cast alloys.

summarized in Table 1.

The addition of silicon up to 1.5 wt% harden vanadium－aluminum alloy very rapidly to levels on excess of 550 VHN as shown in Fig.2. The elements titanium and zirconium moderately increase the hardness of vanadium alloys up to 470 VHN. However, the addition of small amounts of boron and yttrium slightly depresses the hardness, The addition of boron below 0.3wt% is more effective than the addition of yttrium about 1.0 wt% in this respect. Addition of zinc seems to little effect on the hardness.

As shown for Table 1. The differences between as－cast and annealed hardness of V－30%Al－X(X=Si,Y,Ti,B,Zr,Zn)alloys are not so substantial. The two hours annealing of V－30%Al－Si alloy at 1200℃ followed by water quenching slightly reduces the hardness from 468VHN to 443VHN. Addition of zirconium shows similar behavior. In case of V－30Al－0.6Y alloy, relatively large reduction of hardness up to 27%(377VHN)by heat treatment is observed：On the other hand, the alloys which contained boron do not vary hardness by heat treatments. After annealing, Ti added V－30%Al alloy shows 10% reduction of hardness.

It was estabilished that if the weight percents of aluminum exceed 34%, the VAl_3 phase enters into equilibrium with vanadium solid solution by means of a peritectic reaction[7]. To avoid a formation of intermetallic compounds of vanadium, alloys containing up to 32% aluminum which is known to be in the terminal range of solubility limit has been prepared.

Photo 2 is the microstructure of cast V－32%Al alloy. Even though, the exact compostion of phase was not thoroughly determined, it can be reasonably conclude that there exist only solid solution phase. Fig. 3 and Fig. 4 are X－ray diffraction pattern and Energy Dispersive Analysis results of as cast V－32%Al alloys, respectively. No evidence of the formation of intermetallic compound has been detected.

Refinement of grain size by means of recrystallization process has been observed after 1100℃, 24 hrs annealing treatments, Photo 3. shows the above heat treated specimen. It

