The Effect of Hydrogenation on the Compaction of Ti-6Al-4V Powder

D. Tomus[1], R. Lapovok[1], V. Skripnyuk[2], M.R. Barnett[3], M. Gibson[4]

ARC Centre of Excellence for Design in Light Metals, Department of Materials Engineering, [1]Monash University / [3]Deakin University

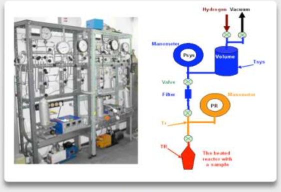
[2] Department of Mat. Eng, TECHNION-Israel Institute of Technology; [4]CSIRO Mat. Sci. and Eng, CSIRO Light Metals Flagship

Introduction

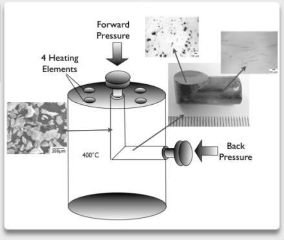
The effect of induced hydrogen on the compactability and sintering of titanium powders have been widely discussed in the literature. The use of hydrogenated powder generally permits the reduction of consolidation temperature and/or pressure. The present research reports on the effect of hydrogenation on the compaction of Ti-6Al-4V powder at low temperatures (500ºC), using ECAP with back pressure; and on the properties of the compacts after a dehydrogenation treatment. In our previous work [10] it was shown that ECAP with BP allows the fabrication of compacts with densities of between 98.3% and 98.6% of theoretical at temperatures as low as 400ºC, and with a green strength of ~750 MPa. Further improvement in the quality of compacts was sought in this work using temporary alloying by hydrogen. It was shown that material consolidated from powder hydrogenated to low levels of hydrogen before compaction and subsequently heat treatment has the potential to offer substantial improvements in mechanical properties.

Experiments

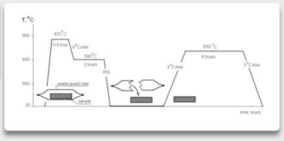
HDH



ECAP



HEAT



METHODS

Microscopy: OM, SEM, TEM

Mechanical: Shear Punch Test (SPT), (Strength, Effective strain) Green Strength (GS),

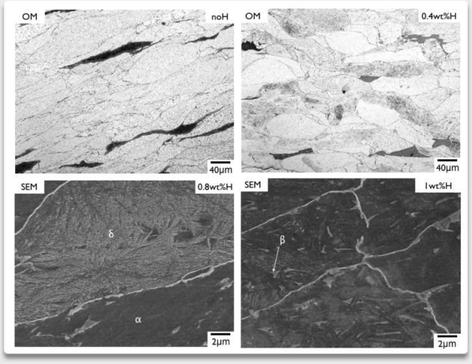
Phases: XRD, Density, LECO

Results

Hydrogenated/Compacted Ti6Al4V powder

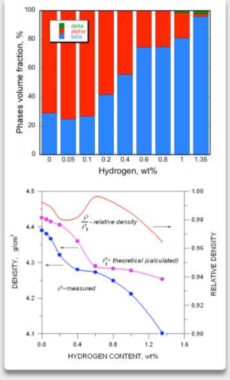
The OM/SEM of ECAPed samples with various hydrogen content are shown bellow with following characteristics:

- ★ A typical microstructure for Ti-6Al-4V, with combination of plate-like alpha and intergranular beta phase is shown;
- ★ Increasing hydrogen content the volume fraction of β-phase is also observed to increase;
- ★ Hydride phase was only observed after the hydrogen content exceed the level of 0.8 wt.%;
- ★The volume fraction of δ phase increased with further hydrogen addition up to 1.35 wt.%.



