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Bulk orientational anisotropy without spatial anisotropy due to powder compaction in Al–Ti–B compacts

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Powder processing of materials typically uses uniaxial compression in the powder-compaction step and might thereby make anisotropic compacts out of initially isotropic powders. Our objective in this study was to ascertain and quantitatively characterize this possible anisotropy in green compacts of Al–Ti–B powder mixtures of three compositions, prepared from elemental powders (having irregular particle shapes), with a view to identifying pitfalls and commercial exploitability. The compacts unexceptionally showed negligible bulk spatial anisotropy but significant anisotropy due to particle reorientation.

Keywords: Powder processing; Anisotropy; Microstructure characterization; Stereology; Correlation functions

Powder processing is among the most important techniques in commercial production of many types of materials, such as ceramics and plastics. It necessarily involves a powder-compaction step. The most widespread technique for powder compaction is die pressing, in which the walls of the die are well known to produce heterogeneities in the compact near the wall, due to wall friction's impeding free compaction. Little studied, though, are the bulk microstructural effects, beyond elementary properties such as porosity, in multiphase powder-processed materials of the uniaxial compression effected by the technique.

The compaction of powders is usually considered as proceeding in four overlapping stages [1]: rearrangement, localized deformation, homogeneous deformation, and bulk compression. In the first stage, rearrangement, particles simply move without deforming to try to lower bulk porosity. Non-spherical particles will tend to reorient—one naturally expects—to project a lower surface area on a plane containing the compression axis. This is because any particle would be in the most stable of stable mechanical-equilibrium configurations when the direction of its longest Feret diameter is nearly "horizontal", compaction being "vertical" (these direction references agree with micrographs, to be introduced). The particles would thus start "leaning on" the loading axis, if not "lying down" perpendicular to it.

Such reorientation, though intuitive and plausible, has not, to our knowledge, attracted the attention of experimentalists. Simulation studies that have attempted to explore these effects (e.g., [2,3]), during rearrangement and later, could benefit from empirical testing of their results. And to know the microstructural effects of powder compaction by die pressing empowers one to design anisotropic materials (as, perhaps, magnetic materials) produced by powder processing, as well as to offset any ills of the anisotropy. Our objectives in this study, accordingly, were (i) to ascertain that the expected anisotropy results and (ii) to use image processing and stereological techniques on montaged large-area micrographs to quantitatively characterize it, in three Al–Ti–B green compacts of different compositions made from the same set of elemental powders. Al–Ti–B powder compacts are of interest as possible structural energetic materials [4].

Microstructural anisotropy could, in general, be the result purely of anisotropic spatial arrangements (as, say, banding of spherical particles in only one direction). We term that *spatial* anisotropy and would differentiate

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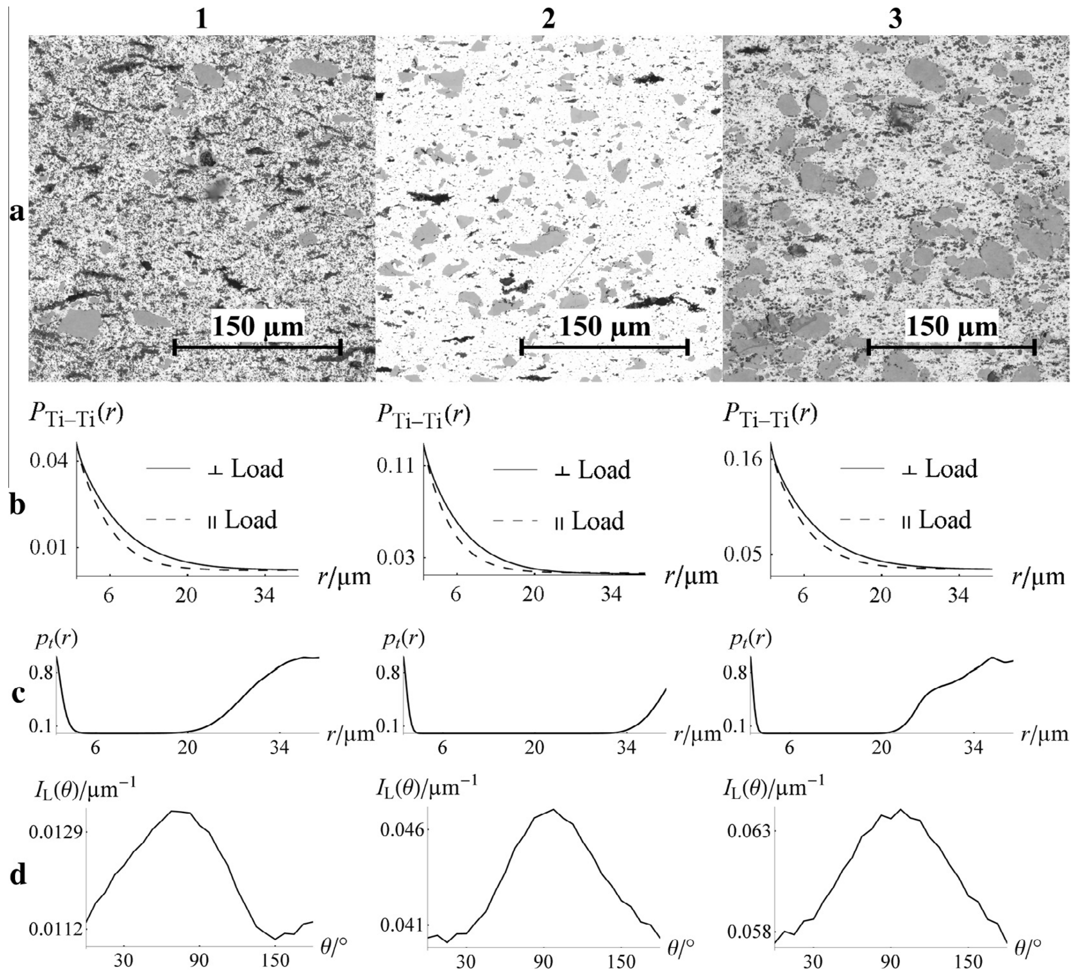

