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Research and Development of Lightweight Repair Mortars with Focus on Their Resistance to High Temperatures

Tomáš Melichar, Jiří Bydžovský, Vít Černý

***Abstract*—**In this article our research focused on study of basic physical and mechanical parameters of polymer-cement repair materials is presented. Namely the influence of applied aggregates in combination with active admixture is specially considered. New formulas which were exposed in ambient with temperature even to 1000°C were suggested. Subsequently densities and strength characteristics including their changes were evaluated. Selected samples were analyzed using electron microscope. The positive influence of porous aggregates based on sintered ash was definitely demonstrated. Further it was found than in terms of thermal resistance the effective micro silica amount represents 5% to 7.5% of cement weight.

***Keywords*—**Aggregate, ash, high, lightweight, microsilica, mortar, polymer-cement, repair, temperature.

I. Introduction

REPAIR mortars are integral part of building materials assortment. These repair materials can be applied in many sectors of reinforced concrete constructions (tunnels, bridges, cooling towers, residential buildings, waste water sumps etc.) Generally polymer-cement mortars with scattered reinforcement are used. When repairing constructions with assumption of higher fire risk the application of repair mortars is one of the possibilities.

Resistance of common cement composites (mortars and concretes) is considerably limited. This fact is directly related to all used components – binders, aggregates, admixtures etc. With growing temperature water leaks as first – 100°C. The leak of free and physically bound water is terminated at 374°C, when water presence is not possible under common conditions. At temperatures around 400°C portlandite disintegrates which with complete disintegration to 800°C. Together with CSH gels portlandite belongs to dominant components of cement matrix. With respect to silica presence in the matrix and aggregates as well the temperature of 573°C can be assessed as one of the critical ones. At this temperature silica modification conversion occurs which is accompanied by considerable volume changes. For temperature 600°C is characteristic the second phase of CSH gel disintegration during which β-C_2S may originate. Also calcite contained either in matrix or in the aggregates starts to disintegrate at temperatures around 700°C. At 800°C ceramic bonds may originate which substitute hydraulic bonds. Over 1000°C it is possible to identify sulphate crystalline phases – silicocarnotite or yeelimite eventually. Further it is possible to record mayenite, larnite and brownmillerite. Wollastonite than may occur within 1100°C to 1200°C. On disintegration of the all mentioned components mainly the gases – H_2O, CO_2, and eventually SO_3 generally escape. Also residual products from disassociation reactions may mean a problem. For instance free lime which is able at contact with water (real situation of fire extinction) to react with formation of $Ca(OH)_2$. By this hydrating reaction volume grows and internal stress occurs in already degraded structure of the cement composite. Generally chemical bonds are broken, porosity grows and thus composite structure is degraded in the cement matrix, aggregates or their interface.

Considering physical and mechanical properties it is evident that at reaching of temperature 1000°C a considerable degradation of cement matrix occurs together with breaks of aggregate-matrix consistency. In terms of construction materials the strength is the decisive parameter. In case of mortars and concretes only compressive strength is considered. At temperatures 600°C to 1000°C straight reduction within 60% to 100% occurs with common composition composites (lime, feldspar or silica aggregates, Portland cement etc.). Therefore fire effects may be fatal - collapse of the construction. This is also intensified by presence of longitudinal steel reinforcement providing tensile strength at bend. With growing temperatures a deformation (prolongation) of the reinforcement occurs and then even results in loss of consistency with cement matrix.

The possibility of mortar and cement resistance growth towards actuation of extreme temperatures has been studied by many scientists. It was found that attention shall be paid to binders, aggregates and scattered reinforcement as well. Polymeric scattered reinforcement play an important role at escaping of gaseous phases from cement composites and possibly also at expansion of some components. At equal distribution and optimal batch (approx. to 5%) of polymeric fibres the thermal resistance of cement composites is considerably increased. According to polymer type the fibres completely disintegrate within approx. 350°C.

According to [1] the best results were obtained at modification of cement matrix with blast-furnace slag. Ash can be used in amounts of 20% to 30% of the cement weight.

