FLEXIBILITY OF CTA BEYOND STANDARDS

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1. ABSTRACT:

A new test method was developed by WACKER to generate controlled shrinkage of concrete blocks laid with tiles. This test method allows defined shear forces to be applied to cementitious tile adhesives, like those occurring under real life conditions. Measuring the remaining tensile adhesion strength after the shear test allows conclusions to be drawn about the damage caused in the tile adhesive by shearing.

The results obtained show that the performance of tile adhesives meeting classification C2 or C2 S1 acc. EN 12004 decrease dramatically to the C1 level or even lower after shearing. Only tile adhesives containing high amounts of polymers, as of class C2 S2, were able to compensate for the applied shear stress.

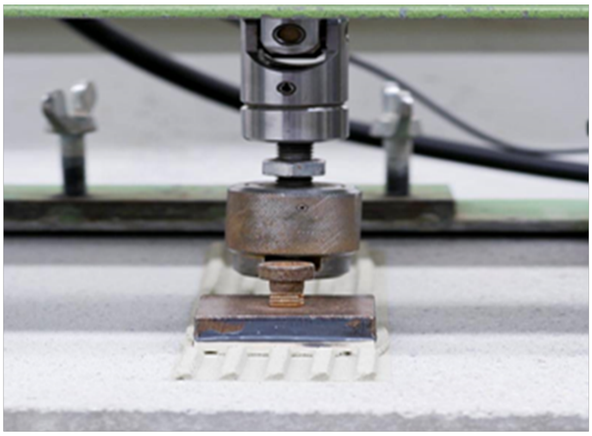
Clearly, high tensile adhesion strength is not sufficient to ensure secure tiling when shear forces are applied. A high level of flexibility, provided by the incorporation of polymers into the tile adhesive, is additionally needed to compensate and prevent the damage caused by shear stress.

2. INTRODUCTION

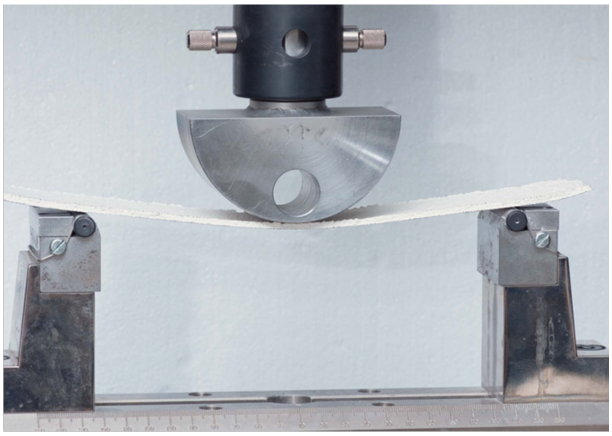
Cementitious tile adhesives (CTA) are classified and tested in Europe according to EN 12004-1 and EN 12004-2. The most important criteria for classification are tensile adhesion strength (tas), measured by a pull-off test, and deformability, measured via deformation of a mortar beam (Figure 1).

These tests and standards allow different CTA qualities to be defined, but only reflect the conditions on the job site or during service to a minor extent. In real life, CTAs are always subjected to shear forces caused by the differential contraction or expansion of substrate and tiles.

These shear forces are becoming even more critical as larger tile formats become more and more popular. A side effect of increasing tile formats is a decreasing amount and area of tile grouts, which are also able to compensate shear forces to a certain extent.



Tensile adhesion strength test



Deformation test

Figure 1. *Tas and deformation test acc. to EN 12004-2.*

In the present work, we provide a test method that allows controlled shear stress to be applied to CTAs, which reflects the real conditions of laid tiles. The test allows a defined deformation of the substrate to be generated, and thus defined shear forces between the substrate and tiles by cyclic compression and decompression of a concrete block laid with tiles. The remaining performance of the CTA after shearing is determined via measurement of the tas.

CTA formulations with varying amounts of dispersible polymer powders (dpp), different composition of polymers, and glass transition temperatures (Tg) were studied according to the developed method.

3. TEST SETUP TO SIMULATE SHEAR STRESS UNDER LARGE FORMAT TILES

Klaus Bonin et al. developed and presented a test setup to simulate the shear forces under a large format tile. For this purpose, they prepared concrete bars of the following dimensions: 1,150 mm long, 150 mm wide and 100 mm deep with a raised support of 50 mm x 100 mm high (see Figure 3) [1].

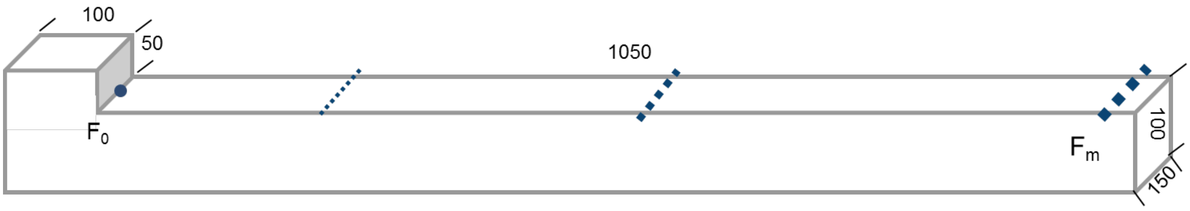


Figure 3. *Dimensions of the concrete bar. The abutment is shown at the left; the right side is open-ended (dimensions in mm).*

Onto these bars, they laid 10 tiles (10 mm x 10 mm) without joints, cut and broken from a large format tile (Atlas Concorde, 1,200 mm x 600 mm, water absorption ≤ 0.1%). Tile adhesives used ranged from type C2 (2% polymer), C2 S1 (5% polymer) and C2 S2 (10% polymer) to C2 S "large" (20% polymer).

