The background of the slide is a scanning electron microscope (SEM) image showing numerous irregular, angular titanium powder particles. The particles vary in size and shape, with some appearing as sharp, elongated shards and others as more rounded, blocky shapes. The surface of the particles shows some texture and detail.

Sintering of Titanium Powder Compacts for Containerless Hot Isostatic Pressing

**PhD Student: Ray Low
Supervisors: Ian Robertson,
Ma Qian & Graham Schaffer**

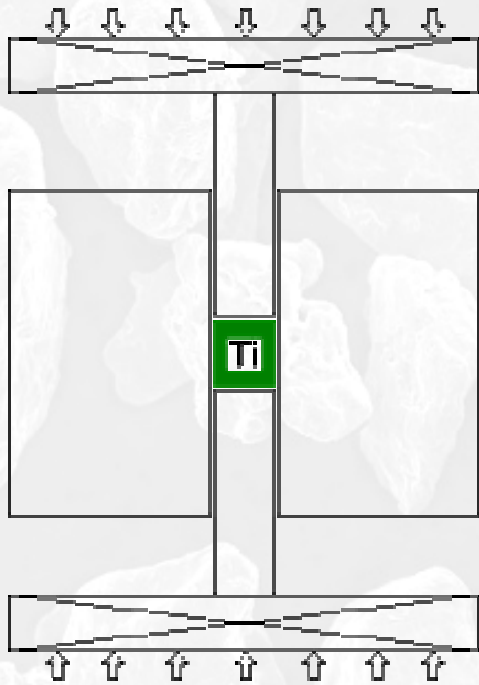


Introduction

- Titanium, highly desirable metal
- Emerging reduction processes
 - Cheap Ti powder
 - Greater utilisation of powder metallurgy (PM)
- Conventional PM, difficult or inefficient
- Novel solution
 - Containerless hot isostatic pressing (CHIP) of sintered powder compacts

