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Quasi-Static and Dynamic Properties of Ti-3Al-2.5V Titanium Alloy Tubes

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Abstract. This paper aimed to study the quasi-static and dynamic properties of Ti-3Al-2.5V titanium alloy seamless tubes. The extrusion billets were hot extruded, and then multipass cold rolled into tubes with outside diameter of 6mm, 8mm, 12mm respectively, and wall thickness of 0.5mm, 0.6mm, and 0.9mm respectively. The quasi-static properties were investigated by MTS™ testing system at strain rate of 10^{-3} s^{-1}, while dynamic compression properties by Split Hopkinson Pressure Bar system at strain rate of 3000 ± 200 s^{-1}. The results show that the values of contractile strain ratio of the tubes are between 1.34 and 1.77. The quasi-static yield strength of the tubes is above 765MPa, which is 75 ~ 80% of that of commercial Ti-6Al-4V plates. The dynamic plasticity of the tubes is comparable to commercial Ti-6Al-4V plates, while the dynamic strength of the tubes is only 50~60% of that of commercial Ti-6Al-4V plates.

1. Introduction

The researches showed that titanium alloys exhibited effect of strain and strain-rate hardening, sensitivity to adiabatic shearing, even phase transformation induced by impact under dynamic loading (strain rate>10^2 s^{-1}) compared to their performance under quasi-static loading conditions (strain rate<10^1 s^{-1}) [1]. The combined values of dynamic flow stress, maximum strain during homogeneous plastic deformation, absorbed energy during homogeneous plastic tested by the Split Hopkinson Pressure Bar (SHPB) system were commonly accepted to evaluate the dynamic load-bearing capacity for titanium alloys. As Ti-6Al-4V alloy is the most widely used titanium alloy, the dynamic deformation/fracture behavior and dynamic properties of various products with typical microstructures have been studied for several years [2-6]. As an extension, a series of Ti-Al-V alloys with a higher or lower elements composition than Ti-6Al-4V alloy are also selected to evaluate the potential of being substitutes [7-8]. However, there are few studies on dynamic properties of Ti-3Al-2.5V alloy. Ti-3Al-2.5V alloy is a near alpha, alpha-beta alloy. It is much more amenable to cold working than Ti-6Al-4V alloy and can be cold worked 75 to 85%, which results in moderately high strength and good ductility.Ti-3Al-2.5V alloy is widely used as tubes, which supply civil or military aircrafts for hydraulic systems. The working pressure in tubes for hydraulic lines usually is up to 21~35MPa. The failure of hydraulic line tubes would be accompanied by sudden propagation of crack at a rapid rate. Therefore, the dynamic properties of the tubes need to be studied. In this paper, Ti-3Al-2.5V hydraulic line tubes with outside diameter of 6mm, 8mm, 12mm respectively, and wall thickness of 0.5mm, 0.6mm, 0.9mm respectively were prepared to investigate the quasi-static and dynamic properties.

2. Experimental

The schematic diagram of the preparation process of Ti-3Al-2.5V hydraulic line tubes was shown in Figure 1. The ingot of Ti-3Al-2.5V titanium alloy was double VAR-melted with 200 kg in weight, which has a composition of 3.05±0.05 wt% Al, 2.69±0.06 wt% V, 0.10±0.02 wt% Fe, 0.10±0.01 wt% O, 0.012±0.002 wt% C, 0.010±0.002 wt% N, 0.0010 wt% H, with the balance of Ti. The β-transus temperature ($T_{\beta\text{-transus}}$) of the ingot was tested as 925±5 ℃. The ingot was forged at the temperature of 1100 ℃ into extrusion billets in diameter of 210 mm, and then extruded at the temperature of 850 ℃ into hollow blooms in outside diameter (OD) of 85mm and in wall thickness (W) of 12mm. The hollow blooms were multipass cold rolled by three routes into tubes with three specifications as OD6×W0.5, OD8×W0.6, OD12×W0.9 respectively. The deformation of final cold rolling process for the tubes with three specificaitons was controlled as 70%, 65%, and 60% respectively. Vacuum annealing, as 500 ℃ / 2 hour/ Furnace cooling, was adopted after cold rolled.

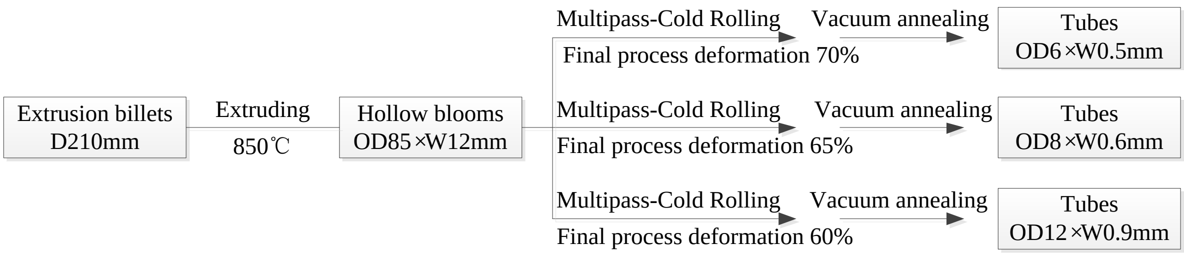

Figure 1. The schematic diagram of the preparation process of Ti-3Al-2.5V tubes

The quasi-static properties were tested by MTS™ testing system at strain rate of 10^{-3} s^{-1}. The specimens for tensile test were 220 mm in total length and 50 mm in gauge length, directly cutting from whole tubes. The contractile strain ratio for the tubes was tested in accordance with SAE AS4076.