Figure 1. (a) Micrographs of Al–Ti–B green powder compacts of compositions, by volume: (1) 4.6% Ti–15% B–Al, (2) 12.7% Ti–10% B–Al and (3) 17.7% Ti–5% B–Al. Titanium is a light-gray particulate phase, boron is a dark particulate phase with very small particles and aluminum is the white matrix; (b) Ti–Ti two-point correlation functions P_{Ti-Ti} parallel to loading ("longitudinal" — vertical direction in micrographs) and perpendicular to loading ("transverse" — horizontal direction in micrographs); (c) the p-value as a function of r for the t-test for equality of $P_{Ti-Ti}(r)$ along and perpendicular to loading, based on sampled 470 × 470 μm windows; (d) intersections divided by length for Ti surfaces as function of theta, $I_L(\theta)$, for the three samples.

it from *orientational* anisotropy arising from non-random orientations of non-spherical particles in the microstructure.

Commercial titanium, boron, and aluminum powders were used in our pellets (compacts). They were AEE sponge titanium (<20 μm), Alfa-Aesar amorphous boron (<6 μm), and Valimet H-2 spherical aluminum (<6 μm). All powders were prepared for pellet making by first keeping them heated at 110 °C in a vacuum for 24 h and then allowing them to settle in an inert atmosphere at room temperature for the same time. To prepare each pellet, the three powders were then measured out, in line with the intended bulk composition, and transferred to a dry, empty plastic bottle (in the inert atmosphere)—one bottle for each composition. The bottle was then sealed and put in a V-shell blender (roughly 0.5 Hz rotation frequency) to mix for 24 h. The mixture was pressed to a 26 000 lbf load to a cylindrical pellet of half-inch (12.7 mm) diameter. The compositions of the three samples used were, by volume, (1) 4.6% Ti–15% B–Al, (2) 12.7% Ti–10% B–Al, and (3) 17.7% Ti–5% B–Al.

Each pellet so produced was at nearly theoretical maximum density and had enough handling strength to be cut along its axis. We metallographically prepared and optically imaged the resulting cross section, which, containing an axis of radial symmetry of the solid, was stereologically the most efficient choice of section [5]. Figure 1a shows micrographs of the three pellets. In each image, the vertical axis, which we term the longitudinal direction, is parallel to the direction of pressing; and the horizontal axis is a perpendicular direction—one of the infinitely many statistically identical directions—which we usefully term *the* transverse direction.

Aluminum has a 0.2% proof stress in the range (20–35) MPa [6, p. 17], titanium over 250 MPa [6, p. 61], and boron either undefined or too high to matter. During compaction of the pellets, therefore, the aluminum particles deform freely and flow into pores, whereas titanium and boron are almost undeformed. The stages of compaction referred to earlier all occur in aluminum particles, judging by the final microstructures produced, in which aluminum–aluminum particle boundaries are undetectable and the porosity is nearly zero. Titanium