Sinter+HIP process

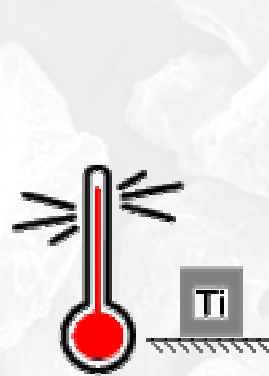
Compaction



400 MPa

Ti-xSi

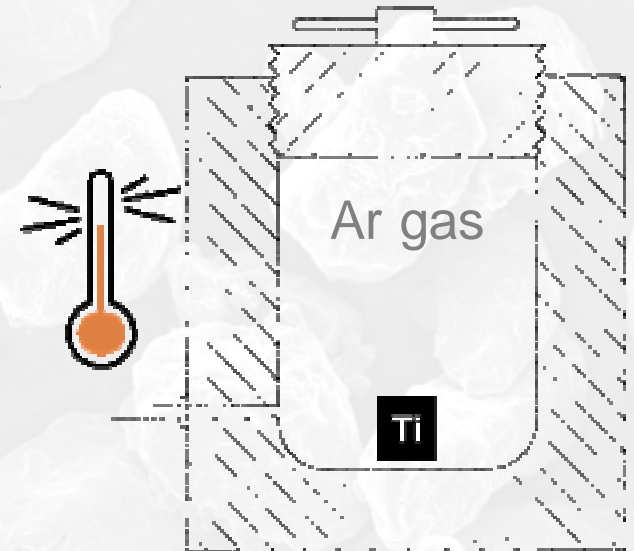
Sintering



1300-1400°C,

High vacuum for 1-2 hrs

CHIPPING



930°C, 100 MPa

for 4 hrs

Surface Densification Phenomenon



Ti-3.3Si

sintered @ 1400-1hr

Below the solidus



Ti-3.4Si

sintered @ 1400-1hr

above the solidus

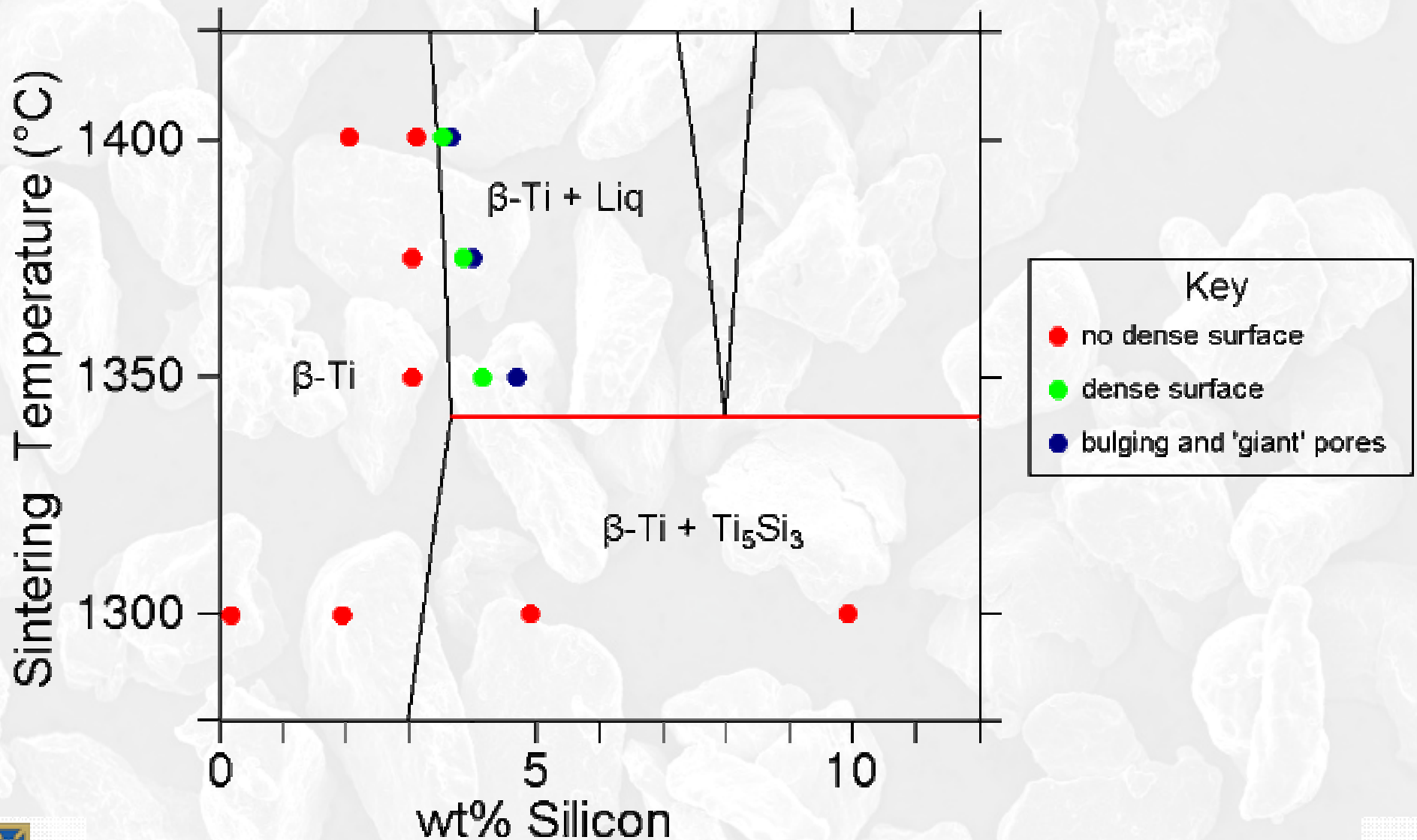


Ti-3.5Si

sintered @ 1400-1hr

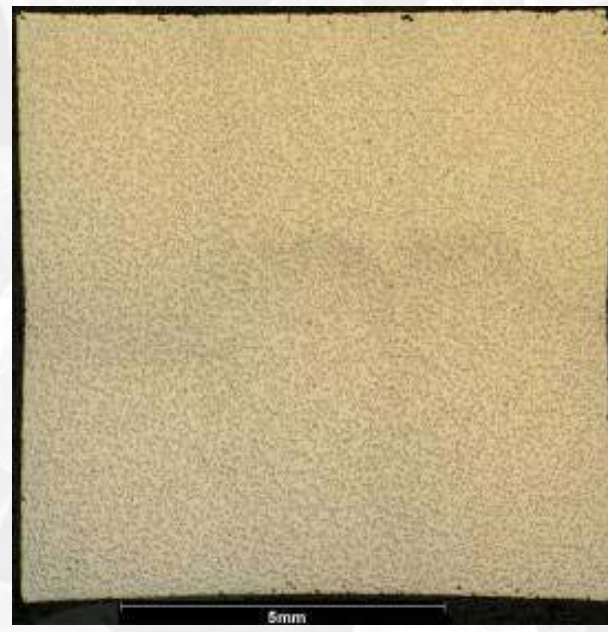
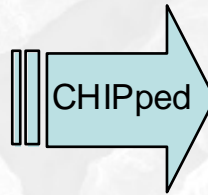
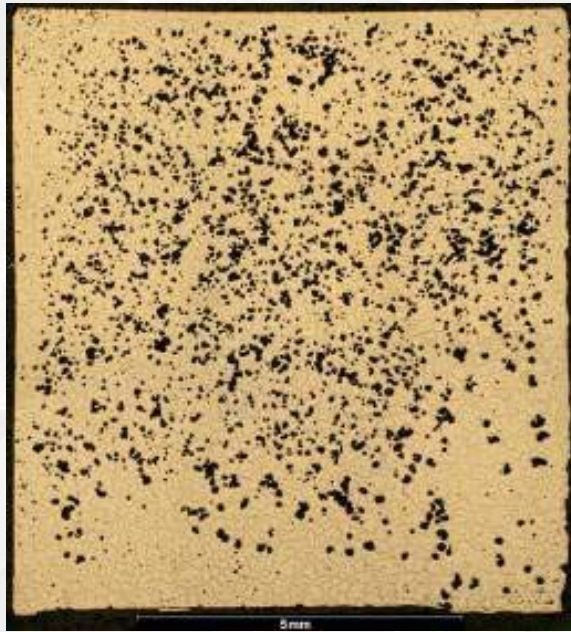
above the solidus

Surface Densification Phenomenon

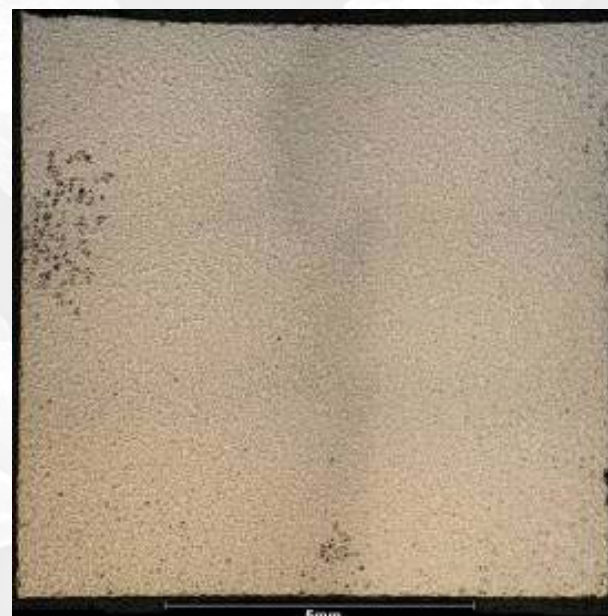
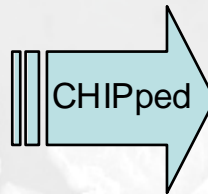


Containerless HIPping Trials

dense surface



no dense surface



Sintering of Titanium Powder Compacts for Containerless Hot Isostatic Pressing

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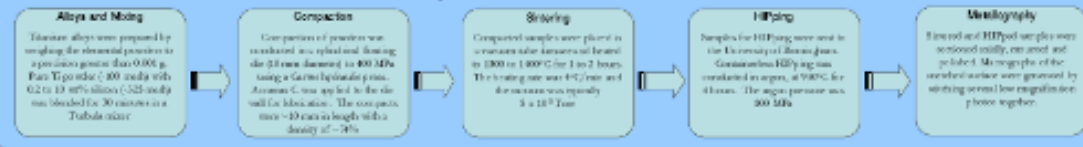
1. Introduction

The potential availability of inexpensive titanium powder via new processes in containerless hot isostatic pressing (HIP) has generated increased interest in titanium net-shape manufacturing utilizing powder metallurgy techniques. Efficient powder metallurgy processing combines low-cost titanium with the attainment of high strength, full density components.

