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P. F. Becher

M. V. Swain

S. Sōmiya



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EDITORS:

P. F. Becher

Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

M. V. Swain

CSIRO, Victoria, Australia

S. Sōmiya

Tokyo Institute of Technology, Yokohama, Japan



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Preface

The papers contained in this proceedings were presented at the symposium on "Advanced Structural Ceramics" held in Boston, Massachusetts, December 1-3, and 1986 sponsored by the Materials Research Society. The symposium addressed recent research in the field of toughened ceramics and included that on transformation toughening and fiber and whisker reinforced ceramics. The symposium was international in character which is indicative of the wide interest in exploring mechanisms to enhance the fracture resistance of ceramics. The research presented at the symposium provides considerable insight into our progress in these areas.

The success of any symposium also reflects the support of others. This symposium was made possible by the financial support of the U.S. Department of Energy through the Division of Materials Sciences, Office of Basic Energy Sciences and the Energy Conversion and Utilization Technologies Materials Program, Office of Renewable Energy. We would like to especially acknowledge A.H. Heuer, D.R. Clarke, F.F. Lange, R.J. Gottschall, and R.M. Cannon for subchairing this session and coordinating manuscript reviews. Their efforts contributed greatly to the success of this symposium. Finally, sincere thanks are extended to Fauna Stooksbury who provided not only secretarial services but also handled and coordinated many of the details required to conduct the symposium and publish the proceedings.

P.F. Becher
M.V. Swain
S. Sōmiya

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PART I

Transformation Analysis

DISPLACIVE PHASE TRANSFORMATIONS IN ZIRCONIA-BASED CERAMICS

B.C. MUDDLE

Department of Materials Engineering, Monash University, Clayton, Victoria, Australia 3168

ABSTRACT

A review is presented of experimental observations of the mechanism and crystallography of the martensitic tetragonal to monoclinic transformation occurring both in dispersed tetragonal ZrO_2 particles in partially stabilized zirconia and in polycrystalline tetragonal zirconia. Preliminary results of determination of the orientation relationship and habit plane for the stress-activated transformation in a CeO_2 -stabilized TZP ceramic are reported and compared with predictions of the crystallographic theory for the transformation. This orientation relationship is such that $(100)_m // (100)_t$ and $[001]_m // [001]_t$, and for this variant of the orientation relationship the habit plane is approximately $(301)_t$. These results are in good agreement with theoretical predictions. Progress in the application of the formal theory of martensitic transformations to the transformations in both types of system is examined critically and implications for theories of transformation toughening are discussed.

Attention is also given to tetragonal $\rightleftharpoons$ orthorhombic and orthorhombic $\rightleftharpoons$ monoclinic transformations occurring in ZrO_2 particles in thin foil specimens of partially stabilized zirconia. Formation of a metastable orthorhombic phase appears a possible, but not essential, intermediate stage in the tetragonal to monoclinic transition. However, present evidence strongly suggests that the orthorhombic structure only occurs in those particles experiencing the relaxed matrix constraints typical of thin foil specimens.

1. INTRODUCTION

Transformation-toughened ceramics constitute a new and important class of materials combining high strength and useful toughness [1,2]. Theories of transformation toughening [3] and transformation-induced plasticity [4] in zirconia-based ceramics involve consideration of the interaction between the stress field of a propagating crack and the strains accompanying the martensitic tetragonal (t) to monoclinic (m) transformation occurring within tetragonal zirconia (t- ZrO_2) in the vicinity of the crack tip. To assess the toughening that may be achieved these theories require a reliable determination of these strains and, since the transformation is displacive, this in turn requires a detailed understanding of the crystallography of the transition. For this reason the transformation has received considerable attention in pure bulk zirconia [5-11], in t- ZrO_2 particles dispersed in a ceramic matrix [11-17] and, more recently, in zirconia-based systems with a microstructure comprising polycrystalline tetragonal phase [11,18]. It is the purpose of the present paper to review briefly experimental observations relating to the t $\rightarrow$ m transformation both in dispersed t- ZrO_2 particles and in tetragonal zirconia polycrystals (TZP), and to assess progress in the application of the formal theory of martensitic transformations.

Attention will also be given to the occurrence of tetragonal $\rightleftharpoons$ orthorhombic and orthorhombic $\rightleftharpoons$ monoclinic transformations in small ZrO_2 particles which are either in unconstrained form or dispersed in the cubic

matrix phase in thin foils of partially stabilized zirconia (PSZ). Identification of a novel orthorhombic (o) phase in MgO-PSZ [19-21] has led to considerable speculation regarding not only its contribution to determining mechanical properties [20,22], but also its possible role in the important $t \rightarrow m$ transition. It has been suggested [19,20], for example, that the orthorhombic phase is an essential intermediate reaction product in the $t \rightarrow m$ transformation and it is thus important that the role of the orthorhombic phase be clearly established.

2. CRYSTALLOGRAPHIC THEORY

The structural change that accompanies a martensitic transformation is characterized by the maintenance of a unique lattice correspondence between unit cells of the parent and product lattices. The existence of this correspondence implies that the change in structure may be accomplished by atomic displacements equivalent to a homogeneous deformation of the parent lattice. When combined with a rigid body rotation, R , the homogeneous lattice strain, B , implied by the correspondence defines the total lattice strain, S_t , that will generate the product lattice in its observed orientation relationship with the parent lattice [23]; i.e.

$$S_t = RB. \quad (1)$$

The total strain provides, however, an incomplete description of the transformation for it is, in most cases, incompatible with the homogeneous shape deformation that accompanies formation of the transformed volume. The shape strain, P , approximates to an invariant plane strain in which the interface plane (i.e. the habit plane) remains invariant and it is rare that the total lattice strain generates a matching plane between parent and product lattices. This apparent incompatibility may be reconciled if it is assumed that the total strain is only locally homogeneous and occurs inhomogeneously on a macroscopic scale in order that the habit plane remain an invariant plane of the shape strain. The shape strain may thus be considered the product of the total lattice strain and an additional strain which periodically relieves the accumulating misfit across the transformation interface and maintains a macroscopically undistorted plane of

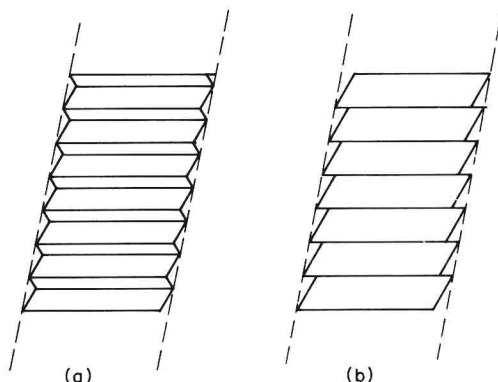


Figure 1 Schematic representation of martensite plates in which the lattice invariant strain involves (a) twinning, and (b) slip.