ENDBERICHT

Projektnummer oder Projekttitel: FO999899234
Richtwert für den Umfang: 10 bis 20 Seiten

1 ZIELE UND ERGEBNISSE

– Vergleichen Sie die erreichten Ergebnisse mit den Zielen, die dem Förderungsvertrag zugrunde liegen. Wurden die Ziele erreicht?
– Beschreiben Sie „Highlights" und aufgetretene Probleme bei der Zielerreichung.

This fifth year project achievements include:

- The development of reliable protocols and expertise to analyse binders using X-ray powder diffraction (XRPD) and X-ray fluorescence (XRF).
- The establishment of a protocol to reliably measure local velocity of a cementitious slurry sheared within two parallel plates using particle image velocimetry (PIV).
- The design, machining and assembly of an autogenous shrinkage setup (no exchange of humidity with the environment).
- The physical-chemical characterization of a sustainable binders including alkali-activated slags, OPC-recycled brick binders using XRPD, XRF and mechanical testing.
- The physical-chemical characterization of old mortars from the Gründerzeit and the proof of concept of their reinforcement using waterglass.
- The manufacturing of large scale (180x75x15 cm^3) sloped composite concrete floors. The overlays were instrumented with distributed fiber optics sensors (DFOS) and strains were recorded in many locations and in the 3 directions.
- The manufacturing of light-weight concretes (density ca. 1210 kg/m^3 and 28-D compressive strength between 10 and 20 MPa) using a new method of bottom-up infiltration.

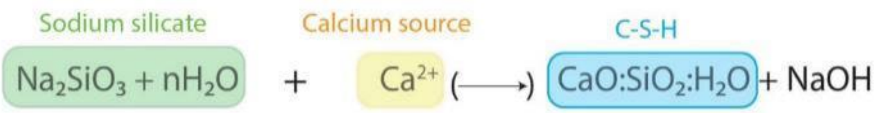
Specific work packages are described in section 2.2 with project abstracts in the next pages.
The team (co-authors of reports) is composed of Benedetta Costa, Dana Daneshvar, Karl Deix, Subhransu Dhar, Johannes Kirnbauer, Teresa Liberto and Agathe Robisson.

Projekt 1: Altmörtelsanierung (WP5, WP7)

Benedetta Costa, Teresa Liberto, Agathe Robisson

Kurzfassung

Die Skyline der Stadt Wien wird bis heute durch das Vorhandensein von gemauerten Gebäuden aus der Gründerzeit (1840-1915) bestimmt. Die Instandhaltung dieser Gebäude sowie ihre Konsolidierung für die Erdbebensanierung und den Ausbau von Dachböden sind wichtig. Der Verfestigungsprozess dieser Gebäude erfolgt in der Regel mit Epoxidharz, einem Duroplast mit niedriger Viskosität, d. h. es ist leicht zu injizieren und reagiert sehr schnell. Das Vorhandensein von ausgehärtetem Epoxidharz führt zu verbesserten mechanischen Eigenschaften des Mauerwerks, ohne sein ästhetisches Erscheinungsbild zu beschädigen oder zu verändern.
Die Verwendung von Epoxidmaterialien kann jedoch Probleme auslösen, indem sie die Wasserdampf-Durchlässigkeitsraten verändern, die Struktur zu stark versteifen und den Recyclingprozess erschweren. Auch das Treibhauspotenzial von Epoxidharz ist sehr hoch.
Ziel dieses Projektes ist es, neue Injektionsmaterialien zu untersuchen, die Epoxidharz ersetzen könnten. Das Ersatzmaterial sollte niedrigviskos sein und ausreichend reagieren, um die Mörtelfestigkeit zu erhöhen.
Zunächst wurde ein alter Mörtel beschafft und charakterisiert. Die Charakterisierung mit der Röntgenpulverbeugung (XRPD) und der Röntgenfluoreszenz (RFA) ermöglichte die Identifizierung der Oxidzusammensetzungen und des Phasengehalts. Zerkleinerung, Siebung und Rheologie halfen, die Bindemittelphase von den Zuschlagstoffen zu trennen. Ein Säureangriff konnte das Verhältnis von Bindemittel zu Aggregat offenbaren, unter der Annahme, dass das Bindemittel hauptsächlich karbonatischer Natur und die Aggregate von silikatischer Natur sind.
Als nächstes wurde Wasserglas als potenzielles Ersatzmaterial identifiziert. Sein Treibhauspotenzial ist mindestens halb so hoch wie das von Epoxidharz und sollte nach der Reaktion in Calciumsilikathydrat (C-S-H), das Haupthydratationsprodukt von Zement, umgewandelt werden. Die Reaktivität des Wasserglases mit dem alten Mörteln wurde durch die Herstellung einer Mischung der Feinfraktion (<250 µm) des Mörtels beurteilt. Die Reaktivität wurde durch die Zugabe von Portlandit und Calciumcarbonat als Quelle für Calciumionen verbessert.
Schließlich wurde angesichts der Knappheit an echtem altem Mörtel ein Modellmörtel entworfen. Es wird für zukünftige Studien dienen und den Zugang zu einer ausreichenden Menge an Mörtel für weitere Tests garantieren.



Vereinfachte Reaktion für die C-S-H-Bildung durch das Vorhandensein von Natriumsilikat (Wasserglas)

Projekt 2: PIV-Untersuchung zementärer Materialien, Heterogenitäten während der Strömung (AP3)

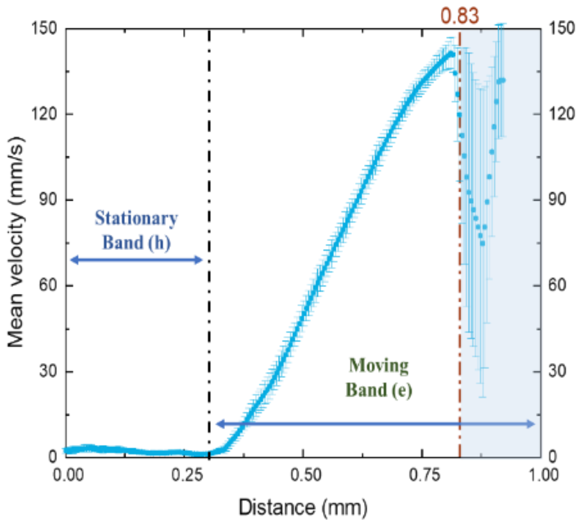
Subransu Dhar, Teresa Liberto, Agathe Robisson

Kurzfassung

Das Auftreten einer heterogenen Strömung kann zu fehlerhaften Daten führen, wenn ein Rheometer zur Messung der Eigenschaften von frischem Zementleim verwendet wird. In Projekten des vergangenen Jahres wurde ein Faktor von mehr als 10 gezeigt, wenn verschiedene Geometrien zur Messung der Streckgrenze des Zementleimes verwendet wurden. In diesem Jahr haben wir die Particle Image Velocimetry (PIV) mit einer Hochgeschwindigkeitskamera implementiert, um das am Rand der rotierenden Platte gemessene Geschwindigkeitsprofil in einer parallelen Plattengeometrie zu analysieren.

Die Ergebnisse wurden erfolgreich erzielt und bestätigen ein stationäres Band im Zementleim in der Nähe der Bodenplatte. In der Nähe der oberen Platte wurde PIV schwierig, da der Zement unscharf war, aber die Analyse der Bilder (die mit sehr hohen Bildrate aufgenommen wurden) zeigte, dass sich der Zement mit der oberen Platte drehte, d. h. als Pfropfenströmung (keine Scherung). Zwischen diesen zwei ungescherten Bändern wurde der Zement ziemlich homogen geschert und zeigte ein eher lineares Geschwindigkeitsprofil.

Diese Technik ist entscheidend, um zu verstehen, wie Zement und andere zementartige Materialien fließen, d. h. wie sie sich beim Gießen oder Pumpen verhalten und wie sich dieses Verhalten mit der Zeit ändert.



Geschwindigkeitsprofile Profil während des rheologischen Fließtests mit paralleler Platte. Geschwindigkeit der oberen Platte von 150 mm/s erreicht. Der Abstand zwischen den Platten beträgt 1 mm. Der schattierte Bereich stellt eine dünne Zementschicht (~0,15 mm) dar, die sich mit ihr dreht und außerhalb des Fokus des Objektivs lag.

