Journal of Materials and Engineering Structures

Research Paper

Influence of re-dispersible powder on the properties of mortars

Phan Van Tien*[a,]

[a]*Falculty of Construction, Vinh University, 182 Le Duan Street, Vinh, Viet nam*

A R T I C L E I N F O

Article history :

Received 30 December 13

Received in revised form 24 January 14

Accepted 24 January 14

Keywords:

Adhesive properties

Rheological properties

Mortar

Re-dispersible powder

A B S T R A C T

This paper presents an experimental study on the effect of a re-dispersible powder on the properties of cement mortars in both fresh and hardened state. The effects of varying contents of re-dispersible powder on the adhesive properties and rheological behavior of mortar in fresh state and on the flexural strength of mortar in hardened state have been investigated. To determine the adhesive properties the probe tack test was used. The tack test results have been exploited to identify the adhesion strength, the cohesion strength and the support' adherence force. The rheological behavior of the mortars was also considered. It is found that the influence of re-dispersible powder on the properties of fresh mortar is quite small. Re-dispersible powder seems to have only indirect and minor effects on the fresh properties through increase of air content. The flexural strength of mortar is determined by three-point bending test at the age of 2, 7, 14 and 28 days. The results indicate that re-dispersible powder decreases the flexural strength of mortar at early-age. However, it improves the flexural strength of hardened mortar, at which the polymer film has fully formed and spans all the materials.

1 Introduction

Re-dispersible powders are polymer binding agents being produced by a spray drying process of special water based dispersions mostly based on Vinyl acetate / Ethylene polymers. It acts as an organic binder, gluing together the filler particles, reinforcing the mortar structure and proving an excellent adhesion at the mortar-substrate interface. Overall latex-modified cement mortar and concrete have increased tensile strength, reduce drying shrinkage, increased durability, and improve adhesion or bond strength over conventional mortar and concrete [1]. Their influence on the properties of cement mortar has been reported by numerous authors, in early-age [2, 3] and in hardened state [4, 5, 6, 7]. On the other hand the effects of re-dispersible powder on the fresh properties, including the rheological behaviour, have been much less investigated [8, 9]. Moreover, to the best of our knowledge, there are no reports concerning the effect of re-dispersible powder on the adhesive properties of cement mortar in fresh state.

Adhesive properties of fresh mortars are decisive from different points of view:

* *Corresponding author. Tel.: +84 917012255.*
E-mail address: vantienkxd@vinhuni.edu.vn

RESEARCH REVIEW of Sciences and Technologies

e-ISSN: 2170-127X,

Placement process (pumping, casting, smoothing, etc.): the mortar paste must display sufficient tackiness to stay on its support, but the adherence must also be limited in order to avoid excessive sticking to the working tool or the ducts of the pumping circuit.

Long term behavior: the quality of adhesion between fresh mortar pastes and the support will condition the long term performance of the solidified product for rendering walls, as well as the efficiency of bonding for adhesive mortars.

Kaci et al. [10] have investigated the influence of water-soluble polymers on the adhesive properties of fresh mortar joints. For those materials used in practice as thin joints to bind construction blocks together, the aim was to characterize the adhesive properties that guarantee an adhesion to the surface but not to the tool.

The adhesive properties of fresh mortar pastes have been characterized in this study using probe tack tests. This kind of tests has been largely employed to characterize polymer-based adhesives [11, 12] and more recently to investigate the tackiness and various failure modes of smectite muds [13]. Kaci et al. [10] have been among the first to use the probe tack test to characterize the adhesive properties of cementitious materials. They have shown that tack measurements allow dissociating several aspects of practical interest, related to adhesive properties [10]:

Interface adherence, which expresses the product’s ability to stand on its support.

Cohesion: this property is related to the yield stress, and characterizes the material’s resistance to flow initiation under extension.

Adhesion strength: this quantity encompasses both cohesion strength and viscous dissipation, and can be employed to characterize adhesion properties under flow conditions.

In order to complete the characterization of placement properties of mortar, the rheological properties are determined at different resin powder contents and compared to the adhesive properties.

