**Development of Composite Cement-Based Adhesive Mixtures for Ceramic Tiles with Enhanced Thermophysical Properties**

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**Abstract**. In this paper, an investigation on a composite cement-based tile adhesive composed of a low-water-demand cement binder and water-soluble polymer additives is reported. Some portion of Portland cement was replaced with local fine limestone filler and a polycarboxylate-based superplasticizer to obtain a binder with lower water requirement and faster setting time. The adhesive dry mix also comprises hydrated lime, methyl hydroxyethyl cellulose (MHEC) and a re-dispersible polymer powder (RPP), in adjusted amounts. The ultimate performance of the developed formulation is achieved, with high tensile bond strength (1.4 MPa, 28 d), low vertical slip (0.2 mm), high water retention ((> 98%)) and rapid strength development. When compared to a standard cement-sand adhesive, the composite formulation exhibited better adhesive strength, enhanced work performance (thixotropy and sag resistance), and enhanced water immersion durability. The adhesive complies with EN 12004 C2 class with the advantage of being affordable as it is made predominantly from local materials. Pilot production proved successful and the scalability of the formulation and its industrial use has led to environmentally friendly, high-performance building materials.

**Keywords:** cementitious adhesive, re-dispersible polymer powder, cellulose ether, tile adhesive, composite binder, thermal conductivity, composite materials, energy-efficient construction, polymer-modified cement.

# INTRODUCTION

Composite tile‑adhesive materials exhibit critical thermophysical properties—notably thermal conductivity, specific heat, and thermal expansion coefficient—which influence thermal response during curing and service. Belbachir et al. [1] showed that polymer‑modified mortars with styrene‑polyacrylic (SPA) latex display lower thermal conductivity than traditional cement mortar, with conductivity decreasing linearly with polymer content and density. This reduction enhances insulation and slows heat rise during hydration and thermal cycling, offering both application advantages and durability benefits.

Specific heat capacity determines how much heat energy a material can absorb per degree of temperature rise—vital during exothermic cement hydration or ambient thermal fluctuations. In fiber‑reinforced cement composites, Researchers measured specific heat over a wide temperature range and found capacity increases with inclusion of glass or carbon fibers, improving thermal buffering compared to plain cement mortar. While the exact data for polymer‑cement tile adhesives is limited, analogous inclusion of polymer modifiers and fine fillers would be expected to elevate specific heat capacity, contributing to dimensional stability under temperature transients [2].

Tile adhesives in modern construction, cementitious tile adhesives are indispensable for fixing ceramic tiles to different supporting bases. It is because of this that conventional tile-fixing solutions were typically cementitious-sand mortars that could be laborious in application and produced weaker bonds. Modern thin-bed tile adhesives are commonly polymer-modified, cement-based materials that consist of cement, mineral fillers (for example sand or limestone) and chemical additives (polymers, cellulose ethers etc.) for improving various performance properties. Polymer modification of cement-based mortar for tiles has been long applied for enhancing adhesion, flexibility, water-tightness, and the life for the adhered tile system. Redispersible Polymer Powders (RPP) (Spray Dried Latex Powders Redispersible in Water) In particular, workability, bond strength, flexural strength, and sag resistance of cementitious tile adhesives are advanced significantly through the addition of redispersible polymer powders (RPP). Also, cellulose ether polymers (e.g., HPMC or HEMC) are commonly used to increase water retention, control rheology, prolong open time, and reduce sag. These polymeres in watery dispersion contribute to the water to promote hydration and (even if laid in thin layer on porous substrates) raining adequate moisture for it and present a thixotrophysl [3]

While polymer additives do work, many Third World countries must import these polymers modifiers and that adds to the expense. Composite tile adhesives based on local materials and with minimum imported additives, such as those that do not have a diminished performance, have increased the interest of researchers. One approach is to provide a low water-demand cement binder---a combination of (reduced water-demand) cement and a calcium aluminate cement usually in the presence of mineral fillers and superplasticizers. Its early strength and shrinkage are fastened due to the partial substitution of Portland cement by fine limestone (carbonates) filler and superplasticizer in a way of decreasing water at a given flow. Such an approach might enable the improvement of the performance of tile adhesive (such as early bond strength and slip resistance) using less expensive, local-availability filler.

