Theory of superplasticity in polycrystalline materials: Stress-induced structural instabilities of grain boundaries

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A fine mechanical analysis of a polycrystalline material subjected to large stresses must distinguish between intergranular and crystalline matter because they have different mechanical properties. Homogeneity is an illusion at the grain level. It is shown that a grain boundary under the action of a strong enough in-plane shear stress becomes unstable, buckling into periodic trenches or a corrugated profile. The former should always occur; the latter demands the existence of steps, intersecting hard particles or triple junctions. Strongly varying stress fields, spontaneously induced to preserve mechanical equilibrium at the grain scale, cause intergranular matter to begin to release and capture vacancies in alternate sectors. The subsequent active lattice diffusion near the buckled boundary causes adjacent crystallites to slide. The effect is translated into the macroscopic scale to derive a closed-form constitutive equation relating stress, strain rate, temperature, grain size, and gr