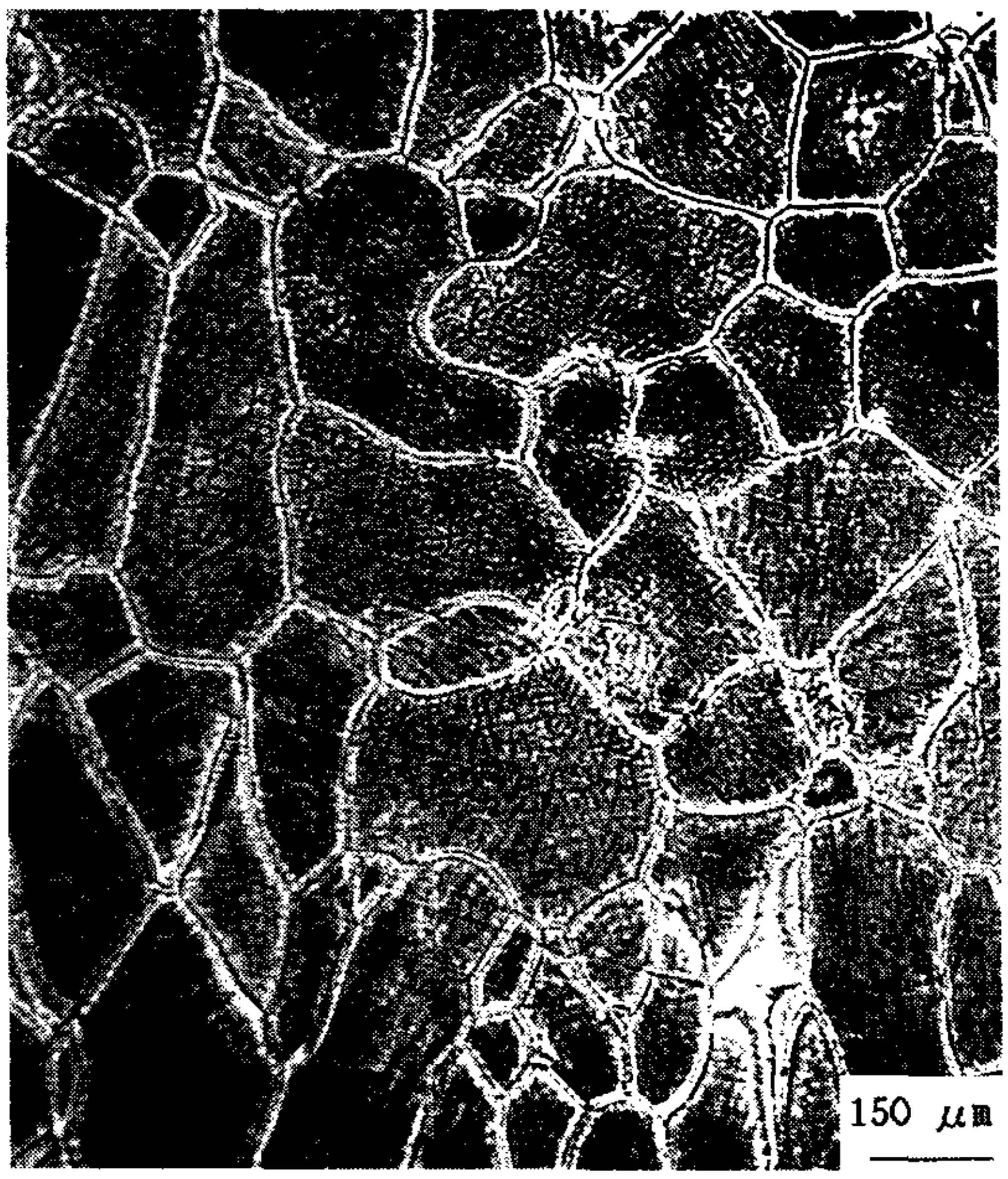

Photo 2. Microstructure of Vamadinm—32% Al alloy, as cast.

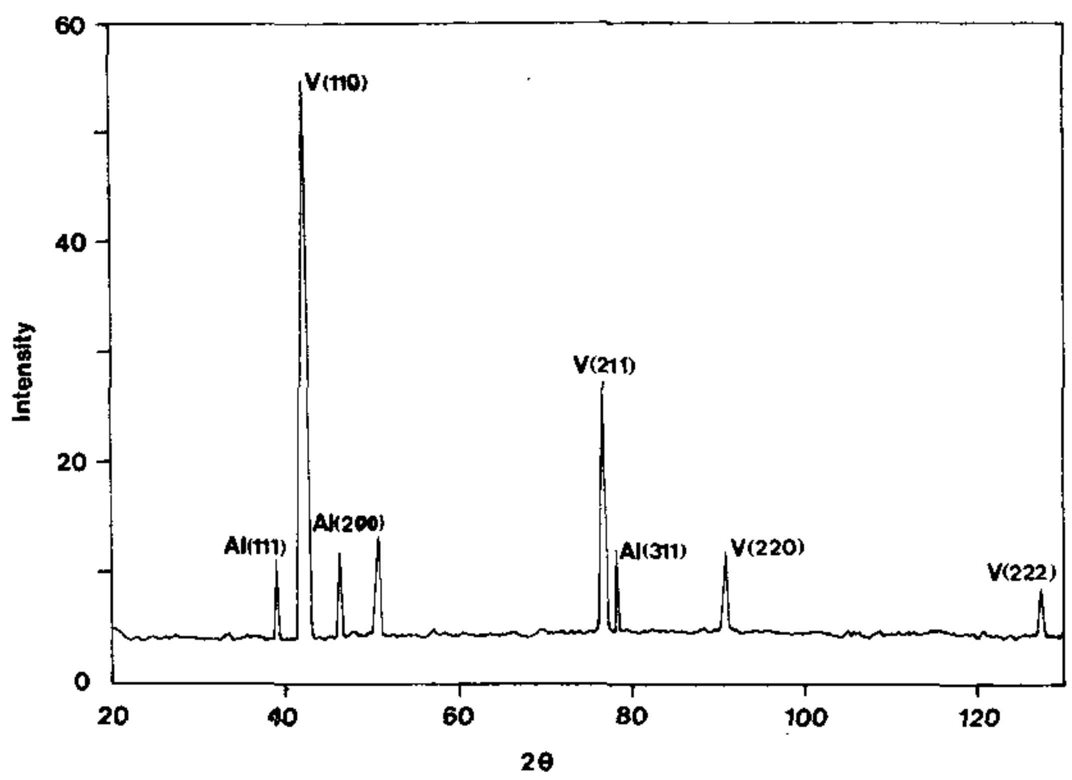

Fig. 3. X—ray diffraction pattern of V—30% Al—0.5%Si alloy.

has been also shown that aluminum was fully dissolved in vanadium, and thus, only solid solution phase is predominate.

Photo 4 is the microstrncture of V—30Al—0.5Si alloy, Due to high affinity of silicon to oxygen, it shows the rectangular networks of oxidantion path. Also, there are segregation of finely dispersed AlSi phase throughout the matrix. Photo 5 is the microstructure of as—cast V—30Al—1.5Si alloy. It also shows a rejected second phase indicating a reduced solubility boundary. The limited vanadium solid solution enters into a eutectic reaction with an intermediate such as AlSi.

