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Published in:
4th International Rilem Conference on Microstructure Related Durability of Cementitious Composites: Microdurability 2020

Published: 01/01/2021

Document Version
Publisher's PDF, also known as Version of record

CONTACT BETWEEN CEMENTITIOUS MATRIX AND FIBRES INFLUENCED BY THE MODIFICATION OF THEIR PARAMETERS

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Abstract

The performance of fibre reinforced cementitious composites depends on the interaction between the cementitious matrix and the fibres on the micro-scale. This interaction is affected by the material and surface properties of the fibre and the micro-scale characteristics of the cementitious matrix close to the fibre surface, creating the interfacial transition zone (ITZ). However, the discussions regarding the effect of the surface properties of fibres on the formation of the ITZ and, as a result, the bond strength between the matrix and the fibres are limited. The present paper reports the progress of the ongoing research project, which concentrates on investigating the contact created by the steel fibres with different characteristics of the surface roughness and cementitious matrix. The results of this study can support the development of efficient fibre reinforced cementitious composites.

Keywords: contact, roughness, wetting, fibre reinforced cementitious composites

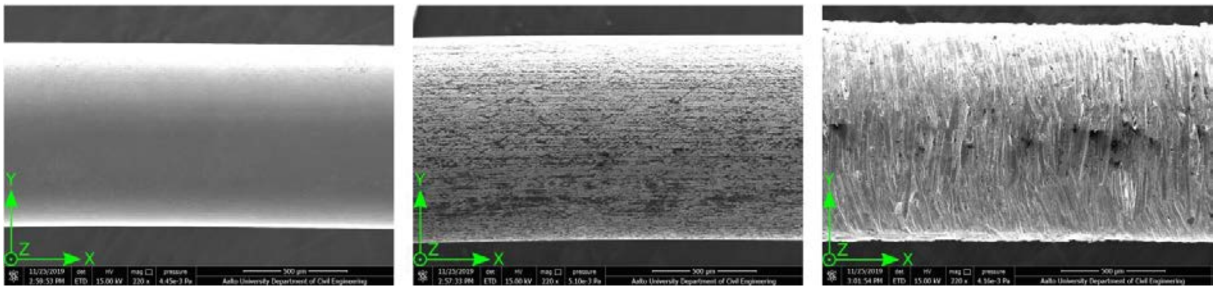
1. INTRODUCTION

The inclusion of fibres into the cementitious matrix can help to restrict the propagation of cracks and improve the ductile performance of the fibre reinforced cementitious (FRC) composites. However, the behaviour of FRC composites at the structural level depends on the stress transferring from the cement-based matrix to the fibres on the micro-scale. The stress is transferred from the matrix to the fibre by the interfacial contact. This contact is provided by the interfacial transition zone (ITZ), that is known to have porous microstructure with precipitation of calcium hydroxide (CH), whose binding property is lower than that of the calcium-silicate-hydrate (C-S-H) phase [1]. The increased porosity in the ITZ is governed by the poor packing of the cement clinker grains [2]. Since fibre is several orders of magnitude larger than the cement clinker grains, it acts as a wall, and the cement grains that are located at the surface of the fibre cannot efficiently fill the space available. Those empty spaces created between the cement grains also may contribute to increased porosity close to the fibre surface, as it was discussed in [3] by comparing the measured roughness of the fibre and the size of the particles that can fill the surface grooves. Authors in [4] discussed that the wetting of the fibre surface can affect the distribution of cement hydrates near the fibre. The relation between the wetting and the roughness of the fibre surface and the quality of contact between the fibre and water-based geopolymer matrix was also observed in [5]. At a more general level, the roughness of the surface is known to have an impact on the wetting properties of a material, as was reported in [6, 7]. The ongoing research work is aimed to investigate the influence of the steel fibre roughness on its wetting properties and their mutual effect on the contact characteristics between the steel fibre and the cementitious matrix, such as packing of cement-based matrix around the fibre and mechanical resistance of fibre to the pull-out from a matrix.

2. MATERIALS AND METHODS

2.1 Materials

Steel fibres with a diameter of 1 mm with different roughness of the surface were examined. The fibres were divided by types of the processing technique applied to receive the different roughness profiles: electro-polished – R1; non-processed (reference) – R2; coarsened with sandpaper – R3 (Fig. 1). The cement-paste was prepared from the ordinary Portland cement (OPC) CEM I 52,5 N.



(a) R1 (b) R2 (c) R3

Figure 1: SEM images of the fibres with different roughness of the surface.

