Ultra thin - ultra strength Ti-based strips

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Titanium alloys are extensively used in a variety of applications due to their good mechanical properties and corrosion resistance. A Ti-25Ta-25Nb β-type titanium alloy was subjected to thermo-mechanical processing and testing with the aim to obtain ultra-thin strips with a thickness of about 36 μm. The obtained strips showed a nanocrystalline structure due to severe plastic deformation (SPD). Data concerning structural changes were obtained by X-ray diffraction, the results showed that in as-cast state the alloy consist in a mixture of β-Ti/α-Ti/α"-Ti phases and in the case of SPD processed state, two β-Ti type sub-phases appear, both showing nano-size crystallites. Obtained mechanical properties were appropriate evaluated, the results showed that in the case of SPD alloy in comparison with as-cast state, a steep increase in ultimate tensile strength of about 255%, a high decrease in elongation to fracture of about 95% and a high increase in elastic modulus of about 130% were obtained.

EXPERIMENTAL

Material synthesis

The investigated alloy has been produced using a vacuum induction melting in levitation furnace FIVES CELES with nominal power 25 kW and melting capacity 30 cm^3, starting from elemental components. Resulted chemical composition in wt.% was: 70%Ti; 25%Ta; 25%Nb.

Severe plastic deformation (SPD) processing

The as-cast alloy was processed by Severe Plastic Deformation (SPD) via Accumulative Roll Bonding (ARB) procedure. In accumulative roll bonding, as shown in figure 1, the rolled material is cut, the surfaces to be joined are roughened and cleaned, the two parts are stacked and are rolled again. Fig. 2 shows a schematic illustration of alloy processing route. After alloys synthesis a thermo-mechanical processing step was performed in order to obtain the ARB precursor. As observed, the thermo-mechanical processing step consists in a cold-rolling deformation up to 85.83% deformation degree, followed by a recrystallization heat treatment at 850°C for 30 minutes, in argon protective atmosphere. The recrystallization heat treatment was performed in order to remove the effects of strain-hardening. For the recrystallization heat treatment a GERO SR 100x500 heat treatment oven has been used. After recrystallization, a second cold-rolling deformation was performed, up to 67.97% deformation degree, in order to obtain the ARB precursor.

After obtaining the ARB precursor, the stacking and cold-rolling process was started, at the end of second ARB pass a 4 stack consisted in 4 strips was obtained. From the obtained stack one strip, with the thickness of about 36 μm, was extracted and further investigated in XRD structural analysis and also mechanically tested. All cold-rollings were performed using a Mario di Maio LQR120AS rolling-mill. The rolling speed was 3 m/min.

Structural investigations

Samples from as-cast and SPD processed material were cutted, with a precision cutter MICROCAT 2000. On one face the samples were polished in order to prepare them for XRD structural investigations. The XRD investigations were performed using a Panalytical X'Pert PRO MRD diffractometer in Bragg-Brentano geometry and using a wave length of Cu k-alpha (λ=1.5418 A). The XRD diffractograms were fitted using MAUD software.

Mechanical testing

Samples from as-cast and SPD processed material were cutted, in order to obtain testing samples with approx. surface dimensions 2.00x40.00 mm. Mechanical properties were investigated using a micromechanical testing module GATAN MicroTest 2000N. The investigations were made at a strain rate of 6.72x10-4 [s-1].

RESULTS

The XRD analysis showed the presence of β-Ti, α-Ti and α''-Ti phases in the case of as-cast state. As observed in XRD diffractogram presented in Fig. 3 one can see that no extra peaks belonging to other phases were detected. The quantities of β-Ti / α-Ti / α''-Ti phases were also calculated using MAUD software. Obtained results show that: β-Ti phase quantity was about 95.41±2.67%, α-Ti phase quantity 0.36±0.17% and α''-Ti phase quantity 4.23±0.41%.

