SIMPOZION

-ZILELE ACADEMICE TIMISENE-

-Comparison of shear and pull-off tests for testing adhesion of different content limestone fillers mortars used as repair system-

-Comparatie intre testele la taiere si cele la intindere pentru masurarea aderentei unui mortar cu diferite procente de filere de calcar folosit ca sistem de reparatie-

R. CHENDEȘ[1], L. COURARD[2], S. DAN[3]
[1]MS. ir. POLYTECHNIC UNIVERSITY OF TIMISOARA,
[2]Prof. dr. ir. UNIVERSITY OF LIÈGE,
[3]Lect. dr. ir. POLYTECHNIC UNIVERSITY OF TIMISOARA.

Abstract: When a repair operation is performed and a new concrete or mortar is applied on the old concrete substrate, it is very importantto have a good bond between the old concrete layer and the repair concrete system. The bond strength is usually evaluated using pure tension tests (pull-off tests), because of the field applicability of this category of tests. However, in most of the applications, shear stress is the main reason of the bond failure. In general, bond strength under tensile is considered smaller than bond strength in shear stress conditions.

The objective of this paper is to compare the results obtained from tensile and shear tests and to potentially determine a mathematical relation between shear and tension. The materials used for tests are Ordinary Portland Cement and modified limestone fillers mortars. Specific humidity storage conditions have been selected.

1.INTRODUCTION

All constructions around the world are subjected to degradation processes, especially those made of reinforced concrete[1]. For this reason, itis necessary to know how to repair them in a rightway[2]. In field of rehabilitation and strengthening of concrete structures, it is a very common situation to lay repair material onto the old concrete. In the repaired structure,the bond between the two layers generally represents a weak point: that's whya high bond strength is absolutely necessary for a successful repair.

It is very well-known that adhesion between repair material and concrete substrate is one of the most important factors affecting reliability and durability of repair. Adhesion depends on many phenomena that are taking place at interfacialzone[3]: bond detrimental layers, wettability of concrete substrate by repair materials, secondary physical attraction forces induced in the system, roughness of surface, moisture content in concrete substrate compared to the repair system.

In the European Standard EN1504, the bond is defined as the adhesion of the applied product or system to the concrete substrate. Adhesion is an important topic in field of construction engineering, because the lack of adhesion can create a lot of problems To avoid bond failure of the repair material due to stresses generated by loads, temperature, moisture gradients etc., it is essential that the repair material achieves strong adhesion to the substrate. When repaired areas fail, it is in many cases due to failure or partial failure of the bond between the old and new material.

The bond strength is determined with pull off tests or with other similar methods because of the field applicability. However,thesemethods measure bond strength under tension in the interface while, in the interface zone, a shear stressappears. Usually the shear bond strength is considered two times bigger than pull-off bond shear stress. Studies [4] indicated that shear bond strength can be considered 2.4 times bigger than tensile bond strength.

Usually, the shear strength of the bond is evaluatedwith slant shear test, due tosimilar approach of the samples preparation with the pull-off test. However, this test is characterized bysome issues, the main problem beingthat failure depends onthe angle of the interface[5] that is normally 30^0(according to the standards).

Shear stress may be also evaluated by direct shear tests where interface is subjected to shear stress and a small bending stress [6].

The objective of this paper is to compare the results obtained from tensile and shear tests and to potentially determine a mathematical relation between shear and tension.

2.EXPERIMENTAL PROGRAM

The whole experimental program is performedin GeMMe laboratory, ArGEnCodepartment, University of Liege, Belgium.

2.1. Materials and mixing proportions

Specific substrate was produced in this study as a mortar (Tab.1)prepared using Composed Portland cement CEM II / B-M 32,5N from HOLCIM (Belgium), whose main constituentsarethe Portlandclinker(K), siliceousfly ash(V)and granulatedblast furnace slag (S). The content ofclinkeris between 65% and 79%.
The aggregate used in the research is a standardized sand CEN-NORMSAND EN 196-1 which is a natural rounded sand. The water/cement ratio was fixed to 0.5.
The repair mortar (Tab.1)was based on limestone fillers modified cement mortars.

2.2. Samples preparation

Two types of specimens were prepared:

- 24 samples for the shear test (160 x 40 x 40 mm) and
- 8 slabs for pull-off test (300 x 300 x 30 mm)

They were made of reference mortar (SM). Each specimen was demolded after 24 hours and stored in water for the next 27 days.

All the mortars specimens used as substrate (SM) were cleaned and roughed with hydro-sandblasting technique [7]. Afterwards, a repair mortar (RM) was applied on the slab or cast with the half of the (160 x 40 x 40 mm) samples.
Samples were than stored at 60% or 90% R.H.