As shown in Photo 6, addition of yttrium gives drastic reduction of grain size. O'Brien and Rowe[8] found that alloys which retained

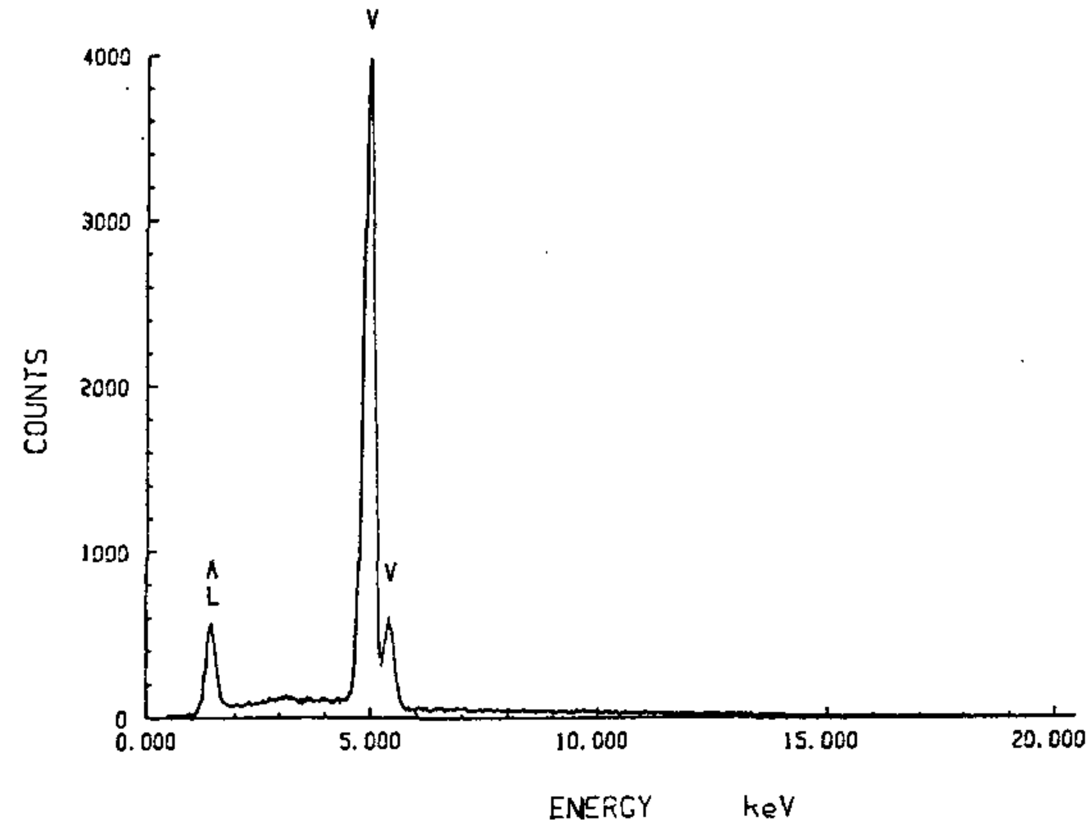

Fig. 4. EDX analysis of V—Al alloy.