Dynamic compression properties were tested by SHPB equipment at average strain rate of 3000±200 s^{-1}. At the strain rate of 3000±200 s^{-1}, visible damages can be observed on the specimens. Specimens for dynamic test were respectively in length of 4mm for OD6×W0.5 tube, 4.5mm for OD8×W0.6 tube, 5mm for OD12×W0.9 tube. Both top and bottom surface of the dynamic specimens were grounded to 800♯ sand paper with the purpose of enhancing a smooth contact with the compression platens during tests. The values of average flow stress σ, maximum strain ε and absorbed energy E during dynamic homogeneous plastic deformation were calculated by stress-strain curves obtained by SHPB compression testing.

The microstructures of the tubes with various specifications were examined by Axiovert 200 MAT optical microscopy (OM). The metallographic specimens were electro-polished, and then etched by a solution with the volume fraction of 2% HF +2% HNO_3+96% H_2O at room temperature.

3. Results

The optical microstructures of the Ti-3Al-2.5V tubes with various specifications are shown in Figure 2 (a)~(c).The microstructures of the tubes with three specifications show similar details, which is mainly composed of elongated α phase and transformed β phase. The size of elongated α phase is about 20~40μm in length and 5~10μm in width. The transformed β phase locates between the boundaries of elongated α phase. Twin structures exist in a certain number of α phase grains, meanwhile almost no recrystallization grains can be observed.

The quasi-static properties of Ti-3Al-2.5V tubes are shown in Table.1.For commercial Ti-6Al-4V plates in 8mm-thick after 750 ℃/ 1 hour/ Air cooling heat treatment, the typical quasi-static properties (in T-direction) are usually tested as 1040~1070 MPa in ultimate tensile strength, 1015~1040 MPa in yield strength, and 11.0~13.0% in elongation. The quasi-static yield strength of the tubes is above 765MPa, which is 75~80% of that of commercial Ti-6Al-4V plates. The values of contractile strain ratio of the tubes are tested from 1.34 to 1.77, indicating that the tubes exhibit radial texture rather than circumferential texture [9].

Figure 3 shows typical true stress-strain curves of Ti-3Al-2.5V tubes performed in SHPB compression experiment at the strain rate of 3000±200 s^{-1}. The stress-strain curves shows the tendency of strain-hardening, which is similar to that of Ti-5Al-3V-0.025Fe-0.044O alloy, but different from that of commercial Ti-6Al-4V ELI and commercial Ti-6Al-4V in our previous study [7].

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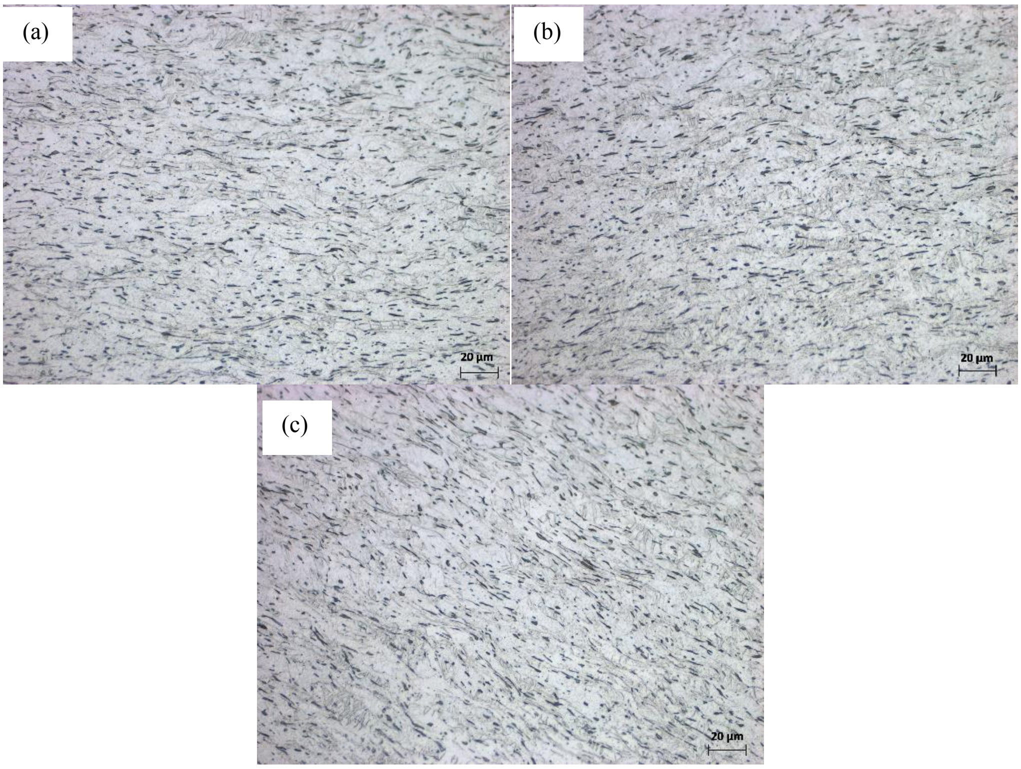