The thus-prepared specimens were stored for 28 d at 10°C and then subjected to 65 climatic cycles (24 h +40°C/12 h -10°C) followed by 177 cycles (24 h +70°C/12 h -20°C) to induce expansion and shrinkage (see Figure 4).

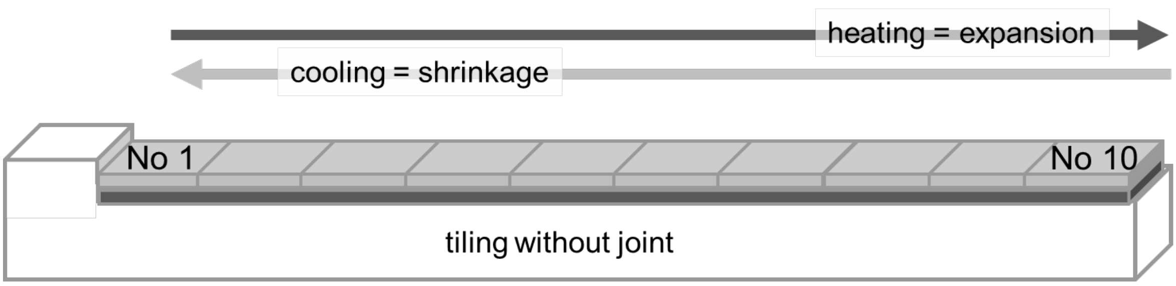


Figure 4. *Tiles bonded to the concrete bar, idealised representation of expansion and shrinkage induced by heating and cooling cycles.*

During the climatic cycling, any debonding of the tiles was recorded. If debonding occurred, the corresponding tiles were not removed, so that the stress transfer via the tiles was maintained. The results of observed tile debonding during the climatic cycles are shown in Figures 5 and 6.

