The Effects of Hydrostatic Pressure on the Compressive Mechanical Behavior of L12 Al3Ti-Based Intermetallic

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A Mn-modified L12 Al3Ti-base intermetallic was subjected to compressive deformation at room temperature under superimposed hydrostatic pressures up to 1000 MPa. It is found that its yield strength is essentially unaffected by hydrostatic pressure. The apparent work-hardening rate of true stress-strain curves increases substantially with increasing hydrostatic pressure. Vickers microhardness of pressurized samples always increases with increasing compressive strain, indicating the work-hardening behavior, but it is independent of the superimposed hydrostatic pressure up to 1000 MPa. The density of microcracks (cm/cm²) observed in specimens compressed under hydrostatic pressure increases with increasing compressive strain for each level of pressure. At each constant compressive strain, the corresponding density of microcracks is higher for specimens tested under 170 MPa hydrostatic pressure than that for specimens tested in the 400 to 1000 MPa hydrostatic pressure range. This may imply that besides propagation, the nucleation stage may also be suppressed by a superimposed hydrostatic pressure. It is proposed that both the cataclastic (characteristic for deformation of some rocks) and plastic deformation occur simultaneously during compressive deformation of Ti trialuminides under hydrostatic pressure.

I. INTRODUCTION

EARLY investigations of the mechanical properties of crystalline solids under triaxial state of stresses (hydrostatic pressure) were attributed to Voigt in 1893 who studied sodium chloride crystals and found that their breaking strength was not affected by hydrostatic pressures up to about 60 kg/cm². Generally, the principal effect of hydrostatic pressure on the fracture behavior of brittle materials is to raise the stress at which cracks will propagate. A dramatic increase in the ductility of some metals has been obtained under hydrostatic pressure. Investigations of the behavior of brittle materials under hydrostatic pressure facilitate the explanation of the fracture mechanism in these materials because of the lack of necking occurring during testing. With regard to the ordered intermetallic compounds, early studies of the effect of hydrostatic pressure on compressive behavior were carried out by Martynov et al. on less-common compounds such as Al13Mg4, PbTe, Bi3Te3-Bi2Se3, V5Ga, Co2Si-CoSi, V5Si, and LaB6. Several interesting conclusions drawn by Martynov et al. are as follows: (a) compressive ductility of investigated intermetallic compounds at room temperature increased with increasing hydrostatic pressure, and at a certain level, it could approach ductility of regular metallic materials tested under normal conditions; (b) the harder the intermetallic the lower the ductility was achieved under hydrostatic pressure; and (c) work hardening was observed to occur after compressive deformation under hydrostatic pressure. More recently, there has been research carried out on the effect of hydrostatic pressure on the mechanical behavior of face-centered cubic (fcc) ordered (L12) Ni3Al compound and body-centered cubic (bcc) ordered (B2) NiAl. In both cases, an increase in tensile ductility was observed under hydrostatic pressure.

The purpose of this work is to examine the effects of a superimposed hydrostatic pressure on the compressive behavior of cubic (L12) Mn-modified Ti trialuminide. In particular, the effect of superimposed hydrostatic pressure on yielding, flow behavior, microcracking, and compressive ductility were investigated. This work represents a continuation of studies on microstructure and compressive behavior of various modifications of Ti trialuminides.

