Adhesive properties of fresh cementitious materials as measured by the tack test

Yaxin Tao[1], Karel Lesage[1], Kim Van Tittelboom[1], Yong Yuan[2], Geert De Schutter[1]
[1]*Ghent University, Ghent, Belgium*
[2]*Tongji University, Shanghai, China*

Abstract
Adhesive properties of cementitious materials in the fresh state were investigated by a tack test in this study. Several aspects were considered including the pulling velocity, the plate surface roughness, the water to cement ratio, and the addition of polymer additives. Normal force versus displacement curves were used to characterize the adhesive properties of fresh cementitious materials.

Keywords: Tack test; adhesion; cementitious material; pulling velocity; surface roughness; polymer.

INTRODUCTION

The tack test is widely used to characterize debonding properties of different types of soft materials such as polymer pastes [1, 2]. It has been shown that the tackiness of these polymer-based materials arises from a complex combination of cavitation and visco-elastic dissipation [3]. However, the adhesive properties of mineral or granular-based materials such as cementitious materials are less investigated [4]. In the present study, we consider the adhesive properties of cementitious materials. These materials are used in practice as thin joints to bind construction blocks (e.g. bricks, stones, etc.) together or to fix tiles on horizontal or vertical surfaces. Adhesive cementitious materials are mainly composed of sand, binder, different mineral fillers, and organic additives. The latter is included to improve in particular the adhesive and rheological properties of the joints in the fresh state. The polymer additives are generally re-dispersible polymer powders or water-soluble polymers such as cellulose ethers [5, 6].

To investigate the adhesive properties of the fresh cementitious material, tack tests were performed and the normal force versus displacement curves were recorded. The influence of the testing protocol (the pulling velocity and the plate surface roughness) and the mixture design (the water to cement ratio and the addition of polymers) was investigated.

EXPERIMENTAL PROGRAM

Materials

CEM I 52.5 N Portland cement was used in this study. For each experiment, 20 grams of cement was used and water to cement ratio included 0.32, 0.34, 0.36, 0.38, and 0.40, as indicated in Table 1. Different types of polymers were used including polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), and vinyl acetate ethylene (VAE). The addition level of the above-mentioned polymers was 3% by the weight of cement (bwoc). In addition, five types of cellulose ethers with different viscosity levels were used including methyl cellulose with a viscosity level of 400 mPa·s (MC-400), hydroxyethyl cellulose with a viscosity level of 30000 mPa·s (HEC-30000), and hydroxypropyl methyl cellulose with viscosity levels of 4000, 100000, and 200000 mPa·s (HPMC-4000, HPMC-100000, and HPMC-200000). The addition level of cellulose ethers was 0.3% by the weight of cement (bwoc). The same mixing procedure was used for each series to have comparable results. A rheometer (Anton Paar MCR 52) equipped with a helix geometry was adopted to prepare the mixtures [7]. The mixing procedure is listed as follows: (1) adding dry materials inside the cup, (2) adding water inside, (3) moving down the helix geometry with a rotational speed of 1000 rpm, (4) mixing from 0-3000 rpm for 30 s, (5) mixing at 3000 rpm for 120s.

Tack test

A rheometer (Anton Paar MCR 102) equipped with parallel plates was employed for the tack test. Two series of plates including smooth plates and rough plates (profile 1×0.5 mm grooves) were used, as shown in Fig. 1. The diameter of the plates amounted to 50 mm. After the mixing process, around 5 grams of fresh material was placed on the bottom plate. Subsequently, the top plate went down and squeezed the fresh paste to reach an initial sample thickness of 1mm. Afterwards, the extra paste was trimmed and the fresh sample was stretched at a constant velocity (10, 30, 50, 100, 200, and 500 μm/s) by moving the top plate upwards, as also indicated in Table 1.

(a) (b)

Fig. 1 (a) Smooth plates and (b) rough plates.

An overview of different conditions used in the tack test is shown in Table 1.

Table 1 An overview of different conditions used in the tack test.