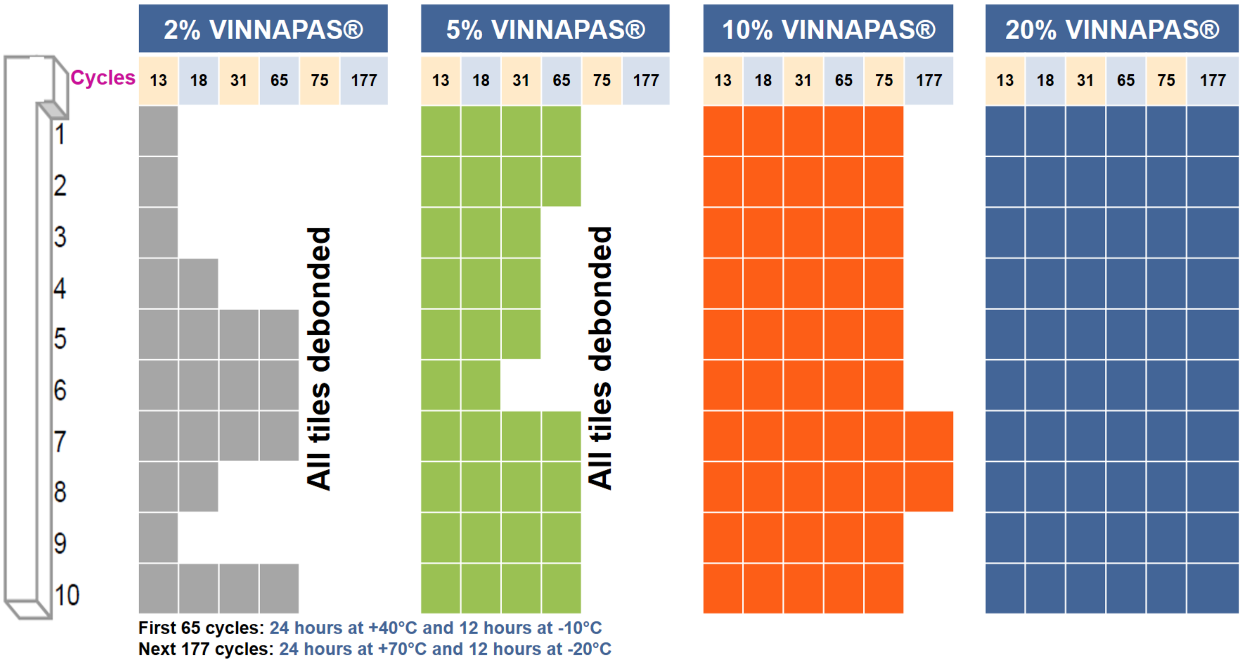


Figure 5. *Schematic display of tiles debonding during climatic cycles.*

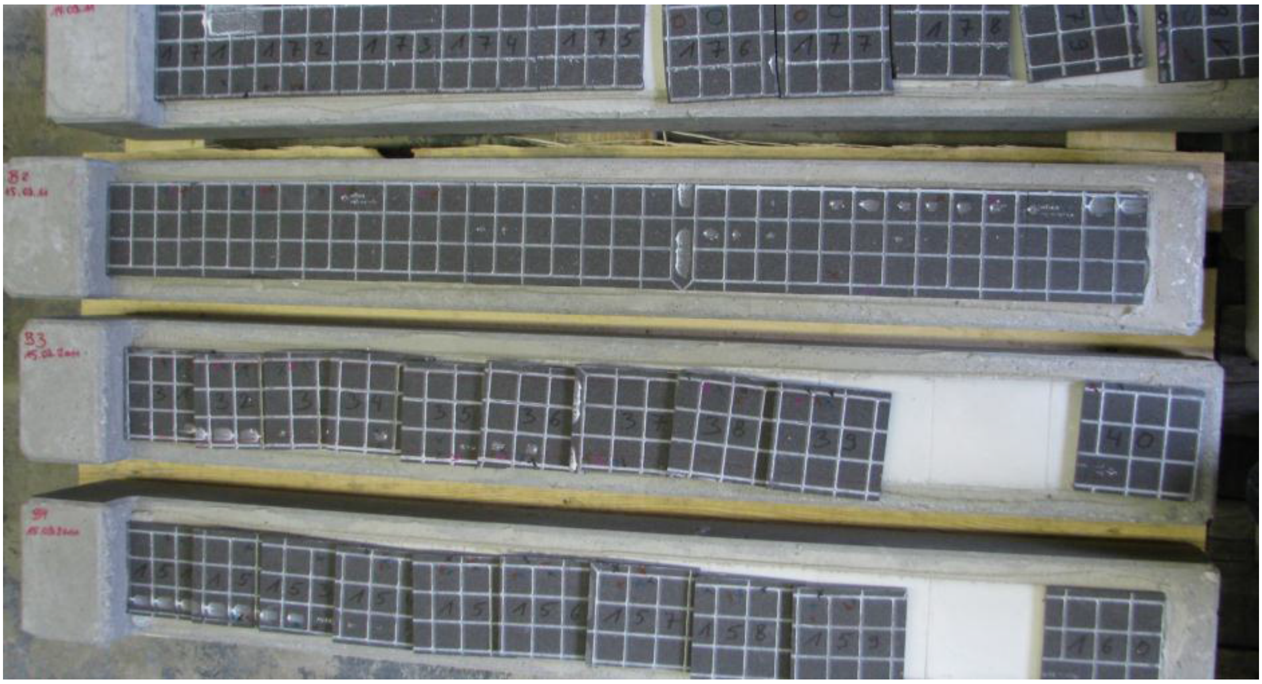


Figure 6. *Picture of concrete bars with intact tiling and debonded tiles after climatic cycles.*

The tas of the different tile adhesive formulations was also determined according to EN 12004-2, to correlate the respective tas with the results of the climatic cycles (see Figure 7).

Formulation		C2	C2 S1	C2 S2	C2 S "large"
Polymer VINNAPAS® 5028 E (VAc/E; Tg +10°C)		2.0%	5.0%	10.0%	20.0%
28 d sc	N/mm²	1.51	1.93	2.76	5.64
Standard deviation		0.26	0.06	0.31	0.22
7 d sc / 21 d water immersion	N/mm²	1.32	1.17	1.35	1.93
Standard deviation		0.25	0.27	0.06	0.18
14 d sc / 14 d +70°C/ 1 d sc	N/mm²	1.72	2.03	2.78	> 5.8
Standard deviation		0.25	0.18	0.25	n.m.
7 d sc/ 21 d water/ 25 freeze/thaw	N/mm²	1.3	1.41	1.74	(**)
Standard deviation		0.07	0.07	0.25	0.07

** Measurement error

Figure 7. *Tas determined according to EN 12004-2.*

Results:

Outstanding adhesive strength values far exceeding the C2 requirements according to EN 12004-1 tile adhesives were obtained for all tile adhesive formulations.

In contrast, tiles bonded to the newly designed concrete test bars using adhesive formulations with low polymer content began to detach at a very early stage during climatic cycling.

As the results show, the adhesive strength value has substantial limitations, and its practical relevance as a means of determining the suitability of a tile adhesive according to EN 12004 for bonding large-format tiles is therefore also limited.

The adhesive strength value according to EN 12004 provides only limited information about the durability of adhesive bonds for large-format tiles under real life conditions.

4. NEW TEST SETUP TO GENERATE DEFINED SHEAR STRESS BETWEEN SUBSTRATE AND LAID TILES

The work of Klaus Bonin et al. showed impressively that high values for adhesion strength on their own do not guarantee a durable lying of tiles if shear stress, induced by thermal cycling, occurs between substrate and tiles. This is even truer as the format of the tiles becomes larger.