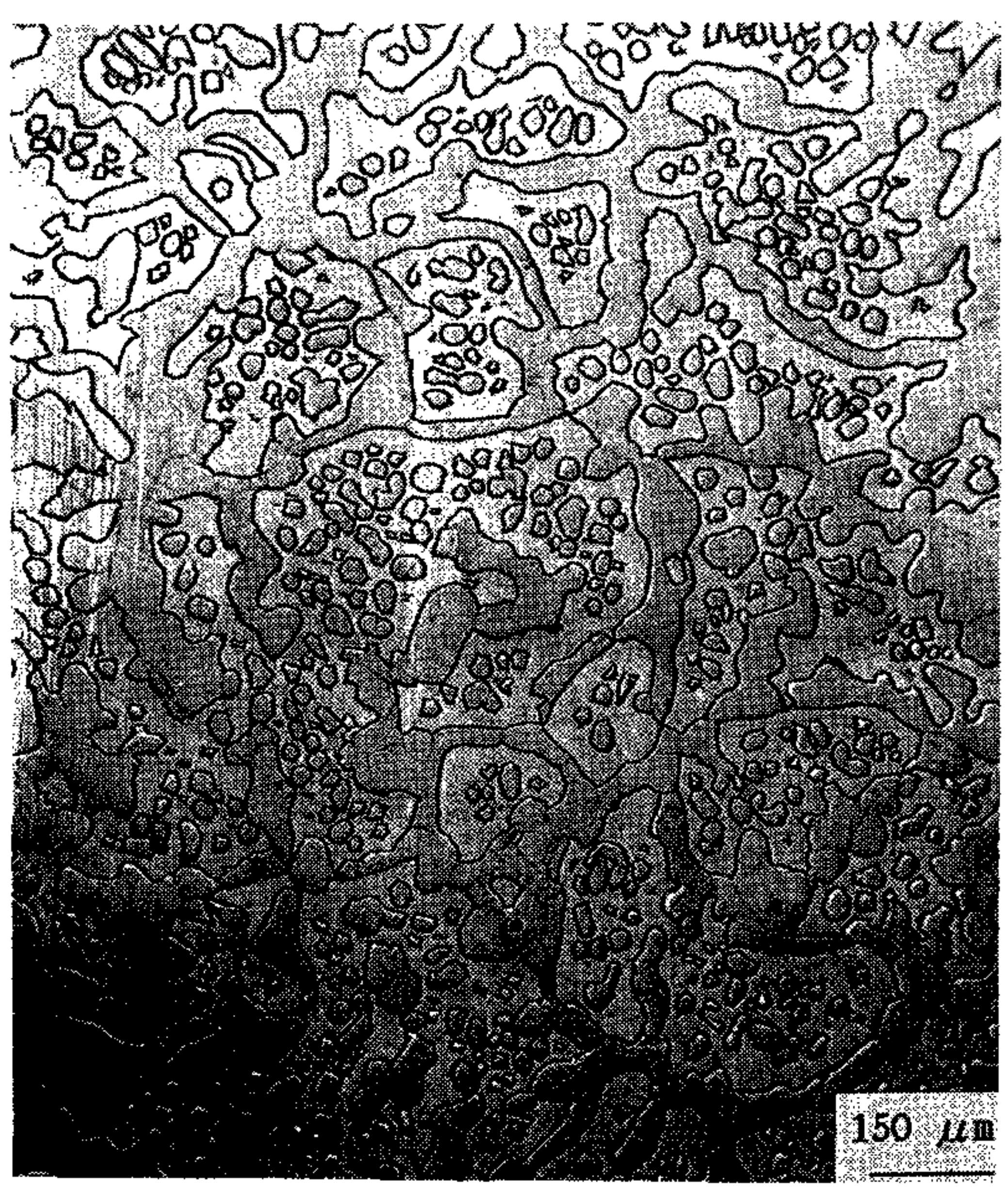

Photo 3. Microstructure of Vanadium—30%Al alloy, annealed at 1100°C, 24hr.