Mismatch in coefficient of thermal expansion (CTE) between adhesive, tile, and substrate can lead to interface stress, debonding, or cracking under temperature variations. Weng et al. [4] presented experimental CTE data for polymer‑modified repair mortars, where CTE values increased with polymer content in some formulations, but could be controlled closer to substrate values depending on polymer type and w/c ratio. Conversely, the use of thermal‑aging‑resistant additives—such as beta‑eucryptite and basalt fiber—has been patented to adjust adhesive CTE to match that of concrete and ceramic tiles (±3 × 10-6K-1), mitigating thermal stress at interfaces. In engineered composite adhesives, managing CTE through tailored fillers and polymer selection is essential for long‑term bond integrity.

Standards and performance: Under European (EN 12004 / ISO 13007) regulation, a standard cementitious tile adhesive (C1) shall obtain a minimum tensile adhesion strength value of 0,5 MPa in various tests, whereas an improved adhesive can (C2) should obtain 1,0 MPa as a minimum bond performance. The adhesive should have suitable open time and low sag (down to 0.5 mm vertical slip for wall applications). Achieving these performances using mostly locally available mineral materials coupled with water-soluble polymer admixture is a desirable end for economic and practical considerations [2, 4].

In the present paper, we propose a new kind of blend based on the cementitious adhesive mortar for ceramic tiles, of a synthetic polymer inorganic matrix with a low-solubility cement binder and water soluble cellulose ether and redispersible polymer powder (RPP). Our objective is to develop an adhesive having certain excellent properties – high bond strength (1 MPa), fast setting with early strength, low sag, and high water retention – with lower dependence on imported additives. In addition, the development adhesive was judged according to standard requirements and a comparative standard product for formulation and important properties.

# MATERIALS AND METHODS

Ordinary Portland cement (OPC) was used as base cementitious material. The LWC was made by mixing OPC with the carbonate rock powder and a superplasticizer. The “microcalcite” limestone filler of high fineness (particles < mostly 5 μm) was used as a partial substitution for cement, and a polycarboxylate-based superplasticizer (trade brand “Polyplast SP-1”) was introduced as a grinding aid and water-reducing admixture. According to preliminary trials, the best content of LWC was determined with 25–30% of limestone microfiller (as a percentage of weight of the cement blend), and 0.5–0.75% of superplasticizer (as a percentage of weight of the cement) added in a grinding mixture.

Mechanochemical activation (grinding together of raw materials) was performed in a ball mill to obtain a high specific surface area (~5000–5500 cm²/g). This co-grinding results in a blended cement for which the water demand and the setting are substantially reduced. As the filler materials for the tile adhesive mixes, the following were used in addition to LWC: - Quartz sand (silica sand)—fine fraction of the mineral material (0.1–0.63 mm fraction), dried and sieved.

Slaked lime (calcium hydroxide) - a fine powder (in accordance with GOST 9179-2018) is consumed in a small amount when used as chemical additive for improvement of mobility and water keeping of the mixture. - Limestone microfiller (microcalcte)-the same finely ground carbonate as used in LWC, aslo introduced separately in dry mix to modify Rheology and strength. - Cellulose ether – in particular\*- methyl hydroxyethyl cellulose (MHEC) WalocelTM 45/10 - a water-soluble polymer used as a thickenng, water retention agent This was added at ∼0.1–0.2% of the dry mixture. Redispersible polymer powder (RPP)- A vinyl acetate/ethylene copolymer powder (ELOTEX™ Seal 74) utilized at ~0.4% of mix. This polymer is redispersible in water upon mixing and serves to polymerize into a polymer film on the cured adhesive, which improves adhesion and flexibility [5, 6].

All materials used were local except chemical additives (SP-1, Walocel, and ELOTEX polymers) that are imported and are widespread in dry mortars.

Blended formulations: Multiple experimental formulations were mixed to determine the proper mix of cement, filler, and additives. Three typical formulations (per 1000 kg dry mix) are listed in Table 1. All these mixes utilize LWC as binder, while the fillers content (sand, lime and microcalcite) and polymer admixtures are slightly different in proportion. Results of performance testing (below) indicated that Mix #1 was the best configuration for the tile adhesive. Mix #1 contains a significantly larger mass of cement and moderate filler, while Mix #2 and #3 each tried a little larger proportion of cement or different proportions of filler. All mixes had the same polymer additive contents (± 0.1%). The best formulation (Mix #1) was then prepared in pilot scale in order to test the properties and estimate the cost.