As it is difficult to generate defined shear stress under laboratory conditions, we had the idea of using a hydraulic press (Toni Technik, max. force 3000 kN), equipped with a large loading chamber to compress concrete blocks laid with tiles, to generate controlled shear forces between concrete block and tiles. In order to simulate cyclic expansion and shrinkage, as it occurs e.g. under outdoor conditions, we applied a cyclic loading and deloading of the compressive force (see Figure 8).

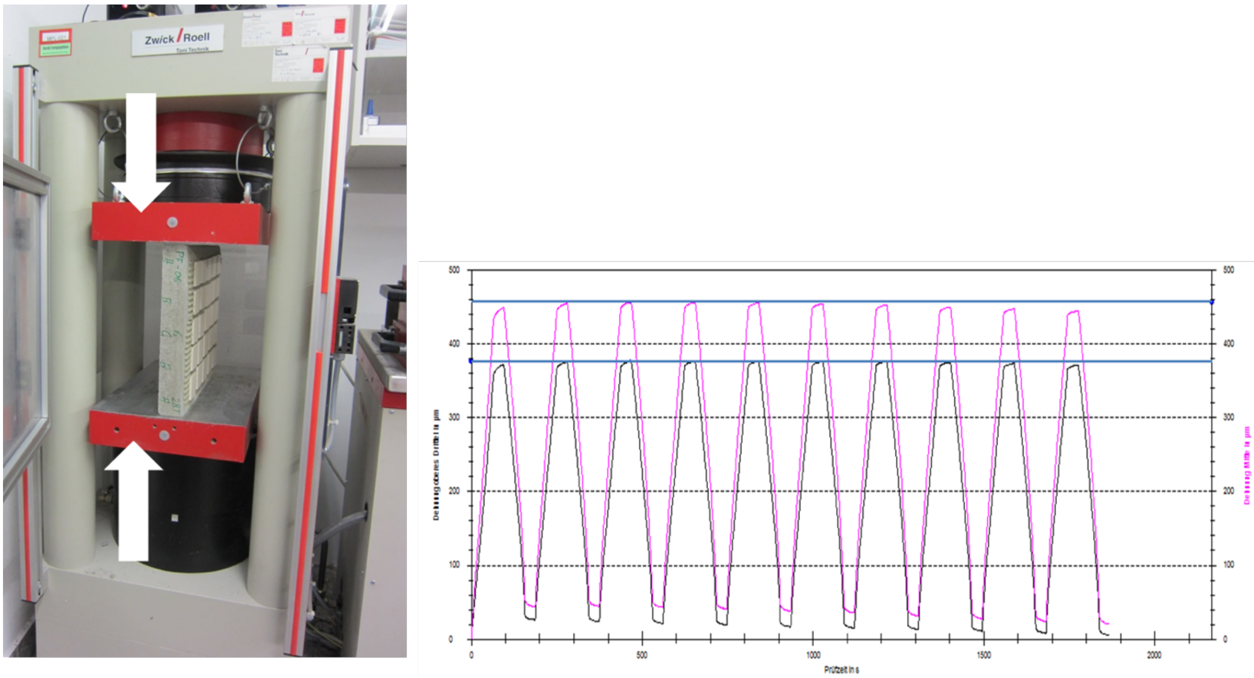


Figure 8. *Hydraulic press loaded with laid tiles on a concrete block.*

In a first step, blank concrete blocks with dimensions of 35 cm height, 40 cm width and 5 cm thickness were used to determine the maximum load until damage, which was achieved at a load of 900 kN. Therefore, we decided to apply a force of 650 kN to ensure a high deformation of the blocks without risk of their damage during testing.

The corresponding deformation of the blocks was measured by transducers.

In the case of the 650 kN load, the block was compressed by 127 µm, which corresponds to a shrinkage of 64 µm under the used tiles or an absolute shrinkage of 1.2 mm/m.

The deformation of the concrete block was almost linear, a significant difference between the compression at the edges and the centre of the blocks could not be determined.