Attaining high strength, full density titanium components is difficult via sintering alone. Conversely, typical hot isostatic pressing (HIP) techniques which are able to attain full density require additional 'canning' and 'decanning' stages of processing, lowering the overall efficiency of the process.

A novel solution is containerless hot isostatic pressing (also known as sinter+HIP) where as-sintered components are HIPped to full density without the need for a container. The sintering stage is the most critical aspect of the sinter+HIP process. A sintered component with negligible surface-connected porosity would show the highest response to containerless HIPping. The effect of liquid phase sintering (i.e. sintering with a small amount of liquid) on surface-connected porosity has been investigated.

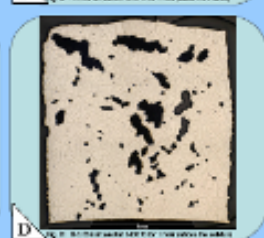
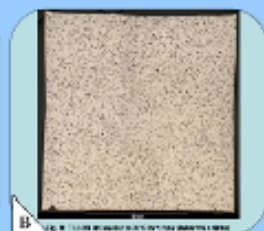
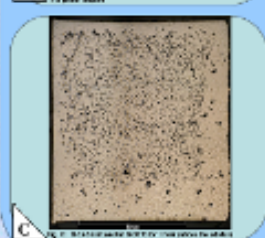
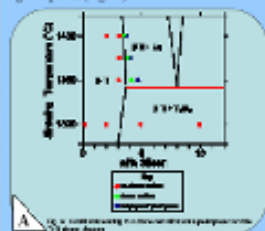
2. Experimental Procedure



3. Surface Densification Phenomenon

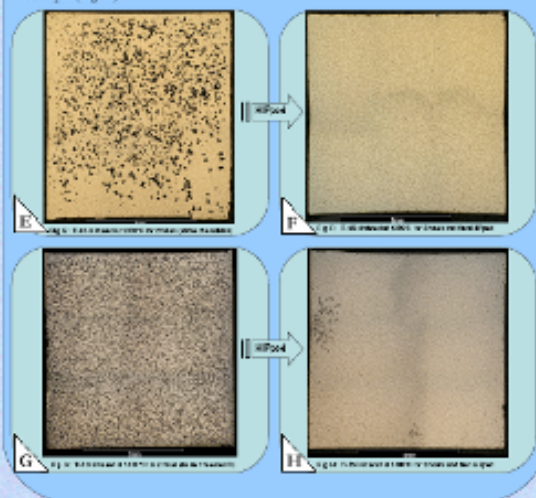
In-situ development of a densified surface with negligible surface-connected porosity has been observed in sintered titanium compacts. The development of this unique microstructure has been linked to the formation of a persistent liquid during sintering. The Ti-6 binary alloy system has been surveyed the presence of surface densification. Fig. A summarizes the results. A typical example of a surface densified sample is Ti-5Nb sintering at 1400°C for 1 hour (compare Fig. C, and Fig. B). Samples with a high amount of liquid had an increased propensity to bulge and form 'gan' pores (Fig. D).

It is proposed that the formation of a dense surface and sample bulging are related to gas production during sintering. It was previously reported that hydrogen gas may be released at high temperatures during sintering. The production of gas during sintering pushes liquid towards the exterior of the compact and causes accelerated densification in the region near the surface. At higher liquid contents, the weaker structure of the compact combined with internal gas production causes outward pores within the compact to expand.



4. Containerless HIPping Trials

Micrographs of samples HIPped with and without an as-sintered densified surface are shown below. Samples with a dense surface (Fig. E) were HIPped to full or near full density (Fig. F) whereas those without a dense surface (Fig. G) had residual porosity near the edge of the sample (Fig. H).



5. Summary and Future Work

Early results have shown that liquid phase sintering is a necessary condition for surface densification. This was observed in the Ti-6 binary alloy system. The mechanism causing this phenomenon appears to be linked to internal gas production. Containerless HIPping may have demonstrated full or near full densities can be reached with this method.

Future work on this project focuses on two areas, 1) understanding the mechanism leading to surface densification, and 2) developing a commercially viable sinter+HIP alloy.