Acta Polytechnica CTU Proceedings **59**:192–196, 2026
https://doi.org/10.14311/APP.2026.59.0192
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Published by the Czech Technical University in Prague

UTILIZATION OF HYBRID CEMENT FOR THE FORMULATION OF TILE ADHESIVE

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Abstract. The global effort to mitigate the environmental impact of the construction industry is increasingly focused on substituting energy-intensive materials with more sustainable alternatives. A key strategy within this approach is the reduction of Portland clinker content, which constitutes the principal component of the most widely used binder in construction applications. Numerous studies have demonstrated that high levels of clinker substitution can be achieved in concrete production without compromising mechanical performance or durability. Nevertheless, many specific applications of such alternative binders remain insufficiently investigated. This study presents an experimental investigation of two cementitious adhesives incorporating a hybrid cement based on milled fly ash. The experimental program focused on pull-off testing of the adhesives, in which Portland cement was progressively replaced with the alternative hybrid binder. The results indicate promising performance characteristics of the developed material. However, the incorporation of hybrid cement was found to reduce the open time of the adhesive, thereby necessitating prompt application and tile placement. On the other hand, the application of hybrid binder requires modification of testing procedures with respect to the different process of hardening.

Keywords: Hybrid cement, fly ash, pull-off test, open time.

1. Introduction

The production of conventional Portland cement, particularly clinker manufacture, represents a significant source of global carbon dioxide emissions. Although the cement industry constitutes a relatively small industrial sector, it accounts for approximately 5–8 % of total anthropogenic CO_2 emissions [1]. Consequently, considerable research efforts have been devoted to the development of alternative binder systems capable of partially or fully replacing Portland cement [2, 3].

The concept of Portland clinker substitution is well established. Various supplementary cementitious materials (SCMs), including fly ash, ground granulated blast furnace slag, and finely ground limestone, are routinely incorporated into Portland cement. In particular, reactive SCMs contribute positively to long-term durability performance [4, 5].

However, the availability of suitable SCMs originating as by-products of power generation and heavy industry is limited in certain regions. This shortage has stimulated the development of alternative binder systems incorporating mineral additives whose direct utilization would otherwise be challenging. Coal ash deposits have been increasingly exploited as sources of reactive components [6]. Nevertheless, these materials generally require additional processing and compositional modification due to elevated free lime content and relatively coarse particle size distribution. Their lower intrinsic reactivity is typically enhanced through chemical activation, most commonly by sodium sulfate addition [7]. The resulting hybrid cement promotes ettringite formation, which significantly contributes to strength development.

Hybrid cement systems have demonstrated promising performance when used as partial replacements of Portland cement in concrete production, particularly for structures subjected to moderate environmental exposure. However, their application in advanced building materials, such as mineral-based adhesives, has not yet been comprehensively investigated.

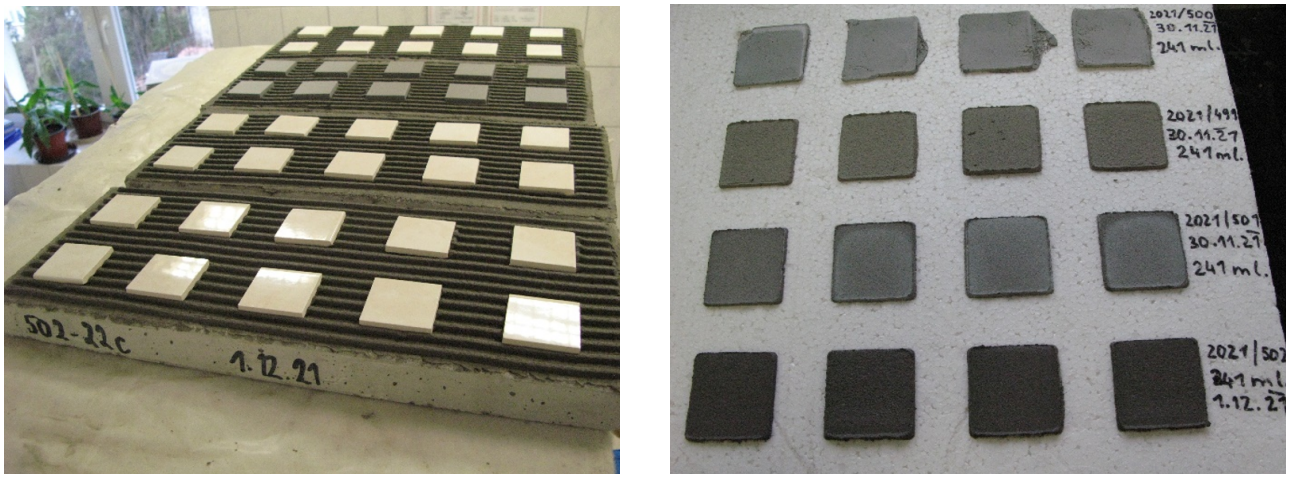
The present study therefore focuses on the experimental evaluation of two cementitious adhesives – a tile adhesive and an adhesive for external thermal insulation composite systems (ETICS) – in which Portland cement was progressively replaced with hybrid cement based on milled fly ash. The experimental program comprised pull-off testing to assess bond strength performance. The results indicate that the incorporation of hybrid cement provides promising mechanical performance. Nevertheless, a reduction in open time was observed, necessitating prompt application and tile placement during installation.

