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Micromechanical properties of macerals in coals from the Ukrainian Donets Basin: maturity trends and implications for unconventional hydrocarbon production

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The mechanical properties of different types of organic matter (macerals) are considered as an important influencing factor for the fracture behavior of organic matter-rich shales and coals, and hence, fracture permeability that directly controls the producibility of unconventional resources such as shale gas or coal bed methane. In an attempt to obtain maceral-specific material properties, nanoindentation tests were carried out on three coal samples from the Ukrainian Donets Basin, covering a maturity range from 0.6 to 1.1 %Rr (vitrinite reflectance). Vitrinite, liptinite and inertinite macerals within these coals were identified based on optical microscopy, and hardness and elastic modulus (E_r) were determined after the standard method established by Oliver & Pharr (1992) for all three maceral groups, using a Cube Corner-Tip indenter in load-controlled mode with a trapezoidal loading profile at a maximum load of 1000 μN (maximum load was held for 10 s; loading/unloading rate: 500 μN/s). The results indicate that the maceral groups are affected differently by maturity changes; The obtained hardness (0.44$\pm$0.05 GPa at 0.62 %Rr; 0.45$\pm$0.02 GPa at 1.1 %Rr) and E_r values (4.90$\pm$0.33 GPa at 0.62 %Rr; 5.08$\pm$0.23 GPa at 1.1 %Rr) of investigated vitrinites do not show a significant response to maturity changes, while liptinites show increasing hardness (0.37$\pm$0.02 GPa at 0.62 %Rr; 0.42$\pm$0.02 GPa at 0.93 %Rr) and decreasing E_r (4.78$\pm$0.68 GPa at 0.62 %Rr; 4.02$\pm$0.15 GPa at 0.93 %Rr) with increasing maturity. Time-dependent deformation might be responsible for the decrease in E_r of liptinites with increasing maturity, which needs to be further evaluated. The influence of maturity changes on the mechanical properties of inertinites depends strongly on the maceral subgroup. Increasing hardness (2.86$\pm$0.20 GPa at 0.62 %Rr; 3.20$\pm$0.19 GPa at 1.1 %Rr) and E_r (9.31$\pm$0.64 GPa at 0.62 %Rr; 11.98$\pm$0.45 GPa at 1.1 %Rr) with increasing degree of coalification was observed for fusinite macerals, while the values remained constant in case of semifusinite. The different deformation behavior of the three maceral groups is reflected in the variable shapes of the obtained load-displacement curves. The main indentation response of vitrinite and liptinite is elasto-plastic, while the deformation behavior of fusinite is mainly elastic. Nanoindentation tests on isolated vitrinite particles in shales yielded significantly higher (up to an order of magnitude) hardness and E_r compared to vitrinites in coals of comparable maturity. Further investigations will help to evaluate the influence of compaction and mineral matrix effects on the discrepancy of micromechanical properties of organic matter in shales and coals.

Reference:

Oliver, W.C., Pharr, G.M., 1992. An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments. J. Mater. Res., 7, 1564-1583.