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Effect of Cold Working and Annealing on the Mechanical and Physical Properties of Ti-20V-4Al-1Sn

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The great advantage of β type titanium alloys is that cold working processes can be applied to the manufacturing process, which are not allowed to conventional α + β alloys such as Ti-6Al-4V. Ti-20V-4Al-1Sn offers the most excellent cold workability in many β titanium alloys. Therefore this alloy has been widely used in various fields including leisure goods such as a golf club and automobile parts. But investigation on mechanical and physical properties of the alloy after cold working is insufficient. Then the purpose of this research is to elucidate the influence of cold working on its characteristics by subsequent heat treatment. The examination method is as follows. 1) The Ti-20V-4Al-1Sn sheet was cold rolled by changing reduction to 0 to 70%. 2) The sheet cold rolled was annealed in β phase region. 3) Mechanical and physical properties and observation of microstructure of the alloy after heat treatment were investigated. Although tensile strength of the alloy cold rolled was increased and elongation was decreases by increasing cold rolling reduction. After annealing tensile strength was constant. Limited drawing ratio showing formability of the 1mm thickness sheet after annealing is same level as commercial pure titanium grade 2.

Keywords; *Ti-20V4Al-1Sn, microstructure, mechanical property, cold formability, physical property*

1. Introduction

The great advantage of β titanium alloys is that cold working processes can be applied to the manufacturing process, which are not allowed to conventional α + β alloys such as Ti-6Al-4V. Ti-20V-4Al-1Sn offers the most excellent cold workability in many β titanium alloys[1,2,3] shown in Figure 1. Therefore this alloy has been widely used in various fields including leisure goods such as a golf club and automobile parts. But investigation on mechanical and physical properties of the alloy after cold working is insufficient. Then the purpose of this research is to elucidate the influence of cold working on its characteristics by subsequent heat treatment

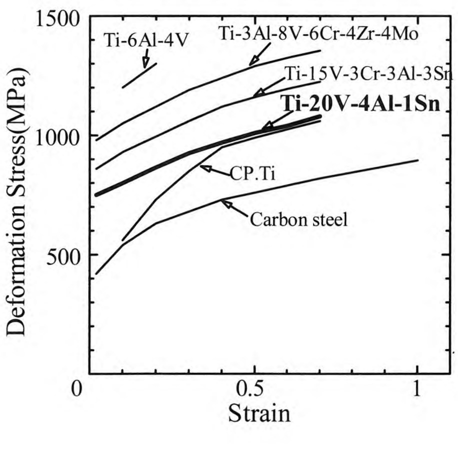


Figure 1. Deformation stress of Ti-20V-4Al-1Sn compared with various titanium alloys[1)]

2. Experiment

4.5mm thickness Ti-20V-4Al-1Sn sheet annealed at 1123Kx900s was prepared. The sheet was cold rolled by changing reduction to 0 to 70% at intervals of 20%. The sheet cold rolled were annealed at 923K, 973K, 993K, 1023K, 1073K, 1123K and 1173K for 300s, 900s and 3.6ks. Mechanical properties of the alloy after annealing such as tensile property, Vickers hardness and deep drawing property were investigated and observation of microstructure of the alloy after heat treatment. Physical properties after cold rolling such as Youngs' modulus, specific heat, thermal conductivity and coefficient of expansion were investigated

3. Result

3.1 Microstructure

Figure 2 shows microstructure of cold rolled and annealed Ti-20V-4Al-1Sn. After cold rolling, grains collapse and are lengthened. More than 40% reduction, grains are deformed largely. After annealing in α + β region (under 1003K), precipitated α phase are observed along deformation band, so it is similar to microstructure of cold rolling. But more than 70% reduction at 973K and more than 40% reduction at 993K, recrystallized single β phase are observed even though α + β region. On the other hand, β region (over 1003K) annealing makes microstructure change to three types. Firstly, deformed grain is observed at low cold rolling reduction and low temperature. Secondary, grain growth is observed at low cold rolling reduction and high temperature annealing. At last, recrystallization is observed at high cold rolling reduction and high temperature annealing.