In this research, the evolution of the flexural strength of mortar with varying resin content from the fresh state through the early age and in the hardened state has also been investigated using the three-point bending test.

2 Materials and experimental methods

2.1 Mix-design

The weight proportion of each constituent of the mortar is given in Table 1.

Table 1: Mix proportioning of constituents of the mortar.

Constituent	Portland cement	Hydraulic lime	Siliceous sand	Cellulose ether	Re-dispersible powder	Water
%(by weight)	15	5	80	0,22	Varied	21

The binder comprises a Portland cement (CEM I 52.5 N CE CP2 NF from Teil-France) and a hydraulic lime (NHL 3.5 Z). The other constituents consist of silica-based sand and a fix content of commercial cellulose ether (méthocel-0353). The mortar composition corresponds actually to a basic version of commercially-available render mortars [19].

In order to minimize phase separation, the sand size distribution has been obtained by combining two contrasted granulometries: a fine sand of mean diameter equal to 0.41 mm, and a coarse sand of mean diameter 1.13 mm. An optimal compacity is obtained by employing 30% of fine sand and 70% of coarse sand. The water dosage rate is fixed to 21% by weight for all the investigated pastes. The only variable parameter is the amount of polymer additives. In the present study, the redispersible water-soluble polymer is a commercial product (vinnapas 5010N), available in powder form and usually employed to formulate industrial mortars. The polymer concentration in the mortar (C_e) is varied according to the following proportions: C_e = [1; 2; 3; 4; 5] % by weight.

2.2 Test methods

2.2.1 Probe tack tests

The probe tack tests have been performed on a rheometer ARG2 of TA Instruments. The lower component of the measuring system is fixed, while the upper component is attached to a shaft. The force transducer is located on the fixed plate, and measurements can be made at torques as low as 0.01 µN.m up to 200 µN.m, with a torque resolution of 0.1 nN.m and a displacement resolution of 25 nrad. The axial force range is from 0.005 to 50 N.

As the mode of preparation has a great influence on the final state of the suspension and therefore on its rheological behavior, we adopt the same experimental procedure for all the investigated formulations. A fine layer (about 3 mm in width, of diameter 40 mm, of fixed weight equal to 0.27 N) is inserted between two parallel plates of high roughness, which allows minimizing wall slippage. The material is left to rest for 2 minutes after casting, in order to avoid possible memory effects. The plates are then separated under a constant velocity, which is chosen among the following values: [10, 50, 100, 300 and 500] µm/s. Under each imposed pulling velocity, the normal stretching force is measured concurrently with the instantaneous distance between both plates. Knowing the initial weight of the mortar, the measurement of the final weight enables us to determine the amount of material remaining on the mobile plate at the end of the test. For further details about the experimental procedure, we refer to Kaci et al. [10].

2.2.2 Rheological measurements

The rheological properties are determined with the same rheometer, equipped with the vane geometry. The latter configuration is particularly well-suited for cement pastes (for granular suspensions in general), as it allows to minimize wall-slippage effects [14, 15, 16]. The gap, or distance between the periphery of the vane tool and the outer cylinder, is equal to 8.3 mm, which is more than seven times higher than the maximum grain size. Accordingly, we may assume that the rheological measurements are not affected by the discrete nature of the paste. On the other hand, the shear rate and shear stress may vary along the gap since it is quite large as compared to the vane diameter. Therefore, the rheological properties cannot directly be inferred from the measured torque and the rotational velocity of the vane tool. A specific exploitation procedure is required, which is detailed in Bousmina et al. [17]. The flow curves were determined under controlled stress conditions, using the same procedure with all the studied samples.

2.2.3 Three-point bending test

Three-point bending test is widely used in determining the resistance in flexion of homogeneous materials. The force required to bend a mortar sample under 3 point loading conditions will be measured (Figure 1).

