Mortar and Paste Rheology: Concentration, Polydispersity and Air Entrapment at High Solid Fraction

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Abstract:
Rheological characterisation of mortar is complicated by phenomena of slip, the formation of shear bands and depletion. At relatively low solid fractions a typical Couette geometry and a medium-size mixer-type rheometer were used to determine flow curves. At higher solid fractions a large-size coaxial cylinder rheometer with multiple blade vane geometry was used up to the point where slippage occurred. The viscosity as a function of concentration responds to the Krieger-Dougherty law, when a mortar is considered as a suspension of sand in a matrix of binder slurry. The limits of this description corresponds to a critical solid fraction above which air is entrapped during the mixing procedure: air content measurements demonstrate this phenomenon. A clear relationship between mortar and slurries was established, based on the measured properties of both binder and sand particles, and on the Farris model for polydisperse suspensions. Intrinsic viscosity can be used as a tool to evaluate shape characteristics of the binder particles. A procedure for mixture optimisation of mortars using this model is demonstrated for the case of a trimodal mortar.

Zusammenfassung:
Die rheologischen Eigenschaften von Mörtel werden durch Slip-Phänomene, die Bildung von Scherbändern und Abnutzung verkompliziert. Bei relativ niedrigen Feststoffanteilen wurden die typische Couette-Geometrie und ein mittelgroßes Mischertyp-Rheometer zur Bestimmung der Fließkurve verwendet. Bei höheren Füllstoffanteilen wurde ein großes koaxiales Zylinder-Rheometer mit mehreren Schaufelblättern bis zu dem Punkt verwendet, an dem Wandgleiten auftrat. Die Viskosität als Funktion des Füllstoffgehalts gehorcht der Krieger-Dougherty-Gleichung, falls Mörtel als Suspension von Sand in einer Bindemittel-Aufschlämmung betrachtet wird. Die Grenze dieser Beschreibung ist bei der kritischen Feststoffkonzentration gegeben, oberhalb derer Luft während des Mischprozesses eingeschlossen wird. Die Messung des Luftgehaltes beweist dies. Eine klare Beziehung zwischen Mörtel und Aufschlämmung wurde basierend auf den gemessenen Eigenschaften des Bindemittels und der Sandkörner sowie auf dem Modell von Farris für polydisperse Suspensionen aufgestellt. Die intrinsische Viskosität kann verwendet werden, um die Partikel des Bindemittels zu charakterisieren. Weiterhin wird ein Verfahren für einen trimodalen Mörtel zur Optimierung des Mörtels mit Hilfe dieses Modells vorgestellt.

Résumé:
La caractérisation rhéologique des mortiers est compliquée par des phénomènes de glissement, de formation de zones de cisaillement locales et de déplétion. Une géométrie Couette classique et un rhéomètre de type malaxeur ont été utilisés pour déterminer les courbes d'écoulement à basse fraction volumique solide. Un rhéomètre à cylindres coaxiaux de grande taille muni d'ailettes a été utilisé pour des fractions solides plus élevées, jusqu'à ce qu'un glissement se produise. La viscosité en fonction de la fraction solide suit la loi de Krieger et Dougherty si l'on considère le mortier comme une suspension de grains de sable dans une matrice eau-liant. Le modèle atteint ses limites pour une fraction solide critique au-delà de laquelle de l'air est entraîné durant la procédure de malaxage: des mesures de la teneur en air confirment ce phénomène. Une relation claire a été établie entre les mortiers et les pâtes, basée sur les caractéristiques mesurées des particules de liant et de sable, et sur le modèle de Farris pour des suspensions polydispersées. La viscosité intrinsèque est proposée comme moyen d'évaluer les caractéristiques morphologiques des particules de liant. Une procédure pour l'optimisation des mélanges de mortiers qui utilise ce modèle est proposée pour le cas d'un mortier tri-modal.

Key words: mortar, paste, slurry, polydispersity, air entrapment, solid fraction

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with an unclear quantity of colloidal particles in suspension. A fitted value from measurements on a slurry, much higher than the viscosity of water, lead to the best results.

This paper shows, for the first time, a clear relation between particle properties, composition and viscosity of mortar. This was possible by measuring and comparing a large number of slurries and mortars. It also indicates at which point the theory of suspension rheology becomes problematic due to air entrapment. More research is necessary about the influence of this entrapped air, the more if the theory is to be extended to mortars with important amounts of artificially entrained air bubbles.

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APPENDIX

The compositions of all tested mixtures by mass ratios of the components are summarized in Table 5. “swc” stands for “standard water content”, an amount which corresponds to a typical value in practice [18]. Trimodal mortars are characterised by total solid fraction ϕ_T; slaked lime slurries are made by diluting the original slurry with different amounts of water.

Mass fractions	sand	binder	water	filler
Bimodal mortars with hydrated lime				
swc	0.723	0.092	0.185	-
swc+5%	0.716	0.091	0.193	-
swc+10%	0.710	0.090	0.200	-
swc+15%	0.704	0.089	0.207	-
Trimodal mortars with hydrated lime and siliceous filler				
ϕ_T = 0.334	0.225	0.144	0.434	0.198
ϕ_T = 0.422	0.270	0.158	0.346	0.226
ϕ_T = 0.609	0.366	0.165	0.200	0.269
ϕ_T = 0.702	0.416	0.158	0.144	0.281
Slurries of hydrated lime				
swc-10%	-	0.355	0.645	-
swc-15%	-	0.369	0.631	-
swc-20%	-	0.383	0.617	-
swc-30%	-	0.415	0.585	-
swc-40%	-	0.453	0.547	-
Slurries of slaked lime				
diluted 1	-	0.265	0.735	-
diluted 2	-	0.273	0.727	-
diluted 3	-	0.297	0.703	-
Slurry of lime-cement				
swc-30%	-	0.589	0.411	-
Slurry of hydraulic lime				
swc-30%	-	0.558	0.442	-
Slurries of cement				
swc-10%	-	0.544	0.456	-
swc-20%	-	0.573	0.427	-
swc-30%	-	0.606	0.394	-
swc-40%	-	0.642	0.358	-

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