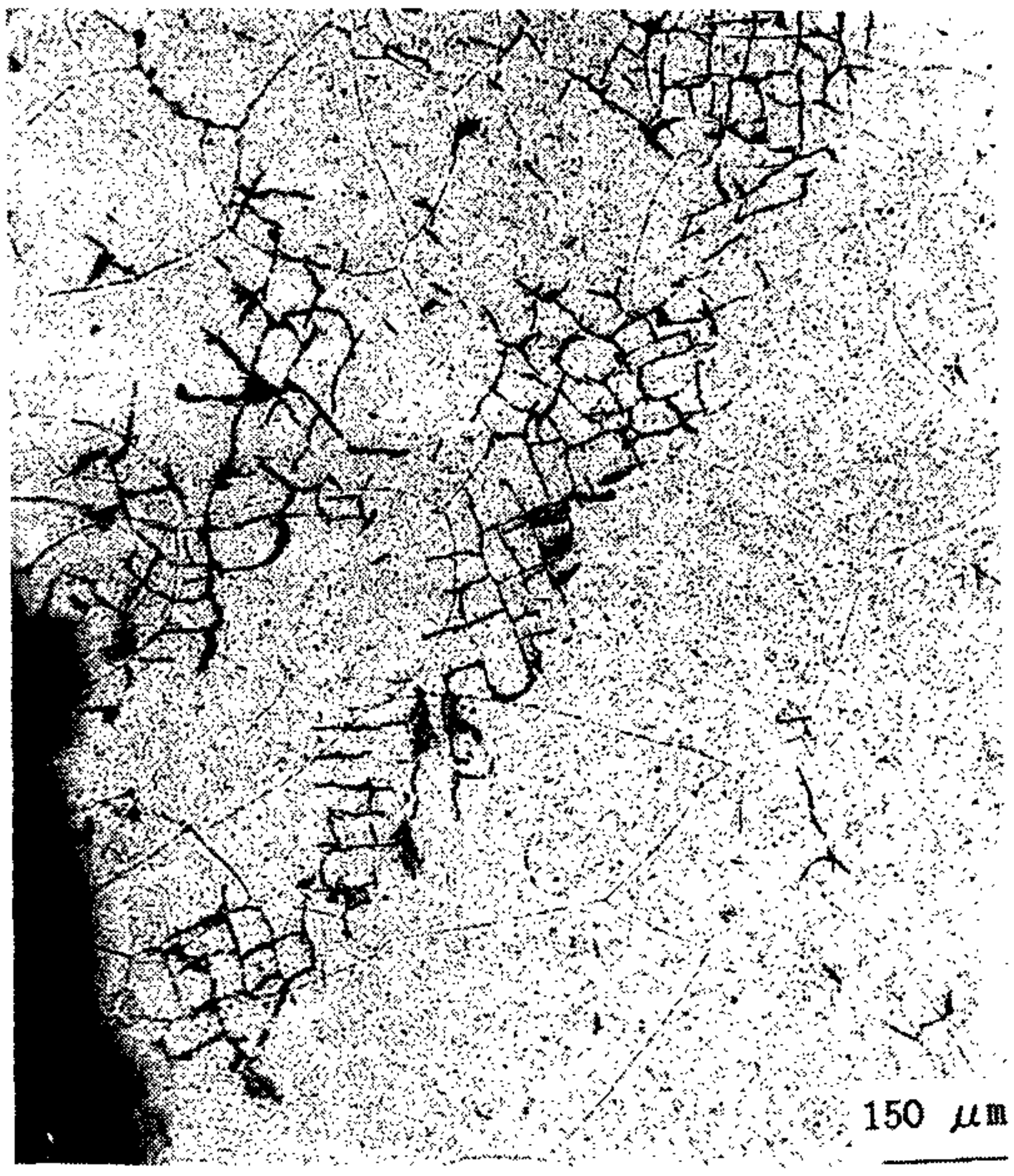

Photo 4. Microstructure of Vanadium−30%Al −0.5%Si alloy, as cast.

Photo 6. Microstructure of Vanadium−30%Al −0.3%Y alloy, as cast.

Photo 5. Microstructure of Vanadium−30%Al −1.5%Si alloy, as cast.

more than 0.1% yttrium contained a second phase, and thus, had a scavenging effect of oxygen. Therefore, increasement of ductility can be expected which has already shown in Table 1.

Fractograph obtained by scanning electron microscopy (Photo 7), quenched V−30%Al alloy has decohesive rupture patterns and fractured at the grain boundaries with some transgranular contribution.

As can be seen at Photo 8 and 9, addition of small amounts of boron or yttrium(0.1%B−0.6%Y) to V−25%Al and V−30%Al alloys increases ductility, however, fracture behaviors were not seems to affect significantly except the appearance of fluting which can be seem in titanium alloy having a relatively high aluminum contents. The fractographes of V−30%Al−1.5%Si (Photo 10) and V−30%Al−8%Ti(Photo 11) also show the brittle and cleavage−like decohesive rupture patterns at grain boundaries.

4. Conclusions

The solidification structure and mechanical properties of V－(25%－30wt%) Al alloy and V－Al－X(=Si,Y,Ti,Zr,B) alloys have been investigated and following results have been obtained.

