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A study on dynamic hydraulic fracture: the relation between crack tip and fluid front

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We present direct observation and theoretical analysis on the relation between the crack tip and the fluid front in dynamic hydraulic fracturing of impermeable material. A laboratory-scale hydraulic fracturing device is built to induce dynamic mode I hydraulic fracture in PMMA specimen. The derived analytic solution of stress intensity factor for this configuration is in good agreement with the existing numerical results and the experimental result obtained using the combination of the digital image correlation and the Williams' series. Taking the horizontal component of crack-flank resistance into consideration, the force-balance equation of the fracturing fluid under constant fracturing pressure accounting for the dynamic relation between the crack tip and the fluid front is established. Results show that the theoretical predictions conform well to the directly observed results of these two fronts. The analysis on energy terms show that the kinetic energy of the fluid occupies over half of the total input energy before the fluid front approaches the crack tip. When the crack slows down or arrest, this ratio further increases. Then we explore the existence of equilibrium state in this dynamic system, which indicates that if the hydraulic fracture propagates at a constant speed V_C, the fluid front will also travel at a constant velocity $P_E V_C$ ($0<P_E<1$) after a certain period of time, and will not catch up with the running crack tip. The separation criterion of the crack tip and the fluid front is established and found to conform well to the experimental data. The dynamic relation between the two fronts in different crack profile proposed by recent experimental research are investigated. Results show that the crack profile and the crack opening level only exert very limited influence. This study provides a better understanding on the dynamic relation between the crack tip and the fluid front in hydraulic fracture.