Series	Pulling velocity (μm/s)	Plate	W/C	Polymer
1	10 30 50 100 200 500	Rough	0.38	None
2	10	Smooth Rough	0.38	None
3	10	Smooth	0.32 0.34 0.36 0.38 0.40	None
4	10	Smooth	0.38	3% bwoc
5	10	Smooth	0.38	0.3% bwoc

RESULTS AND DISCUSSION

Pulling velocity

Normal force versus displacement curves with different pulling velocities are shown in Fig. 2. It was indicated that the curves could be divided into two stages. In the first stage, as the top plate moved upwards, the normal force increased and the fresh material displayed mainly elastic and then viscous-elastic behavior. After passing through a peak, the normal force decreased to around zero and the fresh material showed a viscous-plastic behavior in the second stage. The peak normal force can be used to characterize the adhesion performance of the fresh material [8]. Results showed that the peak normal force increased with a higher pulling velocity. This can be interpreted by the increase in the viscous dissipation, which was also indicated by Kaci et al. [9]. However, the peak of the curves cannot be observed with a pulling velocity higher than 100 μm/s due to the limitation of the frequency of data measurement used in this study (1 Hz).

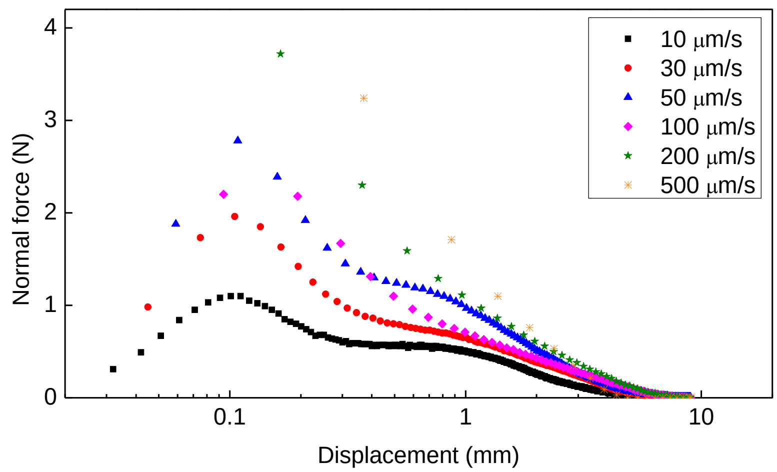

Fig. 2 Normal force versus displacement curves with different pulling velocities.

Plate surface roughness

The influence of the plate surface roughness on the adhesion of the fresh cementitious material was studied, as shown in Fig. 3. The peak normal force measured with the rough plate (1.10 N) was much higher than that measured with the smooth plate (0.66 N). This can be attributed to less slippage at the interface with the rough plate, which would further enhance the adhesive strength in the stretching direction [10]. Nevertheless, both cases presented a similar trend in the latter half of the second stage where the fresh cementitious material mainly showed inevitable extension rather than inward flow. In addition, the critical displacement related to the peak normal force was 0.37 mm and 0.10 mm for the smooth plate and the rough plate, respectively. This further proved that the constraint provided by the rough plate led to less inward flow and an earlier occurrence of rupture of the fresh material.

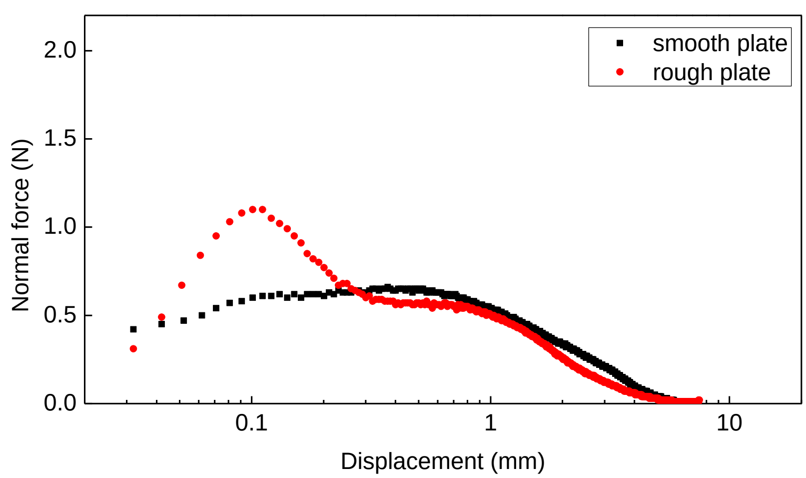

Fig. 3 Normal force versus displacement curves with different plate surface roughness.

Water to cement ratio

The influence of the water to cement ratio on the adhesion of the fresh cementitious material is discussed in this section. The normal force versus displacement curves with different water to cement ratios are shown in Fig. 4. With the increase of the water to cement ratio, both the peak normal force and the critical displacement decreased. For example, the value of the peak normal force was 6.71 N for the cementitious material with a water to cement ratio of 0.32, while the value was merely 0.49 N with a high water to cement ratio of 0.40. Despite the resistance to flow (i.e. the viscous effect), the intrinsic cohesion also contributes a lot to the adhesive strength of the fresh cementitious material [6]. The physical origin of cohesion may include intermolecular forces and capillary effects (bubbles are always present in the sample) [3]. The cohesive strength can be related to the yield stress but under stretching conditions. In this study, with the increase of the water to cement ratio, both the intrinsic cohesion and the resistance to flow reduced, leading to a limited adhesion of the fresh cementitious material.