Figure 2. Microstructures of Ti-3Al-2.5V tubes. (a) OD6×W0.5; (b) OD8×W0.6; (c) OD12×W0.9

Table 1. Quasi-static properties of Ti-3Al-2.5V tubes

Heat treatment	Ultimate tensile strength /(MPa)	Yield strength /(MPa)	Elongation /	Contractile strain ratio /
OD6×W0.5	960±13	820±12	14.0±1.0	1.44±0.10
OD8×W0.6	940±14	800±13	15.0±1.0	1.51±0.10
OD12×W0.9	925±20	780±15	16.0±1.0	1.67±0.10

Typical dynamic properties of Ti-3Al-2.5V tubes are shown in Table.2. In our previous study[10], typical SHPB compression properties of 8 mm-thick commercial Ti-6Al-4V plates were as σ=1460±15 MPa, ε=0.17±0.02, E=255±20 J/cm^3. As a comparison, Ti-3Al-2.5V tubes exhibite comparable dynamic plasticity. However, the dynamic average flow stress, as well as absorbed energy during homogeneous plastic deformation of Ti-3Al-2.5V tubes is only 50~60% of that of commercial Ti-6Al-4V plates. Compared Ti-3Al-2.5V alloy with Ti-6Al-4V alloy, the decreasement in content of Al, V elements results in the deterioration in both quasi-static strength and dynamic strength. The ratio of dynamic flow stress to quasi-static yield strength for Ti-3Al-2.5V tubes is 1.08~1.16, less than that of Ti-6Al-4V plates as 1.40~1.46, indicating that the effect of strain rate hardening for Ti-3Al-2.5V alloy tubes is not obvious.

Compared OD6×W0.5 tube with OD12×W0.9 tube, the quasi-static yield strength is comparable but the dynamic flow stress decrease about 10%. Considering that the values of contractile strain ratio increase about 15%, it is deduced that the dynamic properties of the tubes are sensitive to the fraction of grains with radial texture.

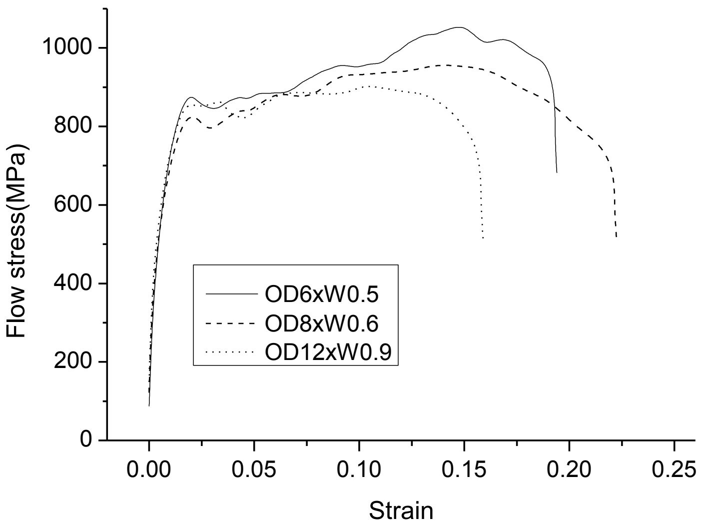

Figure 3. Typical true stress-strain curves of Ti-3Al-2.5V tubes at the strain rate of 3000±200 s^{-1}

Table 2. Dynamic properties of Ti-3Al-2.5V tubes at the strain rate of 3000±200 s^{-1}

Heat treatment	Average flow stress σ/(MPa)	Maximum strain during homogeneous plastic deformation ε/	Absorbed energy during homogeneous plastic deformation E /(J/cm^3)
OD6×W0.5	950±25	0.17±0.01	165±20
OD8×W0.6	890±25	0.17±0.02	155±20
OD12×W0.9	850±30	0.15±0.01	125±25

4. Conclusion

In this paper, Ti-3Al-2.5V tubes in three specifications are prepared with quasi-static yield strength 75 ~ 80% of that of commercial Ti-6Al-4V plates, and contractile strain ratio of 1.34 and 1.77. The dynamic plasticity of Ti-3Al-2.5V tubes is comparable but the dynamic strength is only 50~60% of that of commercial Ti-6Al-4V plates, indicating that effect of strain rate hardening for Ti-3Al-2.5V alloy tubes is not obvious. The dynamic properties of the tubes are sensitive to the fraction of grains with radial texture.

5. Acknowledgement

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