Figure 3 indicates effect of cold rolling reduction and annealing temperature on grain size. Figure 4 shows effect of annealing temperature and time on grain size. They are investigated from Figure 2 and observation of microstructure of the alloy produced by various annealing and cold rolling conditions.

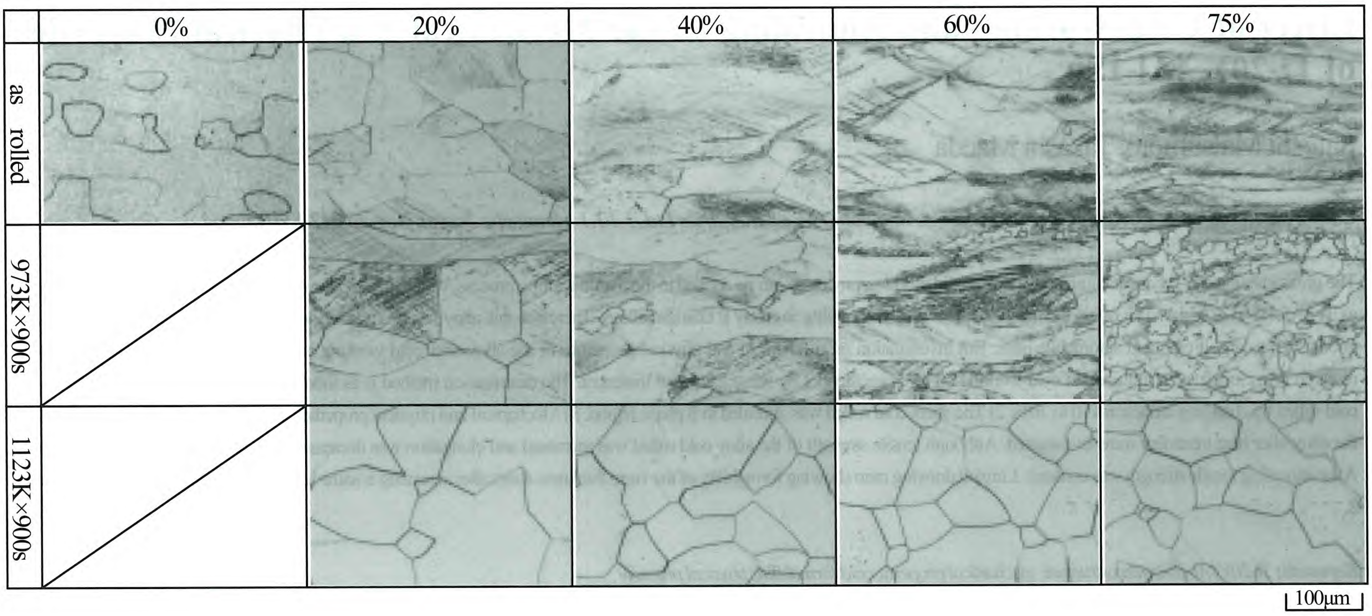


Figure.2 Microstructure of cold rolled and annealed Ti-20V-4Al-1Sn.

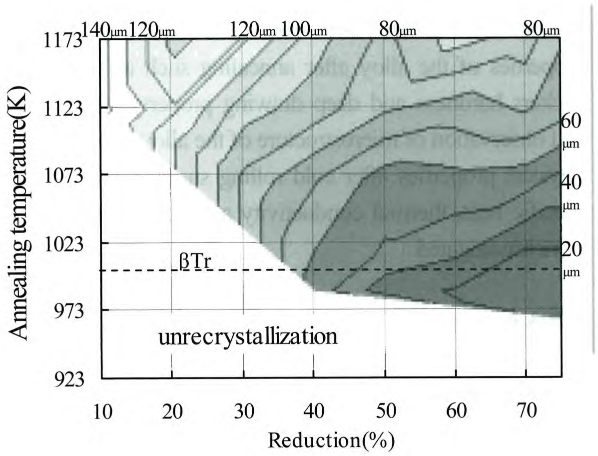


Figure 3. Effect of cold rolling reduction and annealing temperature on grain size (Ann. time: 900s)

