Using "twist-off" and "pull-off" tests to investigate the effect of polypropylene fibers on the bond of mortar/concrete and to evaluate their in-situ compressive strength

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ABSTRACT

In the concrete repair industry, the adhesion between the repair layer and the concrete plays a decisive role in the successful composite performance of the repair layers. Due to the shrinkage and its effect on adhesion loss, in this paper the effect of polypropylene fibers on the adhesion between mortar/concrete has been investigated. A new "twist-off" test has been used to perform the experiments. In all experiments, the results of the "twist-off" test were compared with the results of the "pull-off" test. X-ray diffraction pattern and scanning electron microscopy tests were used to further analyze the results. Also, the effect of fibers on shrinkage and mechanical properties of mortars and its relationship on adhesion between mortar and concrete were investigated. In this regard, the tests of "twist-off" and "pull-off" were used in the laboratory and compared with the outputs of computer modeling. Also, by examining the correlation coefficient between the results of in-situ tests and laboratory tests, calibration diagrams were presented to convert the readings obtained from the "twist-off" and "pull-off" tests into the compressive strength of mortars. The results indicate that for the fibrous sample, the peak intensity of $Ca(OH)_2$ or calcium hydroxide is reduced, resulting in the production of more hydrated calcium silicate or C-S-H gel, which results in improved final properties of the mortar and increased adhesion. Also, on average, the shear and tensile bond strength of 90 days obtained from "twist-off" and "pull-off" tests with the addition of fibers increased by 49.5% and 43.1%, respectively.

Keywords:

“Twist-off”, “Pull-off”, Adhesion, Mortar, Concrete.

Introduction

A common problem caused by poor bond strength between repair mortar and concrete substrate is the shrinkage. In addition to the deformations caused by stresses, volumetric changes resulted from shrinkage or temperature changes are highly significant because these movements are usually not locally or completely restrained in practice, which leads to stress within the mortar. The tensile stresses in mortar and concrete are very destructive, because they have poor elasticity and a high tendency towards cracking. As there is water in the capillary pores of hydrated cement pastes, it should be noted that immediately after the water removal from the capillary pores, the water is also removed from the surface and the shrinkage occurs [1]. Wet curing practices are one of the methods utilized to prevent moisture removal from the interior part of the mortar. One study demonstrated that the bond between the repair mortar and concrete substrate under wet curing practices was about 3.5 times higher than that released in the open space [2].

The purpose of adding fibers to the mortar are to delay cracking, and reducing the width of cracks. Crack formation is prevented in cases where the induced stress in the mortar, due to shrinkage, is less than the tensile strength of the mortar. Fibers sew the two edges of cracks, thus preventing their propagation, which results in reduced shrinkage. A research study conducted on this found that adding polypropylene fibers reduced dry shrinkage of the specimens [3]. The addition of fibers could also have a positive impact on the mechanical properties of cementitious materials; however, in some research studies it has been demonstrated that the addition of too much fibers could produce defects in the properties of the cementitious materials [4-6]. A great deal of research has been conducted concerning the effect of shrinkage on adhesion. In these studies, it was stated that rupture in multilayer systems is often due to inconsistency between characteristics of the repair layer and substrate [7]. One of the important characteristics is shrinkage, as early shrinkage could result in micro-cracks [8]. Shrinkage between two surfaces causes reduced adhesion between them and the occurrence of rupture at the interface [9-10].

The current research study is divided into three parts. Part one explores the effect of fibers on shrinkage of the repair mortars. Part two examines the effect of fibers on the bond strength between the repair mortar and concrete substrate with respect to reduced shrinkage in the fiber containing mortars. In the final part, using the semi-destructive methods, the compressive strength of the repair mortars containing polypropylene fibers is evaluated at different ages.

Methodology

ASTM C157 [11] and ASTM C490 [12] standards were used to measure the shrinkage of repair mortars, and the value of shrinkage can be measured based on the percentile from the relation 1.

$$L = \frac{L_x - L_i}{G} \times 100 \tag{1}$$

Where, L is the length change of the sample, Li is initial sample reading minus Reference rod reading, Lx is the sample reading minus Reference rod reading and G is Reference rod length. The ASTM C109 [13] standard was utilized to measure the mortar compressive strength.

The wist-off test was applied to determine shear bond strength. Moreover, in order to evaluate the mortar compressive strength, 150 mm cubic samples were made and a steel cylinder adhered to the surface without core drilling; after which a twisting moment was inserted into the steel cylinder by using Torsion Testing Machine to separate crushed mortar and the cylinder from mortar surface.