In the case of SPD processed alloy the XRD analysis showed the presence of the β-Ti phase. In fact two sub-beta phases were identified. Obtained results concerning β1-Ti / β2-Ti phase quantities show that: β1-Ti phase quantity was about 55.75±2.59% and β2-Ti phase quantity 44.25±1.61%. The calculated crystallite size (coherent crystalline domains) for both β-Ti phases were as follows: for β1-Ti phase about 6 nm and for β1-Ti phase about 4 nm.

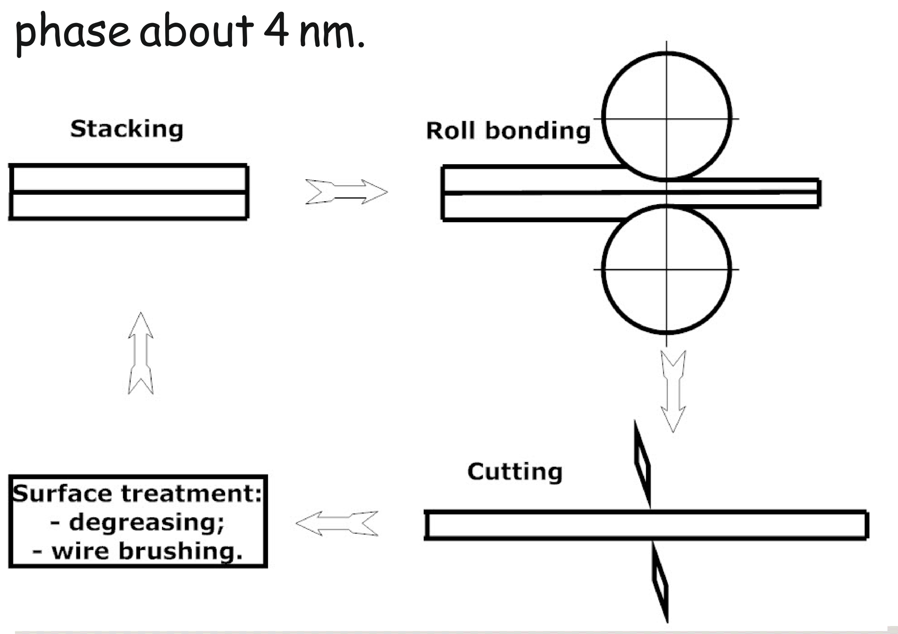

Fig. 1. Schematic illustration of ARB (Accumulative Roll Bonding) procedure

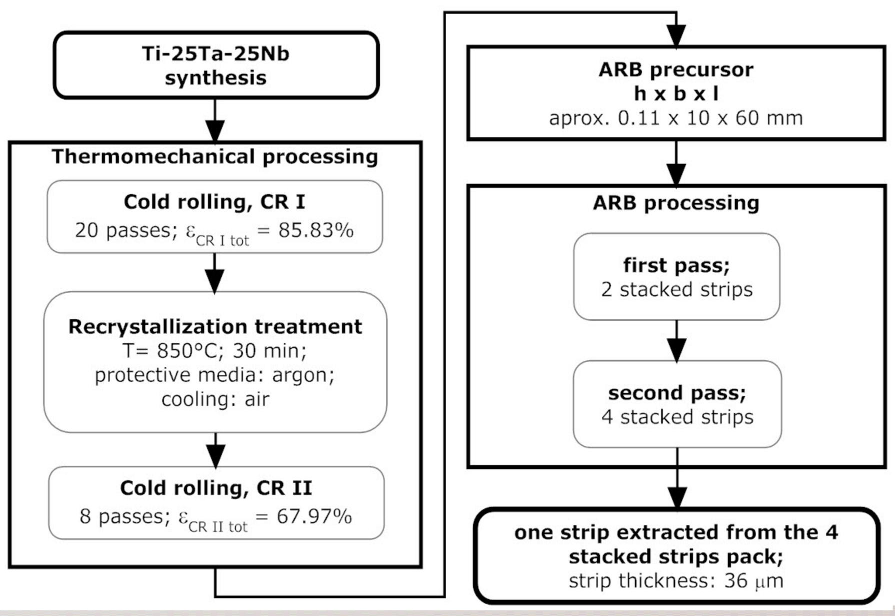

Fig. 2. Schematic illustration of alloy processing

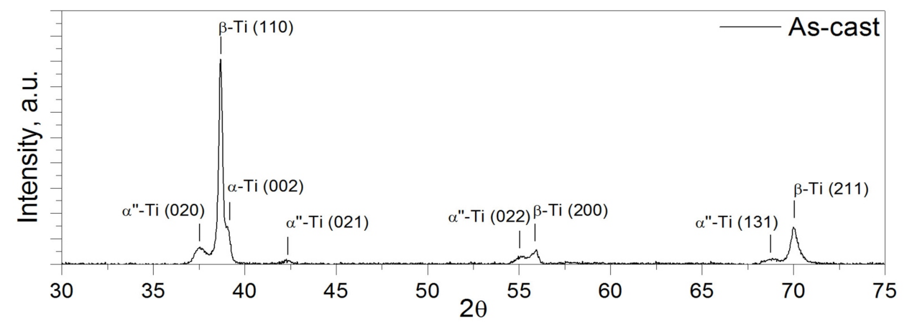

Fig. 4. XRD diffractogram of Ti-25Ta-25Nb alloy in as-cast state

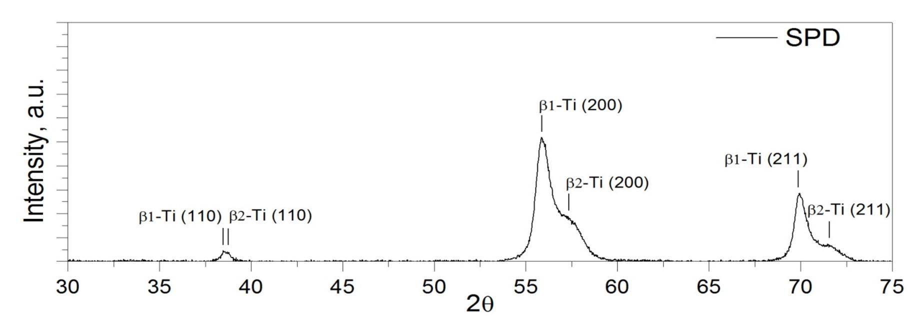

Fig. 5. XRD diffractogram of Ti-25Ta-25Nb alloy in SPD processed state

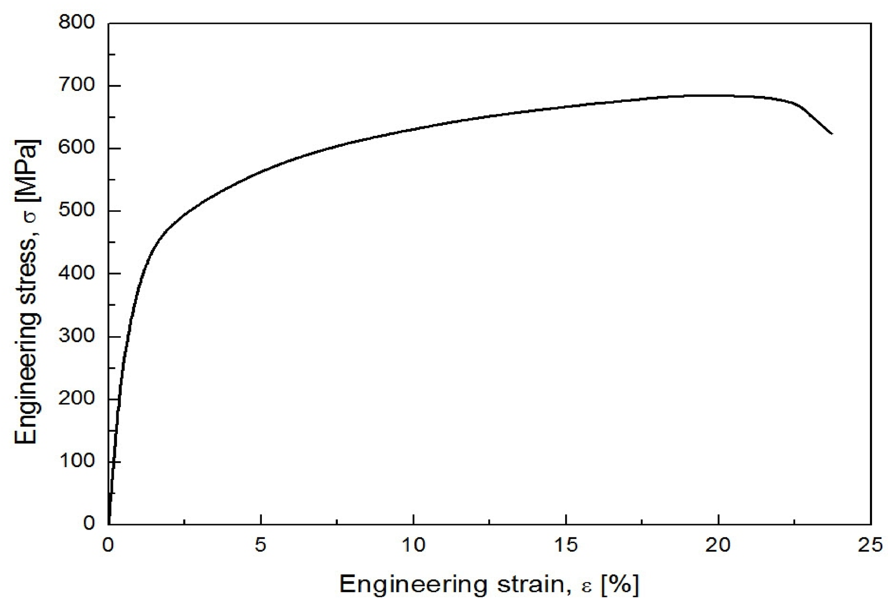

