Extension of the Poiseuille Formula for Shear-thickening Materials and Application to Self-compacting Concrete

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Received: 18.4.2008, Final version: 7.7.2008

Abstract:
In practice, while placing concrete in a formwork by pumping, the pressure generated by the pump is not controlled. In order to enhance the safety on the worksite, and in view of the current economic and ecologic arguments, it would be useful to dispose of an equation able to predict pressure losses based on the rheological properties of the concrete and the pipe configuration. This paper describes the derivation of an extended version of the Poiseuille formula, for shear-thickening materials with a yields stress, described by the modified Bingham equation. This formula is applied to flow-tests with self-compacting concrete. The results prove the applicability of this extended Poiseuille formula, showing that the flow is occurring in laminar regime, with no significant wall slip.

Zusammenfassung:
In der Praxis wird beim Pumpen des Betons in die Verschalung der durch die Pumpe erzeugte Druck nicht reguliert. Zur Verbesserung der Sicherheit auf der Baustelle und im Hinblick auf aktuelle wirtschafliche und ökologische Argumente wäre es nützlich, über eine Gleichung zu verfügen, mit deren Hilfe man die Druckverluste aufgrund der rheologischen Eigenschaften des Betons und der Rohrkonfiguration vorausberechnen kann. Diese Abhandlung beschreibt die Herleitung einer erweiterten Version der Poiseuille-Formel für Scherverdickungsmaterialien mit einer Fließgrenze, wie in der geänderten Bingham-Gleichung beschrieben. Diese Formel wird bei Strömungstests für selbstverdichtenden Beton angewandt. Die Ergebnisse bestätigen die Anwendbarkeit der erweiterten Poiseuille-Formel und zeigen, dass die Strömung im Laminarregime ohne nennenswertes Wandgleiten erfolgt.

Résumé:
En pratique, lorsqu'on pompe du béton dans un coffrage, la pression générée par la pompe n'est pas régulée. Afin d'améliorer la sécurité sur le chantier, et en considérant aussi les arguments économiques et écologiques habituels, il serait utile de pouvoir disposer d'une équation mathématique capable de prévoir les pertes de charge basées sur les propriétés rhéologiques du béton et du système de conduites. Cet article décrit la dérivation d'une version élargie de la formule de Poisseulle, pour matériaux en dilatation avec limite d'élasticité décrite par l'équation de Bingham modifiée.Cette formule est ensuite appliquée à des essais d'écoulement réalisés avec du béton autoplaçant. Les résultats prouvent la validité de cette formule de Poisseulle élargie et montrent que l'écoulement se fait en régime laminaire, sans glissement significatif à la paroi.

Key words: yield stress, shear-thickening, laminar flow, Poiseuille formula, Self-Compacting Concrete

1 INTRODUCTION

Self-Compacting Concrete (SCC) is a special type of concrete which does not need any form of external compaction due to its adapted composition [1 – 2]. Compared to traditional concrete, SCC has a lower yield stress, in order to enhance the fluidity and the self-compactability. On the other hand, it has a higher viscosity, caused by the lower water amount and the higher volume of fine materials in order to maintain the stability (to avoid segregation) [3]. Concrete, in general, also shows time dependent behaviour like thixotropy and non-reversible loss of workability [4 – 8]. Under some conditions, SCC can even show shear-thickening behaviour [9 – 14]. In this case, a more extended rheological model must be applied, which is chosen to be the modified Bingham model (Eq. 1) [10, 11]:

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- The flow is occurring in laminar conditions: This has been proven in Section 5.1, with a Newtonian Reynolds number between 1 and 10, indicating that the flow conditions are far from turbulent.

As a result, this extension of the Poiseuille formula is applicable to the obtained test results with self-compacting concrete, taking into account that no slippage near the wall is allowed. The question remains whether this formula is also applicable to high speed concrete flow, during pumping for example, when discharges are obtained between 10 and 30 l/s, which are a factor 10 to 20 higher than the discharges measured in flow tests described in this paper [15, 16]. This will be investigated through further research.

7 CONCLUSIONS

Based on the steady state rheological properties of fresh self-compacting concrete, including shear-thickening behaviour, an extension of the Poiseuille formula has been developed analytically. This extended Poiseuille formula has been applied to the results of flow tests of concrete through a horizontal steel pipe, where the driving pressure is caused by gravity. The test results indicate that for long pipes of 6, 9 and 12 m, the extended version of the Poiseuille formula is correct, but for short pipes and highly fluid SCC, the influence of the secondary effects is becoming significant.

The pressure losses have proven to be linearly dependent on the length of the pipe, the rheological properties and the discharge. As a result, the flow is occurring in laminar regime with no significant wall slip. Although, the no slip condition is the most difficult to verify and special attention should be paid to it when the concrete has a tendency to segregate. The extended Poiseuille formula is not valid for traditional concrete, due to the absence of shear-thickening behaviour, and this test setup does not seem applicable due to the high yield stress of traditional concrete. Further research must point out whether this formula is also valid during high speed concrete flow, for example due to pumping.

ACKNOWLEDGEMENTS

The authors would like to thank the Fund for Scientific Research (FWO) in Flanders for the financial support and the technical staff of the Magnel and Hydraulics laboratory for the preparation and the execution of the flow-tests

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