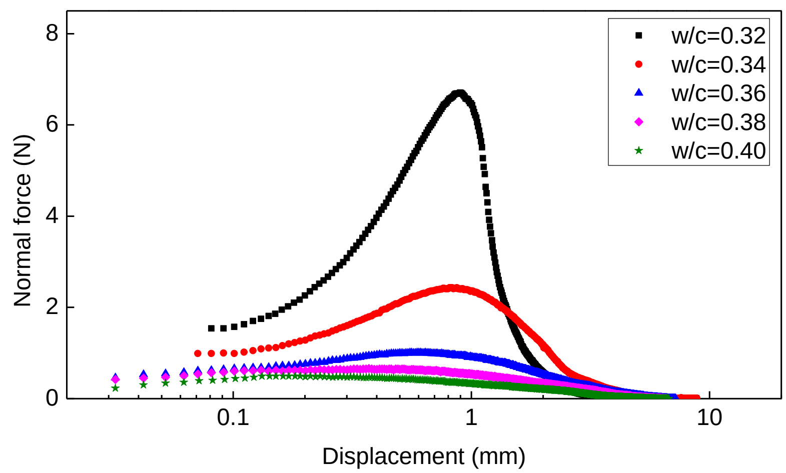

Fig. 4 Normal force versus displacement curves with different water to cement ratios.

Addition of polymers

The adhesion of the fresh cementitious material with different polymer additives is investigated in this section, as shown in Fig. 5. Results indicated that the addition of polymethyl methacrylate (PMMA) increased the normal force significantly, while the addition of polyvinyl chloride (PVC) merely had a slight improvement in the adhesion of the fresh cementitious material. Unfortunately, the addition of vinyl acetate ethylene (VAE) had a negative influence on the adhesion, which was reflected by a decreased peak normal force. Compared to PMMA and PVC, VAE powder is re-dispersible in the fresh cementitious material. As a result, the shear resistance decreased because of the ball bearing action of VAE particles, leading to a lower value of the peak normal force [11].

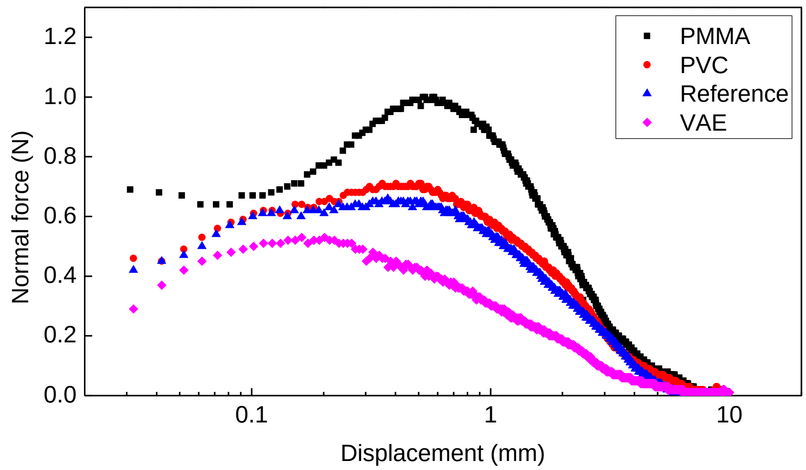

Fig. 5 Normal force versus displacement curves with different polymers.

The influence of different types of cellulose ethers including methyl cellulose (MC), hydroxyethyl cellulose (HEC), and hydroxypropyl methyl cellulose (HPMC) on adhesion of the fresh cementitious material was analyzed, as shown in Fig. 6. It was observed that all types of cellulose ethers improved the peak normal force, especially the cellulose ether with a high viscosity level. For instance, with the addition of HPMC-100000, the peak normal force of the cementitious material amounted to 2.17 N, which was more than three times that of the reference mixture. In addition, the critical displacement of cementitious materials with the addition of cellulose ethers was smaller when compared to that of the reference mixture. It was already reported that cellulose ethers increased the stability of cement-based materials with different effects such as binding water molecules, increasing the solution viscosity, and bridging two or more cement particles with one polymer chain [12]. As a result, both the viscous dissipation effect and the intrinsic cohesion can be enhanced with the addition of cellulose ethers, which further contributed to the adhesion.

