# Ultrasound gel as suitable tool for simulation of the fiber orientation in the fiber reinforced concrete

R. Lovichová[1,a], J. Fornůsek[1], L. Soukupová[2], J. Valentin[2]

[1]*Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, Prague, 166 29, Czech Republic*

[2]*Department of Road Structures, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, Prague, 166 29, Czech Republic*

[a]*romana.lovichova@fsv.cvut.cz*

**Abstract:** Presented paper is focused on the creation of transparent viscous liquid substance based on the ultrasound gel to replace fresh mixture of high-strength concrete within some costly experiments. The description of the viscous behavior of both materials and optimisation of ultrasound gel are shown. Two different methods for determining and measuring the viscosity of selected materials are described. The final solution of ultrasound gel is validated by these experimental methods and it is conveniently used for further experiments where an orientation of steel fibers was examined.

**Keywords:** high performance concrete; ultrasound gel; fiber; orientation; viscosity; viscometer.

## 1 Introduction

Main aim of this research is to find a way to simply imitate an expensive X-ray analysis of fiber reinforced samples and to verify if there is influence of pouring the containing steel fibers into the formwork [1]. The flow table test was selected as a method for comparison of consistency and workability of fresh concrete mixture and ultrasound gel solution, the rotational viscometer was used for measuring of dynamic viscosity of the both materials. Measured data from these tests were successively applied in the optimization of a transparent gel and its further use when the gel with addition of steel fibers was poured into a special formwork.

## 2 Materials

Ultra-High Performance Concrete (UHPC) containing fine-grained aggregate up to fraction 1 mm was used for our experiments. The mixture was developed and created by Experimental center of the Czech Technical University in Prague and tested during previous laboratory experiments. It was proved that the fine aggregate cementitious composites are suitable for high performance concrete mixtures [2]. According to this UHPC mixture an aqueous solution of ultrasound gel was prepared. The viscous gel is a transparent and odorless and it is commonly used for medical purposes. Producer confirmed thixotropic behavior of the gel. The fresh concrete and an ultrasound gel are both viscous and thixotropic. However, materials are similar in some characteristics and different in others. The created gel differ in its transparent look, which was our intention. Viscosity and thixotropy have a significant effect on fiber orientation, particularly due to the behavior changes during the action of external forces. The viscosity values of high performance concrete range from 68 Pa·s to 530 Pa·s [3] and the viscosity values of used ultrasound gel lie between 60 Pa·s and 80 Pa·s. Less viscous concrete has the fibers oriented more than concrete with higher viscosity. It also affects the deployment of the fibers in the specimen. Viscosity is an important parameter, segregation may occur if viscosity is not sufficient [4]. These findings of the investigated materials were used as input parameters to create a substance of similar consistency as fresh concrete [5].

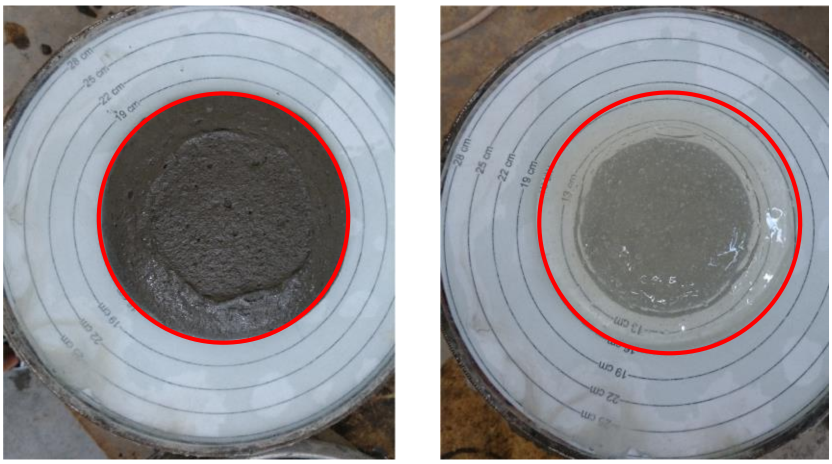
Selection of the type of fibers is limited by place and application purpose. The most suitable are high modulus fibers that can be successfully mixed with cement paste or concrete to produce material with the desired structural characteristics. Steel fibers fulfill these requirements and proves to be a very appropriate choice for interaction with concrete especially with UHPC. The length of fiber cross-sectional shape, tensile strength, ductility and interaction are the main factors which determine the final properties of the fibers in concrete [6]. A steel fibers we used are commonly added to the tested UHPC mixture. A high strength steel microfibers with straight shape, length $L_f$ = 13 mm and diameter d = 0.18 mm and tensile strength of 2400 MPa was used as the dispersed reinforcement in this experimental programme. Microfibers were dosed by volume to the mixture. The dose of the fibers into this UHPFRC mixture is usually 1.5 %. The same amount of steel fibers was applied in an experiment with modified ultrasound gel solution where the orientation of fibers in transparent formwork was investigated.