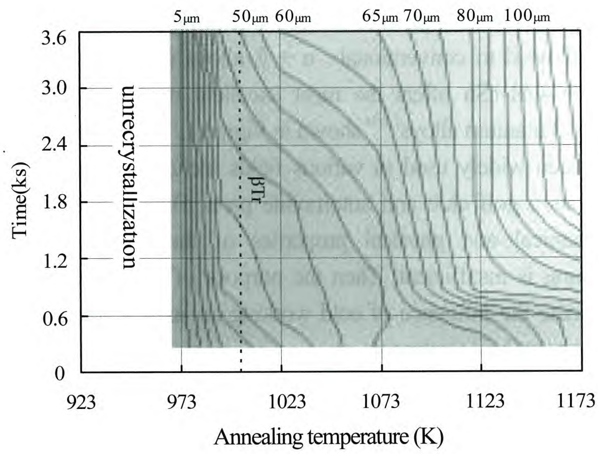


Figure 4. Effect of annealing condition on grain size (reduction 70%)

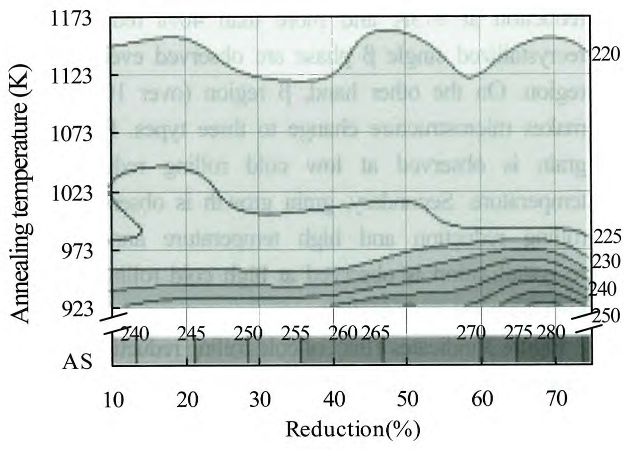


Figure 5. Effect of cold rolling reduction and annealing temperature on Vickers hardness (Ann. time: 900s)

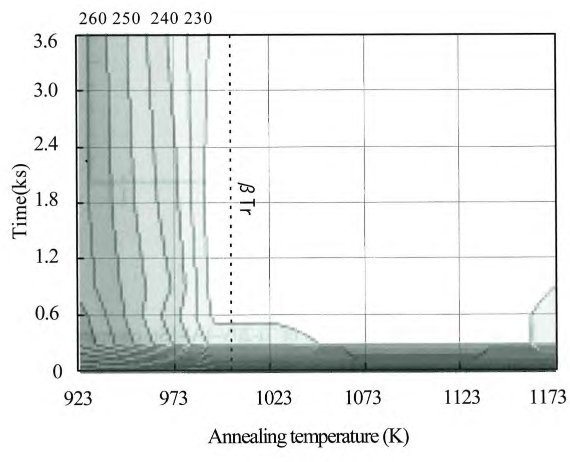


Figure 6. Effect of annealing condition on Vickers hardness (reduction 70%)