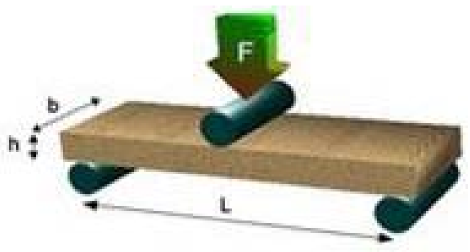

Figure 1: Three point-bending test

The mortar specimen is 10 centimetres long (L), 5 centimetres wide (b) and 2.5 centimetres tall (h). The specimen is placed on two supports that are 10 cm apart (L) and the force is applied in the exact middle of two support (L/2). Starting from zero (0 N), the applied force will be gradually increased until failure takes place. The evolution of the applied forces versus displacement / time is then recorded.

In order to investigate the effect of re-dispersible powder in the mechanical properties of mortar in both early-age and hardened state, the experiments are performed at different ages of the specimens, including 2, 7, 14 and 28 days.

3 Experimental results

3.1 Tack tests results with varying resin content

Figure 2 illustrates typical time evolutions of the normal stretching force, under varying velocities and for the formulation with 2% re-dispersible powder. A semi-logarithmic scale has been retained to bring out the behavior around the peak. The force curves are all qualitatively similar. The initial force increase can be related with elastic and viscous-elastic deformations, under mixed conditions of shear and extensional flows. After reaching a peak which gets more pronounced as velocity increases, the normal force decreases abruptly during the paste progressive rupture, and we observe an inward flow towards the plates' center under tension. After completion of the rupture process, a residual force level is reached.

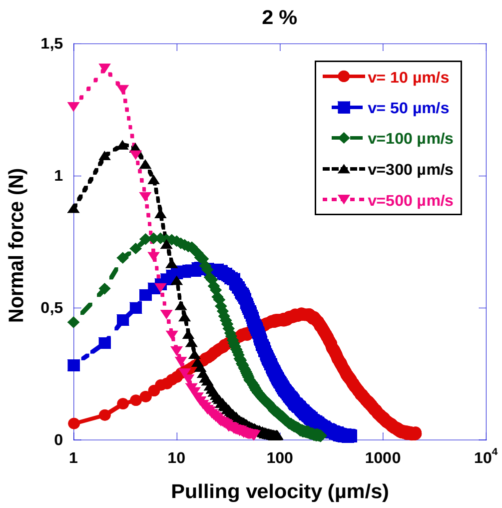

Figure 2: Evolution of the pulling force with time, for varying velocities, and for 2% re-dispersible powder.

Three relevant properties can be directly identified from tack test curves of Figure 2:

The peak value F_{max} is employed to determine the adhesion strength of the material, originating both from flow resistance (owing to viscous effects) and the material's intrinsic cohesion at rest.

The cohesion strength will therefore be identified by considering the adhesion force for pulling velocities tending to zero, i.e. when no viscous effects are present under quasi-static conditions.

Finally, the residual force at the end of the pulling test corresponds to the weight of the material still remaining on the mobile plate, and allows characterizing the adherence at the plate-mortar interface.

3.1.1 Adhesion force

Figure 3 shows the variations of the maximum stretching force, or adhesion force, with pulling velocity for varying resin contents. The adhesion force significantly increases with the pulling velocity. However the curves almost superpose, indicating low effect of resin content. The increase of the adhesion force with velocity is expected and reflects viscous dissipation effects and has also been reported by A. Kaci [10].

The evolution of the adhesion force versus resin content for different pulling velocities is plotted in Figure 4. It indicates that the effect of the resin on the adhesion force is quite low, especially at small pulling velocities. Overall the adhesion force slightly decreases with resin content. The decrease becomes more distinguishable at high velocities. Water-soluble re-dispersible powders are known to increase air-entrainment. The decrease of the adhesion force may be attributed to the decrease of the viscosity of the mortar due to entrained air.