2.2 Methods

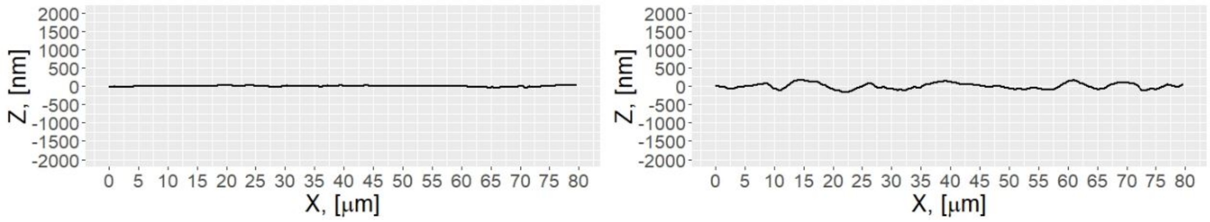
The atomic force microscope (AFM) and stylus profilometer were used to quantify the three different surface profiles of the steel fibre. Contact angle goniometry will be implied to examine the wetting properties of the steel fibres with different surface profiles by studying advancing (water spreading along the surface) and receding (adhesion of the water to the surface) water contact angles of the surface. The packing of the cementitious matrix will be examined with the scanning electron microscope (SEM) and the energy dispersive X-ray (EDX) analysis. The performance of the contact between the steel fibres with different surface profiles and the cement-based matrix will be studied with the pull-out test.

3. PRELIMINARY RESULTS AND DISCUSSION

3.1 Roughness profile of the steel fibres

AFM was used to measure epy fibres with the surfaces R1 and R2. The fibres with the surface R3 were measured with stylus profilometer since the size of this roughness exceeded the measuring limits of the AFM. The measurements were performed in the longitudinal direction of the fibres.

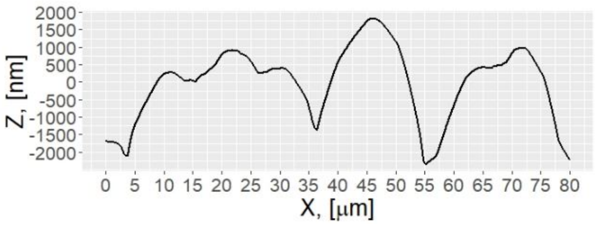
Figure 2 represents the surface profiles of the fibres with different types of roughness. The apparent grooves on the surfaces of the fibres with roughness R2 and R3 may contribute to the



mechanical interlocking between the fibre and the cement-based matrix. The mechanical interlocking was noticed previously in [8] between the cement hydrates and the aggregates with a rough surface.

(a) R1

(b) R2



(c) R3

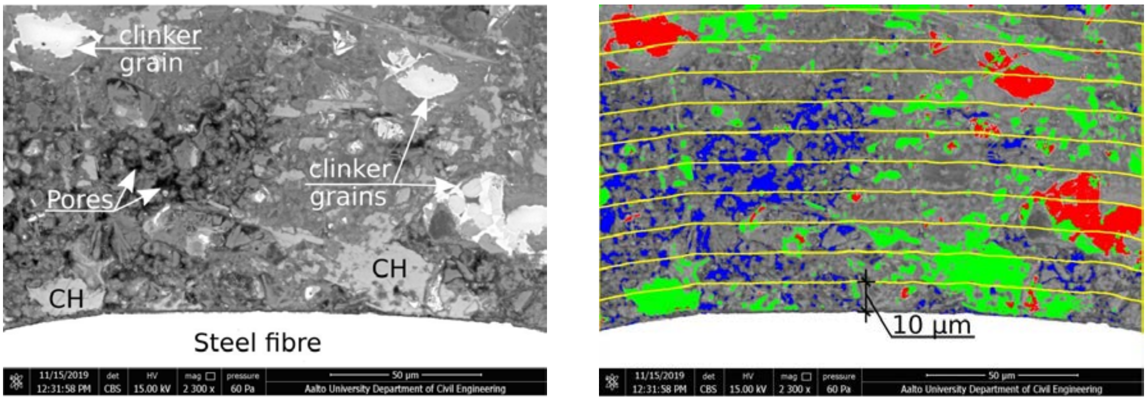
Figure 2: Surface profiles of the steel fibres with different types of roughness.

