Evaluation of Time Independent Rheological Models Applicable to Fresh Self-Compacting Concrete

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Abstract:
Self-Compacting Concrete is a new type of concrete which is more liquid compared to traditional concrete and which does not need any form of external compaction. As a result this type of concrete is suitable for a new placing technique: pumping SCC from the bottom in the formwork and letting it rise in the formwork due to the applied pressure. In order to understand the phenomena occurring during pumping operations, the rheological properties of SCC must be investigated and controlled. Tests have been performed with two different rheometers, which are described in this paper. For the Tattersall Mk-II rheometer, a calibration procedure has been worked out to eliminate secondary flows in the rheometer. Test results indicate that SCC is a thixotropic liquid, having a yield stress, showing shear thickening and having varying properties in time due to the occurring chemical reactions. In this paper, the time dependent effects will not be described. When trying to apply a rheological model to the obtained results, only the modified Bingham model seems appropriate. Applying the Bingham model results in the generation of negative yield stresses while the Herschel-Bulkley model has a parameter with a variable dimension and has a major mathematical restriction. The rheological properties of fresh SCC can be described with the modified Bingham model. A suitable parameter to describe shear thickening is defined as the ratio of the second order term in the shear rate of the modified Bingham model to the linear term (= c/μ).

Zusammenfassung:
Selbstverdichtender Beton (SCC) ist eine neue Form von Beton, die flüssiger ist als traditioneller Beton und keine Art von externer Verdichtung benötigt. Daher ist dieser Typ von Beton für eine neue Betoniertechnik geeignet: Pumpen des SCC vom Boden der Schalung und Aufsteigen des Betons in der Schalung aufgrund des auferlegten Druckes. Um die Phänomene zu verstehen, die während des Pumpens auftreten, müssen die rheologischen Eigenschaften von SCC verstanden und kontrolliert werden. Tests wurden mit Hilfe zweier unterschiedlicher Rheometer durchgeführt, die in diesem Artikel beschrieben werden. Für das Tattersall Mk-II-Rheometer wurde ein Kalibrationsverfahren ausgearbeitet, um die sekundären Strömungen im Rheometer zu eliminieren. Die Testergebnisse zeigen, dass SCC eine thixotrope Flüssigkeit mit einer Fliessgrenze ist, Scherverdickung aufweist und zeitlich variierende Eigenschaften aufgrund der auftretenden chemischen Reaktionen besitzt. In diesem Artikel werden die zeitabhängigen Phänomene nicht beschrieben. Beim Versuch, die erhaltenen Resultate durch ein rheologisches Modell zu beschreiben, erschien nur das modifizierte Bingham-Modell adäquat. Die Anwendung des Bingham-Modells führte zu negativen Fliessspannungen, während das Herschel-Bulkley-Modell einen Parameter mit variabler Dimension und eine grössere mathematische Einschränkung besitzt. Die rheologischen Eigenschaften von einem „frischen" SCC können durch das modifizierte Bingham-Modell beschrieben werden. Ein geeigneter Parameter, um die Scherverdickung zu beschreiben, ist das Verhältnis des Terms zweiter Ordnung in der Schergeschwindigkeit des modifizierten Bingham-Modells zu dem linearen Term (=c/μ).

Résumé:
Le béton autoplaçant est un nouveau type de béton qui est plus fluide, comparé avec le béton traditionnel. Ce béton n'a pas de besoin d'une autre source de compaction que de la gravité. Pour cela, ce type de béton est approprié pour un nouveau moyen de placement: le béton est pompé au dessous du coffrage et monte à cause de la pression appliquée. Pour mieux comprendre le comportement du béton pendant le pompage, les propriétés rhéologiques de ce béton doivent être étudiées. Des essais avec deux rhéomètres différents, décris dans cet article, ont été effectués. Pour le rhéomètre Tattersall Mk-II une procédure de calibration est proposée afin d' éliminer les courants secondaires dans le rhéomètre. Les essais indiquent que le béton autoplaçant est un liquide thixotropique, ayant un seuil de cisaillement, de la dilatation et des propriétés variantes dans le temps causées par des réactions chimiques. Dans cet article, seulement les effets indépendants du temps seront décrits. En appliquant des modèles rhéologiques, seulement le modèle Bingham modifié (modified Bingham model) semble utilisable. Le modèle Bingham genère des seuils de cisaillement négatifs et le modèle Herschel-Bulkley contient un paramètre avec une dimension variante et une grande réstriction mathématique. La dilatation peut être decrite par le quotient des termes quadratiques et linéaires dans l'équation du modèle Bingham modifié (= c/μ).

