Influence of growth process and crystal defects on sapphire brittleness

Jessica Muzy[1], Marc Fivel[2], Serge Labor[1], Denis Guignier[1], José Baruchel[3], Thu Nhi Tran Thi Caliste[3], Vitali Nagirnyi[4], Ivo Romet[4], Thierry Duffar[2]*

*lead presenter: thierry.duffar@grenoble-inp.fr
[1]RSA le rubis SA, BP16, 38560 Jarrie, France
[2] Univ. Grenoble Alpes, CNRS, Grenoble INP, SIMAP, Grenoble, France
[3] ESRF, BP 220, 38043 Grenoble, France
[4] Institute of Physics, University of Tartu, W. Ostwald Str. 1, 50411 Tartu, Estonia

Brittleness of sapphire has been studied by two massively performed bending tests, specifically designed for the study: four point bending and ball on three balls tests. Both show a significantly higher fracture strength for Verneuil crystals compared to EFG ones. For a better understanding of mechanical behavior, transition between elastic and plastic deformation was studied through nano-indentation analysis of pop-in events.
X-ray characterizations performed at the European Synchrotron Radiation Facility (ESRF) helped to analyze the mechanical results, by revealing structural defects in crystals. White beam topography and Rocking Curve Imaging were used, as they are complementary. It was shown that sub-grain boundaries found in Verneuil crystals do not impact the fracture behavior. About one hundredth times more dislocations were measured in the Verneuil crystals compared to EFG. This larger amount of basal dislocations in Verneuil boules appeared to account for the differences in brittleness. The dislocation densities have been related to the temperature fields experienced by the crystals during the growth processes. Characterization of point defects revealed that they are more numerous in Verneuil crystals, especially after annealing, and that they pin dislocations, contributing to the mechanical response of the crystal.
In conclusion, Verneuil crystals high fracture strength is due to higher dislocation densities than in EFG crystals. Higher temperature gradient fluctuations in Verneuil process, especially when the flame is blown-out, lead to higher dislocations densities and consequently to a better resistance to brittleness.