

Introduction

Ultrafine and nanostructured materials have emerged as a new class of high performance materials, exhibiting exceptional strength as well as good ductility. One method of producing bulk ultrafine and nanostructured materials is by consolidating nanostructured particles which can be produced through such non-equilibrium processing methods as mechanical alloying. The challenge, however, lies in the consolidation of these particles without altering their non-equilibrium structures and associated properties since conventional powder consolidation techniques typically involve high temperatures.

In this study, back pressure equal channel angular pressing (BP-ECAP) was used for powder consolidation at relatively low temperatures. Elemental Ti-47at.%Al powder blends were ball milled under different milling conditions. The starting mixture was chosen to fall in the γ -TiAl and α_2 -Ti₃Al two phase region of the Ti-Al binary system at equilibrium. The milled powders were consolidated at various temperatures using ECAP for multiple passes. The microstructure and mechanical properties of the processed samples were characterized.

Ball Milling (BM)

A planetary type ball mill was used in the experiment. The Ti-47at.%Al powder mixture was milled under Argon protection for a fixed time at various speeds to impart different amount of energy on the powders. Table 1 shows the BM conditions for the current experiment.

Sample	a	b	c
Milling time (hrs)	40	40	40
Disc rotation speed (rpm)	200	300	400
Weight of powder (g)	20	20	20
Powder to ball weight ratio	10:1	10:1	15:1

Table 1: Ball milling conditions for the Ti-47at.%Al powder mixtures.

The powders are repeatedly welded, fractured and rewelded during the BM process. The microstructure and phase of the as-milled powders varies significantly depending on the BM conditions. XRD patterns for powder samples (a), (b), and (c) are shown in Figure 1.

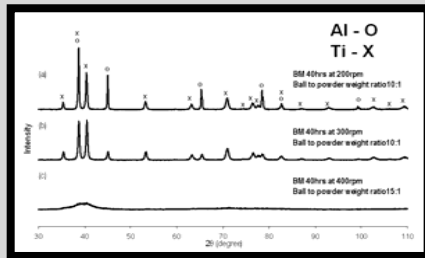
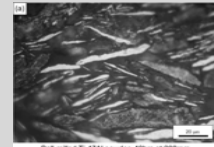


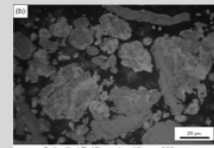
Figure 1: XRD patterns of Ti-47at.%Al milled at different rotation speeds.

Ball Milling (BM) continued

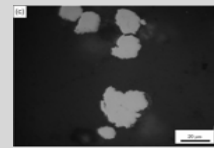
Optical microstructures of the as-milled powders are shown in Figure 2.



XRD patterns show all the prominent Ti and Al peaks, much like the starting powder mixture. Optical images show that the Ti and Al powders were only flattened during milling and individual Ti and Al particles can still be clearly distinguished from the image. Particles were evenly distributed but energy was insufficient to cause alloying.



XRD patterns show a decline in the intensity of the Al peaks. This typically indicates nanocrystallisation of the sample. A slight shift in the Ti peaks towards higher angles suggest some Al dissolution in the Ti lattice. Optical images show that Ti and Al particles were fractured and welded into clusters containing both Ti and Al phases.



XRD patterns show that the Ti and Al powder mixture attained an amorphous state. Optical images of the as-milled powder show rounded particles with a single amorphous phase, which confirms the XRD results.

Figure 2: Optical microscope images of the as-milled Ti-47at.%Al powders.

Consolidation using BP-ECAP

The processed powders were then consolidated into bulk materials using BP-ECAP. ECAP is a SPD technique capable of inducing high accumulative strain on bulk materials through repeated pressing while retaining its starting cross sectional dimensions. The equipment setup of the BP-ECAP is shown in Figure 3.

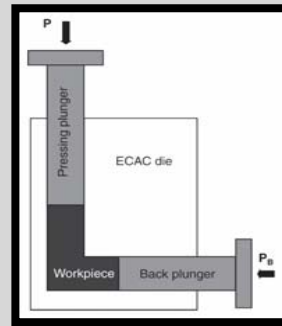


Figure 3: Schematic drawing of the BP-ECAP setup.