**TABLE 1.** Formulations of experimental cement–polymer tile adhesive mixes (per 1 ton dry mix)

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Mix #1 (optimal)** | **Mix #2** | **Mix #3** |
| Low-water-demand cement (LWC) | 350 kg | 320 kg | 350 kg |
| Quartz sand (0.1–0.63 mm) | 500 kg | 500 kg | 490 kg |
| Hydrated lime (Ca(OH)₂ powder) | 30 kg | 40 kg | 30 kg |
| Limestone microfiller (microcalcite) | 115 kg | 135 kg | 135 kg |
| Redispersible polymer powder (RPP) | 3.8 kg | 3.5 kg | 3.5 kg |
| Cellulose ether (MHEC) | 1.2 kg | 1.5 kg | 1.5 kg |

Mix #1 was chosen as the optimal formulation based on test results.

# EXPERIMENTS AND RESULTS

Mixing and application: Dry components were pre-blended to ensure uniform distribution of the polymers and additives. For each test batch, the dry mix was combined with water to prepare the adhesive mortar. The water-to-dry mix ratio (W/M) required to achieve a workable paste (of standard consistency spread 8–12 cm in flow table spread) was recorded. The water demand of the LWC-based mixes was compared to a reference mix made with ordinary cement. The pot life and consistency of each mix were observed. The presence of the superplasticizer in the LWC allowed using a lower W/M (~0.30–0.32 by mass) to reach the desired consistency, whereas a similar mix with regular cement needed ~20% more water for the same workability.

Testing methods: The performance of the developed adhesive was evaluated according to relevant standards, primarily the Russian GOST 31357-2007 (which aligns with international ISO 13007 for tile adhesives). Key tests included: - Working properties: Mixing time (time to achieve a homogeneous paste), open time (adjustment time after application, measured as the time interval after spreading during which a tile can be repositioned, also called correction time), and pot life (the usable life of the mixed adhesive in the bucket).

These were measured by standard procedures (spreading a portion and checking adhesion of a tile at intervals for open time; monitoring viscosity increase for pot life). Workability and sag resistance: The mortar’s ease of application (qualitative observation of troweling-should not “stick to the trowel” or form strings) and vertical slip was tested. Sag resistance was measured by applying the adhesive on a vertical test board at 5 mm thickness and placing a standard tile; the downward movement of the tile was measured after a set time (20 minutes). According to GOST/ISO, no more than 0.5 mm slip is permitted (no visible slip is ideal) [1, 2].

Density, durability, and thermophysical properties of the adhesive were also evaluated. The bulk density of the dry mix was in the range of 1250–1350 kg/m³, and the hardened density was approximately 1400 kg/m³, lower than that of conventional sand‑cement mortars (typically >1600 kg/m³). This reduced density, combined with polymer modification, improves the composite’s flexibility and strain tolerance. Importantly, the measured thermal conductivity of the hardened adhesive was ~0.178 W/m·K, slightly lower than that of the reference adhesive (~0.20 W/m·K), indicating enhanced insulation due to polymer and fine limestone fillers. Such values are comparable to those reported by Belbachir et al. [1] for polymer‑modified mortars, where fillers reduce heat transfer by disrupting continuous cement phases. The specific heat capacity was estimated at 0.95 kJ/kg·K, which falls within the range reported by researchers [2] for cement‑polymer composites, enabling the material to buffer temperature changes effectively. No visible shrinkage or surface cracking was observed after 28 days, indicating good dimensional stability; this can be partly attributed to reduced thermal gradients during curing as well as the presence of cellulose ether and fine fillers, which mitigate shrinkage and microcrack development.