1. The addition of silicon harden vanadium－aluminum alloy very rapidly to levels in excess of 550 VHN. The ti-

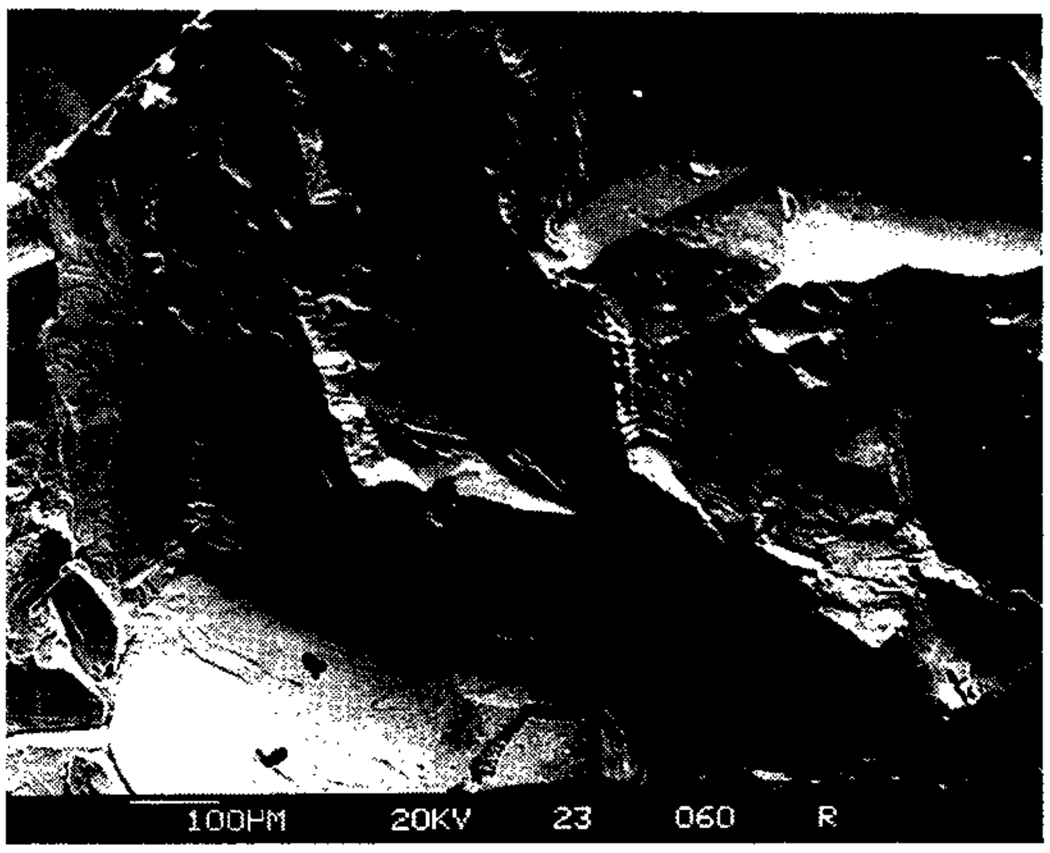

Photo 7. Scanning electron micrograph of fracture surface of V－30%Al alloy (As quenched).

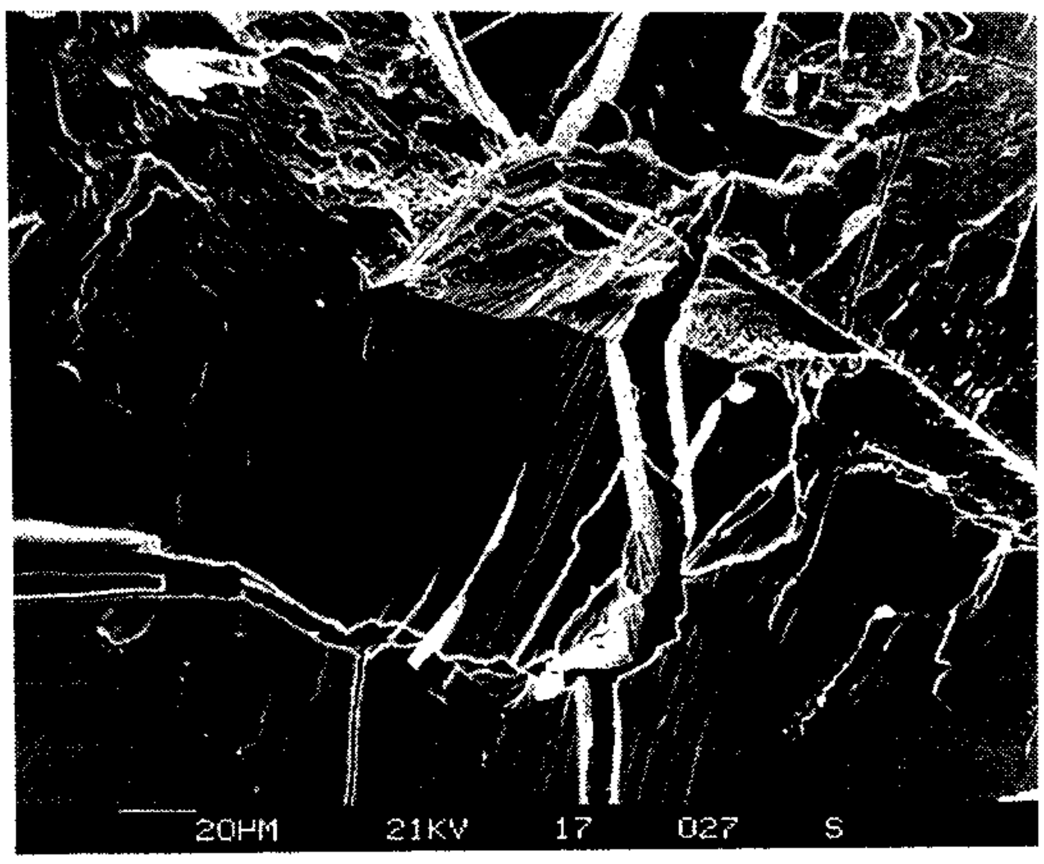

Photo 8. Scanning electron micrograph of fracture surface of V－25%Al－0.1%B alloy (As quenched).