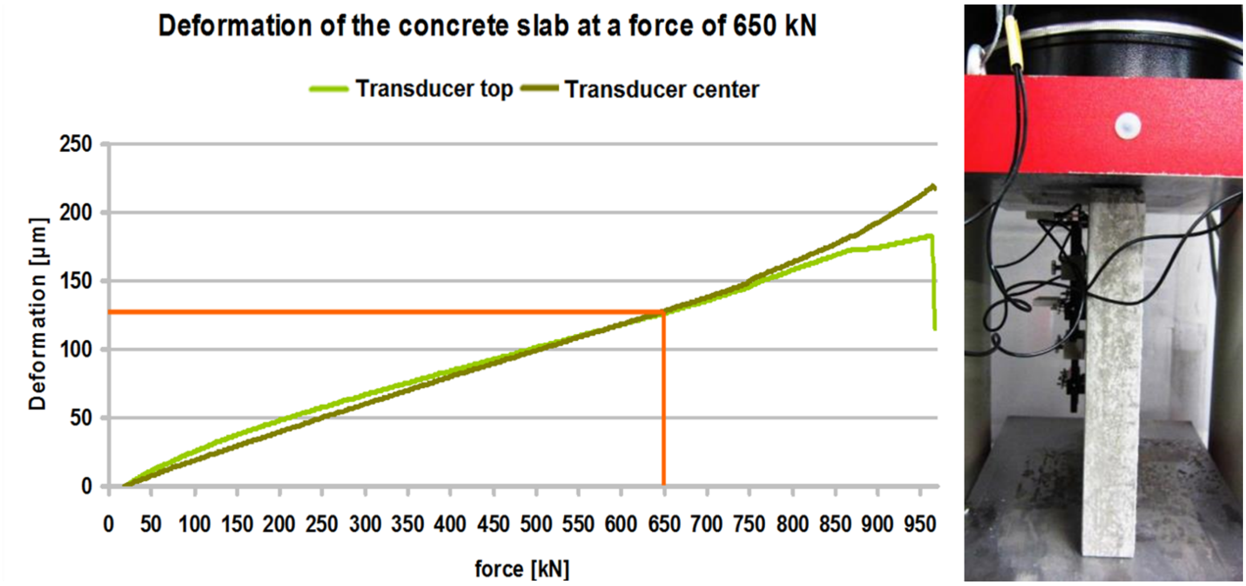


Figure 9. *Deformation of the concrete block measured with transducers at a load of 650 kN.*

To test the CTA, we used tiles of dimensions 5 cm x 5 cm, which were laid via the thin bed technique acc. EN 12004-2 on the concrete blocks in 5 rows with 5 tiles in each row. A distance of 1 cm was kept between each side of the tiles.

After the tiles had been laid, the concrete blocks were stored for 28 d at standard conditions (sc) and then submitted to 10 cycles of compression loading and deloading in the hydraulic press.

The 10 loading and releasing cycles consisted of:

- increase force to 650 kN over 60 s
- hold at 650 kN for 30 s
- release to 0 kN over 60 s
- wait 30 s before starting the next cycle

After applying this cyclic deformation, the tas of the CTAs was measured to determine the impact of the compression on the remaining performance of the CTA. The obtained values were compared to those from non-sheared concrete blocks, stored for 28 d at sc.

5. FIRST TEST SERIES WITH INCREASING AMOUNT OF POLYMER IN THE CTA FORMULATION

A basic C2 CTA-formulation with increasing amounts of polymer powder from 0% to 12% was used for the cyclic shear tests. For the first test series, we chose VINNAPAS® 5028 E, a polymer powder based on vinyl acetate and ethylene, having a Tg ~ 10°C. The CTA were applied on concrete blocks and stored for 28 d at sc as described in EN 12004-2.

The detailed formulations are listed in Figure 10.

OPC Milke CEM I 52,5 R	400	400	400	400	400	400	400	300
Silica sand F 36	295	290	285	275	265	255	235	285
Silica sand F 31	295	290	285	275	265	255	235	285
Tylose MB 3003 P4	5	5	5	5	5	5	5	5
Ca - Formate	5	5	5	5	5	5	5	5
VINNAPAS® 5028 E	0	10	20	40	60	80	120	120
Water/100 g dry mortar [ml]	33	32	31	30	29	28	26	24

Figure 10. *CTA formulations used in first test series.*

Results:

Figure 11 shows the tas after the cyclic shear testing compared to concrete blocks with laid tiles not exposed to shearing.

All CTA formulations with up to 8% of polymer powder exhibit a significant drop in tas after shearing compared to the non sheared. The tas of the formulation without polymer could not even be determined as the tiles fell off during testing. This means that the shearing causes damages in the cementitious matrix of the CTA, reducing the mechanical resistance to a dramatic extent.

The formulations with 1% and 2% polymer powder drop in performance from a C2 level to far below the C1 level. Even a C2 CTA modified with 4% of dispersible polymer powder falls to C1 level. Only the formulations with 12% polymer powder showed no noteworthy decrease in tas and thus, no indication of failure in the CTA matrix during shearing. Obviously, increasing the amounted of added polymer compensates the shear stress that CTA face in real life.