Consolidation using BP-ECAP continued

The die consists of two channels with equal cross sectional areas that intersect at a 90° angle. The powders were packed and placed inside the entrance channel. A load was then applied from the top of the vertical channel by a plunger, forcing the powders through the intersecting plane where they were sheared and deformed. A constant back pressure was imposed on the specimen by the back plunger at the exit channel.

ECAP conditions for samples (a), (b) and (c) are indicated in Table 2. For comparison, ECAP results of the elemental Ti-47at.% powder mixture, indicated as 'Raw', will also be included.

Sample	Raw	a	b	c
Temperature (°C)	350	350	350	350
Back pressure (MPa)	50	50	50	50
Forward pressing speed (mm/min)	20	20	20	20
Number of passes	24	4	8	-

Table 2: BP-ECAP conditions for the Ti-47at.%Al powder mixtures.

Except for the amorphous powder (sample c), all other samples were fully consolidated using BP-ECAP. Optical images of these samples are shown in Figure 4. The amorphous powders were too brittle, and will have to be pressed at the glass transition temperature and will be investigated later.

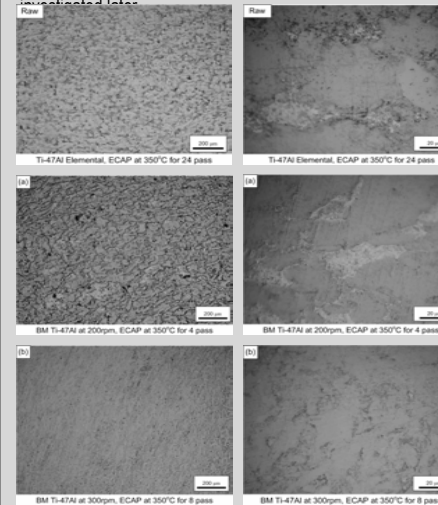


Figure 4: Optical microscope images of the consolidated Ti-47at.%Al samples.

Consolidation using BP-ECAP continued

The consolidated samples were also subjected to compressive tests and Vickers hardness tests. The results are shown

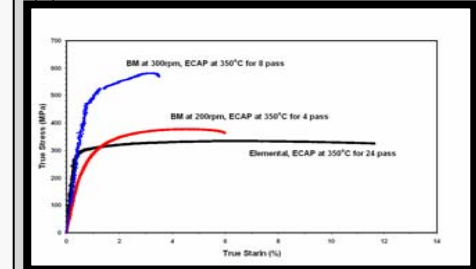


Figure 5: Compressive true stress vs. true strain curve for consolidated Ti-47at.%Al samples.

Sample	Raw	a	b
Yield Strength (MPa)	270	300	500
Vickers hardness (HV)	118	142	215

Table 3: Yield strength and Vickers hardness measurement of the consolidated Ti-47at.%Al samples.

Milling the powders refined the grain structure, and this contributed to the increase in strength. The powder milled at 300rpm (sample b) has a much higher yield strength after consolidation compared to the other samples, owing to its refined powder structure (Figure 2(b)). However, ductility is lowered and the sample failed at a strain of 3.8%. On the other hand the consolidated elemental powder mixture has a relatively low yield strength but exhibits a large stable region and reasonable ductility at room temperature.

Conclusion and Future Works

Ball milled Ti-47at.%Al powder mixtures were successfully consolidated at a relatively low temperature using BP-ECAP. Ball milling has a profound effect on the microstructure and morphology of the powders. The milled powders in turn has a direct effect on the final microstructure as well as mechanical properties of the consolidated samples.

At the moment, more BM work is being conducted to characterize the powder evolution during various stages of milling. Consolidation of the amorphous powder is also underway. Some heat treatment on the consolidated samples will also be carried out to yield the equilibrium intermetallic phase of the current Ti-47at.%Al composition (i.e. γ -TiAl and α_2 -Ti₃Al) while limiting the grain growth.