# 3 Experimental programme

The purpose of the experiments was to design and create a transparent substance that effectively replaces a fresh mix of UHPC during filling into the formwork. Another aim was to demonstrate the effect of the pouring of ultra-high performance fiber-reinforced concrete (UHPFRC) on a final fiber orientation. And also its influence on the mechanical properties of the specimen.

## 3.1 Flow table test

The flow table test apparatus was used for optimisation of the consistency and workability of ultrasound gel in accordance with fresh mixture of UHPC. The fresh mixture of UHPC and a pure ultrasound gel were tested at first. Three tests with a fresh UHPC mixture was performed, all with practically same result, the measured diameters of the spillage circles were 16 cm. After the first flow table tests with a pure gel was clear that it is too dense without any water addition. Therefore doses of water was added, each futher test was performed with the addition of a 10 g of water until the diameter of spillage for ultrasound gel solution correspond with the diameter for the fresh mixture of UHPC. Once the final ratio of ultrasound gel and water was found, two more control measurements with a modified ultrasound gel solution followed. An identical result was evaluated for all three tests, the measured diameters of the spillage circles were again 16 cm. The spillage of both investigated materials has been documented after the flow table test, see Fig. 1.



a) Fresh mixture of UHPC b) Ultrasound gel solution

Fig. 1: Investigated materials after flow table test.

## 3.2 Rotational viscometer

A rotational viscometer Brookfield DV-II+Pro was selected for practical use in further experimental and computational cases after summarization of the different possibilities of viscosity measurement and suitability of individual methods. The viscometer is based on the principle of rotation of the spindle immersed in the sample with the aid of a calibrated spring. The viscous properties of the fluid indicates the degree of reflection of the spring which is measured by rotary encoder. A spindle “RV05” from a basic set of spindles was utilized for measurement and Rheocalc software was used during the testing for data acquisition and analysis. The comparison and measured values of both materials are described on the Fig 2. The dynamic viscosity of the fresh mixture of cement (FMC) decreases from 300 Pa·s to 10 Pa·s with increasing speed of rotation per minute from 0.5 to 25 and for the ultrasound gel solution (UGS) it was from 400 Pa·s to 10 Pa·s with increasing speed of rotation per minute from 0.5 to 35. These results give a good confidence to use the ultrasound gel solution in the upcoming experiments.

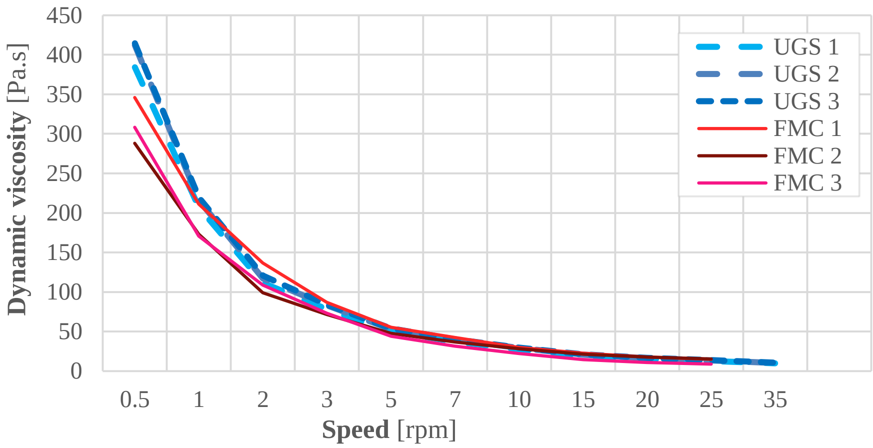



Fig. 2: The measurement of dynamic viscosity of the ultrasound gel solution (UGS) and the fresh mixture of cement (FMC), depending on the number of spindle revolutions per minute.