Projekt 3: Nachhaltiger Beton: alkaliaktivierte Bindemittel, Recyclingziegel, Recyclingbeton: eine Multiskalenstudie (AP5, AP7, AP9)

Teresa Liberto, Dana Daneshvar, Johannes Kirnbauer, Agathe Robisson

Kurzfassung

In diesem Projekt wurden mehrere nachhaltige zementäre Materialien untersucht, um Klinker teilweise oder vollständig zu ersetzen. Insbesondere wurden weitere Charakterisierungstests an schlackenbasierten alkaliaktivierten Bindemitteln (AAS) durchgeführt, die zufriedenstellende mechanischen Eigenschaften bei geringer Umweltbelastung aufweisen. Der Schwerpunkt dieser Forschung liegt auf der Abschätzung der frühen und langfristigen Hydratationsprozesse von AAS, um ein breiteres Verständnis des Kraftaufbaus vom ersten Kontakt mit Wasser bis zum Abbinden zu erhalten. Rheologische Tests wurden bei unterschiedlichen Wasser-Bindemittel-Verhältnissen durchgeführt, um den Strukturaufbau zeitlich zu verfolgen. Kalorimetrie und Röntgenpulverbeugungsmessungen klärten die Kinetik der Hydratation an frischen und festen AAS-Pasten. Die Kombination dieser Techniken zeigt, dass nach einer Stunde nach dem ersten Kontakt mit Wasser die Reaktivität von AAS aufgrund einer schnelleren Ausfällung von C-S-H (Calciumsilikathydrat) schnell ansteigt. Dieser Niederschlag setzt sich im Laufe der Zeit fort und ist für das Abbinden der Paste verantwortlich. Darüber hinaus wurde die Haltbarkeit (d. h. Schwindung) von Standard-AAS-Mörtelprismen untersucht und die hohe Empfindlichkeit von AAS gegenüber Feuchtigkeit oder deren Fehlen hervorgehoben. Eine verbesserte Haltbarkeit von AAS-Mörteln kann ihre Verwendung als nachhaltige zementäre Materialien in der Industrie fördern.
Eine weitere Studie zielte darauf ab, zementäre Mischungen zu optimieren, indem gewöhnlicher Portlandzement (OPC) teilweise durch recycelte Ziegel (RB) ersetzt wurde. Es wurden mehrere Mischungsdesigns untersucht, die einen OPC-Ersatzanteil von 10 % bis 90 % umfassten.
Die Korngrößenverteilung der gemahlenen RB war auf die von OPC abgestimmt, um eine gleichbleibende Packungsdichte zu gewährleisten.
Die Röntgenpulverbeugung (XRPD) wurde eingesetzt, um die chemische Zusammensetzung und die mineralogischen Phasen des recycelten Ziegelpulvers zu untersuchen.
Ausbreitungstests wurden durchgeführt, um den Wasserbedarf von Pasten mit unterschiedlichen OPC-RB-Verhältnissen zu ermitteln.
Nach diesen Vorversuchen wurde für alle Mischungszusammensetzungen ein Wasser-Bindemittel-Verhältnis w/b von 0,5 angenommen. Fließmittel (PCE) wurde ebenfalls hinzugefügt, um eine geeignete Verarbeitbarkeit und Konsistenz zu gewährleisten. Kleine oszillatorische Rheologie (SAOS) wurde durchgeführt, um die frühe Kohäsionsentwicklung der Pasten zu verfolgen. Diese Messungen trugen dazu bei, einen Versteifungskoeffizienten G'_{rigid} zu bestimmen, der mit der Ausfällung von Hydratationsprodukten durch ein theoretisches thixotropes Modell verbunden ist. DieThermokalorimetrie wurde auch verwendet, um die Hydratationswärme für Pasten mit unterschiedlichem RB-Gehalt zu quantifizieren, wobei eine deutliche Abnahme mit dem Anstieg des RB-Gehalts gezeigt wurde. Diese Beobachtung

korreliert mit den Ergebnissen der Festigkeitsentwicklung, die darauf hindeuten, dass ein höherer Ersatz von OPC durch RB mit einer niedrigeren proportionalen Druckfestigkeit einhergeht. Die Druckfestigkeit skaliert nämlich linear mit dem OPC-Gewichtsgehalt.

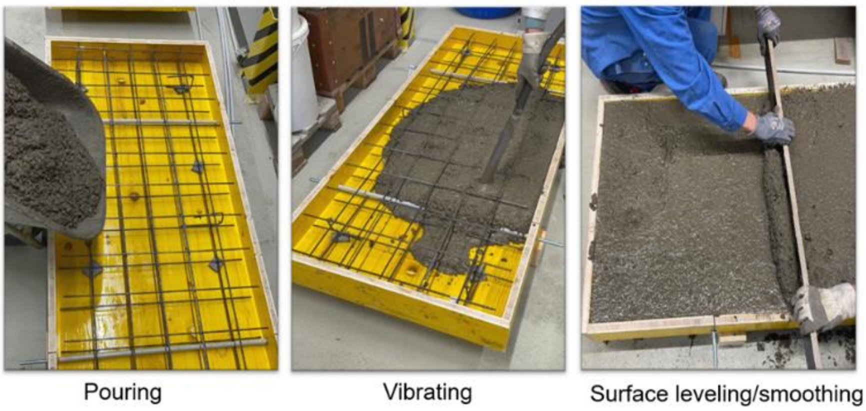
Die Integration von Ziegelpulver als Ersatz für Zement führt zu Komplexitäten, welche die Hydratationsprozesse verändern und die Materialeigenschaften beeinflussen. Während Ziegelpulver aufgrund seiner nicht reaktiven Natur zunächst die Verarbeitbarkeit beeinträchtigen kann, kann dieser Effekt durch den Einsatz von Fließmitteln effektiv gesteuert werden. Interessanterweise zeigt die Studie, dass Test in frühem Alter, einschließlich SAOS- und Kalorimetriemessungen, wertvolle Einblicke in Festigkeitsentwicklung im Laufe der Zeit liefern können.

Projekt 4: Grenzflächen: Verhalten von UHPC als Auflage in geneigten Böden: Einfluss des Winkels auf das Versagen durch Trocknungsschwindung. (AP6)

D. Daneshvar, K. Deix, A. Robisson

Kurzfassung

Eine dünne Schicht Ultrahochleistungsbeton (UHPC) als Aufbeton hat sich als dauerhafte Alternative zu normalem Beton (NC) erwiesen und bietet eine Schutzschicht, um die Lebensdauer von zivilen Infrastrukturkomponenten wie Brückendecks und Straßenbelägen zu verlängern. Bei diesen Anwendungen ist in der Regel eine geneigte Auflage erforderlich, um den Abfluss des Oberflächenwassers zu erleichtern und die Gefahr des Schleuderns von Fahrzeugen, insbesondere in Kurven, zu verringern. Das behinderte Schwinden in Verbundbetonsystemen kann jedoch zur Entwicklung von Spannungen führen, die zu Oberflächenrissen im Aufbeton und zu Ablösungen an der Grenzfläche führen. Das diesjährige Projekt untersucht das behinderte Schwinden in geneigten UHPC-NC-Verbundwerkstoffen und dessen Einfluss auf die Rissentwicklung. Zu diesem Zweck wurden herstellerunabhängige UHPC-Mischungen mit kontrollierten rheologischen und mechanischen Eigenschaften entwickelt, die Gießneigungen von bis zu 20 % ermöglichen. In den experimentellen Tests wurden systematisch die Auswirkungen der wichtigsten Überlagerungseigenschaften untersucht, einschließlich geometrischer Details (z. B. Dicke und Steigung) und Mischungseigenschaften (z. B. Fasereinschluss und Bindemittelzusammensetzung). Um die zeitabhängige Reaktion richtig zu erfassen, wurde eine Serie UHPC-NC-Proben mit den Abmessungen von 180×75×15 cm3 und einer Neigung von bis zu 8 % gegossen. Integrierte, gleichmäßig verteilte faseroptische Sensoren (DFOS) wurden eingesetzt, um die fortschreitenden Verformungen innerhalb des UHPC-Overlays zu überwachen. Es wird erwartet, dass dieses Studienergebnis dazu beitragen wird, die Verwendung von UHPC für Brückendecks und -auflagen zu maximieren, indem es sich auf die potenziellen Probleme der Schrumpfung im frühen Alter konzentriert



Verschiedene Stufen des Gießens in NC-Substraten für die Herstellung von geneigten NC-UHPC-Verbundwerkstoffe

2 ARBEITSPAKETE UND MEILENSTEINE

2.1 Übersicht

Geben Sie in den folgenden Tabellen den Projektfortschritt je Arbeitspaket (bezogen auf den Förderzeitraum) und je Meilenstein an und führen Sie stichwortartig an, wo es zu Abweichungen gekommen ist.
Eine ausführlichere Beschreibung ist unter Punkt 2.2 möglich.

Tabelle 1: Fortschritt der Arbeitspakete (AP)

AP	Bezeichnung	Fort-schritt	Ergebnisse, Abweichungen, Verzögerungen
1	**Projektmanagement** **Project management**	100 %	Update-Meetings werden organisiert. Die Verbreitung während der Konferenz und der Publikationen wird verwaltet. Update meetings are organized. The dissemination during the conference and publications will be managed
2	**Stand der Technik** Literature	100%	Updates in Berichten für jedes WP. Updates in reports for each WP.
3	**AP 3: Entwicklung rheologischer Prüfungen und Verfahren** **WP 3: Development of rheological tests and procedures**	100%	High speed image recording was performed and images analyzed with particle image velocimetry (PIV). The velocity field could be identified over the whole gap and confirms shear banding in cement sheared between 2 parallel plates. The shear history was evidenced.

AP	Bezeichnung	Fort-schritt	Ergebnisse, Abweichungen, Verzögerungen
5	**Einfluss der Zementpartikelgrößenverteilung und beschaffenheit (Vorhandensein von nachhaltigen Bindemitteln) auf die Betonrheologie, die Schäumbarkeit, und das Erstarrungsverhalten** **Influence of cement particle size distribution and nature (presence of sustainable binders) on concrete rheology, foamability, and setting properties**	100%	Concurrent techniques of calorimetry, rheology, XRD. And mechanical testing were used to understand the behavior of binders made of alkali-activated slags (AAB) and recycled brick – OPC binders. The shrinkage of drying prims made with AAB was also measured, highlighting the sensitivity of this class of materials to humidity or lack thereof.
6	**Schnittstellen zwischen altem und neuem Betonen** **Interfaces between old and new concretes**	100%	Based on the numerical simulation of year 4, geometries were selected for the experimental campaign. Overlay materials (UHPC and recycled UHPC) were characterized fresh and hardened. A setup was custom-made to measure autogenous shrinkage. Composite specimen of 75 cm by 180 cm were prepared, with a slope of 8%. The overlays were instrumented with an array of optical fibers to measure strain evolutions in the 3 dimensions and in various places of the boards.