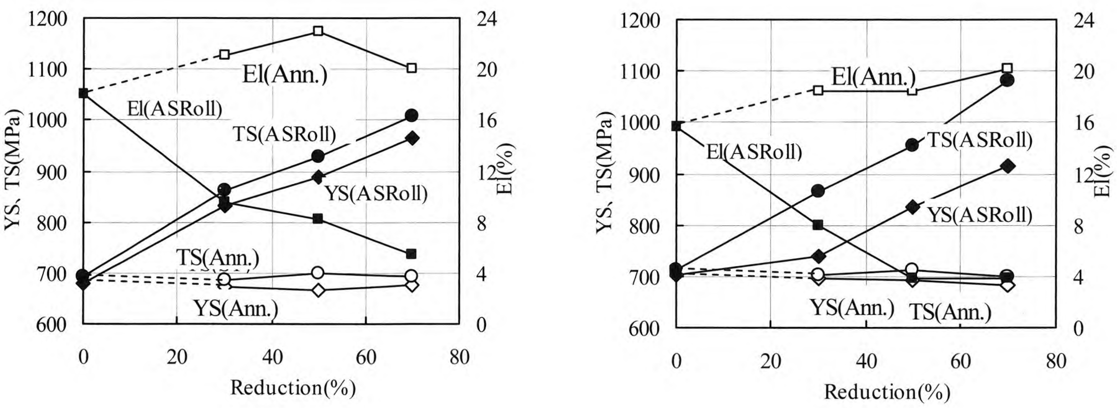
3.2 Mechanical properties

This alloy has work hardening property, so cold rolling makes this alloy harden shown in Figure 5 under part. As cold rolling reduction increase, the hardness of the alloy rises. After annealing, hardness decreases in all annealing conditions in spite of non-recrystallization in low reduction and low annealing temperature. For example, Vickers hardness of 75% reduction is 280, but hardness after annealing at 923K is 250. Over β transus (1003K), the hardness becomes constant. Figure 6 shows effect of annealing time and temperature. The hardness is constant in spite of grain size after annealing in β region.

Although tensile strength of the alloy cold rolled was increased and elongation was decreases by increasing cold rolling reduction. After annealing at 1123K tensile strength was constant. Figure 7 shows tensile property of Ti-20V-4Al-1Sn cold rolled and annealing after cold rolling in rolling direction and transverse direction.

Furthermore, this alloy possesses excellent cold formability, so it is expected that cold deep drawing property of the alloy is good. Generally, commercial pure titanium is superior in deep drawing property; it is applied variously with this characteristic. If deep drawing property of the alloy is good, new application development is enabled. Therefore deep drawing property of the alloy is investigated. Table 1 shows result of deep drawing test of the alloy compared commercial pure titanium and Ti-15V-3Al-3Cr-3Sn as a representative β type titanium alloy.

Limited drawing ratio (LDR: max blank diameter / punch diameter) varies with annealing temperature. LDR of the alloy annealed at 1023K and 1173K is 2.4 of a level same as commercial pure titanium grade 2 and better than Ti-15V-3Al-3Cr-3Sn. On the other hand, the ratio at 1223K is 2.35. This is lower than the ratio at 1023K and 1173K, because of roughness increase caused by grain size increase. Therefore, this alloy having cold drawing property brings about new possibility of fields.



(a)rolling direction (b)transverse direction

Figure 7. Tensile property of Ti-20V-4Al-1Sn cold rolled and annealing (1123K×900s) after cold rolling

Table 1. Deep drawing property of Ti-20V-4Al-1Sn compared with commercial pure titanium and Ti-15V-3Al-3Cr-3Sn

Blank diameter			84	85	86	88	90	92	94	95	96	98	108	limited drawing ratio (max blank diameter / punch diameter)
drawing ratio			2.1	2.125	2.15	2.2	2.25	2.3	2.35	2.375	2.4	2.45	2.7	
Ti-20V-4Al-1Sn	Ann. Temp.	1023K	OK			OK			OK		OK	NG		2.40
		1173K	OK			OK			OK		OK	NG		2.40
		1223K	OK			OK			OK		NG			2.35
CP-Ti[4,5]	Gr.1		OK		OK	OK	OK					OK	OK	≧2.70
	Gr.2(soft)		OK			OK						OK	OK	≧2.70
	Gr.2(hard)		OK		OK	OK		OK	OK		NG			2.35
	Gr.3		OK		OK	NG								2.15
Ti-15V-3Al-3Cr-3Sn[5]				OK			OK			NG				2.25

thickness:1mm (Ti-15V-3Al-3Cr-3Sn: 0.7mm)
punch diameter: 40mm
lubricant: polyethylene sheet
OK: Finishing drawing without cracking NG: Cracking while drawing