II. EXPERIMENTAL PROCEDURE

The Mn-modified L12 Al3Ti-base alloy was induction melted according to the procedure described in Reference 8. Homogenized (1050 °C/72 hours) material was used for mechanical testing in compression under hydrostatic pressure. Its composition, measured by a quantitative X-ray energy dispersive spectroscopy (LINK QX2000), is given in Table I. Porosity was measured by a Java image analysis software package by Jandel Scientific, Corte Madera, CA and was determined to be 3.1 ± 0.2 pct. Initial (as-homogenized) microstructure of the alloy was investigated by optical (Nomarski contrast), scanning, and transmission electron microscopies (TEMs). Cylindrical specimens (d = 3 or 4 mm, and the ratio h/d = 1.7, where h is the height of the specimen) for compression tests were first cut out by using a precise wire saw, then machined, and subsequently polished with a SiC powder (800 grit). The faces of the specimens were lubricated for compression testing with a silicone grease. The range of hydrostatic pressures used was from 0.1 MPa (atmospheric pressure) to 1000 MPa. Cylindrical specimens were encapsulated...
Table I. Fully Quantitative Energy Dispersive Spectroscopy Results of the Alloy Studied (Mn-Modified L1₂ Al₃Ti-Base; Homogenized at 1050 °C for 72 h)

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<td>Mn-modified</td>
<td>63.0 ± 0.3</td>
<td>28.7 ± 0.2</td>
<td>8.2 ± 0.3</td>
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Note: At least five readings were taken for each element.

(sleeved) in thin-wall (50 μm) capsules made out of annealed copper (99.9 pct purity). The tests were performed on hydraulic mechanical testing equipment that supplied a constant hydrostatic pressure throughout the duration of the test. The hydrostatic pressure was measured by the manganin coil directly in the pressure vessel. The pressure medium was extraction naphtha. The deformations during the tests were measured by the induction sensor with a 3-μm accuracy. The loads were measured by the piezoelectric monocrytalline dynamometer with a maximum capacity of 20 kN and an accuracy of ±4 pct. The piezoelectric dynamometer was calibrated at ambient pressure with respect to the standard dynamometer. It was found that the sensitivity of the piezoelectric crystal used for measurements of load was independent of the hydrostatic pressure up to 1 GPa. The applied strain rate was $2 \times 10^{-3}$ s⁻¹. Figure 1 shows the setup for the testing under hydrostatic pressure. A detailed description of the hydrostatic pressure apparatus and the test procedure are given elsewhere.¹¹

The compressed specimens were cut approximately at half of their height, perpendicularly to the compression axis, polished on a 0.25-μm diamond paste, and observed in the optical microscope (under Nomarski contrast) in order to measure the cracking parameters, i.e., total length of cracks, total length of cracks per unit area (density of cracks), total number of cracks, and the number of cracks per unit area of the specimen. The microcracks were measured on five areas of each specimen according to the schematic shown in Figure 2.

III. RESULTS

A. As-Homogenized Microstructure

Investigation of the initial, as-homogenized microstructure by optical and scanning electron microscopy did not reveal the existence of a second phase. The material appeared to be a single, L1₂ phase. However, TEM studies have revealed the presence of platelike precipitates (Figure 3) identified by the electron diffraction as Al₃Ti. These precipitates have been observed by other investigators (see recent reviews on trialuminides by Kumar,¹² Morris et al.,¹³ and Wu and Pope¹⁴) in Ti trialuminides containing more than 26 to 27 at. pct Ti.

B. True Stress vs True Strain Curves

The plots of true stress vs true strain (calculated as $\varepsilon = \ln (h/h_0)$, where $h$ is the current height of the specimen and $h_0$ is the height of the specimen before the test) for Mn-modified Al₃Ti alloy at various superimposed hydrostatic pressures are shown in Figure 4. Table II shows the values of true strain in compression for specimens 1 to 7 from Figure 4 and several others tested additionally (specimens 8 to 10) at various levels of hydrostatic pressure. Specimens that fractured at the end of the test are indicated in Table II. Compression tests of specimens 3, 4, 6, and 7 were terminated without fracture due to reaching the maximum capacity of the dynamometer. Specimen 5 was deformed to fracture beyond the maximum capacity of the dynamometer. Additionally, several specimens have been compressed to various stages of true stress and strain without fracture.

![Fig. 1—Setup for the compression testing under a superimposed hydrostatic pressure.](image)

![Fig. 2—Schematic used for calculating the microcracking parameters on the transverse cross section of specimens tested under a superimposed hydrostatic pressure.](image)