AP	Bezeichnung	Fort-schritt	Ergebnisse, Abweichungen, Verzögerungen
7	**Einrichtung zur Messung der Infiltration (Renovierung alter Mörtel)** **Device for the measurement of infiltration (Renovation of old mortars)**	100%	Old mortars from Gründerzeit were sourced and analyzed with XRD, XRF, rheology (for reactivity), and acid attacks. This characterization is crucial to understand how the repair material could react with the old mortar. The repair material was selected to be waterglass. Using mixtures of powdered mortar, waterglass and an extra source of calcium ions (portlandite and calcium carbonate), reinforcement ability of water glass was measured. The compressive strength increased from 0 (powder) to a few MPa. A model mortar was also designed to resemble the old mortar and its reactivity measured though compressive strength change and carbonatation.
9	**Einrichtung zur Charakterisierung von Volumenänderungen oder Begrenzungsdruck von RA-Betonen** **Device for characterization of volume changes or confining pressure of RA concretes.**	100%	A new setup was designed from scratch. Due to the high compliance of the custom-made frame, the setup was eventually installed on the Zwick machine and the compliance measured. The protocols are now in place and a successful experiment currently runs. Autogenous shrinkage measurements were performed in UPHC and R-UHPC.

AP	Bezeichnung	Fort-schritt	Ergebnisse, Abweichungen, Verzögerungen
10	**Hohe Wärmedämmung in einem doppelwandigen Turm** **High thermal insulation in a double-walled tower**	100%	The infiltration setup from year 3 was improved to sustain higher pumping pressure. Three binders were optimized and could infiltrate 1-m high packs of expanded clay beads of various sizes. The densities of the hardened lightweight concretes were measured between 1130 and 1210 kg/m3 and 28-D compressive strength between 10 and 20 MPa.

2.2 Beschreibung der durchgeführten Arbeiten

- Beschreiben Sie die im Berichtszeitraum durchgeführten Arbeiten aller beteiligten Partner, strukturiert nach den Arbeitspaketen.
- Konnten die Arbeitsschritte und -pakete gemäß Plan erarbeitet werden? Wo gab es wesentliche Abweichungen?

AP 3: Development of rheological tests and procedures

Motivation

Understanding heterogeneities in cementitious pastes under flow is essential to properly characterize these pastes. This is possible using particle imaging velocimetry (PIV).

Materials and methods

For imaging the sample between parallel plate, ordinary Portland cement paste was used (Der Contragress cement powder; C_3A-free, Lafarge-Holcim). To prepare 10 ml of the sample, the cement was mixed with distilled water in an ultra-turrax mixer (IKA) at a water/cement ratio of 0.4. Three steps were involved in the mixing. Step 1: The paste was mixed for three minutes at 6000 rpm. Step II: The sample was kept at rest for 10 minutes. Step III – Before loading the cement paste for experiments, it was further mixed for a full minute at the same speed.
Anton Paar rheometer was used for the rheology studies. Serrated parallel plates of diameter 25 mm was used and the gap between the plates was kept at 1 mm for all the experiments.

<u>Experimental protocol</u>

As observed earlier, flow heterogeneities were observed while measuring the yield stress of cement pastes: The paste in parallel plate geometry showed band formation under shear. To further investigate the behaviour of the band it was necessary to study the local velocity profile of the moving band. In order to observe the velocity profile a high-speed camera was used (Photron: Fast Cam. SA4). The camera was focused in the gap between the parallel plates.

PIV measurement

The cement paste was loaded and a gap of 1 mm was maintained between the top and bottom plates. Two separate experiments were carried out by imposing angular velocity of 3 and 6 rad/s to the top plate. The images were recorded at a speed of 6000 frames per second for the higher angular velocity and with 5000 frames per second for the lower one. The aspect ratio of an individual picture in pixels for the higher imposed angular velocity was 896x752 and 1024x800 for the lower imposed angular velocity. In both cases, images were recorded after a rest period of 120s from the onset of shear 301 consecutive images were analysed using MATLAB PIVlab toolbox.

Result and discussion

Velocity profile of the sheared cement suspension

Once the cement suspension was loaded in the rheometer parallel plates, a constant angular velocity was imposed to the top plate. Two experiments were done with imposed angular velocities of 3 and 6 rad/s, corresponding to edge velocities of 75 and 150 mm/s, respectively. Fig. 3.1 a and b represent the velocity profiles for the imposed angular velocity of 3 and 6 rad/s, respectively. In either of the velocity profiles, we observe a stationary band close to the bottom plate and then a sheared band. The formation of these two distinct bands has been reported in our earlier work. Close to the top plate, a region was out of the focus of the camera lens, and the region showed erroneous velocity vector values. It is marked by a shaded region in the Fig 3.1 a and b. A detailed visual observation of the series of images obtained showed that this layer of ~0.15 mm corresponded to a layer of cement which was moving with the plate rather than getting sheared (i.e., plug flow).

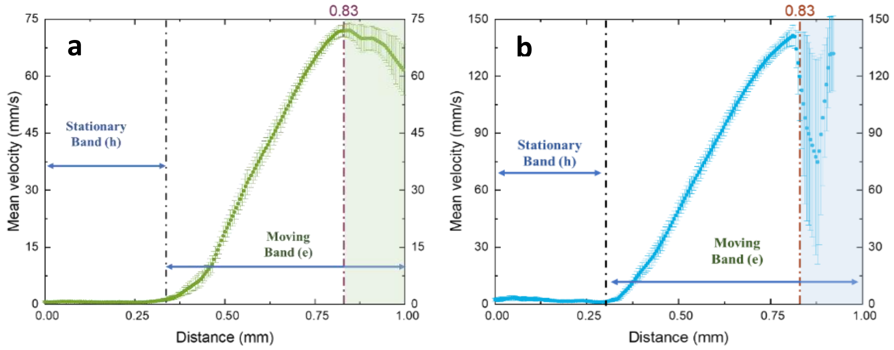


Fig. 3.1 - a and b respectively represent the velocity profiles for the imposed angular velocity of 3 and 6 rad/s. These angular velocities correspond to an edge velocity of 75 and 150 mm/s respectively. The gap between the plate was 1 mm. The shaded region represents a thin layer of cement (~0.15 mm) rotating along with it and was out of focus of the lens.

Finally, the influence of shear history on the behavior of cement pastes sheared within two parallel plate was evidenced. As shown Fig. 3.2, the torque response of a paste shear at 3 s^{-1}, either directly after being placed on the rheometer plate, or after being sheared 300 s at 6 or 0.6 rad.s^{-1}, is very different. After being sheared at low velocity (0.6 rad.s^{-1}), the torque is about a third of the un-pre-sheared sample.

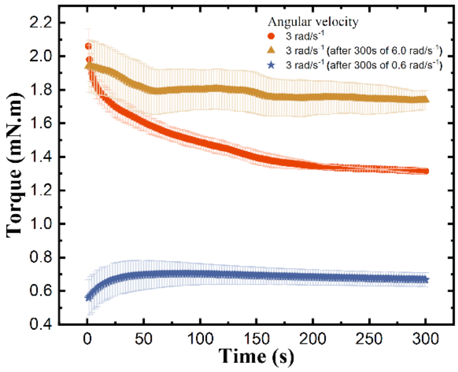


Fig. 3.2 – Influence of shear history on a cement paste – Torque evolution with time at constant imposed angular top plate velocity.

Conclusions

In the present work, we analyse the velocity profile of cement paste, sheared between a parallel plate rheometer, with upper rotating plate and stationary bottom plate. Initially the validity of the PIV code is successfully checked and the remaining experiments are then performed. On measuring the velocity profile of the 1 mm gap we observe a stationary band close to the bottom plate and a moving band close to the top plate. These results confirm our previous findings. We observe that within the sheared band, the velocity profile is linear. A thin layer of cement paste, of width ~0.15 mm, is seen to be attached to the top plate and rotating along with it.

Acknowledgements

Some of the measurements were performed at Univ. de Lyon, Université Claude Bernard Lyon 1, CNRS, Villeurbanne, France, in collaboration with Prof. Catherine Barentin.

AP 5: Influence of cement particle size distribution and nature (presence of sustainable binders) on concrete rheology, foamability, and setting properties

Fresh properties and durability of alkali-activated slag (AAS)

Motivation

AAS are part of the broader family of alkali-activated binders with slag as a precursor. They are a sustainable alternative to ordinary Portland cement (OPC), where OPC can be fully substituted by slag and liquid or solid activators. This study expands the previous results shown in the reports of years 3 and 4 by studying the properties of fresh and solid AAS pastes. Moreover, AAS standard mortar durability (focusing on shrinkage) was assessed.

Materials and methods

The formulation of the AAS was kept as in the previous studies and consisted: 91.5wt% of GGBS (Ground Granulated Blast-furnace Slag, Ecocem), 5wt% of Na_2CO_3,

and 3.5wt% of $Ca(OH)_2$. Fresh pastes at water to solid ratio w/s of 0.4, 0.5 and 0.6 were studied via small oscillatory rheology (i.e., SAOS). Calorimetry tests were performed at a w/s=0.4 using a custom-built semi-adiabatic setup. Fresh and solid pastes are studied via in-situ and ex-situ X-ray powder diffraction (XRPD), respectively, using the methods described in [1]. In-situ XRPD was made at w/s=0.6 to have a spreadable paste. Ex-situ XRPD were made at w/s=0.4 in time. To prepare AAS mortars following the ÖNORM EN 196-1, 4x4x16 cm^3 prisms were made with a w/b=0.5 and standard sand in a ratio of 1:3 by the weight of the binder.
The weight loss and drying shrinkage (according to DIN 52450) of AAS mortars were measured in time. Distilled water was used for all the formulations mentioned above.