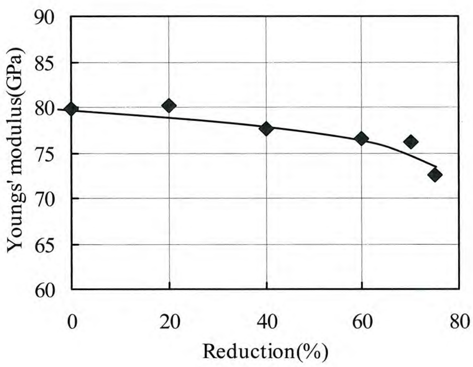


Figure 8. Youngs' modulus of Ti-20V-4Al-1Sn after cold

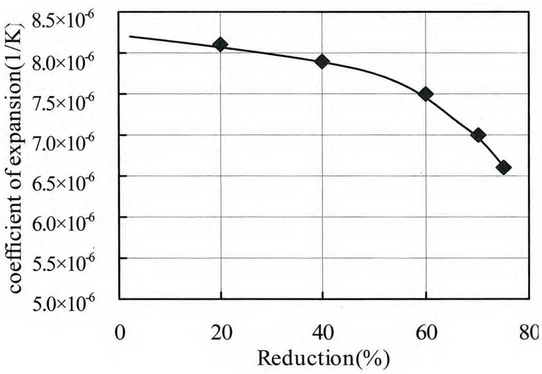


Figure 9. Coefficient of expansion of Ti-20V-4Al-1Sn after cold rolling

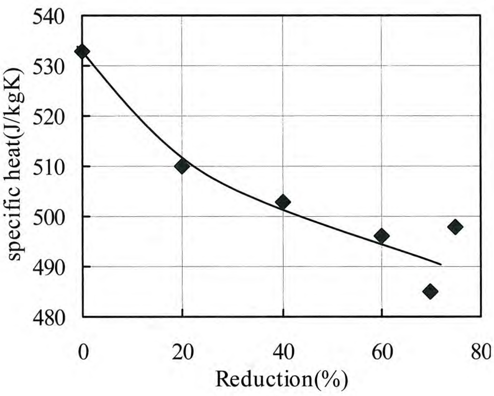


Figure 10. Specific heat of Ti-20V-4Al-1Sn after cold rolling

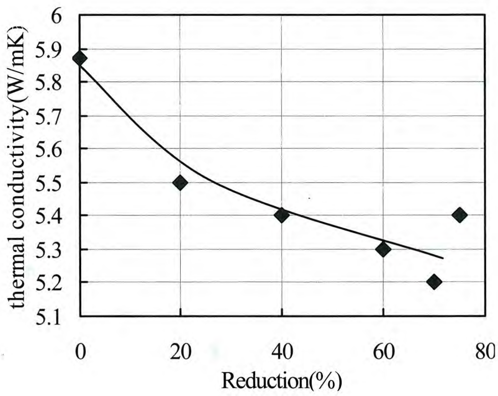


Figure 11. Coefficient of expansion of Ti-20V-4Al-1Sn after cold rolling

3.3 Physical properties

Physical properties such as Youngs' modulus (Figure 8), coefficient of expansion (Figure 9), specific heat (Figure 10), and thermal conductivity (Figure 11) of Ti-20V-4Al-1Sn cold rolled are investigated. All properties decrease with increasing cold rolling reduction.

4. Conclusion

Effect of cold working and annealing on the mechanical and physical properties of Ti-20V-4Al-1Sn are investigated as below.

1) The grain size of Ti-20V-4Al-1Sn varies with cold rolling reduction and annealing condition. Vickers hardness is increased by cold rolling, but in recrystallization region, Vickers hardness is constant although grain size is changed.

2) Deep drawing property is same level as commercial pure titanium grade 2

3) Physical properties of the alloy decrease with increasing cold rolling reduction.

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