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Strengthening effect of compactive shear bands and associated carbonate nodules in arkose sandstone: a natural analog of composite multilayer

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We characterized the mechanical properties of compactive shear bands (CSB) with cataclasis and associated calcite-cement concretions in high-porosity arkose sandstone of the Northern Apennines, Italy (Loiano Sandstones). The CSBs, localize carbonate diagenetic structures in the form of isolated or multiple spheroid or irregular-shape nodules and tabular concretions, which weather out in positive relief with respect to the poorly-cemented host rock (HR). Porous sandstones are pressure sensitive rocks and their mechanical (Uniaxial Compressive Strength – UCS) and petrophysical (porosity, permeability) properties may change significantly during volumetric deformation. Pore cement precipitation affects these same properties to an extent that is larger than that of the CSBs alone.

We recorded Schmidt hammer rebound indexes, along a transect that intercepts different domains: poorly-consolidated pristine HR, concretions with and without CSBs, and zone of bands (ZB). We also performed the same measurements for each of these features separately, to obtain reference values for comparison with the transect values. The aim of our work is to understand the variations of rock strength across the CSBs and the associated concretions with respect to the HR. The complex combination of different rock parameters, such as Young's modulus, rock strength and cementation are reflected in the hammer rebound values. We observed, both from the transect and single measurements, that pristine HR shows the lowest UCS values (∼24 MPa). Nodules associated to ZB have higher UCS values (∼70 MPa) with respect to nodules alone or associated with one single CSB (∼49 MPa). This indicates that strength increase is not caused only by cementation, but also by ZB-related strain hardening, i.e. cataclasis and porosity reduction (compaction), that form a dense microstructure within the CSBs. Where cement is present UCS values show wider scatter with respect to pristine HR, since cementation may be inhomogeneously distributed. The cementation controls UCS, because it reduces porosity enhancing the porosity decrease caused by compaction and cataclasis in the CSB. UCS, therefore, is dependent on the mechanical and petrophysical properties of the pristine HR, on the cement type, and on the cement effect on HR properties. Nodules, regardless the presence of CSBs, have higher UCS values with respect to the pristine HR, because cement precipitates at the grain contacts inhibiting rotation and sliding of particles thus, increasing the cohesion. Nodules associated to ZB, however, are the most cohesive and strongly indurated feature in outcrop: (i) cataclasis increases friction by clast roughening and, (ii) compaction enhances the degree of packing, increasing cohesion. All that, promotes a strain hardening effect of the band. The combined effect of cataclasis, compaction, and cementation, degrades porosity and permeability and produces a strengthening effect of the Loiano Sandstones, and in particular of the assemblage CSB–concretion. In analogy with laminae-reinforced composite materials, we show a model, based on "rule of mixtures", that quantifies the strengthening effect of concretions and CSBs in the overall rock system.