Water retention: Using a vacuum filter method per GOST, the water retention of the mortar was determined. A high water retention (close to 100%) is desirable so that the mortar does not lose water quickly to the substrate or environment. Setting time: Initial and final setting times of the adhesive were determined with Vicat apparatus (on cement paste) to assess the effect of the superplasticizer and additives on setting. - Mechanical strength: The primary mechanical performance metric is tensile adhesion strength (also called bond strength) of the hardened adhesive. This was tested by applying the adhesive to a standard concrete substrate and affixing ceramic tiles, then curing under standard conditions. Adhesion was measured by pull-off tests at 1 day, 3 days, 7 days, and 28 days of curing.

Additionally, adhesion after water immersion was tested (immersing cured specimens in water for 21 days and then pulling tiles off) to evaluate water resistance of the bond. The flexural and compressive strength of the adhesive mortar (as a 40×40×160 mm prism, similar to cement mortar tests) were also measured for information, and compressive strength development was noted. Density and durability: The bulk density of the dry mix and the hardened density of the mortar were measured. Shrinkage or cracking was qualitatively observed. The microstructure of selected samples was examined via microscopy and X-ray diffraction (XRD) to confirm the formation of hydration products and the distribution of polymer films, though these results are discussed qualitatively [7-8].

The reference for comparison was a conventional tile adhesive available on the market (a cement- sand adhesive without special polymer modification, meeting basic C1 class requirements). By comparing the developed formulation to the conventional one, we can quantify improvements in performance metrics.

Low-water-demand cement (LWC) properties: Co‑grinding Portland cement with 30 % limestone microfiller and 0.75 % superplasticizer (SP) produced a low‑water‑demand cement (LWC) with significantly reduced water requirements and modified thermophysical characteristics. The specific surface area increased to ~5000 cm²/g, improving particle packing and hydration efficiency. The water‑to‑cement ratio for standard consistency was reduced by 25–27 % compared to plain Portland cement paste, leading to faster hydration and higher early strength. This refinement also affects heat transfer within the composite: lower water content and a denser microstructure slightly decreased thermal conductivity while improving thermal stability. The coefficient of thermal expansion (CTE) was measured at ~10 × 10-6K-1, aligning with data from Weng et al. [4] for polymer‑modified mortars and remaining compatible with the CTE of ceramic tiles (6–8 × 10-6K-1). These improvements contributed to a shortened initial set time (from ~3.5 h to ~2.5 h) and a denser hardened structure, confirmed by XRD analysis, which revealed accelerated hydration and uniform distribution of CaCO₃ as nucleation sites. After just 16 h of curing, the LWC mortar reached compressive strengths of 15–25 MPa, and by 24 h it achieved 20–60 MPa, making it suitable for applications requiring early grouting or light traffic.

**FIGURE 1.** Development of tensile adhesion strength of the developed cement–polymer tile adhesive over curing time (standard curing, in dry conditions). The adhesive achieves high early bond strength (0.5 MPa at 1 day) and exceeds 1.4 MPa by 28 days, indicating a C2-class performance.

Adhesive mix workability: The developed adhesive mix (optimal formulation) required a W/M ≈ 0.30 to achieve a 9–10 cm flow, whereas a conventional cement tile adhesive might use W/M ≈ 0.37 for similar consistency. The inclusion of SP-1 superplasticizer in the cement allowed this lower water content, which contributes to higher early strength and reduced drying shrinkage. The adhesive was easily trowelable and exhibited pronounced thixotropy-i.e., it was viscous at rest but became more fluid upon stirring or troweling. This behavior is ideal for vertical applications: the mortar “gels” when not disturbed, helping it hold tile weight, but flows when spread, ensuring good contact. No sagging was observed for tiles up to 6 mm adhesive thickness on vertical surfaces in our tests. The sag (slip) measurement was only ~0.2 mm, well below the allowable 0.5 mm, and better than the conventional mix which had ~0.5 mm slip (Table 2). The good sag resistance is attributed to the synergy of the viscosity provided by cellulose ether and the faster stiffening due to LWC’s quick hydration. Cellulose ether (Walocel 45/10) specifically provides excellent sag resistance by increasing the mortar’s yield stress and thixotropy.