Tomáš Melichar, Jiří Bydžovský and Vít Černý are with the Institute of Technology of Building Materials and Components, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic (phone: +420-541-147501; fax: +420-541-147502; e-mail: melichar.t@fce.vutbr.cz, bydzovsky.j@fce.vutbr.cz, cerny.v@fce.vutbr.cz).

However significant improvement of cement matrix is noticeable only to 600°C. Positive findings in connection to cement composite parameter degradation due to high temperatures were found at cement substitution by volcanic ash within 20% [2]. In the publication [3] the authors present their research dealing with mixing binder. As cement substitution with 25% the ash, microslica and their combinations were tested. Maximum exposition temperature was 800°C. Upon obtained results micro silica in 10% amount was selected as optimal substitution component. The research presented in [4] is focused on study of cement ash substitution influence in combination with silica nanoparticles. In case of formulas with content of both tested components strengths comparable with specimens not stressed with high temperatures were obtained with test samples at temperature of 700°C. XRD analysis results refer to formation of new bonds in the matrix at 700°C. Research of mortars with aluminium oxide nanoparticle content is stated in [5]. More significant improvement in compressive strength can be seen only within temperatures 400°C to 600°C. At 1000°C the influence of aluminium oxide nanoparticles is insignificant. Positive influence of titan nanoparticles at temperatures even to 600°C was shown in [6]. Compressive strength improvement by 14% was verified in comparison with reference specimens. Influence of aggregate types on cement composite parameters exposed to high temperature actuation was analyzed for instance in [7]. Here the scientists studied the possibility of lightweight aggregates application - perlite, vermiculite and pyrofilite. The best stability considering stress by high temperatures showed mortars with content of expanded perlite. Development and research of fire resistant mortars to 900°C is presented in [8]. Possibility of application of the blast-furnace slag as binder substitution even to 80% was also tested. Pumice-stone was used as aggregate. Mortars with 40% content of blast-furnace slag were evaluated as the best ones considering the findings. Compressive strength of these mortars after having been exposed to 900°C reached $18 N.mm^{-2}$ at gradual cooling (therefore residual compressive strength – 44%). At quick cooling (with water) the mortar showed strength $16.2 N.mm^{-2}$ (therefore residual compressive strength – 40%).

No relevant information relating to application of ash agloporite was found in available scientific literature. It is sintered ash based cellular aggregate. The aggregate production is carried out by auto-burnout. They are therefore artificial aggregates produced from power energy industry by-products. Production energy intensity of these aggregates is then very low. Considering the fact the aggregates are produced at temperatures ranging from 1000°C and 1200°C its very good resistance towards high temperature actuation can be assumed.

II. Formulas Proposal and Methodology

A. Composition of Formulas

On proposing of developed mortar compositions all findings and knowledge gained from study of foreign special literature were considered. Blended cement CEM II/B-M (S-LL) 32,5 was used as a binder. This type of cement contains 65% of clinker and 35% of admixtures (blast-furnace slag and limestone). Aggregates to cement volume ratio was 3.7:1. In order to obtain the required workability, consistency with base and adhesion of the mortar in fresh condition a polymeric admixture in amount of 3% (related to cement weight) was applied. The water-cement ratio was always modified to provide a 160 mm diffusion of the mortar. This value characterizes a mortar with good workability for manual application on repaired construction. At selection of the aggregates the attention was paid to lightweight aggregates – ash agloporite. These aggregates formed the only one aggregate component with fraction 0 to 4 mm. For improvement of parameters at high temperatures polymeric fibres were used. Because it is a mortar intended for thicker repairs fibres of larger sizes than usual for this type of material were tested. Polyolefin fibrillated fibres were added in the mortars in amounts of $5 kg.m^{-3}$. To provide sufficient parameters for repair materials with static function according to [9] a very fine-grained active admixture based on amorphous SiO_2 was used. It was dosed in 5 to 10 % (related to cement weight). It was not a binder substitution.

B. Preparation, Curing and Testing

Test specimens with dimensions 40 × 40 × 160 mm were stored 28 days and treated in accordance with [10]. Subsequently they were loaded with temperatures 200°C, 400°C, 600°C, 800°C and 1000°C. Reference specimens were not thermally exposed. Temperature curve course is defined in [11]. Cooling was carried out gradually in the furnace, i.e. speed approx. $1°C.min^{-1}$. In accordance with relevant standards – [9], [10] and [12] the basic physical and mechanical parameters were tested and their changes (density, compressive strength and tensile strength at bend). From the selected specimens samples were taken for evaluation of microstructure.