The surface profiles R2 and R3 may also affect the spreading of the water, that can be captured by the grooves of the surface. The abrupt spreading of the water along the rough surface was explained before in [9] as the “slip-stick” behaviour of the water droplet on the rough surfaces. The peaks of the surface profile work as barriers, which block further movements of the water and capture water in surface grooves. The spreading and sticking of the water at the surface of the steel fibre is crucial for the formation of the hydrates and the micro-bleeding, i.e. packing of the cement-based matrix in the close vicinity to the fibre.

3.2 Packing of the cementitious matrix around the steel fibres

Sufficient packaging of the cementitious matrix around the fibre, especially decreased porosity, promotes lower permeability, thus decreasing the possible corrosion of the steel fibres. In addition, the denser cement-based matrix in the vicinity of the fibre is contributing to better contact between mentioned constituents, therefore increasing the resistance to the cracking of the FRC composite and reducing the subsequent destruction of the material.

In the scope of the on-going study, the packing of the cementitious matrix near the steel fibre is planned to be investigated as follows. The point EDX analysis will be applied to identify the CH and unhydrated cement clinker grains, such as alite, belite, aluminate and ferrite, on the backscattered electron (BSE) images based on the chemical composition. Then the grey-level values of the identified cement phases will be measured with the BSE images. The measured grey-level values will be used to segment pores, CH and unhydrated cement clinker grains on the BSE images, as it is demonstrated in Figure 3(b). The image segmentation techniques based on the grey-level histogram, such as overflow criteria and minimum between the peaks, are also considered to verify the measured grey-level values. The distributions of the three mentioned cement-paste phases will be examined with a distance of 100 μm from the fibre surface. The volume fraction of pores, CH and unhydrated cement clinker grains will be calculated with the step of 10 μm (Fig. 3(b)).



(a) (b)

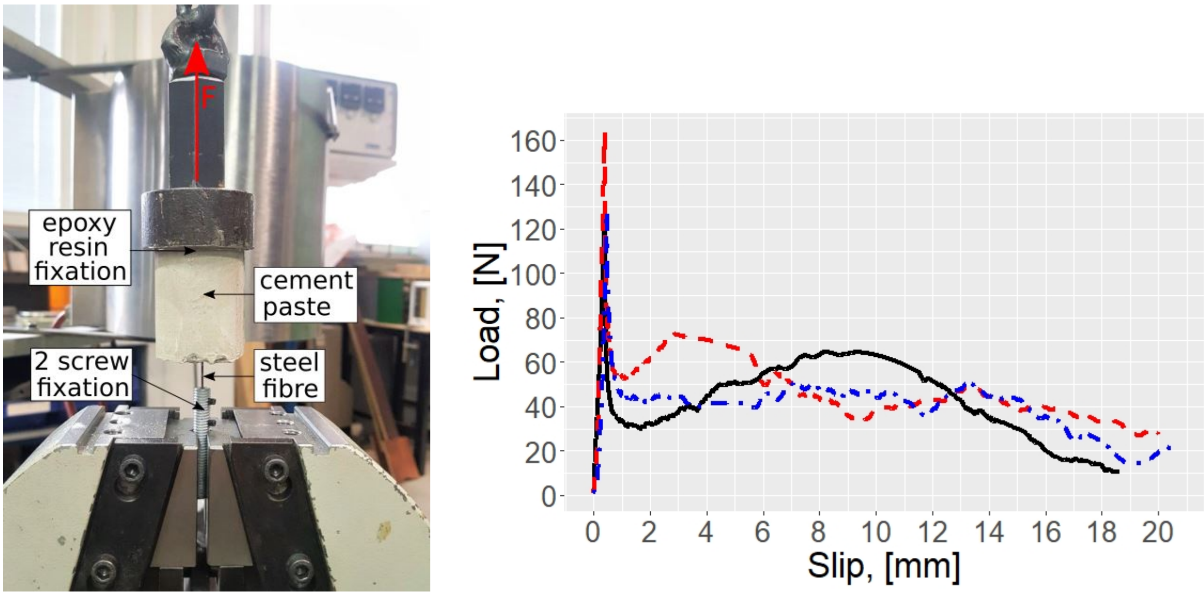
Figure 3: (a) Example of SEM image. (b) Example of the segmented SEM image. The distributions of pores (blue), CH (green) and unhydrated clinker grains (red) will be analyzed with the step of 10 μm stripe-wise, which are marked with yellow lines.

3.3 Single fibre pull-out test

The quality of the packing of the cementitious matrix around the fibre, i.e. contact, can be also defined with the performance of the pull-out test.