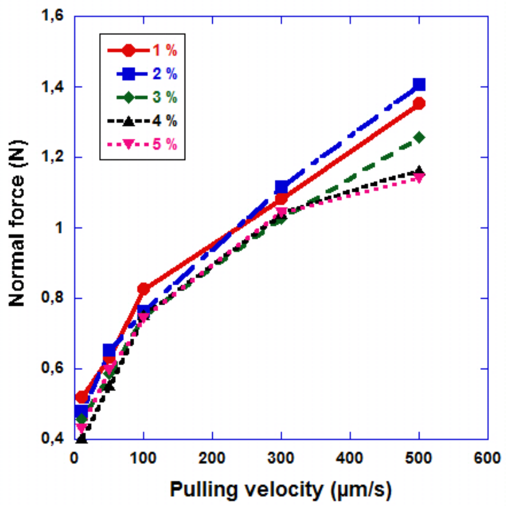

Figure 3: Evolution of the adhesion force versus pulling velocity for varying polymer contents.

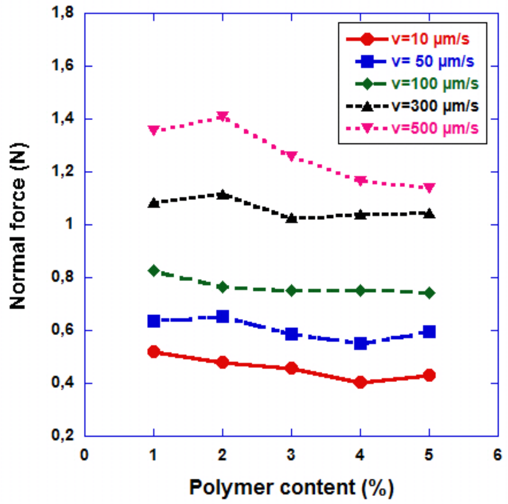

Figure 4: Evolution of the adhesion force versus resin content for different pulling velocities.

3.1.2 Cohesion force

The cohesion force can be identified as the adhesion force corresponding to the lowest value of pulling velocity that can be attained with our rheometer (10 µm/s). As illustrated in Figure 5, the cohesion force evolution with varying polymer content is non-monotonic. Increase the resin content first leads to the decrease of the paste cohesion. For a concentration of 4%, we can observe a minimum of the cohesion force, before increase again at higher concentrations. However the depth of the minimum is quite small. Even though the tests were prepared 3 times, we are wondering if this minimum is physical or this rather corresponds to a plateau.

The decrease of the cohesion force may also be attributed to air-entrainment. The presence of air bubbles may represent leak points for rupture growth and leading to the decrease of the peak force.

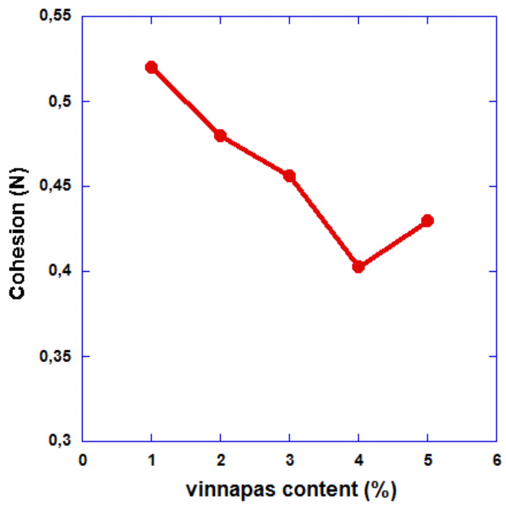

Figure 5: Evolution of the cohesion force when varying resin content.

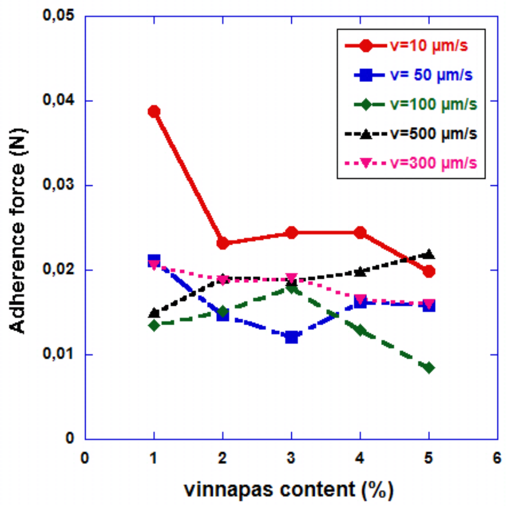

Figure 6: Evolution of the adherence force versus resin content for different pulling velocities.