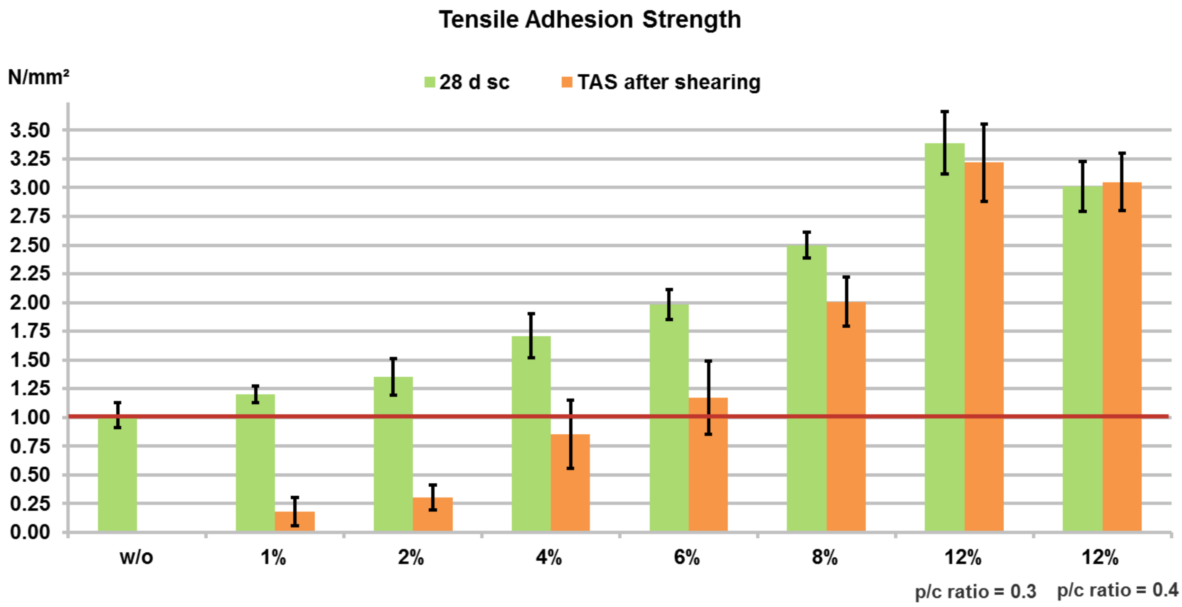


Figure 11. *Tas after shearing compared to concrete blocks stored for 28 d at sc.*

6. SECOND TEST SERIES WITH POLYMER POWDERS DIFFERING IN POLYMER COMPOSITION AND TG

Based on the results of the first test series (impact of the amount of polymer in the CTA formulation), we further studied the effect of the composition and the Tg of the polymers.

The chosen polymer powders with their polymer composition and the corresponding Tg are listed in Figure 12.

VINNAPAS®	Polymer Composition	~TG [°C]
7055 E	VAc/VeoVa/E	-14
5044 N	VAc/E	-7
7034 E	VAc/VeoVa/E	5
5028 E	VAc/E	10
8620 E	VAc/VC/E	13
5010 N	VAc/E	16
2012 E	S/A	20

Figure 12. *Dispersible polymer powders used in the second test series.*

All polymer powders were tested in 6 different CTA formulations: a "C0" without any polymer powder, a basic C2 with 2% polymer powder, a C2 S1 with 6% polymer powder, and three C2 S2 formulations with 12% polymer powder but different amounts of cement to investigate the effect of varying polymer to cement ratios (p/c) p/c = 0.25, p/c = 0.3 and p/c = 0.4.

The corresponding formulations are listed in Figures 13 and 14.

For this second test series, newly manufactured concrete blocks had to be used, which exhibited a different compression behaviour compared to the blocks used in series 1. A load of 450 kN led to a deformation of ~ 200 µm of the block, resulting in a deformation of ~ 100 µm under the tile or a corresponding absolute shrinkage of ~ 2 mm/m (Figure 15).

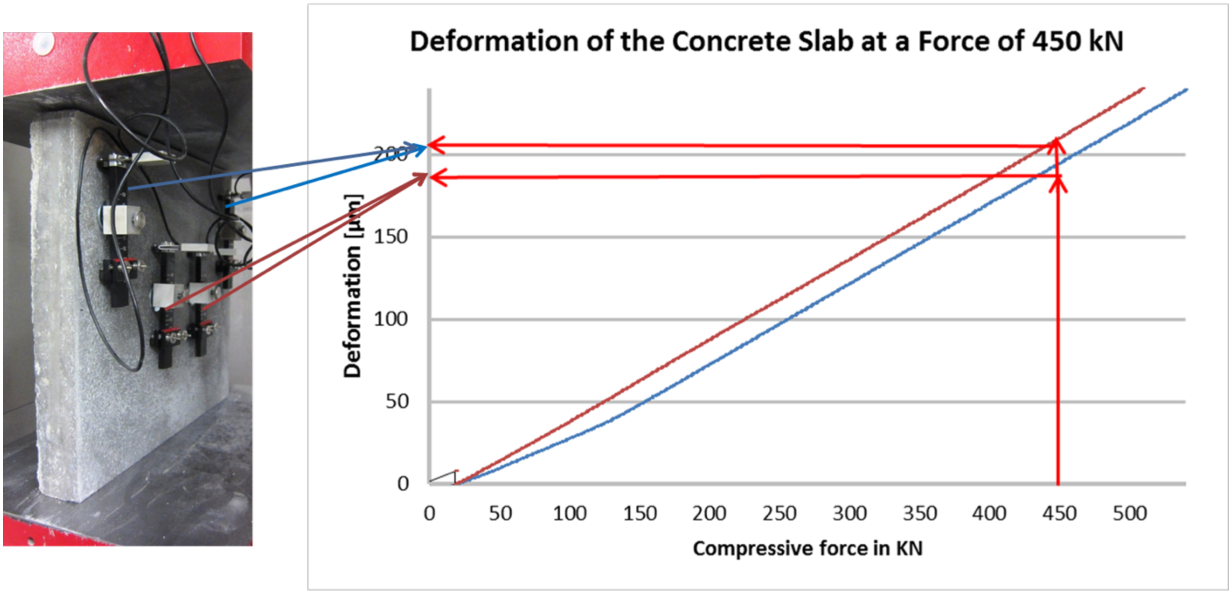


Figure 15. *Deformation of the concrete block measured with transducers at a load of 450 kN.*

Results:

Figures 16 and 17 show the tas after shearing compared to the non-sheared concrete blocks.