III. Results and Discussion

The following charts (see Figs. 1 to 3) show comparison of results for setting of monitored material characteristics and their percentage changes at mortars exposures to high temperature ambient. All the formulas contain agloporite and different micro silica doses (for instance AG-7.5S means mortar with 7.5% micro silica content).

Bulk density courses are with growing temperatures relatively stabile for particular formulas. At 1000°C a density decrease occurs within 19% to 21%. The steepest decrease of values is evident within 22°C to 400°C. Microsilica influence on density is insignificant.

With respect of compressive strength the formula containing 7.5% of micro silica can be evaluated as the best. Very interesting strength value course is seen with mortars exposed to 400°C and 600°C. Residual strengths of mortars exposed to 1000°C reach approx. 17% in case of reference formula and also formulas with 5% micro silica admixture. Materials containing 7.5% to 10% of admixture retain approximately 24% compressive strength. It is therefore obvious that the most significant difference is between mortars containing 5% and 7.5% micro silica. Compressive strength of AG-7.5S formula after loading with temperature 1000°C was set to approx. 7.9 N.mm^{-2}.

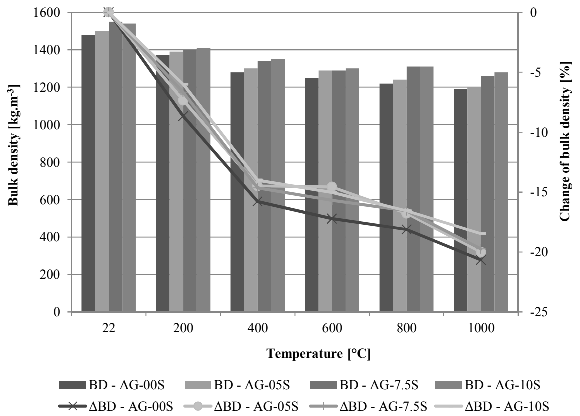


Fig. 1 Comparison of bulk density (BD – bulk density, ΔBD – change of bulk density)

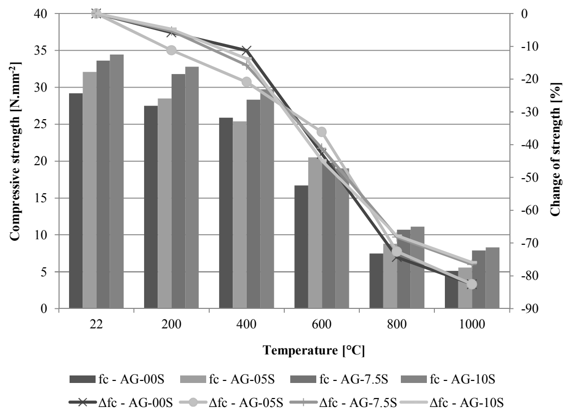


Fig. 2 Comparison of compressive strength (fc – compressive strength, Δfc – change of compressive strength)

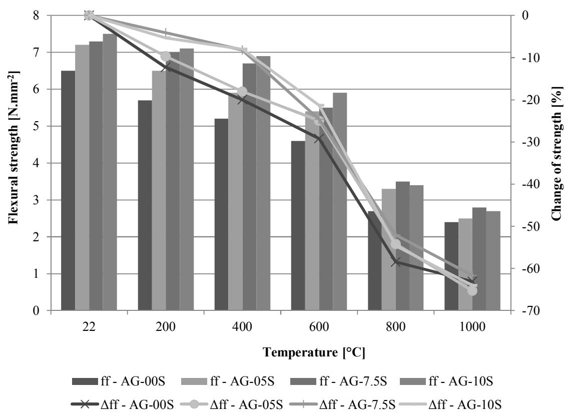
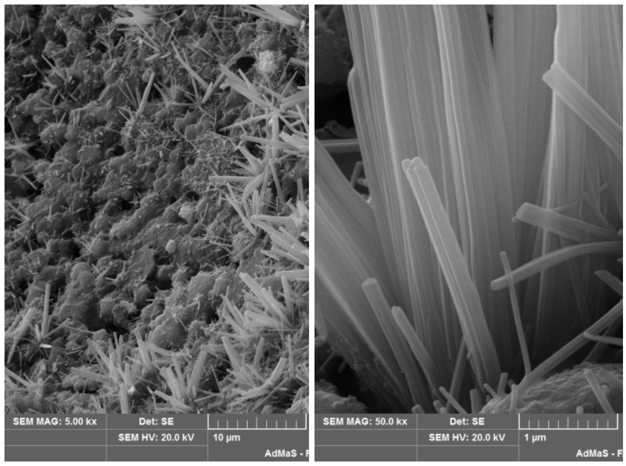