2. Experimental program

The experimental program focused on modifying the composition of two commercially available

	CaO [%]	**SiO_2** [%]	**Al_2O_3** [%]	**Fe_2O_3** [%]	**MgO** [%]	**SO_3** [%]	**K_2O** [%]	**Na_2O** [%]
CEM I 42.5 R	63.0	18.7	5.3	3.1	2.6	3.2	0.8	2.1
H-cement	17.09	46.91	16.91	6.47	1.68	3.65	3.17	2.52

TABLE 1. Chemical composition of used binders.



(A). (B).

FIGURE 1. Samples of adhesives for pull-off testing of tiles a) and from EPS board b).

cementitious–polymer adhesives originally based on Portland cement. The first adhesive was designed for ceramic tile installation, while the second was intended for bonding expanded polystyrene (EPS) insulation boards within external thermal insulation composite systems (ETICS). The primary objective of the development was to incorporate hybrid cement based on milled fly ash in order to improve the environmental performance of these products through partial replacement of Portland cement. The research was conducted within a collaborative framework, in which two selected commercial adhesives were systematically reformulated by gradually substituting Portland cement with hybrid cement. The performance of the modified adhesives was subsequently evaluated with particular emphasis on bond strength, assessed by pull-off testing.

2.1. MATERIALS

Two commercially available cementitious–polymer adhesives manufactured by Stachema Ltd. were selected as the reference materials. In these products, the original Portland cement component was progressively replaced with a hybrid cement (hereinafter referred to as H-cement) produced by Považská cementáreň, a.s. H-cement is formulated on the basis of milled fly ash and ground granulated blast furnace slag, with a minor addition of Na_2SO_4 serving as a chemical activator. The binder system contains approximately 20 % Portland clinker, resulting in a substantially reduced clinker factor compared to conventional cements. The chemical compositions of H-cement and CEM I 42.5 R, which is commonly used in the production of the investigated tile adhesive, are presented in Table 1. The detailed formulation of the selected commercial adhesives is proprietary and therefore cannot be disclosed.

2.2. METHODS

Open time represents a critical parameter for successful tile installation. Therefore, each adhesive must undergo standardized testing in which the time-dependent reduction of bond strength after application of the adhesive mortar is evaluated. The detailed testing procedure is specified in ČSN EN 12004-1 [8]. Open time is defined as the maximum time interval (in minutes) after adhesive application during which tiles can be placed while still achieving the required bond strength.

In the test procedure, the adhesive mortar is applied onto a substrate and left under standard laboratory conditions. Tiles are subsequently placed onto the adhesive layer after predetermined time intervals. The first interval (5 minutes) serves as the reference condition, followed by longer exposure periods of 10 and 20 minutes. After 28 days of curing, pull-off (tensile adhesion) testing is performed. Prolonged exposure of the fresh adhesive to air leads to partial surface drying, which may reduce adhesion to the concrete substrate. During testing, the maximum pull-off force is recorded, together with the mode and location of failure. The experimental setup is illustrated in Figure 1.

