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# Consolidation of Ball-Milled Titanium - Aluminium Powders via Back Pressure Equal Channel Angular Pressing

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## Introduction

Ball-milling (B-M) is a powerful and versatile mechanical process by which elemental powder blends are milled to achieve solid state alloying at the atomic level, often leading to formation of an amorphous phase or solid solubility extension in otherwise immiscible element pairs. At a micro-scale level, BM can also be used for grain refinement and for fine dispersion of elements or reinforcing particles within a matrix. For practical applications purposes, it becomes necessary to consolidate the powder in to a bulk material.

In this study, consolidation of B-M Ti-Al powder using back pressure ECAP (BP-ECAP, Fig. 1) will be investigated. BM powder in a finely mixed unreacted state (nominal composition Ti-47 at.% Al) and in a supersaturated solid solution state (nominal composition Al-10 at.% Ti) were used in the investigation. The results will form the basis for further research on the consolidation of other ball-milled Ti-Al systems.

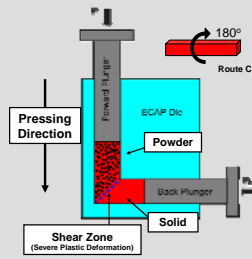


Figure 1: BP-ECAP setup.

## B-M (finely mixed) Ti – 47at.% Al

A planetary type ball-mill was used in the experiment. Elemental Ti and Al powder were mixed to the Ti-47at.%Al composition and milled at 300 rpm for 40 hr under vacuum. Ball to powder weight ratio was 10:1 and 1 wt.% stearic acid was added as process controlling agent. Optical microscope image and XRD pattern of the as-milled powder is shown in Fig. 2.

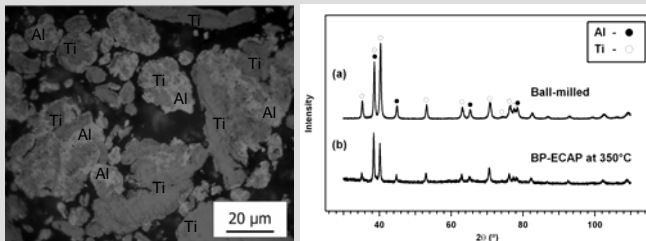


Figure 2: Optical microscope image of as-milled Ti-47at.%Al powder and its corresponding XRD pattern.

Individual Ti (darker phase) and Al (lighter phase) particles were fractured and cold welded repeatedly to form small clusters of finely dispersed two phase Ti-Al structure. Size of clusters range from 2 μm – 50 μm and the average size is less than 20 μm with a generally spherical morphology.

Grain size of the as-milled powder was estimated from the XRD pattern. Average grain size of Ti and Al were determined to be 30 nm and 28 nm respectively.

BP-ECAP consolidation was carried out at 350°C for 12 passes with a induced back pressure of 200 MPa. Optical microscope image and TEM image are shown in Fig. 3. No pores were observed, indicating full densification was achieved. TEM image shows nano-Ti phase embedded within the Al matrix.

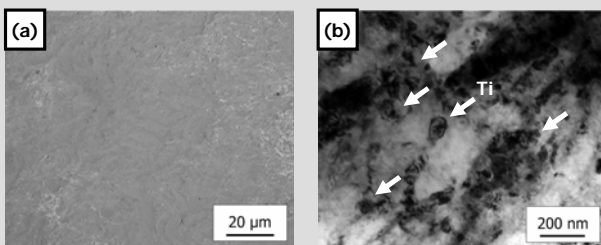


Figure 3: (a) Optical microscope image and (b) TEM image of the consolidated sample.

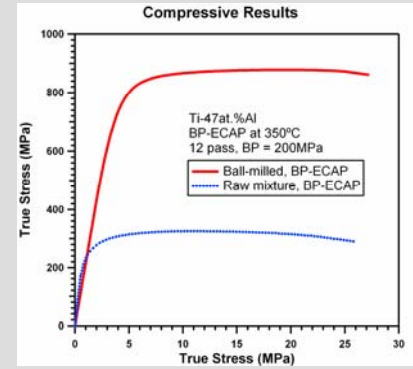


Figure 4: Compressive test results for consolidated Ti-47at.%Al sample.

Compression results are shown in Fig. 4. It is seen that after BM the yield strength of the sample is significantly higher, possibly due to grain refinement and dispersion hardening from the embedded nano-Ti phase. Presence of Al allows the material to retain its plasticity after BP-ECAP.

## B-M (supersaturated) Al – 10at.% Ti

Milling conditions for Al-10at.%Ti is 400 rpm for 40 hr with a ball to powder weight ratio of 15:1. Optical microscope image and XRD pattern of the as-milled powder is shown in Fig. 5.

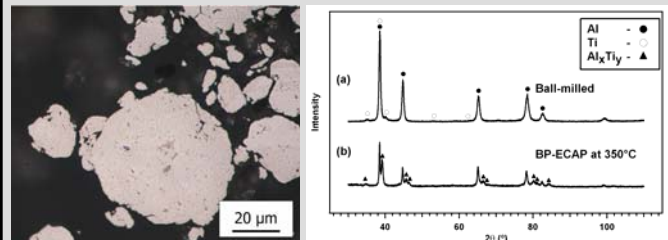


Figure 5: Optical microscope image of as-milled Al-10at.%Ti powder and its corresponding XRD pattern.

From the above XRD pattern, it was estimated that about 8at.% Ti dissolved in Al to form Al(Ti) solid solution. Optical image of the as-milled powder after BP-ECAP at 350°C is shown in Fig. 6, along with the compressive test results. Dissolved Ti thermal decompose to form an Al-rich intermetallic phase after BP-ECAP. Yield strength of the sample was observed to increase with increasing amount of dissolved Ti.

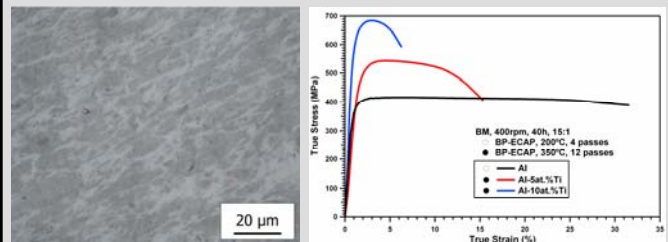


Figure 6: Optical microscope image and compressive test results of BP-ECAP consolidated Al-10at.%Ti sample.

## Conclusion

Multiphase Ti-Al based bulk materials were produced using B-M and BP-ECAP. B-M Ti-47at.%Al shows significant increase in strength due to refined grains and presence of nano-Ti phase while the micro-Ti and Al phase still allow retention of plasticity.

A supersaturated solid solution Al(Ti) was produced from B-M of Al-10at.%Ti powder. After BP-ECAP at 350°C an Al-rich intermetallic phase was formed from thermal decomposition of the dissolved Ti, leading to increase in strength.