3.1.3 Interface adherence

The adherence force is taken to be equal to the weight of product remaining on the mobile plate at the end of the tack test, and corresponds to the residual value of the stretching force after completion of the rupture process. Although the adherence force is clearly not a material property, from a practical point of view, it will determine the tackiness for render mortars, and the effective bonding between masonry elements for adhesive mortars. Figure 6 represents the variations of the adherence force with pulling velocity, for varying resin content, indicating a decreasing of the interface adherence at low resin content before reaching a plateau at high contents. This may be attributed to the increase of the quantity of entrained air.

3.2 Rheological behavior with varying resin content

Flow curves in the stress-controlled mode, such as illustrated in Figure 7, allow determining in particular the yield shear stress that characterizes the onset of fluid flow. With the employed vane geometry, the smallest measurable shear-rate value is about 0.01 s^{-1}, and will therefore serve as the lower bound for fluid flow. The flow curves are those of shear thinning fluids for all investigated concentrations. Figure 7 indicates that the apparent viscosity (stress divided by corresponding shear rate) decreases with increasing resin content. This is rather surprising since addition of the powder means increase of solid concentration. It is to be noted that the rheological properties (and also the tack properties) are determined while polymer film is not formed yet. We will resume this discussion below when considering the evolution of the rheological parameters.

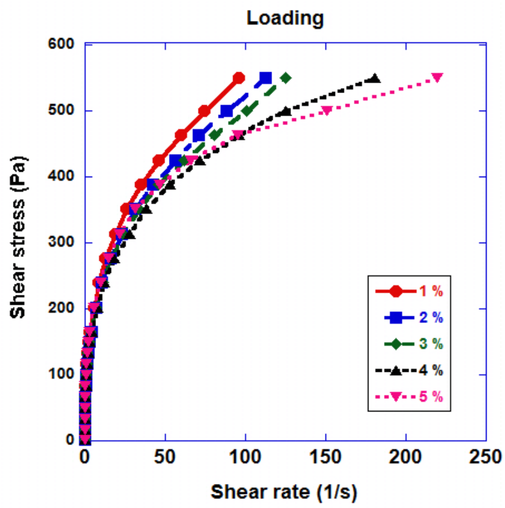

Figure 7: Flow curves obtained in the stress-controlled mode using different polymer contents

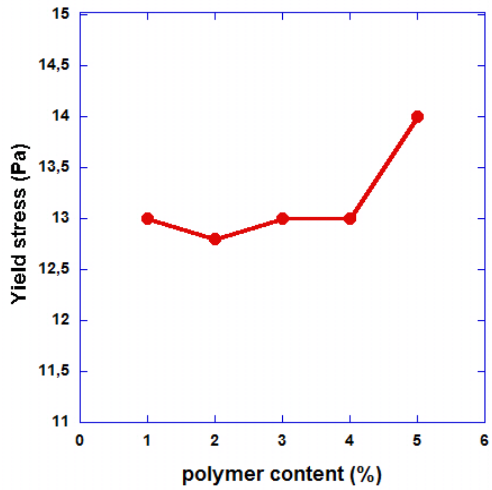

Figure 8: Evolution of the yield stress with resin contents

The yield stress is related with the cohesion of the material, and should therefore be correlated to the cohesion strength identified during tack tests. It is measured directly by determining the applied stress for which we have a finite shear rate. The evolution of the yield stress with varying resin content is represented in Figure 8 which indicates that the effect of resin powder on the resistance of mortar to shear initiation is not significant. Overall the yield stress varies around an average value up to a dosage rate of 4%. A small increase of the yield stress at 5% of resin powder can be observed.