Key words: concrete, self-compacting concrete, Tattersall rheometer, Bingham model, Herschel-Bulkley model

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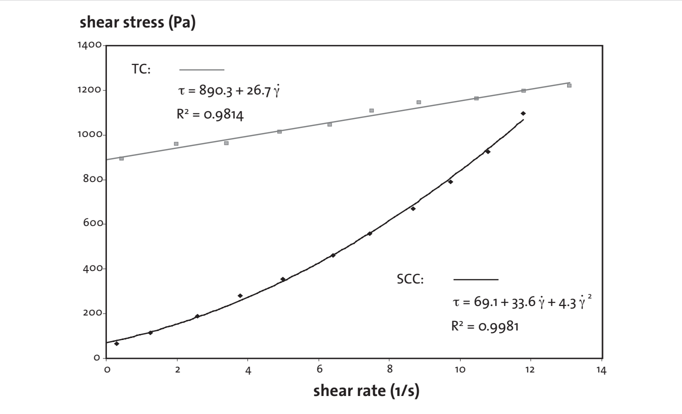

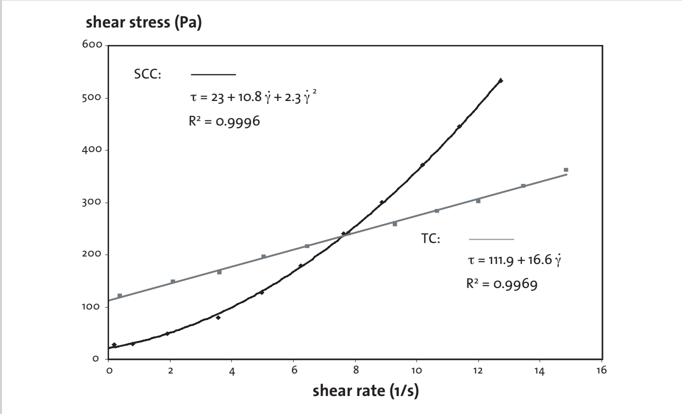

Figure 13 (left): SCC is much more fluid compared to TC with an equal amount of water and cement.

Figure 14: SCC and TC with an equal fluidity: TC needs more water to achieve this fluidity.

Mk-II rheometer has a more complex geometry. A calibration procedure has been worked out to eliminate secondary flows and transforming the data of torque and rotational velocity to shear stress and shear rate.

Self-Compacting Concrete can be classified as a thixotropic liquid having a yield stress, showing shear thickening and having a decrease in workability (fluidity) in time due to chemical reactions. The Bingham model cannot be applied to describe the rheological properties of SCC, due to the generation of negative yield stresses.

The Herschel-Bulkley model describes the behaviour better, but it has a parameter with a variable dimension and it overestimates the yield stress, due to a mathematical restriction in the region of low shear rates. The modified-Bingham model, being an extension of the Bingham model and a second order Taylor development of the Herschel-Bulkley model, is suitable to model the rheology of SCC. Shear thickening can be analysed by the parameter c/μ.

When comparing a Self-Compacting and a traditional concrete, suitable for standard practical applications according to the European standards, SCC is much more fluid from a rheological point of view. Traditional concrete can be made as fluid as SCC, but the traditional concrete has less strength and cannot be applied in all situations when considering durability.

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