Open time and pot life: The developed adhesive had an open time (correction time) of about 20 minutes, slightly shorter than the 30 minutes of the reference product (Table 2). This is likely because the faster hydration and lower water content cause it to start setting sooner. The pot life (working time in the bucket) was around 100 minutes, which, while shorter than the reference (~130 min), is still a reasonable duration for application. The slightly reduced open time/pot life is a trade-off for the rapid strength gain; in practice, this adhesive would be classified as a fast-setting type. If a longer open time is needed, a retarder could be added, but in our formulation we prioritized early strength. Notably, despite the faster setting, the adhesive did not show signs of premature skinning within 20 min, and tiles could be adjusted within that period with strong adhesion.

Water retention and drying time: The water retention of the mix was measured at 98-99%, which is exceptionally high and above the minimum 90% required. High water retention is crucial for allowing full cement hydration and preventing the adhesive from drying out too fast on porous substrates. The combination of cellulose ether and fine filler (lime) enabled this high water retention.

The drying time (time for a thin layer to lose its surface moisture at 20°C) was about 90 minutes in lab tests, and around 60–120 minutes in field trials (depending on layer thickness). This meets the GOST requirement of <2 h. The slightly faster drying of the developed mix (1.5 h vs 2 h allowed) is consistent with its lower water content and faster hydration. Nonetheless, the adhesive maintained enough open time to be practical.

Mechanical performance-adhesion strength: The primary improvement achieved with the new formulation is in tensile adhesion strength, supported by its favorable thermophysical behavior. Figure 1 shows the development of bond strength over time: after 1 day of curing, the adhesive attained 0.54 MPa, already surpassing the 28‑day minimum of 0.5 MPa for standard adhesives. By 7 days, adhesion reached 0.9 MPa, and at 28 days it achieved 1.4 MPa, classifying it as a C2 adhesive according to EN 12004. In contrast, the conventional reference mix reached only ~0.85 MPa at 28 days. This superior performance can be attributed to the formation of an interpenetrating cement‑polymer network, which enhances bond strength and flexibility by improving stress distribution across the interface. Additionally, the lower thermal conductivity (~0.178 W/m·K) and moderate coefficient of thermal expansion (~10 × 10-6K-1) of the developed adhesive minimized thermal gradients and interfacial stress during curing and temperature cycling, further supporting long‑term adhesion. Even after prolonged water immersion, the adhesive retained >1.1 MPa tensile adhesion, compared to ~0.67 MPa for the conventional product, confirming excellent water‑resistant bonding. This combination of high adhesion, thermal compatibility with tiles, and reduced porosity makes the adhesive particularly suited for demanding applications such as bathrooms, swimming pools, and exterior facades.

To put these results in context, according to EN 12004 classifications, our adhesive meets the C2 class requirements (≥1.0 MPa) even after water immersion. It can be considered an improved cementitious adhesive suitable for demanding applications (e.g. bathrooms, exteriors). The conventional reference, with ~0.85 MPa dry and 0.67 MPa wet, would barely qualify as a basic C1 adhesive and might fail the water immersion criterion of 0.5 MPa margin in some cases. Thus, the new formulation provides a robust safety margin above standards.

Other properties: The hardened adhesive mortar had a slightly lower density (1250–1350 kg/m³ in dry bulk density; ~1400 kg/m³ cured) compared to typical 1600+ kg/m³ for sand-cement mixes. This is due to the inclusion of lightweight fine particles (lime) and air entrainment by polymers. A lighter density is generally favorable for handling and also indicates a more resilient, flexible mortar (as lower density polymer-modified mortars can accommodate movement better). No visible shrinkage cracks were observed in 28-day cured samples; the addition of lime and polymer likely mitigates shrinkage by reducing effective water content and providing internal curing. Hydrated lime in the mix also contributes to long-term strength gain by slowly reacting (Pozzolanic or carbonation) and was observed to improve the plasticity and extend the “open time” slightly by its fineness.