Phases analysis with H

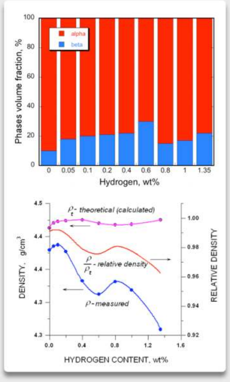
- ★ α/β phase were identified and quantified from XRD;
- ★ Change in α/β ratio was observed as H content increases;
- ★ When the hydrogen level reached 0.8 wt.%, additional δ phase was identified;
- ★ Maximum relative density was at 0.6 wt.%H;



Phases analysis - deH

★ Constant α/β ratio was observed after dehydrogenation;

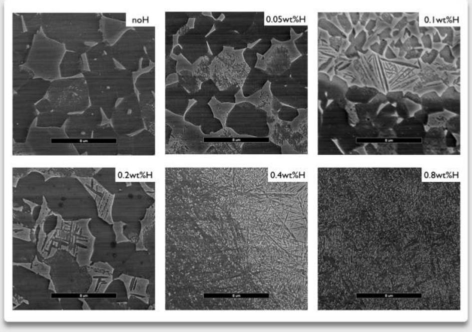
★ The measured relative density of the compacts after dehydrogenation displayed a maximum of 99.2% at small levels of H, if the Ti6Al4V powder was charged with 0.05-0.1 wt.% of hydrogen.



Dehydrogenated Ti6Al4V compacts

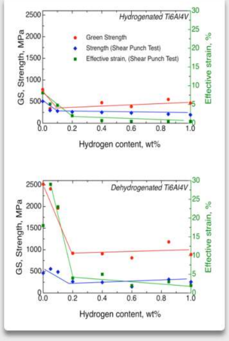
The SEM of compacts after dehydrogenation shows:

- ★ A uniform microstructure consisting of well-distributed equiaxed α-phase with intergranular β-phase in the sample with no initial hydrogen content;
- ★ Increase in volume fraction of β-phase due to addition of hydrogen ranging from 0.05 to 0.1 wt.% as the presence of hydrogen lowers the beta transus temperature and refine the grains of α and β phase;
- ★ A microstructure consisting of lamellar β and acicular α' when the initial hydrogen increased to 0.2wt.%;
- ★ Predominantly acicular α' phase was observed when the initial hydrogen content was greater than 0.4 wt.%.

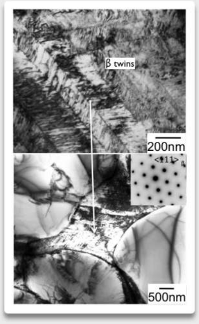


Mechanical properties

- ★ All the mechanical properties decrease with increasing H content;
- ★ Bellow 0.2wt%H the specimens have minimum flow stress and maximum ductility hence improved compactability;
- ★ The mechanical properties of the dehydrogenated compacted powder are comparable with those of bulk Ti6Al4V [1].



TEM after 0.1wt%H



Discussion

★Usually, α-phase can be seen as a harder phase than β-phase. After hydrogenation the hardness of β-phase is higher that that of α-phase as hydrogen atoms diffuse into β-phase and distort its crystallographic lattice parameters.

★The specimens with low hydrogen content (0.05-0.2wt%) retained equiaxed α grains indicating a deformation below the β-transus temperature. At higher hydrogen content, the microstructure with coarse α lath and fine needle α' martensite with clear β grain boundaries indicates a deformation above β-transus.

★ Analyzing the results of the mechanical properties, density and microstructure it can be seen that small levels of hydrogen introduced into Ti6Al4V powder before compaction and then subjected to a dehydrogenation heat treatment significantly improves mechanical properties, namely strength and ductility, as well as relative density of compacts compared to those produced without hydrogenation [2].

★ The microstructure which induce the optimum mechanical properties consists of equiaxed dislocation free α-grains and deformed β-grains where plastic deformation is accommodated by twinning in specimen with initial 0.1 wt%H and dehydrogenated [3].

Conclusions

★ The combination of specific features of observed microstructure explains the optimum balance between increased strength and ductility in the samples hydrogenated to low levels of hydrogen.

★ An increase in the volume fraction of β-phase, the excellent shape accommodation of the particles due to severe plastic shear deformation as discussed in [4] and the diffusion bonding of particles were the main reasons for the excellent compaction of Ti6Al4V powder.

★ After the dehydrogenation the diffusion bonding was completed and the microstructure was altered, depending on the level of hydrogen content.

★An exceptionally high ductility of 29%, in combination with a relatively high strength of ~560MPa, was measured in a shear punch test on specimens which had a prior hydrogen level of 0.05 wt.% before dehydrogenation.

References

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