In addition to the open time evaluation, direct pull-off testing was conducted on concrete substrate blocks. A 5 mm thick layer of tile adhesive was applied and

cured for 28 days under humid conditions. Subsequently, aluminum pull-head discs were bonded to the hardened adhesive surface, and pull-off testing was carried out. This procedure is commonly used for the assessment of repair mortars [9] and enables direct comparison with analogous cementitious products.

A similar methodology was employed for the adhesive intended for bonding expanded polystyrene (EPS) boards within external thermal insulation composite systems (ETICS). The ETICS adhesive was locally applied in a thin layer onto EPS boards (Figure 1b). After 28 days of curing under humid conditions, pull-off testing was performed (Figure 2).

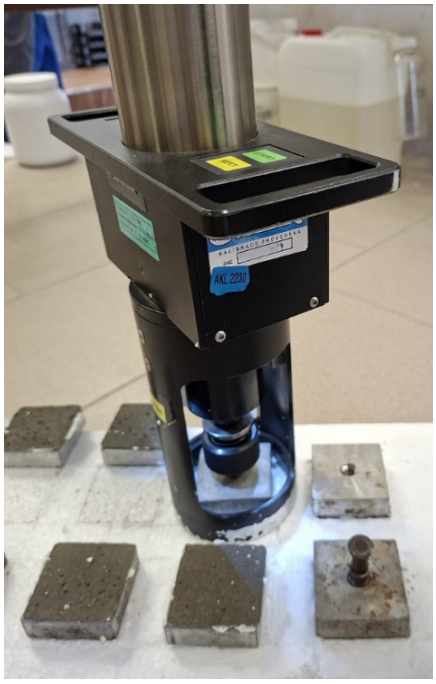


Figure 2. Pull-off testing of adhesive from EPS board after 28 days.

3. Results

The experimental program was primarily focused on pull-off testing of two commercially available cementitious–polymer adhesives, in which Portland cement was progressively substituted with hybrid cement based on milled and chemically activated fly ash. The results obtained for the tile adhesive are summarized in Table 2 and graphically presented in Figure 3.

The evaluation of open time revealed a progressive reduction in tensile adhesion strength to the concrete substrate with increasing replacement of Portland cement by H-cement. At the lowest replacement level (25 %), the initial adhesion remained relatively high; however, this mixture exhibited a slightly greater reduction in bond strength after delayed tile placement (10 minutes) compared to the reference composition. Higher replacement levels proved increasingly ineffective in maintaining adequate adhesion performance.

Mixture	Obtained adhesion [MPa]	
	10 minutes	20 minutes
TA-R	0.69	0.37
TA-25	0.77	0.27
TA-50	0.57	0.14
TA-75	–	–
TA-100	–	–

Table 2. Results of pull-off tests of tile adhesive.

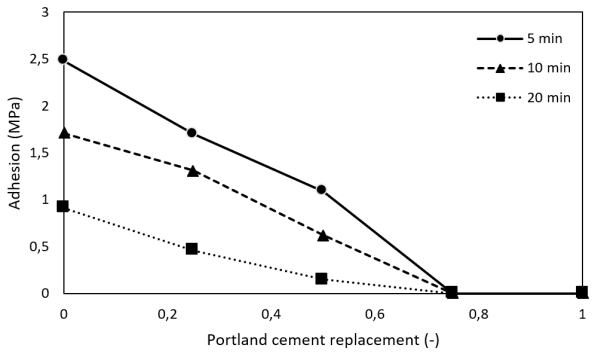


Figure 3. Results of pull-off tests of tile adhesive.

Complete replacement of Portland cement resulted in delamination of the test assembly, and therefore no measurable adhesion was obtained.

The reduced bond strength of the hybrid cement-based adhesive to the concrete substrate can likely be attributed to the gradual formation of ettringite, which may adversely affect the integrity of the interfacial transition zone. Furthermore, previous research has demonstrated that this binder system is highly sensitive to moisture loss during curing, which can negatively influence hydration processes, particularly at the exposed surface following application to the substrate [10]. An additional reason for reduced adhesion is the value of the water-cement ratio. Current experiences show that mortars containing hybrid binder attain optimal adhesion when a lower dosage of water is used.