Fig. 5. Strain - stress curve of Ti-25Ta-25Nb alloy in as-cast state

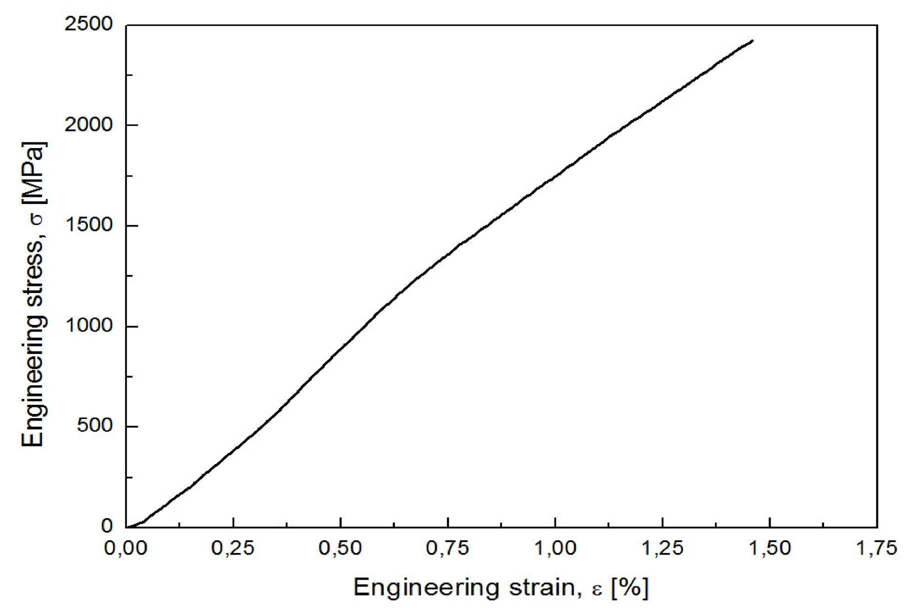

Fig. 6. Strain - stress curve of Ti-25Ta-25Nb alloy in SPD processed state

In Fig. 5 the strain - stress curve for as-cast state is shown. As seen in Fig. 5 one can say that for the as-cast state a high plateau of plastic flow is presented at a stress level of about 600-650 MPa. The plastic flow plateau represents about 80% of the total strain to fracture. Other obtained mechanical properties were calculated from the stress – strain curve, such as: ultimate tensile strength (σUTS) 682.89 MPa, yield strength (σYS) 428.44 MPa, elongation to fracture (εf) 24.47% and elastic modulus (E) 40.11 GPa. In the case of SPD processed state the strain - stress curve is showed in Fig. 6. In comparison with as-cast alloy a different behaviour was observed: no plateau of plastic flow is observed. The other obtained mechanical properties were calculated as follows: ultimate tensile strength (σUTS) 2423.49 MPa, elongation to fracture (εf) 1.46% and elastic modulus (E) 92.11 GPa.

CONCLUSIONS

From all performed experiments data concerning changes in structure and mechanical properties for the investigated Ti-25Ta-25Nb alloy were obtained. XRD structural investigations showed that: in as-cast state the alloy consist in a mixture of β-Ti/α-Ti/α"-Ti phases; in the case of SPD processed state two β-Ti type phases appear, both phases show nano-size crystallites. Mechanical investigations in the case of SPD processed alloy show a steep increase in ultimate tensile strength of about 255%, a high decrease in elongation to fracture of about 95% and a high increase in elastic modulus of about 130%. For this alloy in SPD state is difficult to achieve high strength and high ductility at the same time.

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