Results and discussions

Paste fresh and solid properties

SAOS results are plotted Fig. 5.1. The averaged normalized elastic shear modulus $<G'_N>$ (captures structuration, i.e. buildup of cohesion) ($<G'_N(t)> = G'(t)/G'(0)$) is plotted as a function of time for AAS pastes at w/s equal to 0.4, 0.5 and 0.6. For each paste, a remixing after each hour of rest was done until mixing was not possible any more.

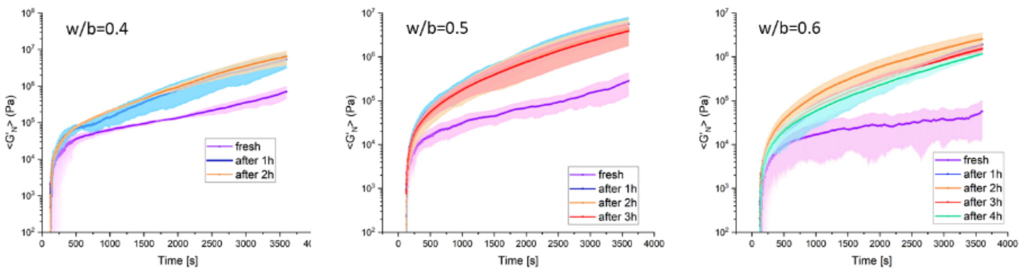


Fig. 5.1: Normalized elastic modulus $<G'_N>$ (captures structuration, i.e. buildup of cohesion) as function of time for AAS pastes at w/s (or w/b) equal to 0.4, 0.5 and 0.6. For each paste, a remixing after each hour of rest was done until setting. Three new samples were tested for each curve. ($<G'N(t)> = G'(t)/G'(0)$).

All three concentrations show an increase in cohesion after 1 h from contact with water, as well as a faster increase after the 1h-remix. This can be associated with the increase of calcium silicate hydrate precipitation rate, verified by in-situ XRPD presented below in Fig. 5.2 (top). Calcium aluminosilicate hydrates, abbreviated C-S-H or C-A-S-H in this report, are the main hydration product in AAS. Moreover, $<G'_N>$ increases with a decreasing amount of water, as expected.

In-situ XRPD curves on fresh AAS pastes (10’ to 450’ after contact with water) show an increase in low angle intensity, corresponding to the formation of early-age C-A-S-H. This increase became steeper after 1h (not shown here), confirming the results observed in rheology.

Drying shrinkage of AAS mortars

The results of the drying shrinkage and weight loss of standard AAS mortars in time are shown in Fig. 5.2.

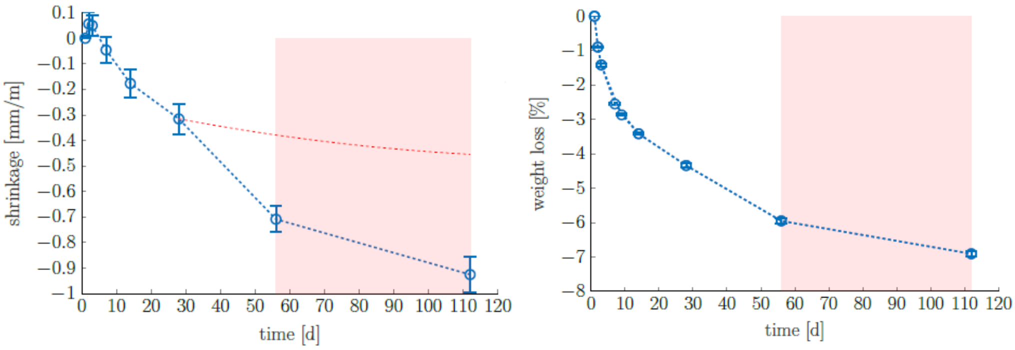


Fig. 5.2: Drying shrinkage (left) and weight loss (right) of AAS mortar in time. The red dotted line in the left box is the expected trend. The red box in both graphs highlights the days in which the storage conditions are unregulated.

The test prisms initially exhibited a slight swelling, but, after about 5 days, started to shrink. After 28 days, we would expect the shrinkage to converge to a plateau (as drawn in Fig. 5.3 by the red dotted line. These results highlight the key role of humidity in the curing of AAS mortars. Further studies with controlled RH are planned for the next future.

Conclusions

This study shows that alkali-activated slag pastes undergo a similar hydration mechanism to cement, both in fresh and solid states. Moreover, the formation of C-S-H start soon after contact with water and can be traced by small oscillatory rheology (i.e., SAOS) as well as in-situ XRPD. The structuration of C-S-H in time (days) is then responsible for the development of solid mechanical properties. Substantial shrinkage was measured in AAS mortars in low humidity conditions, demonstrating the key role of humidity during curing. Further studies with controlled RH are planned.

Acknowledgments

This work was partially done by Matthias Pudelko in the framework of his master thesis „Dauerhaftigkeit von schlackenbasierten, alkalisch aktivierten Bindemitteln (AAB)“ [2].

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Development of low-CO2 mortar with recycled bricks

Motivation

This study aimed to develop and optimize a cementitious mixture by partially substituting ordinary Portland cement (OPC) with recycled brick (RB) powder. Various mix designs are explored, with OPC replacement percentages ranging from 10% to 90%.

Materials and methods

The recycled brick powder is prepared from recycled bricks (Heulz UNI 25 plan + Wienberger Porotherm 25-38 Plan) through a multi-step process involving crushing, air suction and sieving. The process is adapted so that the particle size distribution (PSD) of brick powder matches as closely as possible the one of OPC. This ensures similar packing density in the wet mixture. Recycled bricks are crushed in a jaw crusher, and particles of different sizes are separated using air suction and then sieved. The portion going through the 63 micron sieve was used in this study. Laser diffraction spectroscopy is employed to measure the PSD and confirm size matching with cement particles.

X-ray powder diffraction (XRPD) is used to investigate the chemical composition and the mineralogical phases that constitute the brick powder. The sample is micronized to ensure an average particle size lower than 50 microns (Refer to AP7 for more details). A PANalytical X'Pert Pro was used in Bragg Brentano geometry. All the diffraction data were collected using a $COK_{\alpha1,2}$ radiation (1.789 Å). Thanks to the presence of an internal standard (ZnO), it was also possible to obtain a quantitative analysis (QPA) of the sample phases.

The heat of hydration is quantified using a TAM Air isothermal calorimeter to monitor the heat flow generated at a constant temperature of 25°C.

To measure strength evolution over time, many different mortar mixes were prepared, with the proportions by weight binder:sand of 1:3 and water to binder ratio 0.5. Mortar samples with 10%, 30%, 50%, 70%, and 90% brick powder replacement on a mass-to-mass basis are prepared. The samples were demolded after 1 day and then stored in a climate chamber at a temperature of 20 degrees Celsius and a relative humidity of 60% until the day of testing. Flexural and compressive strength tests are conducted on 3, 7, 28 and 56th day samples. Compressive strength measurements are carried out in triplicate samples (4x4x16 cm and 2x2x8 cm) and the normalized average results on the 28th day are reported.

Results and discussions

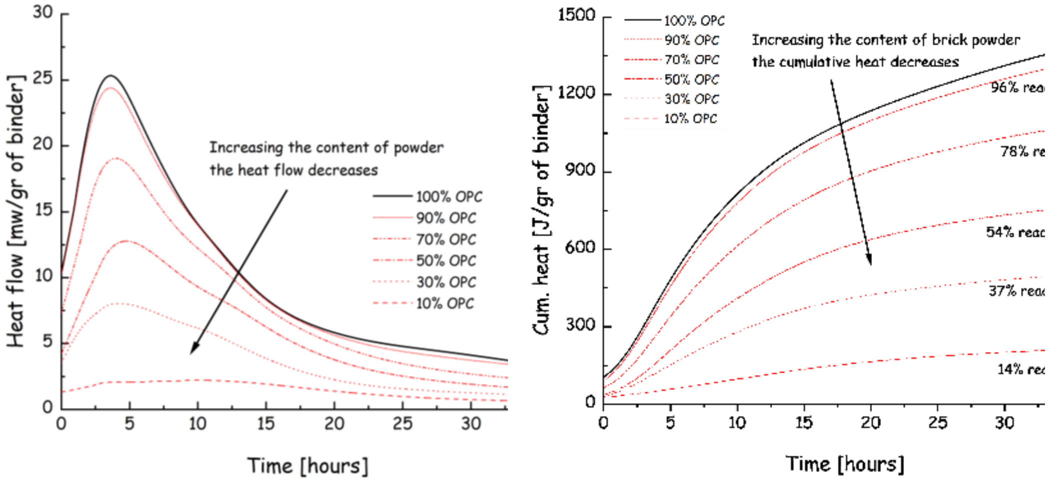
Due to the difficulty of the data interpretation (i.e., numerous peaks were overlapping), some phases present a slight imprecision on the quantity estimation.

