Report on Measurements of Workability and Rheology of Fresh Concrete

Reported by ACI Committee 238

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This report provides a comprehensive view of workability of fresh concrete and a critical review of the tests available to measure workability and rheological performance of fresh concrete. The report discusses the factors affecting the performance of fresh concrete and provides a better understanding of the issues related to the design of workable concrete, from no flow (zero-slump) to flow like a liquid (self-consolidating concrete).

Keywords: rheological measurements; rheology; workability; workability measurements.

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ACI 238.1R-08 was adopted and published February 2008.

CHAPTER 1—INTRODUCTION

Fresh concrete properties are related to the properties of hardened concrete. Poor placement or consolidation leads to honeycombing, which reduces compressive strength and increases permeability, thereby leaving the concrete open to chemical attack. Nevertheless, fresh concrete properties are not always properly measured or predicted. The main measurement of workability, the slump test, is not always applicable; at the same slump value, two concretes may exhibit different workabilities. On the other hand, hundreds of tests were designed over the years to measure the workability of concrete. The question is how to select the proper test for the application at hand and how to interpret the results obtained to predict the performance of the concrete in the field in the fresh state.

To address these questions, it is necessary first to define workability in terms of fundamental physical entities, as described in the science of rheology. Therefore, this report has four main parts:

1. Definitions related to rheology and workability;
2. Critical review of the tests available to measure the workability and rheological performance of fresh concrete;
3. Discussion of the factors affecting the performance of fresh concrete; and
4. Examples that illustrate the application of rheology and material science to predict or improve the performance of fresh concrete in the field.

This report presents issues related to the design of a workable concrete for an application. Workable can mean no flow (zero-slump) or flow like a liquid (self-consolidating concrete [SCC]), depending on the application.

CHAPTER 2—RHEOLOGICAL TERMS RELATED TO CONCRETE

2.1—Notation

c = insignificant constant
g = gravity
h = height of slump cone mold
K = consistency
n = power index representing deviation from Newtonian behavior
s = slump, mm
V = volume of slump cone
α = time-dependent parameter
β = constant
$\dot{\gamma}$ = shear rate
ϕ = concentration of solids
ϕ_m = maximum packing density
η = viscosity of suspension
$[\eta]$ = intrinsic viscosity
η_{pl} = plastic viscosity
η_r = relative viscosity
η_s = viscosity of the matrix
η_∞ = apparent viscosity at very high shear rate
ρ = density, kg/m^3
τ = shear stress, Pa
τ_o = yield stress not Bingham
τ_B = Bingham yield stress

2.2—Definitions

Definitions related to concrete rheology and flow are listed in this section. These definitions were taken from the Cement and Concrete Terminology page of the ACI website (http://www.concrete.org/Technical/CCT/FlashHelp/ACI_Terminology.htm). Several of these definitions were based on Hackley and Ferraris (2001), which presents concrete rheology in the wider context of concentrated particle systems.

Bingham model—

$$\tau = \tau_B + \eta_{pl}\dot{\gamma}$$

$$\dot{\gamma} = 0 \text{ for } \tau < \tau_B$$

where
τ = shear stress;
τ_B = yield stress;
η_{pl} = plastic viscosity; and
$\dot{\gamma}$ = shear rate.

The Bingham model is a two-parameter model used for describing the flow behavior of viscoplastic fluids exhibiting a yield stress.

bleeding—the autogenous flow of mixing water within, or its emergence from, a newly placed mixture caused by the settlement of solid materials within the mass.

consistency—the degree to which a freshly mixed concrete, mortar, grout, or cement paste resists deformation. (See also: **consistency, normal**; **consistency, plastic**; and **consistency, wettest stable**.)

consistency, normal—(1) the consistency exhibited when a mixture is considered acceptable for the purpose at hand; or (2) the consistency of cement paste satisfying appropriate limits defined in a standard test method (for example, ASTM C187).

consistency, plastic—condition of mixture such that deformation would be sustained continuously in any direction without rupture.

consistency, wettest stable—the condition of maximum water content at which cement grout and mortar will adhere to a vertical surface without sloughing.

consistency factor—a measure of grout fluidity, roughly analogous to viscosity, that describes the ease with which grout may be pumped into pores or fissures; usually a laboratory-measured parameter in which consistency is reported in degrees of rotation of a torque viscometer in a specimen of grout.

consolidation—The process of reducing the volume of voids in a mixture, usually accomplished by inputting mechanical energy. (See also **vibration**, **rodding**, and **tamping**.)

finishing—leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce desired appearance and service. (See also **float** and **trowel**.)

impending slough—consistency of a shotcrete mixture containing the maximum amount of water such that the product will not flow or sag after placement.