Results and Discussion

Results illustrates the dry shrinkage of repair mortars with and without fibers at different ages. The results indicate that the shrinkage of all mortars starts after leaving the curing practices. Over time, the shrinkage of mortars increases, and the samples cured with curing agents obtain a higher value than the samples cured with water. The process of shrinkage is accelerated because the curing agents are not completely able to prevent the moisture outflow from the mortar, the outflow of free water from mortar and then the outflow of adsorbed water during the week of curing practices. Therefore, the mean 90-day shrinkage of M1 and M2 mortars containing polypropylene fibers was 11.1% and 14.3% lower than mortar without fibers, respectively. It was also observed that shrinkage was very high at an early stage, and the rate of shrinkage decreased over time.

The addition of fiber to the mortars cured with water increased shear bond strength between the repair mortar and concrete substrate to 29.2% and 43.4% at ages of 42 and 90 days, respectively. Moreover, shear bond strength for the samples cured with the curing agents was 34.4% and 51.5% at the ages of 42 and 90 days, respectively. Compared to mortars without fibers, the increase in shear bond strength of mortar with fibers is due to the increased crack width control and fiber shrinkage.

Adding fiber to the mortars cured with water increased the tensile bond strength between the repair mortar and concrete substrate to 19.6% and 41.7% at ages of 42 and 90 days, respectively. Furthermore, tensile bond strength for the samples cured with the curing agents was 22.7% and 39.1% at the ages of 42 and 90 days, respectively. The improvement in tensile bond strength evident in the mortar with fibers is due to the increased crack width control and fiber shrinkage.

Conclusion

In conclusion, adding PP fibers to the mortar reduces the dry shrinkage and improves adhesion between the mortar and concrete.

- Given the strong correlation between the results of the twist-off and pull-off tests, it is better to use a simpler and cheaper twist-off test device rather than an expensive pull-off device to determine the bond between the repair mortar and concrete substrate.

- The twist-off and pull-off tests can be used as a semi-destructive and functional test to evaluate the compressive strength of mortars with and without fibers at different ages and in situ.

References

[1] A.M. Neville, Properties of concrete, fifth ed., Harlow, United Kingdom, 2012.

[2] M. Naderi, Adhesion of Different Concrete Repair Systems Exposed to Different Environments, J. Adhesion. 84 (2008) 78-104. https://doi.org/10.1080/00218460801888433.

[3] L. Lifang, W. Peiming, Y. Xiaojie, Effect of Polypropylene Fiber on Dryshrinkage Ratio of Cement Mortar, J. Build. Mater. 8 (2005) 373-377.

[4] R.A.S. Mohamed, Effect of polypropylene fibers on the mechanical properties of normal concrete, J. Eng. Sci. 34 (2006) 1049-1059.

[5] D.S. Dharan, A. Lal, Study the effect of polypropylene fiber in concrete, Int. Res. J. Eng. Tech. 3 (2016) 616-619.

[6] S. Vikrant, V. Kavita, S. Kene, N.V. Deshpande, Investigation on Compressive and Tensile Behavior of Fibrillated Polypropylene Fibers Reinforced Concrete, Int. J. Eng. Res. Appl. 2 (2012), 1111-1115.

[7] G.P. Tilly, J. Jacobs, Concrete repairs: Observations on performance in service and current practice, Watford, UK, 2007.

[8] H. Beushausen, M. Alexander, Localised strain and stress in bonded concrete overlays subjected to differential shrinkage, Mater. Struct. 40 (2007) 189–199.

[9] D. Wu, W. Gao, J. Feng, K. Luo, Structural behaviour evolution of composite steel-concrete curved structure with uncertain creep and shrinkage effects, Compos. B. Eng. 2016, 261-272.

[10] G. Martinola, H. Sadouki, F. Wittmann, Numerical model for minimizing the risk of damage in a repair system, J. Mater. Civ. Eng. 13 (2001) 121–129.

[11] ASTM C157, Test method for length change of hardened hydraulic cement mortar and concrete, West Conshohocken PA, American Society for Testing and Materials, 2008.

[12] ASTM C490, Standard practice for use of apparatus for the determination of length change of hardened cement paste, mortar, and concrete, West Conshohocken PA, American Society for Testing and Materials, 2011.

[13] ASTM C109, Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens), American Society for Testing and Materials, 2013.