Table 5.1. Mineral composition of reclaimed bricks from XRPD

Detected Phase	Quantity (wt. %)
Quartz (SiO_2)	~35
Amorphous	~21
Anorthite ($CaAl_2Si_2O_8$)	~14
Feldspar ($X(Al, Si)_4O_8$)	~5
Biotite ($K(Mg,Fe^{2+})_3[AlSi_3O_{10}(OH,F)_2)$	~5
Calcite ($CaCO_3$)	~4
Minor phases	~16

The water demand of pastes was then evaluated using the mini slump cone test, with varying amounts of OPC replaced by RB. Based on the findings, a water-to-binder ratio of 0.5 is chosen for all the mixes, and liquid superplasticizer (PCE) is added OPC/RB pastes to adjust the flow and maintain a workability comparable to 100% cement paste.

The heat flow and heat of hydration are shown for the different pastes in Fig. 5.5. The addition of brick powder as a cement replacement significantly hinders the reactivity, as expected and as observed by rheology.



a) b)

Figure 5.3 - a) Hydration heat flow evolution; b) Cumulative heat release

Compressive strength development with age shows a dependence on the cement replacement level. Higher replacement levels result in lower compressive strength compared to the control, with the strength linearly increasing with the OPC content (Fig. 5.4).

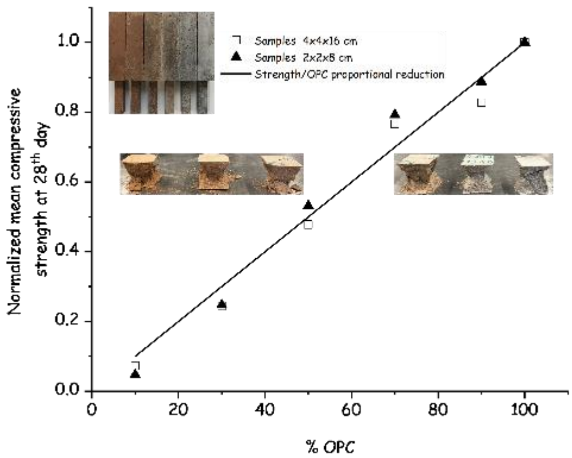


Fig. 5.4 – OPC-RB samples, Strength development at 28th day by varying OPC content

Conclusion

It becomes evident that the introduction of recycled brick powder as a replacement for cement introduces a complex dynamic system, wherein the reactivity of the mixture is hindered, potentially altering the rate and extent of hydration processes, and consequently affecting the overall mechanical properties of the resulting material.

The inclusion of recycled brick powder in concrete can have an impact on workability due to its non-reactive and high water absorption nature. However, it is demonstrated that this effect can be effectively mitigated by incorporating superplasticizers into the mix. It is important to note that the strength of the concrete is reduced proportionally to the content of brick powder. However, the potential benefit on utilization of brick powder offers the advantage of construction demolition waste reduction from discarded bricks. This not only promotes sustainable construction practices but also contributes to the efficient utilization of landfill space.

Acknowledgments

This report is based on the work made by Dr Milot Muhaxeri from the University of Prishtina (Kosovo) as a visitor researcher at TU Wien.

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AP6: Interfaces between old material and new concrete: Evaluation of Restrained Shrinkage Impact in Sloped UHPC-NC Composites: Experimental campaign and specimen preparation

Motivation

Thin bonded UHPC overlay is a durable, cost-effective, and sustainable solution to strengthen and protect the existing old concrete structures exposed to excessive loading and harsh environmental conditions. Repairing and strengthening with UPHC overlay covers a wide range of applications such as bridge decks, rigid pavements, slabs, and floors. A transverse cross slope is typically applied in the overlay to ensure the proper drainage of surface water and provide a level of safety to prevent car skidding while driving through road curves (superelevation).
Considering the outlined research gaps and questions, the current study established an experimental study to evaluate shrinkage in sloped UHPC-NC composites. The experimental tests systematically cover the effects of key overlay characteristics including overlay geometry (thickness and slope) and overlay material properties (fiber inclusion and recycled cementitious materials).

Materials and methods

Concrete mixtures

The normal concrete (NC) substrates were prepared with the DER CONTRAGRESS ordinary Portland cement (CEM I 42.5 N, C3A free). The average 28-day cube compressive strength of concrete was measured equal to 45.3 ± 1.6 MPa.
Typical UHPC mix designs are self-compacting, as the presence of superplasticizer reduces their yield stress. Developing a UHPC mix design that can be applied in sloped form with sufficient slope stability is a challenging task.

More than 50 different types of UHPC mixtures were considered and the relevant fresh, hardened state and slope stability characteristics were investigated. After all assessments, we specifically designed our non-proprietary UHPC with a 28-day compressive of 135 MPa that allows sloped casting by up to 20%.

To assess the impacts of overlay material composition, specifically fiber inclusion and recycled cementitious materials, on the shrinkage performance of UHPC-NC composites, we considered three different UHPC mix designs in this study namely reference, fiber-reinforced and fiber-reinforced recycled UHPC. The summary of developed UHPC mix designs are presented in Table 6.1. In recycled UHPC, 30% of cement was volumetrically replaced by the thermally activated milled recycled high performance (TmRHPC) powder. The TmRHPC power is a sustainable cementitious binder developed and characterized by the authors in a separate study. The promising performance of test samples made of TmRHPC motivated the authors to use and upscale this newly developed green cementitious in large UHPC overlay specimens and assess their shrinkage and structural performance.

Table 6.1 - UHPC mix designs

UHPC type	W/C	PCE (%)	PVA fiber (Vol. %)	Steel fiber (Vol. %)	Compressive strength at 28-D (MPa)	Flexural strength at 28-D (MPa)
Reference	0.26	2	-	-	135.3	14.1
Fiber reinforced	0.26	4	0.15	2	154.8	27.9
Fiber reinforced	0.32	4.5	0.15	2	138.1	26.6

Distributed fiber optic sensing (DFOS)

Distributed fiber optic sensors using Rayleigh scattering were implemented. Rayleigh backscattering Optical Frequency Domain Reflectometry (OFDR) provides a remarkably higher spatial resolution of up to 1 mm, an appropriate and reliable approach to monitor shrinkage and crack formations in concrete structures (Güemes & Soller, 2009).

Autogenous shrinkage

Given the importance of decorrelating drying shrinkage (exchange of water with the environment) from the autogenous shrinkage (no exchange of water with the environment), a custom-made setup was designed (see Figure 6.1) to individually measure and characterize the autogenous of UHPC mixtures in accordance with ASTM C1698.

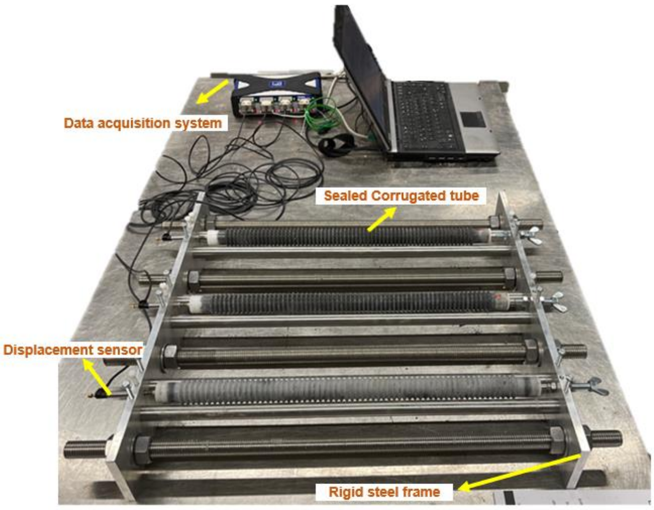

Figure 6.1 - Custom-made autogenous shrinkage setup at TUW

<u>Specimen preparation and casting</u>

In this study, six concrete UHPC-NC composite specimens with dimensions of 180 × 75 × 15 cm^3 were cast. As presented in Table 6.2, the specimens were divided into three groups concerning the UHPC overlay type and each group comprises two flat and sloped specimens.

Table 6.2 Categories of UHPC-NC specimens

Group	Specimen No.	Overlay	Slope (%)
1	1	REF-UHPC	0
	2		8
2	3	Fiber reinforced UHPC	0
	4		8
3	5	Recycled reinforced UHPC	0
	6		8

The thickness of NC was fixed to 10 cm in all specimens. Considering the recommended range of UHPC thickness in strengthening/repair applications, the UHPC thickness was chosen to be 5 cm in flat specimens. In sloped specimens, the thickness of the UHPC overlay on the thinner side was identical to that of flat specimens (5 cm), and the slope of 8% was applied in the longitudinal direction, reaching the thickness of 20 cm in the thicker edge. It must be highlighted that this steep slope, above 5%, was intentionally selected to assess the impacts of extreme slope values on time-dependent properties (shrinkage) and structural performance of UHPC-NC composites.

<u>Normal Concrete substrates</u>

Specific formworks were designed and prepared to cast the NC substrate. To provide sufficient load-bearing capacity against induced bending stresses, steel reinforcement mesh made of 6 mm bars with a spacing of 20 cm was used in the

NC substrate. the steel reinforcement mesh was placed in two layers distancing 8 cm from each other. The concrete cover of 1 cm was considered and similarly, a gap of 1cm was provided between the bottom side of the mesh and the formwork by placing the concrete rebar chair. Moreover, two steel rods were placed at one-third of the specimen length to provide sufficient lifting points.

<u>Distributed fiber optic sensing (DFOS) layout</u>

To obtain a comprehensive set of strain data within the UHPC overlay, a specific DFOS layout was designed in collaboration with Dr. Philipp Preinstorfer, from the Institute of concrete structures at TU Wien. As depicted in Figure 6.2, this design comprises seven transverse sections spacing 30 cm, and three longitudinal ones, i.e., two along the centerline at two different levels and one close to the edge of the specimens.