CTA without Polymer	
OPC Milke CEMI 52.5 R	400
Silica sand F 36	295
Silica sand F 31	295
Tylose MB 3003 P4	5
Ca formate	5
Water/100g dry mortar [mL]	33

CTA with 2% Polymer	
OPC Milke CEMI 52.5 R	400
Silica sand F 36	285
Silica sand F 31	285
Tylose MB 3003 P4	5
Ca formate	5
VINNAPAS®	20
Water/100g dry mortar [mL]	31

CTA with 6% Polymer	
OPC Milke CEMI 52.5 R	400
Silica sand F 36	265
Silica sand F 31	265
Tylose MB 3003 P4	5
Ca formate	5
VINNAPAS®	60
Water/100g dry mortar [mL]	29

Figure 13. *"C0", C2 and C2 S1 formulations.*

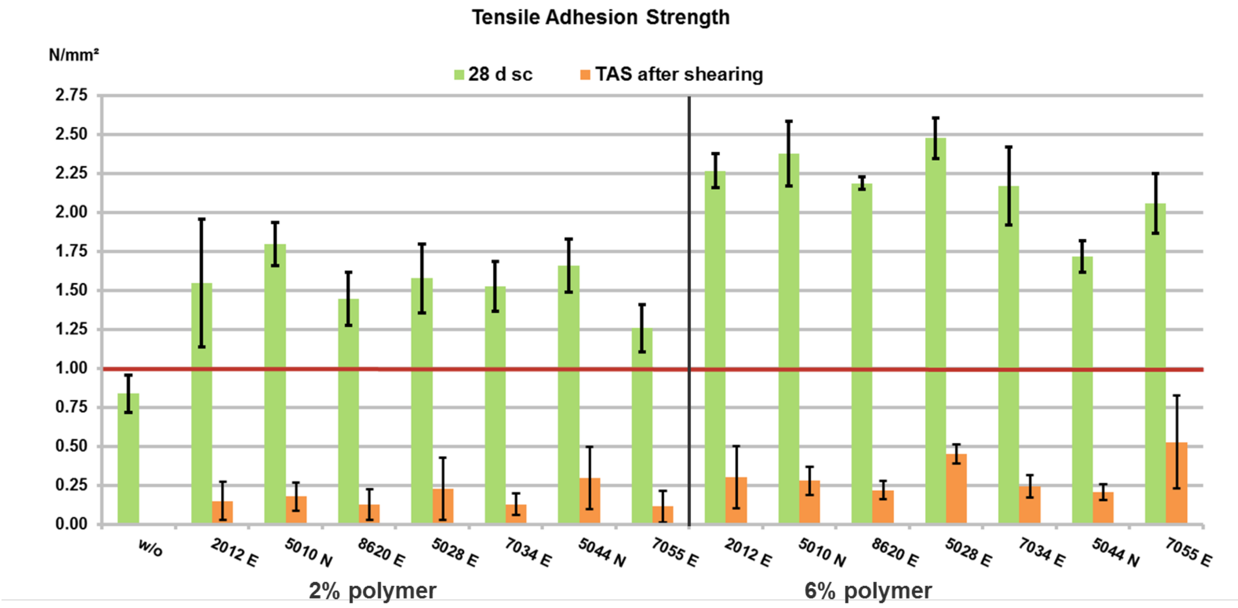


Figure 16. *Tas of "C0", C2 and C2 S1 formulations after shearing compared to non sheared blocks.*

The drop in tas after shearing compared to non-sheared blocks is even more dramatic than in the first series.

Again, the tiles laid with a non-polymer-modified CTA fell off during the test. The tas of the basic C2 and the C2 S1 formulations declines from C2 level to far below C1 level. The different performances of the polymer powders after shearing cannot be deduced from the results of these formulations.

CTA with 12% Polymer	
OPC Milke CEMI 52,5 R	480
Silica sand F 36	194
Silica sand F 31	194
Tylose MB 3003 P4	6
Ca - Formate	6
VINNAPAS®	120
Water/100g dry mortar [ml]	29

polymer/cement ratio p/c = 0,25

CTA with 12% Polymer	
OPC Milke CEMI 52,5 R	400
Silica sand F 36	235
Silica sand F 31	235
Tylose MB 3003 P4	5
Ca - Formate	5
VINNAPAS®	120
Water/100g dry mortar [ml]	26

polymer/cement ratio p/c = 0,3

CTA with 12% Polymer	
OPC Milke CEMI 52,5 R	300
Silica sand F 36	285
Silica sand F 31	285
Tylose MB 3003 P4	5
Ca - Formate	5
VINNAPAS®	120
Water/100g dry mortar [ml]	24

