Mechanical properties of coal macerals: A nanoindentation study

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The mechanical properties of kerogen macerals are considered 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. We investigated the mechanical properties of macerals (liptinite, vitrinite, inertinite) in 12 Carboniferous coals from the Ukrainian Donets Basin, covering a maturity range from 0.62 to 1.47 %Rr (vitrinite reflectance). Nanoindentation tests were conducted as the inherent inhomogeneity of coals with differing maceral and mineral proportions requires characterization at the micro-/nanoscale. Maceral-specific material parameters such as hardness (H) and reduced elastic modulus (E_r), as well as the dominating deformation type (plastic vs. elastic) estimated from the shape of the individual load-deformation curves, were correlated with coal rank and parameters related to the depositional setting (e.g. ash yield).

The results indicate that apart from maturity, multiple factors control the mechanical properties of macerals in coals. H and E_r of vitrinites do not follow a clear maturity trend, as a result of multiple influencing factors like mineral matter inclusions, depositional conditions, complex changes in the organic matter structure with increasing rank, and possibly the generation of nanoporosity at advanced maturity levels. A good correlation was found between the bulk ash yield and the mechanical strength of vitrinites at comparable rank (~ 0.7 %Rr).

The mechanical properties of inertinites do not correlate with coal rank; instead, they are mainly controlled by the prevailing conditions (temperature, exposure) during paleo-wildfires, indicated by a correlation of the measured inertinite reflectance with both H and E_r. Liptinites are strongly influenced by transformational processes related to devolatilization at low to medium rank, as well as later hydrocarbon generation, resulting in a peak of H and E_r at medium rank (~0.7 %Rr). Variations in the depositional environment (e.g. increased organic S content due to marine influence) might play an additional role.

In order to achieve a better understanding of the interdependency between mechanical properties and microstructural features (e.g. nanoporosity, mineral inclusions), advanced characterization techniques such as transmission electron microscopy (TEM) are required.