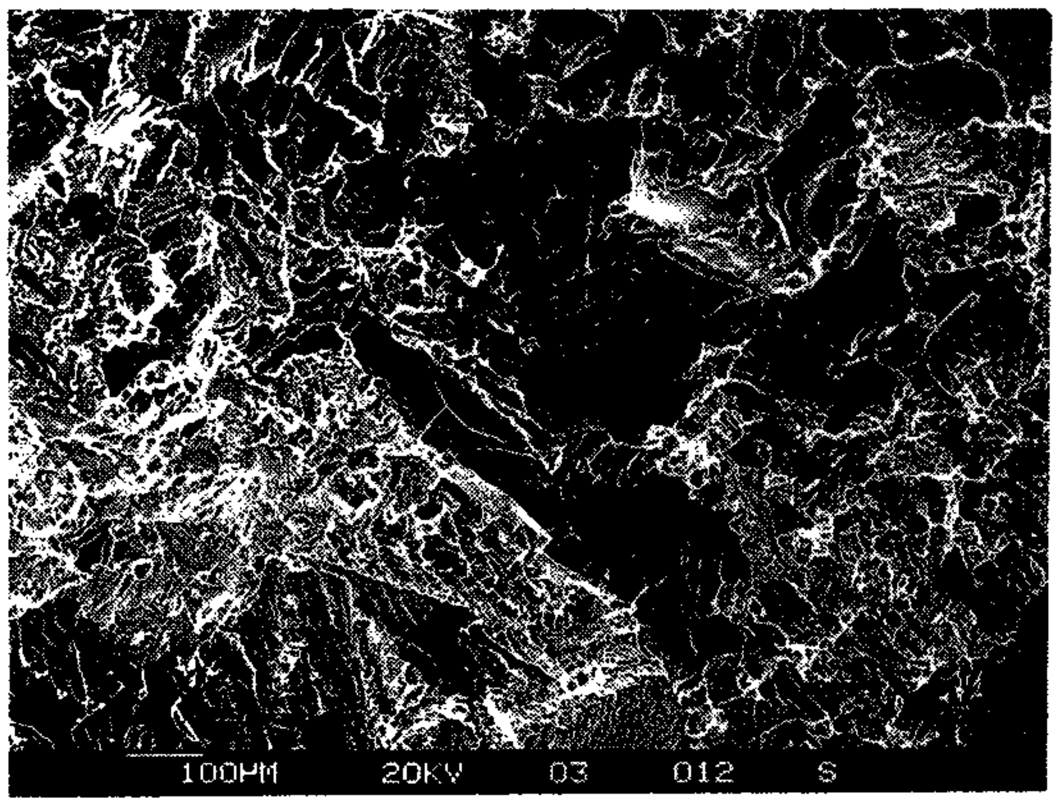

Photo 9. Scanning electron micrograph of fracture surface of V－30%Al－0.6%Y alloy (As quenched).

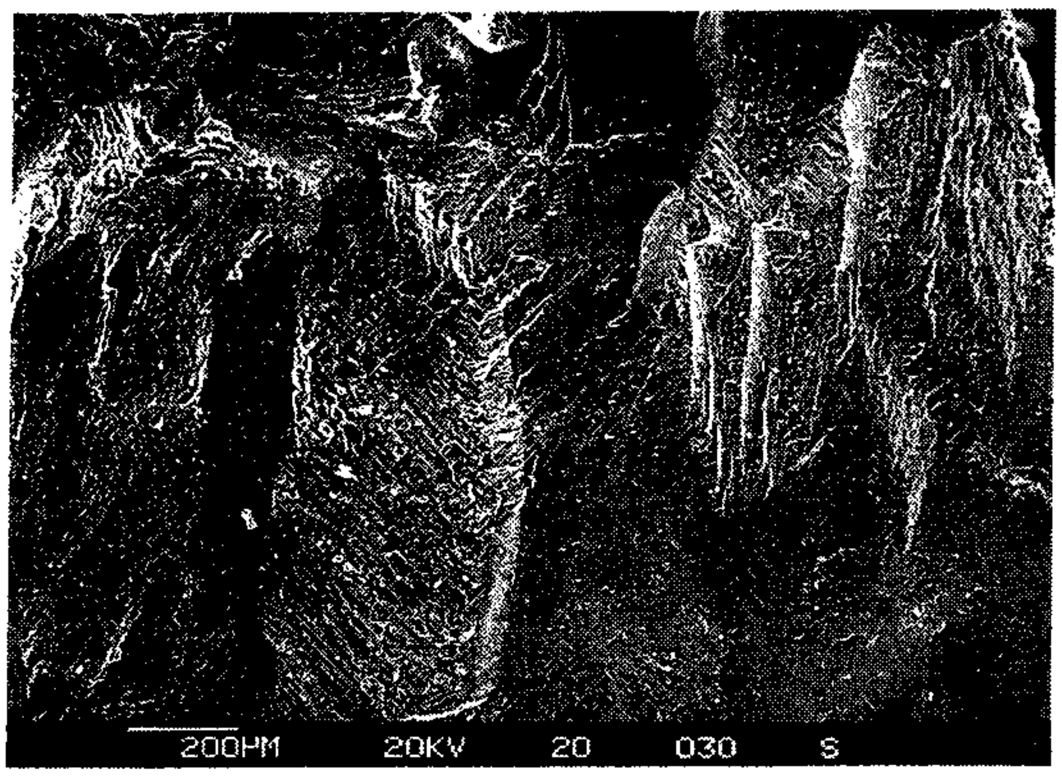

Photo 10. Scannong electron micrograph of fracture surface of V－30%Al－1.5%Si alloy (As quenched).