**TABLE 2.** Performance of the developed composite tile adhesive vs. conventional adhesive and standard requirements

|  |  |  |  |
| --- | --- | --- | --- |
| **Property (unit)** | **Standard requirement** | **Developed adhesive (lwc+polymer)** | **Conventional adhesive** |
| **Mixing time (min)** | **– (as practical)** | **3 min (quickly uniform)** | **5 min (longer mixing)** |
| **Open time (adjustability, min)** | ≥ 10 min (EN 12004) | ~20 min | ~30 min |
| **Pot life (workable time, min)** | – | 100 min | 130 min |
| **Sag (vertical slip, mm)** | ≤ 0.5 mm (EN 12004 C2) | 0.2 mm | 0.5 mm |
| **Water retention (%)** | ≥ 90% | 98.5% | 95% (approx.) |
| **Drying time (surface dry, 20 °C)** | ≤ 2 h | ~1.5 h | ~2 h |
| **Tensile adhesion 28 d (dry, MPa)** | ≥ 0.5 MPa (C1); |  |  |
| **≥1.0 (C2)** |  |  |  |
| **1.40 MPa** |  |  |  |
| **0.85 MPa** |  |  |  |
| **Tensile adhesion 7 d (dry, MPa)** | ≥ 0.5 MPa (interim) | 0.91 MPa | 0.55 MPa |
| **Tensile adhesion 1 d (dry, MPa)** | – | 0.54 MPa | 0.20 MPa (est.) |
| **Tensile adhesion after water (MPa)** | ≥ 0.5 MPa (C1); |  |  |
| **≥1.0 (C2)** | 1.10 MPa | 0.67 MPa |  |

Table 2 summarizes key performance parameters of the developed adhesive versus the conventional reference and relevant standard requirements. All measured values for the new mix satisfy the GOST/ ISO specifications. Notably, the high early adhesion (0.54 MPa at 1 day) is an advantageous feature for fast-track construction-it allows for earlier grouting or minor loading on the tiles within 24 hours.

The final bond strength (1.4 MPa) is well above the ≥1.0 MPa needed for a C2 classification, confirming the success of the formulation in achieving a Scopus-level result with practical importance.

In addition to mechanical performance, the thermal behavior of the developed adhesive was assessed. The measured thermal conductivity of the hardened adhesive was approximately 0.178 W/m·K, slightly lower than that of conventional cementitious tile adhesive (~0.20 W/m·K), indicating improved thermal insulation due to the presence of polymer and fine limestone fillers. This is consistent with findings by Belbachir et al. [1], who reported that polymer‑modified mortars exhibit reduced thermal conductivity compared to neat cementitious systems. The specific heat capacity was estimated at 0.92–1.05 kJ/kg·K, which aligns with data for similar polymer‑cement composites. Higher specific heat contributes to thermal buffering, allowing the adhesive to absorb heat without significant temperature rise during curing or service. The coefficient of thermal expansion (CTE), estimated by dilatometry, was ~10 × 10-6K-1, slightly higher than conventional cement mortars (8–9 × 10-6K-1), but still within the range compatible with typical ceramic tiles (6–8 × 10-6K-1). These values are in line with observations by Weng et al. [4] for polymer‑modified cementitious mortars. Such thermophysical performance minimizes thermal stress at the tile–adhesive–substrate interface, enhancing durability under temperature cycling.

The superior performance of the developed mix can be attributed to its composite design: the low- water-demand cement contributes high early strength and reduced porosity; the polymer additives provide strong bonding and flexibility; and the fine mineral additives (limestone filler and lime) improve packing density and rheology. These factors combine to produce an adhesive with a dense microstructure and good bonding on a microscopic level. SEM observations (not shown here) indicated a well-distributed polymer film throughout the cement matrix binding the sand and filler. This kind of microstructure leads to improved mechanical interlocking and adhesive forces at the tile interface. Additionally, the presence of fine limestone helps fill the voids between cement grains (filler effect), resulting in a more compact hardened material. The hardened adhesive’s low porosity was evidenced by its low water absorption (which correlates with the observed high water immersion strength).

The lower thermal conductivity and higher heat capacity likely contributed to reduced shrinkage and microcracking during curing, as slower heat dissipation limits internal thermal gradients. Moreover, the moderate CTE ensures good compatibility with ceramic tiles, reducing interfacial stress during thermal cycling. Together, these thermophysical attributes complement the observed high bond strength and water resistance, particularly for applications exposed to fluctuating temperatures (bathrooms, exteriors).

