The full three-dimensional stress state of 172 individual bulk grains in austenitic stainless steel 316L at 0.1 and 1% sample elongation has been determined with sufficient accuracy to allow comparison with the theoretical Bishop-Hill stress states for plastically deforming grains as well as calculation of the resolved shear stresses on the individual slip systems. At 0.1%, the resolved shear stresses exhibit quite large variations between grains of similar orientation. When averaging over similarly oriented grains, the resolved shear stresses correspond to the Schmid factors for uniaxial tension. At 1%, only about half of the grains were close to a Bishop-Hill stress state. The stress state of the other half of the grains was closer to the applied uniaxial stress, in between Bishop-Hill states, or in some cases none of these. The orientation dependence of the assigned stress states deviate somewhat from the theoretical expectation. These deviations are found to originate from a larger tensile stress component than in the theoretical Bishop-Hill stress states and to be associated also with deviations from axisymmetric plastic strain. This conclusion was supported by finite-element crystal plasticity simulations.