Complementary pull-off tests conducted in accordance with the procedure commonly applied for repair mortars confirmed a proportional decrease in adhesion strength with increasing levels of Portland cement substitution. Specimens with the highest replacement ratios exhibited premature delamination prior to testing. These findings indicate that the adhesion performance of the investigated hybrid cement system to mature concrete substrates is insufficient. However, the problematic aspect could be the prescribed curing and following manipulation with the samples. Hardening hybrid cement is sensitive to contact with water due to risks of activator leaching. The corresponding results are presented in Figure 4.

The final testing campaign focused on evaluating the effect of Portland cement replacement in

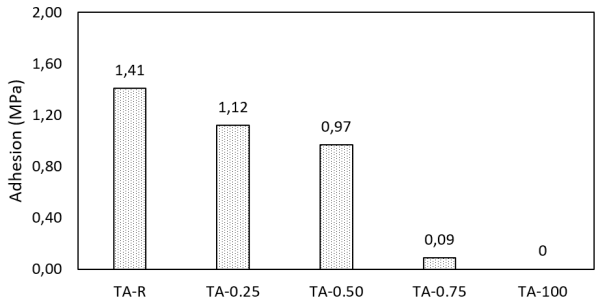


FIGURE 4. Adhesion after 28 days to concrete blocks.

a cementitious–polymer adhesive intended for bonding expanded polystyrene (EPS) boards within external thermal insulation composite systems (ETICS). In addition to the maximum pull-off force, the failure mode was carefully monitored during testing.

Three principal failure scenarios were distinguished in accordance with the standard testing procedure. Failure within the EPS substrate indicates that the adhesive bond strength exceeds the tensile strength of the EPS. The presence of EPS residues on the pull-head suggests comparable values of adhesive bond strength and EPS tensile strength. Conversely, failure occurring at the interface between the EPS board and the adhesive layer indicates insufficient adhesion.

The obtained results are summarized in Table 3, which presents both the measured adhesion values and the corresponding failure modes. Compared to the tile adhesive, these results are more encouraging. A 25 % replacement of Portland cement with H-cement provided bond strength comparable to that of the reference mixture, without a significant change in failure character. Although higher replacement levels (50 %) still exhibited measurable adhesion, the observed shift in failure mode indicates progressive deterioration of interfacial performance. The improved adhesion to EPS compared to concrete substrates is likely related to the specific surface morphology and lower elastic modulus of EPS.

Mixture	**Adhesion** [MPa]	**Zone of the rupture**
EPSA-R	0.11	EPS
EPSA-25	0.09	EPS
EPSA-50	0.11	20 % EPS
EPSA-75	0.06	EPS – adhesive
EPSA-100	0.03	EPS – adhesive

TABLE 3. Results of pull-off tests of adhesive for EPS boards.

Overall, the partial substitution of Portland cement with H-cement in EPS adhesives appears to represent a technically feasible and environmentally beneficial application of this low-clinker hybrid binder.

4. Conclusion

The presented experimental program investigated the applicability of hybrid cement based on chemically activated milled fly ash in adhesive systems for ceramic tile installation and EPS-based external thermal insulation composite systems. The main findings can be summarized as follows.

The incorporation of H-cement in tile adhesive formulations resulted in a significant reduction in adhesion to mineral concrete substrates. Consequently, the open time for this application was substantially shortened, limiting its practical applicability.

Adhesion to concrete decreased proportionally with increasing levels of Portland cement replacement.

In the case of EPS adhesive, replacement of 25 % of Portland cement with H-cement provided bond strength comparable to the reference mixture. The feasible replacement level appears to be slightly below 50 %, as adhesion at this level remained higher than the tensile strength of the EPS substrate, although a gradual shift in failure mode was observed.

The following research will be focused on the applications where the previous research confirmed good potential, such as self-healing ability, resistance to high temperatures, and resistance to aggressive environment.

Acknowledgements

This research was supported by the internal project competition of CTU in Prague through the project SGS and the project INODIN (Innovative methods of materials diagnostics and monitoring of engineering infrastructure to increase its durability and service time – CZ.02.01.01/00/23_020/0008487) co-funded by European Union.

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