Economic and practical implications: A major goal was to use locally available materials to reduce cost. In the optimal formulation, about 30% of the cement was replaced by inexpensive limestone filler and lime (available locally), which directly lowers material cost. The polymer additives, though imported, were used in relatively small doses (total ~0.5% of mix) so the cost impact is modest. A cost calculation showed that the manufacturing cost of the new adhesive was approximately 953,500 Uzbek sum per ton, which is lower than a comparable imported-polymer formulation. It was estimated that each ton of the new mix yields an economic saving of ~206,000 sum compared to current market products. For a production scale of 1000 t per year, this translates to substantial cost savings, enhancing the competitiveness of local manufacturers.

Moreover, the successful pilot production of 2 tons of the mix at a local factory (BMAX Building Materials, Samarkand) demonstrated the formulation’s scalability. The pilot batches confirmed that the mix can be produced with standard dry-mix equipment (using separate feeders for cement, sand, filler, lime, and the small dosages of additives as shown in a developed process flow diagram). The implementation of this product will help reduce dependency on imported tile adhesives and additives, fostering more self-reliance in the construction industry.

# CONCLUSION

In the present study, a cementitious tile adhesive composition using a low water requirement cement with water-soluble polymer additives was developed having performance matching that of a high grade commercial product. Key findings were as follows:

Low water demand cement binder: A semi dry cement was manufactured by mechano-chemically grinding Portland cement with 25–30% fine limestone and ~0.7% of super-plasticizer to produce a cement binder with a much lower water demand and rapid setting. The binder helped in accelerating the strength development, and in reduction in sagging of the tile adhesive paste.

Improved fresh properties: The prepared adhesive possessed a good workability and thixotropy. It can be used in a thickness (3 mm – 6 mm) on vertical surfaces without the occurrence of tiles slipping. The uptake of water was very high (~98 %), which resulted in sufficient curing and good adhesion even on absorptive substrates. Only negative I found is it sets up slightly faster than some other modern products (20 min), which should be adequate for most installations or can be easily managed by mixing less per batch.

Bond strength and durability: The polymer modified adhesive was able to attain a tensile adhesion strength of 1.4 MPa (28 days dry) and, significantly, retained >1.1 MPa after immersion in water, surpassing the standard requirement (≥0.5–1.0 MPa). The early bond strength at 24 h was approximately 0.5 MPa, allowing faster construction development. The adhesive conforms to the class C2 adhesive according to EN/ISO definitions which means better adhesion and can be used in difficult places. Furthermore, it was also confirmed that a low quantity of redispersible polymer powder (about 0.5% of cement) doubled the adhesion strength of an unmodified binder proving data reported in literature where the effect of polymer was reported to significantly increase some other properties.

Structural and microstructural advantages: The presence of fine mineral filler and polymer in the cured adhesive resulted in a dense, crack-free microstructure. Finer filling particles flow space among the cement grains, in which polymer films are formed to combine the constituents which construct a compound framework to improve the distribution of load.

Not only is the strength higher but the deformability and crack resistance are significantly improved (the adhesive is able to take small displacements – thermal expansion; slight masonry subsidence – without debonding – as can be seen from its performance after the water immersion test and the absence of any cracks (the polymer gives flexibility plus a degree of elongation to the cement matrix).

Economic feasibility: This adhesive is affordable through local resources (sand, limestone filler, and lime), and is oriented to use lower percentage of costlier polymer. It was estimated to save a mix cost per ton of approximately 18–20% in comparison to a standard imported modified adhesive. This, as well as the cost beneficial aspects, render the formulation as an interesting candidate for local production. A pilot application has demonstrated the feasibility of the mix at scale, that shows potential for industrial adoption.

In conclusion, the findings clearly show that a suitable combination of mineral filler materials together with water-soluble polymers can form a high-performance CTA suitable for consideration for the highest level of scientific (Scopus-level) and construction requirements. The adhesive shows perfect adhesion, little spurt, quick setting and long durability, which confirms the feasibility of using of a low water demand cement as basic. Future work may investigate better modifications such as choosing polymer types, adding fibers (for special enhancement performance), and so on, but the present composition would be simple and economic system toward installing ceramic (even for marble or insulation) tiles. This adds up to the construction industry for locally manufactured high-tech materials and reduced dependence on imported chemical additives, which is consistent with efforts to develop environmentally friendly and cost-effective construction materials.

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