## 3.3 Simulation of pouring mixture

Based on the findings and results described above an experiment with an ultrasound gel containing fibers was performed. The created gel mixture was mixed with steel microfibres of the same dose as is usual to add into the UHPFRC mixture. This gel mixture was then poured into a special transparent formworks in the horizontal and vertical direction. An orientation of fibers was observed and studied due to a pouring of mixture and an impact of the formwork walls. See the photos bellow where the formworks filled with fiber ultrasound gel are shown (Fig. 3).

a) Filled horizontal formwork

b) Filled vertical formwork

Fig. 3: The orientation of fibers in the matrix of the ultrasound gel after pouring into the transparent formwork.

The fibers in a horizontal formwork are oriented preferentially perpendicular to the direction of the pouring – horizontally (Fig 3 a). There is the visible influence of the formwork walls in their vicinity on the orientation of the fibers. This phenomenon is particularly noticeable in side view where the fibers follow a boundaries of the form on the bottom and on the sides (Fig 3 a – bottom). Mostly random fiber orientation was in the vertical formwork (Fig 3 b). The orientation of the fibers was more in vertical direction along the walls of formwork and more horizontal in the middle of thickness of the prism and close to the bottom. Fiber orientation was affected by formwork walls almost across the entire cross-section due to the small width of formwork.

The simulation of storing the fresh mixture of concrete replaced by transparent material with same consistency proved an influence of arrangement and orientation of steel fibers in a fresh mixture of high-strength concrete.

## 4 Conclusion

The optimal consistency of the ultrasound gel solution was found with the aid of the flow table test. The final ratio of the ultrasound gel and water was modified to 1:0,566. The dynamic viscosity of the materials was measured on the rotational viscometer Brookfield with spindle "RV05". The measured values are shown on the Fig. 2 and they confirm comparable dynamic viscosity of tested materials. The dynamic viscosity of investigated materials decreases from a values about 350 Pa·s to 10 Pa·s with increasing speed of rotation per minute from 0.5 to 25 (35).

The assumption was that the fibers are oriented perpendicular to the pouring direction of the mixture. And the assumption has been proven by our experiments. The fibers are oriented in the horizontal direction when a liquid composite is also poured into the horizontal formwork. The orientation of the fibers was also affected by walls of formwork especially when the width of formwork was smaller.

## Acknowledgement

The authors gratefully acknowledge the financial support from the Grant Agency of the Czech Technical University in Prague, the grant No. SGS15/060/OHK1/1T/11.

## References

[1] J. Fornůsek, M. Tvarog. Characteristics of Fiber Reinforced Cementitious Composites in Dependence on Casting Direction. In: Applied Mechanics and Materials 732: 377-380 (2015).

[2] R. Lovichová, P. Padevět, J. Fornůsek. Changes of the Properties of Cement Paste with Fly Ash Exposed to the High Temperature. In: Key Engineering Materials 677: 138-143 (2016).

[3] C. Hu, F. Larrard. The rheology of fresh high-performance concrete. In: Cement and Concrete Research 26(2):283-294 (1996).

[4] P. Stähli, R. Custer, J. G. M. van Mier. On flow properties, fibre distribution, fibre orientation and flexural behaviour of FRC. In: Materials and Structures 41:189-196 (2008). ISSN 1359-5997.

[5] B. Zhou, Y. Uchida, Fiber orientation in ultra high performance fiber reinforced concrete and its visualization. In proc.: VIII International Conference on Fracture Mechanics of Concrete and Concrete Structures (2013) paper 160, Toledo (Spain).

[6] M. Beddar. Fibre-reinforced concrete. In: Concrete 38(4) 47 (2004). ISSN 0010-5317.