Anomalous Porosity after Liquid-Phase Sintering of Titanium Powders

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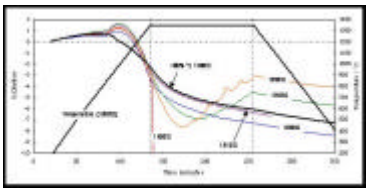
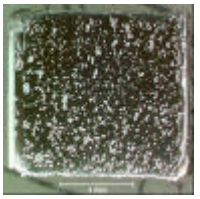
Introduction

- Titanium powder was blended with nickel or silicon powders, compacted and sintered.
- Sintering was carried out under vacuum for a range of binary compositions at various temperatures in a dilatometer.
- In the case of titanium powder prepared via the hydride-mill-dehydride (HDH) route, a large amount of porosity was found after sintering at temperatures where a liquid phase formed.
- During the sintering heat treatment, the "green" component initially contracted, but later expanded if a small fraction of liquid was present.
- Porosity was less pronounced in the case of titanium powder prepared by other means.

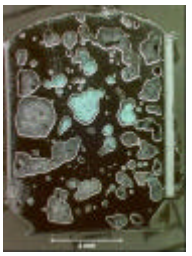


Dilatometer traces for Ti-5%Si sintered for up to two hours

Compacts, initially 10 x 10 mm cylinders, sectioned longitudinally after sintering (axis horizontal)



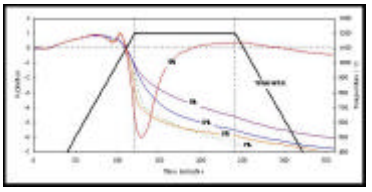
Ti-5Si after heating to 1380° C (19% porosity)



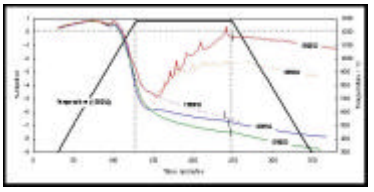
Ti-5Si after heating to 1400° C (41% porosity)

Condition 1 – Liquid Phase

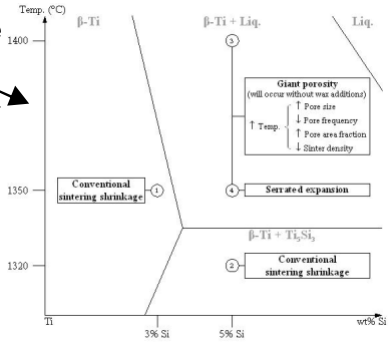
- Dilatometry indicated normal sintering behaviour for Ti-Ni sintered for two hours at 1200°C with Ni contents up to about 8%.
- Swelling and "giant" porosity occurred at 9% Ni.
- For Ti-7%Ni sintered for two hours, swelling and "giant" porosity occurred at temperatures above about 1270°C.
- These and similar results for Ti-Si indicate that a small amount of liquid phase is a necessary condition for anomalous porosity.



5-9%Ni 1200° C 2 hr

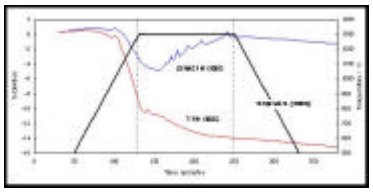


7%Ni 1200-1300° C 2 hr



Condition 2 – Powder Type

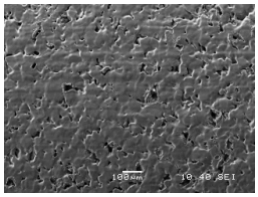
Giant pores formed in sintered HDH powder but to a much lesser extent for powder from a different production route.



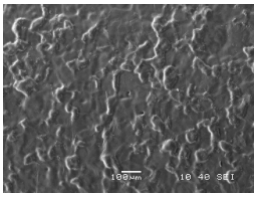
Ti from two different production routes (CERAC is HDH)

Condition 3 – Closed pores

Giant pores developed when sintering advanced to the point where the pores closed (when the compact was about 90% dense, regardless of green density).



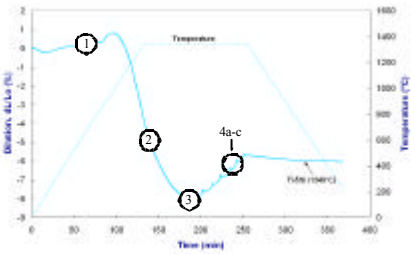
5%Si 1350°C zero minutes – pores open to surface



5%Si 1350°C 20 minutes – pores closed (mostly)

Possible Mechanism

Hypothesis: Giant porosity is due to evolution of hydrogen from HDH titanium powder during sintering (at high temperature under vacuum).

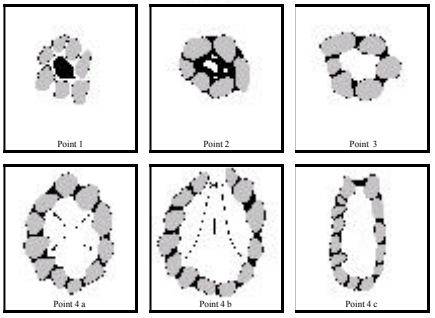


Point 1 – Aggregate of solid Ti and alloying (Ni or Si) particles.

Point 2 – Temperature raised above the eutectic temperature, liquid phase forms, strength of compact reduced, sintering proceeds rapidly.

Point 3 – Pores close, hydrogen gas no longer escapes, contraction due to sintering halted.

Point 4 – High gas pressure expands pores. Gas occasionally forces a passage to the surface and escapes.



Conclusion

Liquid-phase sintering of titanium may be compromised by the evolution of dissolved hydrogen. However, the advantages of liquid-phase sintering of Ti powders might still be realised by using low-hydrogen powders or more effective dehydrogenation of conventional powders, a better sintering vacuum, dehydrogenation during sintering before formation of the liquid phase, or by limiting the sintering time after the pores close.