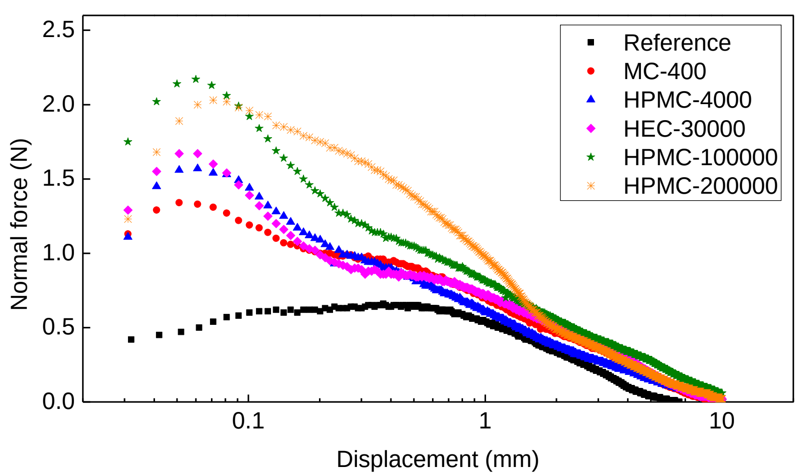

Fig. 6 Normal force versus displacement curves with different cellulose ethers.

CONCLUSIONS

The adhesive properties of fresh cementitious material were investigated by the tack test in this study. Based on the experimental results, the following conclusions can be drawn:

(1) The normal force versus displacement curves measured in the tack test showed two main stages including an elastic/viscous-elastic stage and a viscous-plastic stage.
(2) The peak normal force increased with higher pulling velocity, while some peaks cannot be observed due to the limitation of data acquisition.
(3) A rough plate was beneficial to improve the adhesion due to the constraints of the inward flow of the cementitious material.
(4) The increase in the water to cement ratio resulted in a reduced adhesion.
(5) Cellulose ethers, especially the ones with high viscosity levels, presented a significant improvement in the adhesion.

REFERENCES

[1] Y.-Y. Lin, C.Y. Hui, H. Conway, A detailed elastic analysis of the flat punch (tack) test for pressure-sensitive adhesives, Journal of Polymer Science Part B: Polymer Physics, 38 (2000) 2769-2784.

[2] H. Lakrout, P. Sergot, C. Creton, Direct observation of cavitation and fibrillation in a probe tack experiment on model acrylic pressure-sensitive-adhesives, The Journal of Adhesion, 69 (1999) 307-359.

[3] P.L. Drzal, K.R. Shull, Adhesive failure of model acrylic pressure sensitive adhesives, The journal of adhesion, 81 (2005) 397-415.

[4] Y.O. Mohamed Abdelhaye, M. Chaouche, H. Van Damme, The tackiness of smectite muds. 1. The dilute regime, Applied Clay Science, 42 (2008) 163-167.

[5] A. Kaci, R. Bouras, M. Chaouche, P. ani, H. Brossas, Adhesive and rheological properties of mortar joints, Applied rheology, 19 (2009) 51970.

[6] V.-T. Phan, Relationship between the adhesive properties and the rheological behavior of fresh mortars, École normale supérieure de Cachan-ENS Cachan, 2012.

[7] D. Jiao, K. El Cheikh, C. Shi, K. Lesage, G. De Schutter, Structural build-up of cementitious paste with nano-Fe3O4 under time-varying magnetic fields, Cem. Concr. Res., 124 (2019) 105857.

[8] S. Kawashima, M. Chaouche, D.J. Corr, S.P. Shah, Influence of purified attapulgite clays on the adhesive properties of cement pastes as measured by the tack test, Cem. Concr. Comps., 48 (2014) 35-41.

[9] A. Kaci, R. Bouras, V.T. Phan, P.A. Andréani, M. Chaouche, H. Brossas, Adhesive and rheological properties of fresh fibre-reinforced mortars, Cem. Concr. Comps., 33 (2011) 218-224.

[10] Z. Toutou, N. Roussel, C. Lanos, The squeezing test: a tool to identify firm cement-based material's rheological behaviour and evaluate their extrusion ability, Cem. Concr. Res., 35 (2005) 1891-1899.

[11] Y. Ohama, Handbook of polymer-modified concrete and mortars: properties and process technology, William Andrew1995.

[12] P.-C. Aïtcin, R.J. Flatt, Science and technology of concrete admixtures, Woodhead publishing2015.