At 22 days, minimum 3 cores (50mm diameter) were taken from slab samples and replaced into original storage conditions until 28 days. Just before testing, samples were glued with epoxy resin on steel dollies.

Mortar mixture	Binder		Sand [%]	Water [%]	W/C
	CEM II 32,5N[%]	Limestone addition [%]			
I	22	0	67	11	0,5
R1	22	0	67	11	0,5
R2	19	3	67	11	0,5
R3	15	7	67	11	0,5
R4	13	9	67	11	0,5

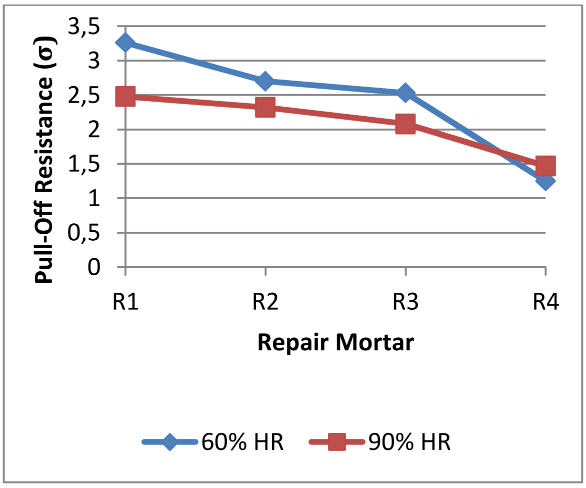
Tab. 1 Initial and repair mortar

3. RESULTS AND DISCUSSIONS

3.1. Pull-off test

The pull-off tests were performed as direct tensile tests using an Instron 5585 machine. The minimum adhesion value, measured by pull-off test, should be greater than 1.5 MPafor structural repairs and 0.5 MPafor non-structural repairs [8]. Theresults are presented with regard to storage conditions and repair mortar (Table 2 and Fig. 1). Results given in Table 1 are the average value obtained on 3 samples.

Repair system	Pull-off strength (MPa)
R1-60%	3.26
R1-90%	2.63
R2-60%	2.93
R2-90%	2.49
R3-60%	2.75
R3-90%	2.08
R4-60%	1.25
R4-90%	1.47



Tab. 2PTull-off strength **Fig. 1Pull-off test interpretation**

From Fig.1 we can conclude that the pull-off strength is always bigger for 60%than for 90% RHunder 30% substitution of cement by limestone. But even for high substitution values, adhesion remains high. For both R.H. storage conditions, the bond strength is getting smaller with increasing limestone content.

3.2. Direct shear test

Results from the initial direct shear test(Fig.2)are inconclusive: air bubbles were observed at the interface in the repair mortar. Adhesion doesn't seem to concern the entire interlayer surface butonly the darker zones from the interface(Fig.3). Values of the bond shear strengthare between 0.9 and 6.8 MPa. For these reasons, samples of size 60 x 40 x 40 mm were cut from the pull-off slabsand the shear tests were performed again.The results of the shear test using the new samples are presented in Tab.3.

In the case of R4-90%RH, due to human error input, an eccentricity was introduced, that lead the shear stress to be applied to the initial mortar, instead of the interface. Because of this error, the results obtained were higher than normal tendency (Tab.3). Consequently, the results for this specific system were omitted from the graphic representations.

Fig.2Direct shear test **Fig.3Example of interface**

Repair system	Shear strength (MPa)
R1-60%	6.18
R1-90%	5.62
R2-60%	6.88
R2-90%	4.49
R3-60%	2.61
R3-90%	2.81
R4-60%	2.64
R4-90%	6.74

Tab. 3Bond shear strength

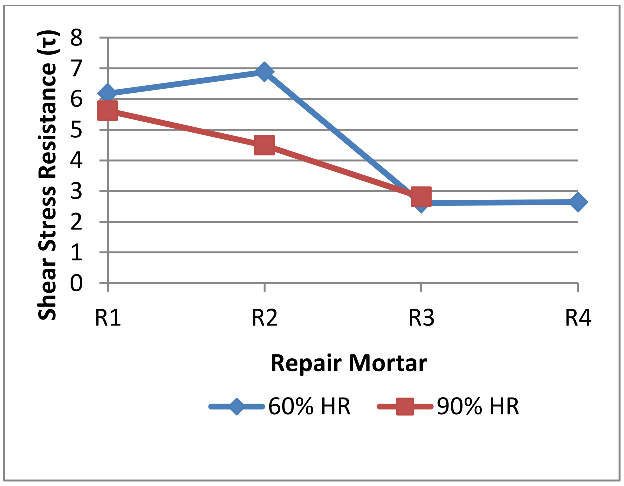


Fig. 4Shear test interpretation

Fig.4 is giving results of shear strength for the two different relative humidity (RH) storage conditions and the different repair mortars.