The steel fibre with a total length of 50 mm was cast into the cement-paste cylinder with a diameter of 45 mm. The cracks that are initiated in FRC composite can reach the fibre, which is bridging the crack, any point of the fibre length. For this reason, the several embedded fibre lengths of 10 mm, 20 mm, 30 mm and 40 mm were selected to study the range of the load-bearing capacities of the fibre. The setup of the pull-out test was designed to eliminate the influence of possible compressive stress, that may occur from the fixation of fibre or cement cylinders (Fig. 4 (a)). The load was applied with the rate of 0.1 mm/min. Figure 4 (b) illustrates the results of the preliminary pull-out tests of the non-processed fibre (R2) with the embedded length of 20 mm.

Figure 4 (b) illustrates the occurrence of the varying hardening behaviour after the adhesion breakage during slippage. This behaviour may be attributed to the additional mechanical anchorage provided by the roughness of the fibre surface and non-uniform ITZ structure, which result in the interlocking between the cementitious matrix and the steel fibre. This response is typical for the general contact of rough surfaces, that was discussed previously in [10]. The possible occurrence of the slip softening or hardening behaviour during the slippage of fibre from the cementitious matrix was explained in [11] by the nature of the interaction and the damage developed along the interface during the slip.



(a) (b)

Figure 4: (a) Setup for single fibre pull-out test. (b) Example of the load-slip curve obtained with single fibre pull-out test. The embedded length was 20 mm and the type of fibre roughness was R2 – non-processed.

4. CONCLUDING REMARKS

The combination of several measuring techniques are used in the present study to examine the relation between roughness, packing of the cement-based matrix in the vicinity of the fibre and mechanical performance of the contact between the cement-paste and fibre. This research has the potential to increase understanding of the interaction between the cementitious matrix and steel fibres considering the filling effect and interlocking between the fibre grooves and the cement hydrates and water spreading affected by the roughness of the fibre on the micro-scale.

ACKNOWLEDGEMENTS

The research leading to these results received funding from the Doctoral program of the School of Engineering, Aalto University.

REFERENCES

[1] Lee, S.F., Jacobsen, S. 'Study of interfacial microstructure, fracture energy, compressive energy and debonding load of steel fiber-reinforced mortar'. *Mat. and Str.* **44** (2011) 1451 – 1465.

[2] Scrivener, K. L., Crumbie, A. K. and Laugesen, P. 'The Interfacial Transition Zone (ITZ) Between Cement Paste and Aggregate in Concrete'. *Interface Sci.* **12** (2004) 411 – 421.

[3] Eik, M., Antonova, A. and Puttonen, J. 'Roughness of steel fibre and composition of cement paste close to fibre surface'. *Journal of Adv. Concr. Tech.* **17** (2019) 628 – 638.

[4] Xu, L., Deng, F. and Chi, Y. 'Nano-mechanical behavior of the interfacial transition zone between steel-polypropylene fiber and cement paste.' *Constr. and Build. Mat.* **145** (2017) 619 – 638.

[5] Ranjbar, N., Talebian, S., Mehrali, M., Kuenzel, C., Metselaar, H. S. C. and Jumaat, M. Z. 'Mechanisms of interfacial bond in steel and polypropylene fiber reinforced geopolymer composites'. *Comp. Sci. and Tech.* **122** (2016) 73 – 81.

[6] Wenzel, R. N. 'Resistance of solid surfaces to wetting by water'. *Industrial and Eng. Chem.* **28** (1936) 988 – 994.

[7] Kubiaka, K.J., Wilsona, M.C.T., Mathia, T.G. and Carval Ph. 'Wettability versus roughness of engineering surfaces'. *Wear.* **271** (2011) 523 – 528.

[8] Qudoos, A., Rehman, A. U., Kim, H. G. and Ryou, J. S. 'Influence of the surface roughness of crushed natural aggregates on the microhardness of the interfacial transition zone of concrete with mineral admixtures and polymer latex'. *Constr. and Build. Mat.* **168** (2018) 946 – 957.

[9] Shanahan, M. E. R. 'Simple theory of "stick-slip" wetting hysteresis'. *Langmuir* **11** (1995)1041-1043.

[10] Jiménez, A.-E. and Bermúdez, M.-D. 'Friction and wear'. In: Davim, J. P. (eds.), Tribology for Engineers. Woodhead Publishing, 2011, 33-63.

[11] Bentur, A. and Mindess, S. 'Fibre reinforced cementitious composites'. Crc Press, 2006, 31 – 97.