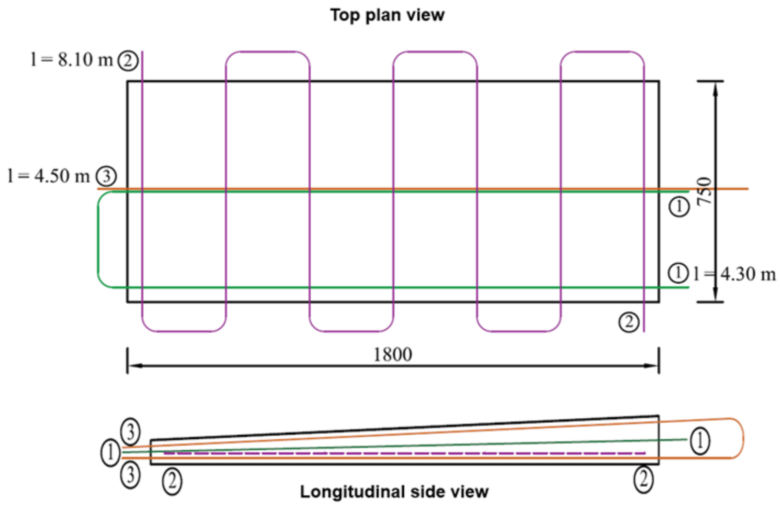

Figure 6.2 - Designed layout of optical fibers embedded in the UHPC overlay

Given the DFOS layout presented above, a continuous optical fiber of 18.5 meters was prepared for each specimen. The preparation of optical fiber includes several splicing steps. Optical Fiber splicer OFS-80 was used to splice the pigtail and termination to the ends of the optical fiber:

The installation of the optical fibers was then carried out. To this end, the prepared spliced optical were passed through overlay formwork holes, anchored, and eventually pre-stressed.

<u>Ultra-high performance concrete overlay</u>

Before UHPC casting, the top surfaces of the NC substrate were first cleared of any debris. The water was then sprayed on the substrate to minimize the absorption of water from the fresh overlay into the NC. This prevents an immediate water loss of overlay in the early stages and may help to achieve a greater interfacial bond (Daneshvar et al., 2022). For each specimen, three batches of UHPC mixtures (each 50 L) were continuously prepared and poured. It must be emphasized that vibration and compaction were not used. The UHPC was carefully spread and leveled using a hand tool to keep the alignment of pre-

stressed optical fibers unchanged. The specimens were eventually covered with thin plastic sheets.
After one day, the plastic sheets were removed and the mechanical dial gauges (dilatometer) were mounted and installed on the edge and corner of each UHPC overlay to measure the delamination at these critical points (see Figure 6.3). Furthermore, a thermocouple was placed in the center point of the UHPC overlay to capture the temperature changes mainly caused by the cement heat of hydration over the first days.

Figure 6.3 - An example of prepared sloped UHPC-NC composites. The mechanical dial gauge was mounted on the top of the UHPC overlay and a thermocouple was embedded in the center of the UHPC overlay.

Progress, future perspective, and expected results

Design, preparation, and casting of the large-scale UHPC-NC were successfully carried out over six months. The development of shrinkage strain and cracking is recorded by the DFOS system, corner while edge delamination is recorded by LVDTs, surface cracking patterns by visual field observation and temperature by thermocouple sensors. The aforementioned measurements are still ongoing. Apart from this, individual characterization tests such as autogenous shrinkage, Vicat setting times, and fresh and hardened state tests have been performed.

Acknowledgement

The installation of the fiber optics and the sensor reading was done in collaboration with Dr Preinstorfer, from Forschungsbereich Stahlbeton- und Massivbau, Institut für Tragkonstruktionen at TU Wien.
Fallaha Maja contributed to the preparation of the thermally activated concrete in the framework of her Bachelor thesis “Entwicklung von nachhaltigem U-HPC”.

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AP7: Renovation of old mortars – Material for infiltrations

Motivation

The skyline of the city of Vienna is still defined by the presence of masonry buildings. Old masonry is typically composed of bricks and mortar, where the mortar layer represents the most permeable portion. The use of epoxy materials during consolidation can trigger issues, by modifying vapor water transmission rates, stiffening the structure too much [Katosioti et. Al, 2009], as well as making the recycling process difficult. Its global warming potential is also very high.
The aim of this study is to replace epoxy with a more eco-sustainable injection solution having comparable properties for the consolidation of these buildings.

Materials and methods

Before selecting a possible candidate for the injection process, a detailed study on the masonry mortar composition has been performed. This was possible thanks to a collaboration with PORR Industry that donated several drilled cores coming from a masonry dated from ca. 1850 – 1900 (Fig. 7.1).

Fig 7.1 - Drilled core from an old masonry in Austria.

The analysis of the properties of the old mortar, including its chemical composition, was fundamental to understand its possible interactions with an injection material. Several physico-chemical analyses were done during this first step. X-Ray Power Diffraction (XRPD) was performed to identify the mineralogical assemblage of the old mortar. The diffractometer is equipped with an X-ray source which generate a monochromatic beam that, interacting with a polycrystalline sample (classic powder), is able to discriminate all the mineralogical phases that belong to it. The quantitative analysis was done adding a known dosage of an internal standard (usually ZnO) mixed with the sample, in order to be able to quantitatively access the weight of the present phases. The powder analysis was done using an X'Pert Pro from Panalytical in Bragg Brentano geometry. The phase quantification (QPA) was performed using the Rietveld method [Gualtieri, 2000], through the Software PROFEX. The powder with a size lower than 250 µm was milled and analyzed using a $COK\alpha_{1,2}$ radiation (1.789 Å).
In addition, X-Ray fluorescence (XRF) analysis was completed to obtain the oxide composition of the mortar, using AXIOS advanced WD-XRF from Panalytical at the XR Center of TUW. The sample was prepared with the firing method (glass beads).
To quantify the binder to aggregate ratio, a hydrochloric acid attack was carried out. The test was performed on a representative sample composed of 10-12 pieces of mortar.

Sodium silicate solutions, most commonly known as waterglass (Wasserglas), have been selected as a candidate for the consolidation process. Several sodium silicates with different molar ratio, from 2 to 3.4, were tested.

Results and discussions

Old mortar binder characterization

The old mortar was manually removed from the bricks and sieved using a column of sieves with different meshes (250, 90 and 63 µm).
As reported in literature, the real binder (active part) is typically defined as the finer fraction, able to pass the mesh of 63 µm [E. Pecchioni et.al, 2018)]. Given the small amount of masonry, the amount of collected binder was insufficient. Consequently, powders obtained from sieving with bigger size meshes (90 µm and 250 µm) were obtained and used to prepare pastes for testing.
The mineralogical composition of the old mortar (sieved through 250 mm), detected with XRPD, is reported in the Table 7.1.

Table 7.1 – Quantitative results of XRPD analysis on the old mortar (< 250µm)

Detected Phase	Quantity (wt. %)
Quartz (SiO_2)	~58
Calcite ($CaCO_3$)	~16
Muscovite ($KAl_2(Si_3Al)O_{10}$)	~10
Amorphous	~7
Feldspar	~5
Minor phases	~4

Tab.7.1 show the identification of phases that belong to the old binder (calcite) and those related to the aggregates, such as quartz, feldspar, muscovite. The XRPD did not detect any kind of residual hydraulic phases, such as alite (C3S) or belite (C2S); this suggests that this old mortar was not made from hydraulic cement (OPC) but is likely an air hardening mortar, or aerial mortar [Arizzi et. Al, 2021]. The presence of calcite as the only phase related to the binder means that the precursor of this reaction, and the principal player for the development of the strength was portlandite ($Ca(OH)_2$). The portlandite is not present anymore, showing that the mortar fully reacted.
The difference in chemical nature between the binder (carbonate fraction) and the aggregates (silicate nature) justifies the acid attack method to estimate the binder fraction. The ratio binder to aggregates b:a was estimated at 1:4.

Repair material

Sodium silicate (i.e., waterglass) has been selected as the repair material, with the aim to re-precipitate calcium silicate hydrate (C-S-H) in-situ and enhance the mechanical properties of the mortar. C-S-H is the main product that comes from the hydration of ordinary Portland cement and is responsible for the development of strength.
The global warning potential of sodium silicate is high (0.3 kg to 3.3 kg CO_2-eq. kg^{-1} depending on the type and source [Witzleben 2022], but remains lower than epoxy (6.7 kg CO_2-eq. kg^{-1}) [Chard et al., 2019]. Sodium silicate solutions typically contain 30-55 wt% of sodium silicate in water.

In the old mortar, calcite is already present, but its solubility in water is low (0.015 g/L at 20°C). A small quantity of portlandite (CH) (solubility=1.73 g/L at 20°C –) was added to accelerate the reaction rate.
For this series of experiments, SiO_2/Na_2O molar ratios of 3.2 and 3.4 were chosen, with concentrations of sodium silicate in water of 34 to 37 wt%.
This first test campaign aims at testing the reactivity of waterglass with old mortar, rather than evaluating its injectability. To do so, the old mortar powder (as prepared above with sieve 250 mm) was mixed with waterglass with 2 different molar ratios (MR), portlandite, various amounts of calcium carbonate, and water, and prepared in small cylinders of height 15 mm and diameter 10 mm. Calcium carbonate was added with concentrations of 2,5 and 10 % weight in respect to the dry powder (old mortar + CH in solution) (referred to as bwop, by weight of powder).
The cylinders were demolded after 1 day and compressive strength measured after 4 days. Fig. 7.2 shows preliminary results.
Results show that increasing the quantity of calcium carbonate ($CaCO_3$) inside the paste, increases the compressive strength. It acts both as a filler and as an active phase during the reaction with the sodium silicate [Firdous et al., 2021].
Moreover, the quantity / type of waterglass seems to influence the 4-day compressive strength. Further characterization is needed.