Fig. 3 Comparison of flexural strength (fb – flexural strength, Δfb – change of flexural strength)

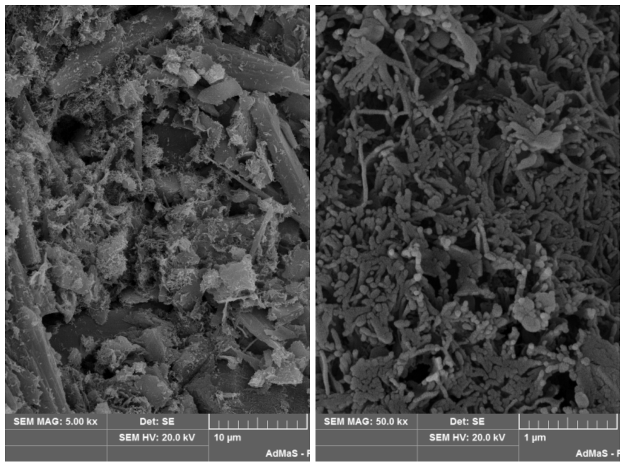
Contrary to compressive strengths there is approx. 40% decrease at exposition temperature 1000°C with flexural strengths. Again the 7.5% micro silica addition can be assessed as the most effective. For both the obtained strengths and thermal resistance of mortars as well.

The following figures (see Figs. 4 and 5) show structure of selected formulas with 5% micro silica content. It is the reference sample, i.e. stored in laboratory conditions at 22°C and the exposed to 600°C.



(a) (b)

Fig. 4 Microstructure AG-05S, exposure temperature 22°C, enlargement (a) 5000×, (b) 50000×



(a) (b)

Fig. 5 Microstructure AG-05S, exposure temperature 600°C, enlargement (a) 5000×, (b) 50000×

From the figures above (see Figs. 4 and 5) a structure degradation of tested mortar polymer-cement matrix can be seen. A higher porosity of the sample exposed to 600°C can also be noted. At 50000× enlargement also higher decomposition rate of matrix crystalline phases is evident. At present analyses for complex evaluation of microstructure degradation are carried out - setting of chemical composition, x-ray diffraction and differential thermal analysis. The reason is identification and quantification of crystalline phases which are characteristic for cement, or polymer-cement composite materials respectively. Emphasis is mainly placed on decomposition processes of typical hydrating products and formation of new phases which do not commonly occur (at common thermal conditions) in cement composites.

IV. CONCLUSION

By the study of basic parameters of mortars containing sintered ash based lightweight aggregates and active silica admixture it was found that it is possible to produce a material with sufficient parameters for application in real constructions (i.e. repairs with statistical function). With respect of subsequent research the development and research of 7.5% micro silica content matrix will be accentuated. Upon the results this dose appears as optimal. Parameters can be improved also by further modification of cement binders. Particularly blended cement containing 60% of Portland cement and 40% of slag could be used. By this limestone would be excluded from the binding component. The amount of active (latently hydraulic component) would be increased which also have a positive impact on cement matrix thermal resistance towards high temperatures. In the next phase it will be necessary to focus on other essential parameters - consistency with base, frost resistance. Since very highly porous aggregates are used it will be necessary to verify namely the properties characterizing product service life (resistance to chemically aggressive ambient, frost resistance etc.).

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