polymer/cement ratio p/c = 0,4

Figure 14. *C2 S2 formulations with 12% polymer powder and varying p/c ratios.*

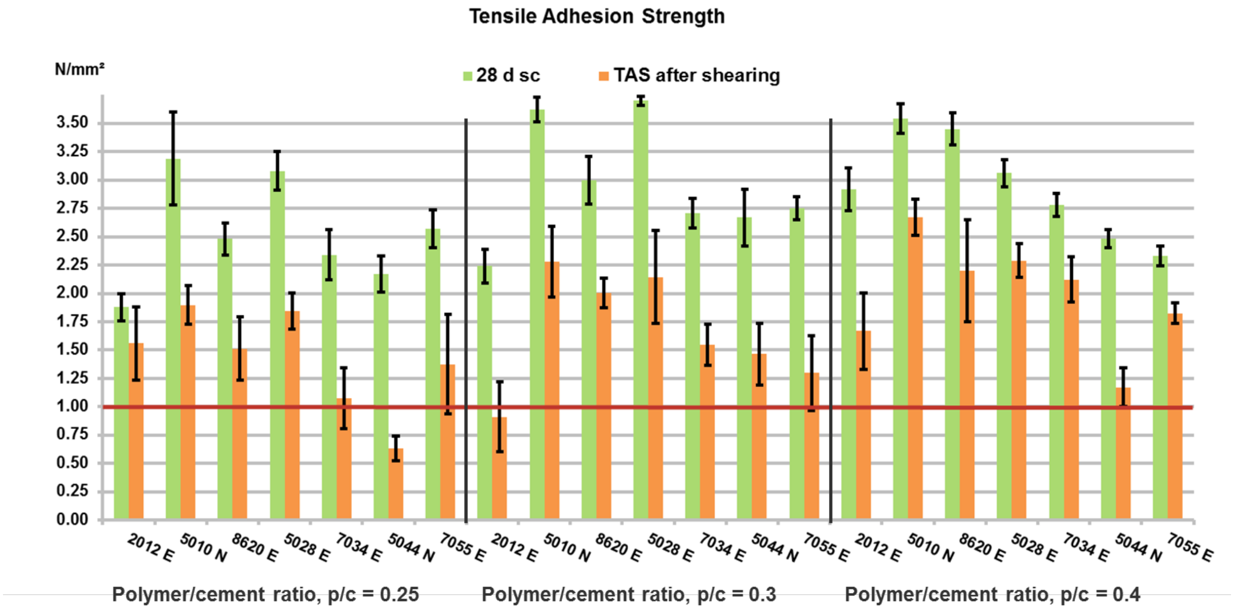


Figure 17. *Tas of C2 S2 formulations with 12% polymer powder and varying p/c – ratios after shearing compared to non-sheared blocks.*

For the C2 S2 formulations, a clear advantage in performance of the formulations with a high p/c-ratio can be observed. This again supports the hypothesis that an increasing amount of polymer and also a higher ratio of polymer to cement enables the CTA to compensate shear forces and prevents damages in the CTA matrix.

Concerning the impact of the polymer's Tg, there seems to be a trend in all three C2 S2 formulations that an increasing Tg leads to a higher performance after the shear test.

This can be explained by the prevailing temperature of 23°C during the test. The mechanical resistance of thermoplastic polymers decreases if temperatures are raised above their Tg. For this reason, low Tg polymers exhibit high mechanical strength at low temperatures in the range of their Tg and thus, high Tg polymers have higher mechanical strengths at higher temperatures.

Two exceptions are VINNAPAS® 2012 E, based on styrene/acrylics with the highest Tg of ~ 20°C, performing on a rather low level; and VINNAPAS® 7055 E, based on vinyl acetate/ethylene/VeoVa with the lowest Tg of ~ -14°C, performing at a higher level. Possible explanations need to be studied in further investigations.

7. CONCLUSIONS

A new test method was developed by WACKER: it allows controlled shrinkage or shear forces to be applied to a composite comprising concrete block, CTA and tile. The first test series with high compression of the concrete blocks and the corresponding high induced shear forces show a dramatic loss of performance of CTA formulations with low polymer contents.

Formulations without polymer modification fail completely during the test. C2 S2 CTAs with higher polymer contents exhibit almost no loss in performance after application of shear stress. This demonstrates very clearly, that, for a secure tiling under real life conditions in which shear forces are always occurring, the most important characteristic of a CTA is not only high bond strength but also high flexibility and ability to absorb shear stress. This flexibility can only be achieved by an adequate incorporation of polymer in the CTA formulation.

8. OUTLOOK

The shear forces applied in this work were high, reflecting rather extreme real life conditions, because we wanted to see if there is a measurable effect. The results show that there is an effect and that it is even possible to differentiate between polymers of varying Tg. In further works, it is possible to adapt the test parameters (applied shear force, prestorage of the specimen i.e. wet) to the conditions that a CTA will face during its utilization phase. It is also planned to conduct the shear tests at low temperatures to study the performance of low Tg polymers, which should outperform polymers with a high Tg under these conditions.

9. REFERENCES

[1] Klaus Bonin et al., Drymix Mortar Yearbook 20013, New test set up to fix large format tiles with cementitious tile adhesive