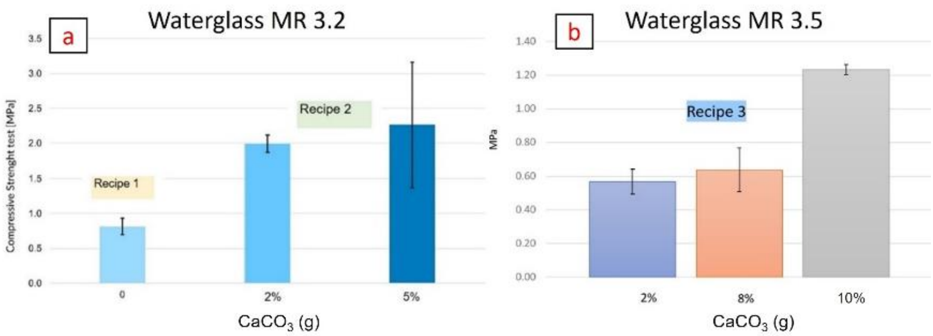

Fig. 7.2 - a) Compressive strength test of small prisms after 4 days with a) 3.2 ratio waterglass and b) 3.5 ratio waterglass.

Conclusion

This project was focused on the investigation and characterization of an old mortar, a new alternative injection material (i.e., waterglass) and the design of a synthetic mortar representative of the old mortar.
XRD, XRF characterization enabled the identification of the oxide compositions and the phase content. Crushing, sieving and rheology helped separate the binder phase from the aggregates. Next, the reactivity of waterglass with the old mortar was assessed by preparing a mixture of the fine fraction (<250um) of the mortar. Reactivity was enhanced by adding Portlandite and calcium carbonate as a source of calcium ions. Finally, a synthetic model mortar was prepared. It will serve for future studies, guarantying the access to a sufficient quantity of mortar.

Acknowledgments

PORR Company for the collaboration and for providing us drilled cores form historical buildings.

Dr. Nicola Döbelin, developer of the PROFEX software for all the support during the data treatment.
XRPD tests and analysis were conducted both at the University of Padua (CiRce center) in collaboration with Prof. MC Dalconi and Dr. Bellotto, and at the X Ray Center at the TUW.

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AP9: Recycled aggregate concretes: recipe optimization for concrete made with recycled concrete based on packing & measurement of volume changes during internal sulfate attacks

Motivation

Volume changes are responsible for durability issues in concrete. Mitigating local heating during the casting of large concrete pieces (leading to shrinkage when temperature drops), minimizing drying on the concrete surface (leading again to inhomogeneous shrinkage) and avoid swelling (due to concrete hydration product post reaction) are a constant focus of concrete manufacturers and end-users.
During this project, setup to measure autogenous shrinkage was designed and built (WP6) and a protocol to measure drying shrinkage using fibers optics was also assembled. Here, the focus is on volume gain, i.e. swelling, that may occur during sulfate attacks and secondary ettringite formation (Year 4 project). A setup that can be used to monitor swelling under a constant load, or monitor confining load under constant displacement is necessary to quantify these volumes changes (under controlled load), or stress build-up (under controlled displacement).

Materials and methods

The main design difficulty is that the setup should have very low compliance. The bulk moduli of cementitious materials are rather high, and if the setup is compliant, the confinement will be released when the load increases, resulting in no further load increase.

After more failed attempts during this year projects with a custom-made frame that showed too high compliance, the confining setup was assembled within the Zwick machine. Using the Zwick machine allows to perform both controlled displacement tests (sample is fully confined and load build-up is measured) and load controlled tests (load is an input and displacement is recorded).

Fig. 9.1 shows the setup installed in the Zwick machine and shows computer acquisition while running the test.

Fig. 9.1 – Customized swelling setup assembled on the Zwick machine. The setup is assembled inside the oven and the shaft connected to the load cell. A thermocouple is placed in the water bath.

Results and discussions

The on-going test results is shown Fig. 9.2. Temperature fluctuations exist but average temperature is constant. The load is slight increasing.

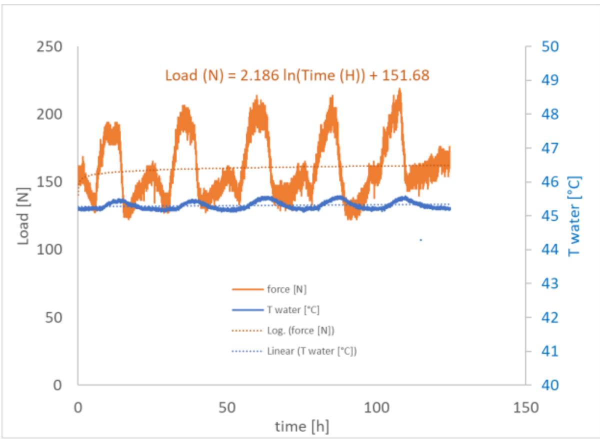

Fig. 9.2 – Test currently running – Load and temperature as a function of time

<u>Autogenous shrinkage measurements</u>

Using the setup described in WP6, autogenous shrinkage measurements were performed. Reported on Fig. 9.2 are preliminary results on the UHPC of WP6.

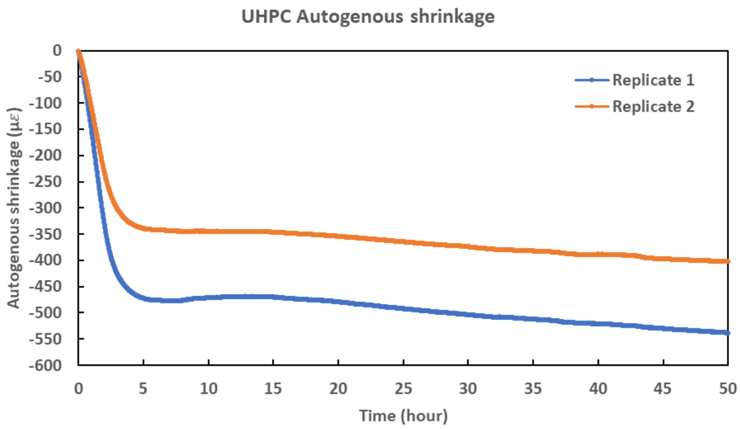

Figure 9.2 – Autogenous shrinkage as a function of time of the UHPC. Time zero corresponds to final setting time of the concrete

Conclusions

After many attempts, a stiff confining customized setup was assembled. The frame initially designed showed during the preliminary test campaign that its compliance was too high and did not permit the full confinement of the sample. Eventually, the setup was further modified to be adapted to the Zwick machine. The compliance of the whole system was measured to be 22.3 10^{-3} mm/kN. An experiment is currently running. A slight load increase is detected, despites load fluctuation matching with temperature fluctuation.

Acknowledments

This work was done In the framework of the master thesis of Robert Dulguerov „Entwicklung einer Anlage zur Messung des Ausdehnungsdrucks in einer begrenzten Umgebung “ at TU Wien.

AP10: High thermal insulation in double-walled tower

Motivation

Structural lightweight concrete, with its versatility, cost-efficiency, and sustainability, offers a compelling solution for modern construction. It serves both load-bearing and insulating functions in a single layer, reducing the need for additional work. This material monolithic structure simplifies maintenance and promotes recyclability. In contrast to conventional materials like polystyrene and mineral wool, which have limited lifespans and recycling challenges, structural lightweight concrete eliminates the need for extra insulation layers, reducing costs and reliance on highly skilled labor.

Materials and methods

Our study focuses on the analysis of the infiltration of a cement paste into a pack of light weight aggregates made of expanded clay beads. Such infiltration is challenging because 1) cement paste is a dense suspension of water and ca. 45 vol% of 10 micron-size particles, and has a non-negligible yield stress 2) the paste needs to travel through a tortuous path formed by the packed beads, 3) the beads are

themselves porous and if not pre-saturated in water, have been shown to pull water out of the cement paste and cause filtration, eventually preventing the pumping.
To investigate such systems, a set up was built where a cement paste is pumped through a pipe filled with clay beads, from the bottom to top. The pipe is instrumented with a pressure sensor that allows the measurement of pressure at the bottom of the pipe where the beads lay.
The influence of parameters such as bead size range, bead water pre-saturation and paste water-to-cement ratio on the pumping ability was explored. Rheological properties of the cement slurry as well as density and thermal conductivity of the hardened concrete were measured.
Eventually, mixtures of cement with micro-silica were explored. The rheology of the paste was also modified by changing the recipe (water-to-cement ratio, superplasticizer content, solid additive particle size distribution, admixtures), targeting a mixture with low segregation, low filtration ability, and thus improved ability to be pumped through the pack of beads.

Setup

The final set up consists of a plate of UHPC (ultra-high performance fiber reinforced concrete), to which four threaded rods are attached. To fix the pipe, a cross made of metal was welded and fixed by means of nuts. This support can be placed either on a specially welded stand or on concrete blocks.
From the top down, the final setup consists of a tube attached to a lid. This lid is used to collect the cement paste that has travelled through the whole pack of beads and exits in the upper part. The actual tube used for the experiments is either an orange channel PVC tube with a diameter of 11 cm or a transparent Plexiglas tube. In the lower part of the tube, a holder was attached and held a mesh with the help of screws and internal seals. This mesh function is to hold the LECA beads within the pipe. Directly below the net is a hole and a holder for a pressure sensor. The pressure sensor is a fully welded pressure sensor with a flush diaphragm from the company Baumer.
To ensure a functioning transition that can withstand the existing pressures, a pipe transition was attached to the pipe. This pipe transition was closed at the bottom with a lid and a seal. A hose connection adapter was integrated into the cover, which establishes the connection by means of a hose to the eccentric screw pump.