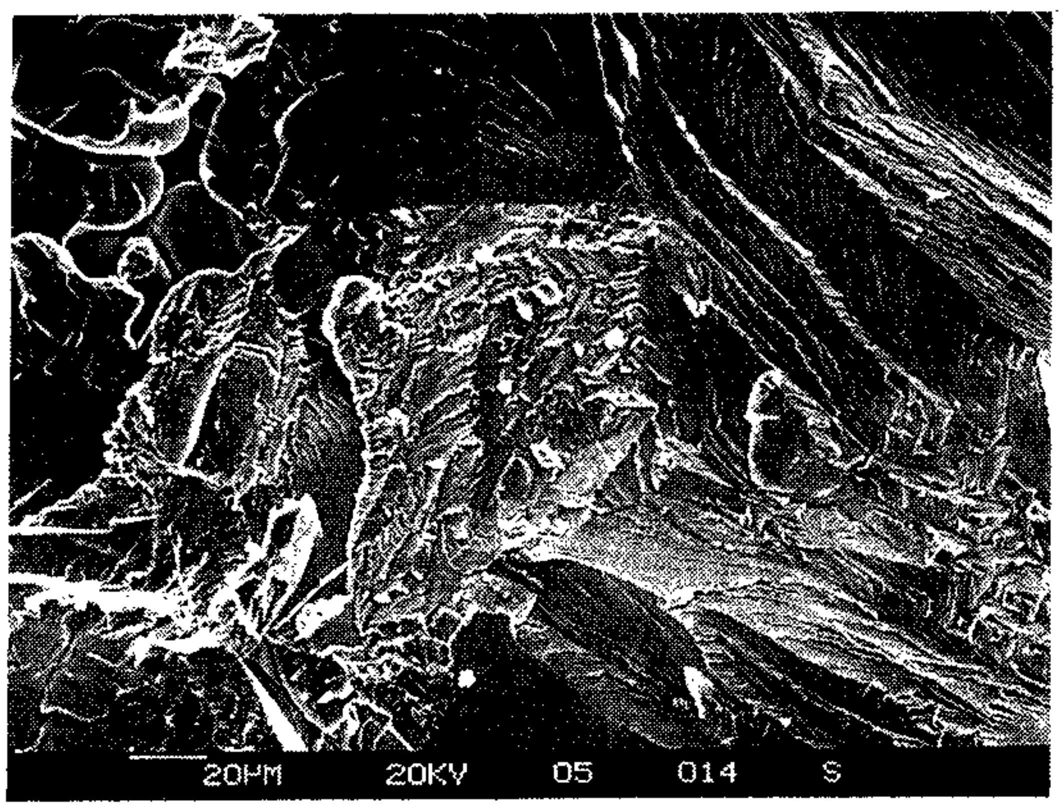

Photo 11. Scannong electron micrograph of fracture surface of V－30%Al－8%Ti alloy (As quenched).

tanium, zircon, are moderate in this respect. Boron and yttrium moderately deppresses the hardness. Zinc seems to little effect on the hardness.

2. The two hours annealing of V−30%Al −Si alloy at 1200°C follwed by water quenching slightly reduces the hardness from 468VHN to 443VHN. Zirconium shows similar behavior. Up to 27%(377VHN) reduction of hardness by heat treatment is observed in V−30Al−0.6Y alloy.
3. Microstructure of as−cast V−30Al−1.5Si alloy shows a rejected phase. The limited vanadium solid solution enters into a eutectic reaction with an intermediate phase such as AlSi.
4. Quenched V−30%Al alloy has decohesive rupture patterns and fractured at the grain boundaries with some transgranular contribution.

후기

본 연구는 1988년도 문교부 연구비 지원으로 수행되었으며 이에 감사드립니다.

References

1. W.Rostoker, A.Yamamoto : Trans. ASM, 46, (1954)1136
2. W.Rostoker, Yamamoto and R.E.Riley : Trans. ASM, 48, (1956)560.
3. B.R.Rajala and R.J.Van Thyne : J.Lesscommom Met. 3, (1961)489
4. F.C.Holtz, R.J.Van Thyne : Dispersion strengthened vanadium alloys Report II TRC−B6007−6, (1965)IIT.
5. W.Pollack, R.W.Buckman., R.T.Begley, C.Thomas, E.C.Bishop : Development of high strength vanadium alloys : WCAP−3487−16, 1967. Westing House Electrical Cop.
6. G.A.Whitlow, R.A.Nadler, R.C.Svedberg : Vanadium alloy cladding development : WARD−3791−47, 1970 Westing House Ad. Reactors Div.
7. W.Rostoker, The Metallurgy of Vanadium. John Wiley & sons, (1958)57
8. W.L.O'Brian, E.A.Rowe : Bureau of Mines Report 6553 : (1964) Westing House Washington D.C. US dep't of Interior.