Overall the effect of re-dispersible powder on the rheological properties of fresh mortar is insignificant. Their influence should be due mainly to the increase of air content. Increasing of air content may have to consequences: On one hand we will have a decrease of the viscosity of the mortar and on the other air bubbles will increase cohesion due to capillary forces. This may depend on the shear rate interval considered. At low shear rate, capillary effects may dominate, this explain the slight increase of the yield stress (Figure 8). At high shear rate, viscous effects are dominant and the viscosity of the mortar should decrease with air content. This may explain the decrease of the apparent viscosity at high shear rates that can be observed in the Figure 7.

3.3 Resistance in flexion of mortar with varying resin content

The effect of resin powder on the resistance in flexion of mortar has been investigated from the early-age (2 and 7 days), represented in Figure 9, through the hardened state (14 and 28 days), represented in Figure 10.

In early-age state, the results indicate that increasing resin content would lead to the decreasing of the resistance of mortar in flexion, representing by the significant reducing of the maximum load which can be applied on the specimen. Reversely, the resistance in flexion of hardened mortar increase with the increasing of resin content (see Figure 10).

In order to investigate the effect of re-dispersible powder on the flexural strength of hardened mortar, the evolution of the maximum forces, which were measured at the crack initiation, as a function of resin content and age of the specimens, are plotted in Figure 11. It indicates that in early-age, the effect of re-dispersible powder on the flexural strength of mortar is insignificant. Generally the flexural strength of mortar slightly decreases with the increase of resin content. The monotonically decrease of the flexural strength with the increase of re-dispersible content in early-age state has also been observed and reported by G.Barluenga in case of Styrene-Butadiene-Rubber latex modified mortar [9]. Reversely in hardened state, the addition of resin powder improves the resistance in flexion of mortar. This can be explained by the formation of polymer film in hardened state, which prevents crack propagation [18].