Cement

Holcim cement – Der Blaue CEM I 52.5 R, was used in all experiments. This cement is categorized as a high-performance cement, as it exhibits an high early strength, reaching around 41 MPa after just 2 days. Moreover, it also attains a remarkable strength after 28 days, consistently meeting the desired minimum of 52.5 MPa.
A PCE-based superplasticizer (SP) was used (ACE 430, BASF).

Expanded clay beads

Laterlite expanded clay is a versatile construction material known for its lightweight (from approx. 320 kg/m³), excellent thermal insulation (λ≈0.09 W/mK), and sound-absorption properties. It is fire-resistant (Euroclass A1), extremely durable, and immune to rot and pests. It is eco-friendly and widely used in construction, offering high drainage capacity, making it perfect for various applications. The spherical granules come in different sizes, such as 0/2, 2/3, 3/8, and 8/20.

Experimental protocol/ Results and discussions

Mixing protocol

The same mixing steps and durations were followed in all mixes for consistency, as mixing intensity (RPM) and duration are known to affect fresh mix properties. Indeed, higher RPM and longer mixing decrease yield stress and viscosity by increasing superplasticizer adsorption on cement particles.
To enable a meaningful comparison of the cement slurry before pumping and to assess important factors like yield stress and flowability, we consistently conducted two tests: a spread test employing a Hägermann cone and a funnel test using a mini V funnel.

To mitigate filtration issues, micro-silica was added to the cement mix, inspired by the composition of UHPC (Ultra-High-Performance Concrete). Currently, we have successfully managed to pump through expanded clay beads in the 8-20 mm and 3-8 mm size ranges, as well as a mixture consisting of 70% 8-20 mm and 30% 3-8 mm.

After infiltration, the tubes were left as is for 25 days. On the 25th days, cores were cut (Fig. 10.1, right), and left in ambient conditions for 3 days.
On the 28th day, the density of the cores was measured. Densities of concrete show rather homogenous values and between 1130 and 1210 kg/m^3. A drop in density is observed with higher infiltration path (cores towards the top) likely due to water accumulating on the cement air interface and diluting the cement paste.

Compressive strength was then measured on hardened specimens the same day, as shown Fig. 10.1 (right).

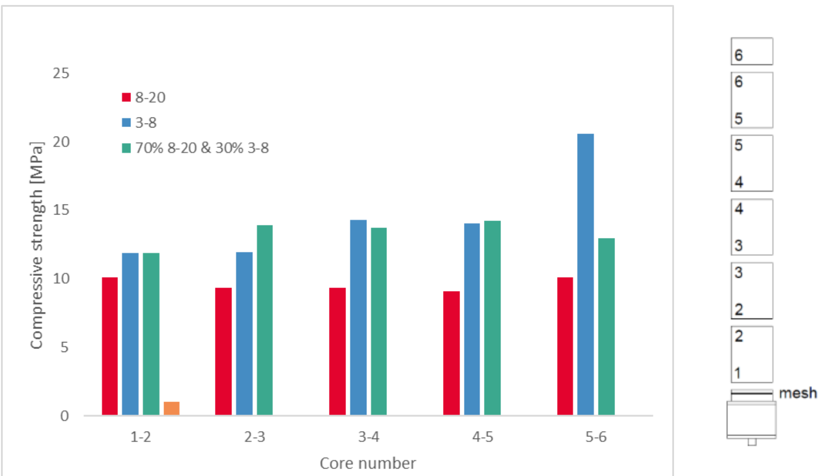

Fig. 10.1 – Compressive strength of lightweight concrete samples prepared by infiltrating a pack of expanded clay beads

Conclusion

First, a robust infiltration setup was built. The setup could withstand all pumping pressures used in this campaign without failing or leaking. Then, a cement slurry was

design that allow the infiltration of small (3-8mm) expanded clay beads. Finally, several experiments were succesfully run, i.e. the cement slurry could penetrate through the whole height of packed beads (1 m high).
Successful infiltration could not be achieved without prior wetting of the surface of the expanded clay beads with water, due to their high water absorption. Additionally, it should be noted that a relatively high proportion of superplasticizer (1.2 %bwoc) and retarder (~0.60 %bwoc) is necessary to enable infiltration over a height of 1 meter.
Densities of lightweight concretes were measured to be in the range of 1130 and 1210 kg/m^3 and 28-D compressive strength between 10 and 20 MPa.
The mechanical properties, water absorption of the clay beads, bead size and packing, as well as cement paste rheological characteristics such as viscosity and yield stress all influence the infiltration process.

Acknowledgments

This work was done within the framework of the master thesis of Bernhard Stuchlik „Untersuchung zur Infiltration von Zementschlämmen für die Herstellung von Leichtbeton“.

3 PROJEKTTEAM UND KOOPERATION

- Gab es wesentliche Veränderungen im Projektteam (interne Schlüsselmitarbeiter*innen und Drittleister)?
- Bei Konsortialprojekten und Forschungskooperationen: Beschreiben Sie die Zusammenarbeit im Konsortium.

Benedetta Costa, Projektassistentin, wurde mit 01. September 2022 angestellt.
Dana Daneshvar, Projektassistan, ist vom 28. Juli 2023 bis zum 5. Februar 2024 (insgesamt 6 Monate) an der Princeton University beurlaubt. Er wurde mit einem Mashall-Stipendium ausgezeichnet.

4 WIRTSCHAFTLICHE UND WISSENSCHAFTLICHE VERWERTUNG

- Beschreiben Sie die bisherigen Verwertungs- bzw. Weiterverbreitungs-aktivitäten. Ist eine Verwertung möglich?
- Listen Sie Publikationen, Dissertationen, Diplomarbeiten sowie etwaige Patentmeldungen, die aus dem Projekt entstanden sind, auf.
- Welche weiterführenden F&E-Aktivitäten sind geplant?
- Wie werden die im Projekt geschaffenen Prototypen weiterverwendet?

Preise
Dana Daneshvar erhielt das Marshall-Plan-Stipendium und nutzte es für einen 6-monatigen Forschungsaufenthalt an der Princeton University.

Teresa Liberto wurde mit dem „Andreas Dieberger – Peter Skalicky – Wissenschaftspreis“ ausgezeichnet, für ihre herausragende wissenschaftliche Forschungsarbeit im Fachgebiet der Energie und Umwelt.

Publikationen
Liberto, T., Dalconi, M.C., Dal Sasso, G., Bellotto, M. and Robisson, A., 2023. Structure–function relationship during the early and long-term hydration of one-part alkali-activated slag. *Journal of the American Ceramic Society*, *106*(9), pp.5187-5202.
Daneshvar, D., Liberto, T., Dalconi, M.C., Stoellinger, W., Kirnbauer, J. and Robisson, A., 2022. Development of a sustainable binder made of recycled high-performance concrete (HPC). *Case Studies in Construction Materials, 17, p.e01571*.
Daneshvar, D., Behnood, A. and Robisson, A., 2022. Interfacial bond in concrete-to-concrete composites: A review. *Construction and Building Materials, 359, p.129195*.
Liberto, T., Nenning, A., Bellotto, M., Dalconi, M.C., Dworschak, D., Kalchgruber, L., Robisson, A., Valtiner, M. and Dziadkowiec, J., 2022. Detecting Early-Stage Cohesion Due to Calcium Silicate Hydration with Rheology and Surface Force Apparatus. *Langmuir, 38(48), pp.14988-15000*.

Lang Bericht
FFG-Berichte und Langberichte befinden sich allgemein zugänglich auf der Website der Österreichische Bautechnik Vereinigung

Bachelorarbeit:
Fallaha Maja: Entwicklung von nachhaltigem U-HPC (2023)

Diplomearbeit:
Matthias Pudelko: Durability of slag-based Alkali Activated Binder (AAB) (2023)

5 ERLÄUTERUNG ZU KOSTEN UND FINANZIERUNG

Beschreiben und begründen Sie wesentliche aufgetretene Abweichungen vom Kostenplan.
Klicken oder tippen Sie hier, um Text einzugeben.

6 PROJEKTSPEZIFISCHE SONDERBEDINGUNGEN UND AUFLAGEN

Falls im Förderungsvertrag projektspezifische Sonderbedingungen und Auflagen vereinbart wurden, gehen Sie bitte konkret auf die Erfüllung der noch offenen Sonderbedingungen und Auflagen ein.
Schriftliche Nachweise können im eCall hochgeladen werden.
Klicken oder tippen Sie hier, um Text einzugeben.

7 MELDUNGSPFLICHTIGE EREIGNISSE

Gibt es besondere Ereignisse rund um das geförderte Projekt, die der FFG mitzuteilen sind? Beispielsweise

- Änderungen der rechtlichen und wirtschaftlichen Einflussmöglichkeiten bei den Fördernehmer*innen,
- Insolvenzverfahren,
- Ereignisse, die die Durchführung der geförderten Leistung verzögern oder unmöglich machen,
- Weitere Förderungen für die im Projekt abgerechneten Kosten (Mehrfachförderung).

Klicken oder tippen Sie hier, um Text einzugeben.