There is no clear influence of storage conditions on shear strength. It seems however that 60% R.H. is more favorable, at least until 30% limestone substitution rate (R3). Above this value, behaviors seem to be similar.

3.3. Comparison between test results

This comparison wants to establish potential relationship between the shear and pull-off strengths (Tab.4). Results are compared to literature.

Repair mortar	RH	Pull-off strength (σ) [MPa]	Shear stress strength (τ) [MPa]	Ratio τ/σ	Other researches	
R1	60%	3.26	6.18	1.90	2.0 from (9)	2.4 from(4)
	90%	2.48	5.62	2.27		
R2	60%	2.70	6.88	2.55		
	90%	2.32	4.49	1.94		
R3	60%	2.53	2.61	1.03		
	90%	2.08	2.81	1.35		
R4	60%	1.25	2.64	2.11		
	90%	1.47	6.74	4.59		

Tab. 4 Comparison between pull-off and shear test results

From other researches, it seems that ratio between shear and pull-off strength is around 2.4 from (4)and around 2.0 from (9) where it says that "*The shear strength is 2 times bigger than adhesion strength as generally admitted" from researches like* (10), (11), *(12).*"

Values from our experimental program suggests that, for repair mortar R1 and R2,this is more or less the case. For bigger limestone filler content (R3), the ratio is closer to 1.0. In the case ofR4-90% RH, we cannot draw any conclusions but for R4-60% RH the value is near to the one proposed in the literature .

4.CONCLUSIONS

The following conclusions may be drawn from the present investigations concerning the suitability of local-available limestone fillers for using in cement based repair materials:

- Limestone fillers are suitable for the design of repair materials,
- 60% R.H. seems to be more profitable for adhesion strength development;
- Shear strength is always higher than pull-off strength;
- Ratio between shear and pull-off strengths is in accordance with references in literature, at least for reasonable limestone fillers content.

More investigations are however needed for better understanding and comparisons, specially through Scanning Electron Microscope and Fluorescent Microscope observations and analysis.

Acknowledgments

This research project was supported by the scientific cooperation program between foreign agencies of Wallonia-Brussels International (Belgium) and Government of Romania. A special grant of two months has been offered for performing the research project in the *Laboratoire des Matériaux de Construction* of the University of Liège, Belgium.

References

1.) CourardL, Van der Wielen A and DarimontA. (2009) From defects to causes: pathology of concrete and investigation methods. 17th Slovenski kolokvij o betonih, Ljubljana, Slovénie (19 mai 2009):29-48.

2.) Vaysburd AM, Emmons PH (2000) How to make today's repairs durable for tomorrow—corrosion protection in concrete repair. *Constr Build Mater* 14(4):189–197

3.)Czarnecki L. (2005) Polymers in Concrete. Personal reflections on the edge of the new century.*Concrete International*, 8: 1-7

4.)Silfwerbrand J. (2003). Shear Bond Strength in Repaired Concrete Structures. *Materials & Structures* 36: 419-424.

5.)Austin, S., Robins, P., and Pan, Y. (1999). Shear Bond Testing of Concrete Repairs. *Cement and Concrete Research*, 29: 1067-1076.

6.)Li S., D.G. Geissert, S.E. Li, G.C. Frantz, E.J. Stephens, Durability and bond of high-performance concrete and repaired Portland cement concrete, Joint Highway Research Advisory Council, Project JHR 97- 257, University of Connecticut, 1997, 232 pp.

7.)Bissonnette B., Courard L., Beushausen H., Fowler D., Trevino M., Vaysburd A.. (2013) Recommendations for the repair, the lining or the strengthening of concrete slabs or pavements with bonded cement-based material overlays. *Materials and structures*46: 481-494.

8.)EN 1015-12

9.)Perez F., Morency M., Bissonnette B. and Courard L.. (2008) Correlation between the roughness of the substrate surface and the debonding risk. ICCRRR08 International Congress on Concrete Repair, Reinforcement and Retrofitting, (Alexander et al (eds), 2009 Taylor & Francis Group, London), Cape Town (2008): 949-956.

10.) Saucier.F., (1990) La Durabilite de L'adherence Des Reparations En Beton. Ph.D. Thesis, Sciences and Engineering Faculty, Universite Laval, Quebec, Canada, CRIB.

11.)Granju J.L., (1996), Fibre reinforced thin concrete overlays :The mechanism of their debonding in relation with theircracking. Concrete Repair, Rehabilitation and Protection, pp. 583–590.

12.)Momayez A., Ehmasi M.R., Ramezanianpour A.A. and Rajaie H. (2005), Comparison of methods for evaluating bond strength between concrete substrate and repair materials, Cement and Concrete Research, 35, 748–757.