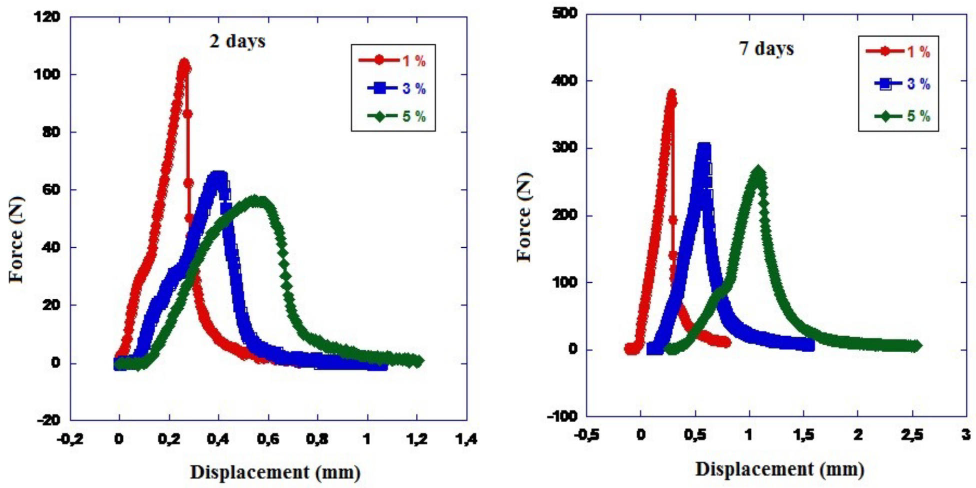

Figure 9: Resistance of mortar in flexion in early-age state

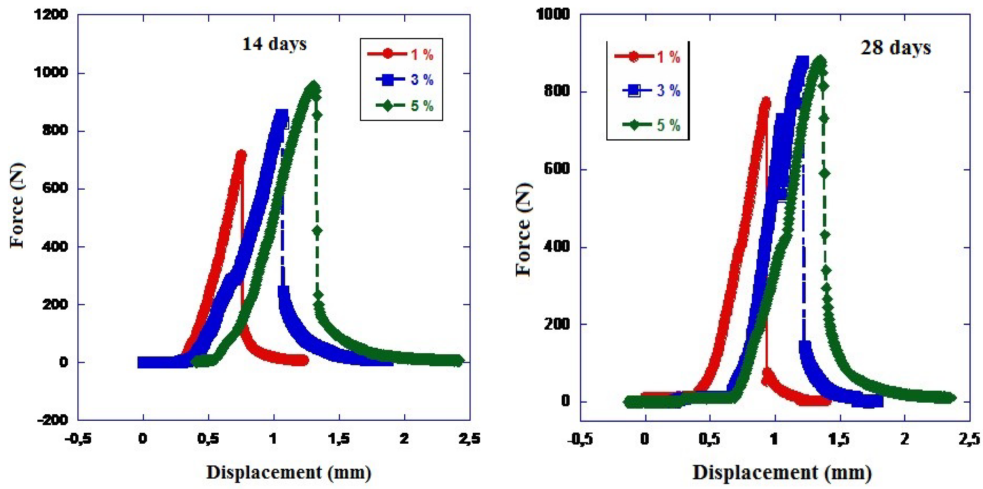

Figure 10: Resistance of mortar in flexion in hardened state

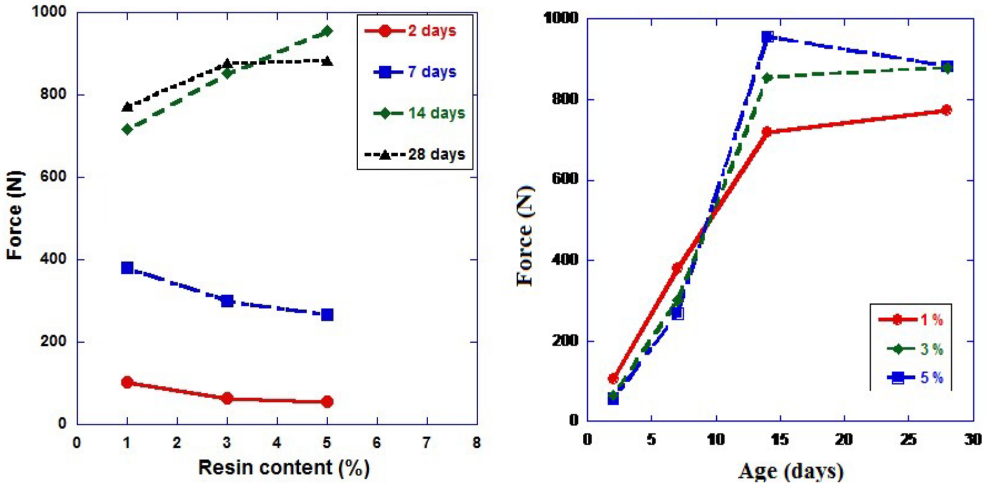

Figure 11: Evolution of the maximum applied force obtained in three-point bending test

4 Conclusion

In the present paper, we have undertaken a systematic study of the properties of fresh mortars that can be derived from tack tests and rheological experiments. Starting with a reference mortar paste, the effect of re-dispersible powder in combination with a cellulose ether-based polymer has been investigated.

In general, the effect of resin powder on the fresh properties of mortars, including adhesive properties and rheological behavior, is insignificant. The results indicate that the re-dispersible powder seems to have only indirect and minor effects on the fresh properties through increase of air content. These results are in agreement with the recommendation of the producer indicating that the resin powder do not change the rheological properties. Actually re-dispersible powder is mainly used to improve mechanical properties of mortar and adherence in the hardened state. Our investigation on the effect of re-dispersible powder on the flexural strength of mortar in both the early-age and hardened state have proved it. In early-age, re-dispersible powder slightly reduces the flexural strength of mortar. However, in hardened state, the effect is reversed. Re-dispersible powder improves the flexural strength of the mortar. This observation can be explained by the formation of polymer film, which prevents crack propagation. In hardened state, the polymer film is fully formed and spans all the materials.

Acknowledgements

We are grateful to the company ParexLanko-France and Vinh University for sponsoring this investigation.

REFERENCES

[1]- M. Nakayama, J.J. Beaudoin, Bond strength development between latex-modified cement paste and steel, *Cement Concrete Res.* 17 (1987) 562-572.

[2]- A.M. Betioli, J. Hoppe Filho, M.A. Cincotto, P.J.P. Gleize, R.G. Pileggi, Chemical interaction between EVA and Portland cement hydratation at early-age, *Constr. Build. Mater.* 23 (2009) 3332-3336.

[3]- A. Messan, P. Ienny, D. Nectoux, Free and restrained early-aged shrinkage of mortar: Influence of glass fiber, cellulose ether and EVA (ethylene-vinyl acetate), *Cement Concrete Comp.* 33 (2011) 402-410.

[4]- R. Wang, P.M. Wang, L.J. Yao, Effect of redispersible vinyl acetate and versatate copolymer powder on flexibility of cement mortar, *Constr. Build. Mater.* 27 (2012) 259-262.

[5]- J. Schulze, O. Killermann, Long-term performance of redispersible powders in mortars, *Cement Concrete Res.* 31 (2001) 357-362.

[6]- F. Zhao, H. Li, S. Liu, J. Chen, Preparation and properties of an environment friendly polymer-modified waterproof mortar, *Constr. Build. Mater.* 25 (2009) 2635-2638.

[7]- M.H.F. Medeiros, P. Helene, S. Selmo, Influence of EVA and acrylate polymers on some mechanical properties of cementitious repair mortars, *Constr. Build. Mater.* 23 (2009) 2527-2533.

[8]- A.M. Betioli, P.J.P. Gleize, V.M. John, R.G. Pileggi, Effect of EVA on the fresh properties of cement paste, *Cement Concrete Comp.* 34 (2012) 255-260.

[9]- G. Barluenga, F. Hernandez-Olivares, SBR latex modified mortar rheology and mechanical behaviour, *Cement Concrete Res.* 34 (2004) 527-535.

[10]- A. Kaci, R. Bouras, M. Chaouche, P.A. Andreani, H. Brossas, Adhesive and rheological properties of mortar joints, *Appl. Rheol.* 19 (2009) 51-70.

[11]- C. Creton, L. Leibler, How does tack depend on time of contact and contact pressure? *J. Polym. Sci. Pol. Phy.* 34 (1996) 545-554.

[12]- A. Zosel, Adhesion and tack of polymers: influence of mechanical properties and surface tensions, *Colloid Polym. Sci.* 263 (1985) 541-553.

[13]- Y.O.M. Abdelhaye, M. Chaouche, H. Van Damme, The tackiness of smectite muds, 1. The dilute regime, *Appl. Clay Sci.* 42 (2008) 163-167.

[14]- E. Bauer, J.G.G. de Sousa, E.A. Guimaraes, F.G.S. Silva, Study of the laboratory Vane test on mortars, *Build. Environ.* 42 (2007) 86-92.

[15]- J.R. Stokes, J.H. Telford, Measuring the yield behaviour of structured fluids, *J. Non-Newton Fluid.* 124 (2004) 137-146.

[16]- L. D'Aloia Schwartzentruber, R. Le Roy, J. Cordin, Rheological behavior of fresh cement pastes formulated from a self compacting concrete (SCC), *Cement Concrete Res.* 36 (2006) 1203-1213.

[17]- M. Bousmina, A. Ait-Kadi, J.B. Faisant, Determination of shear rate and viscosity from batch mixer data, *J. Rheol.* 43 (1999) 415-433.

[18]- N. Ukrainczyk, A. Rogina, Styrene-butadiene latex modified calcium aluminate cement mortar, *Cement Concrete Comp.* 41 (2013) 16-23.

[19]- H. Paiva, L.P. Esteves, P.B. Cachim, V.M. Ferreira, Rheology and hardened properties of single-coat render mortars with different types of water-retaining agents, *Constr. Build. Mater.* 23 (2009) 1141-1146.