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Crushed bricks as aggregate in cement based binder

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Abstract. The work deals with the impact of crushed brick on properties of Portland cement binder. The source of brick recycled materials is not only the demolition waste, but also the waste from brick production. One way to reduce the amount of this recyclate is to use it in cement-based composite. The advantages of using bricks as aggregate are their lower bulk density compared to conventional aggregates. Economic and ecological benefits are also important, because less natural sources need to be mined. First, the phase composition of used brick aggregate, its particle size and morphology were analysed. Test specimens with different content of brick recyclate were prepared and tested for the mechanical properties. Subsequently, the microstructure of prepared samples was examined using a scanning electron microscope. The phase composition of samples was analysed by X-ray diffraction analysis.

1. Introduction

The industry of building materials is largely dependent on natural raw materials which are not bottomless. One of the most commonly used materials is concrete, which consists of cement matrix, and aggregates. Cement matrix consist of Portland cement, water and other minorities [1]. The major part in most often represented concrete are fine and coarse aggregates 60–75% [2] which are largely obtained by mining. On the other hand, there is a lot of material that is produced from demolition or as a byproduct in the production of other building elements such as precast concrete or brick production. These materials can be sorted and processed so that they can be used as aggregates for concrete production. There are several motivations for reusing these materials. The first is the conservation of natural and economic resources. The second is solving the problem of waste accumulation. Last but not least, these are legal measures dealing with waste management.

Ceramics or fired brick were used as early as 3000 BC in early Indus Valley cities like Kalibangan [3]. Re-use of brick was common in Mediteranea by Romans, who used bricks as aggregates in Roman concrete (Opus caementum) [4].

This paper deals with the use of crushed bricks as type of fine aggregate replacing sand in cement-based concrete/composite. In a way, the paper is linked to previous paper: “Application of brick ground dust in systems based on Portland cement” which deals with partial replacement of cement by brick dust and addresses the influence of hydration of Portland cement by finely ground brick dust [5]. In the current article the amount of cement is constant and standard silica sand is replaced by brick recycled material.

The use of bricks as aggregates is investigated in many works in two ways. One way is adding of fine ground fraction as a micro-filler or possibly pozzolan. The other way is the application of brick aggregates into concrete in fractions of about 2 cm or larger without the fine fraction. Aggregates partially reduce the total bulk density but also mechanical properties of brick-concrete. This material is



used as one type of aggregate in lightweight construction concrete. It is usually stated that concrete using fine brick aggregate up to 15% is comparable to normal concrete. [6] However, the porosity of the brick body must be kept in mind, which causes high absorption of water. High water absorption can have the benefit of “internal curing effect” [7, 8].

Despite of the benefits, the use of brick pulp also results in reduced strengths, increased water absorption causes increased demand for mixing water and increased difficulty in mixing. This paper deals with the study of the effect on mechanical properties using crushed bricks of fraction 2 mm or less, including a fine fraction of less than 63 microns. The fraction was mainly used because the fine particles are always formed during the grinding of bricks. The compressive strength of bricks is about 20 MPa [9]. Crushing of bricks results in not only a brittle fracture and size reduction but also in abrasion and formation of fine fractions.

2. Materials and methods

Crushed bricks were produced by grinding bricks which had unsuitable shape or were defected and unsaleable. Bricks were produced in plant Hevlín in South Moravia region (HELUZ). Other used material was standard silica sand defined by ČSN EN 196-1. Portland cement CEM I 42.5 R from Mokrý plant (Heidelberg cement group) was used as a binder. Tap water was used as mixing water. The mineralogical composition was analyzed by powder X-ray diffraction analysis (XRD, Empyrean, Panalytical). The phase composition of raw materials is shown in figure 1 and present phases with explanatory notes are written in table 1.

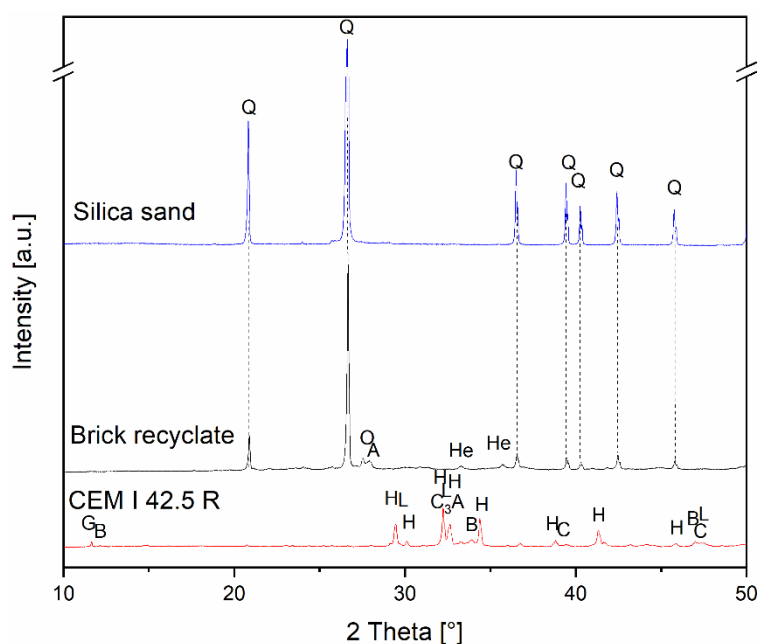


Figure 1. XRD analysis of used materials (Q – Quartz; O – Orthoclase; A – Albite; He – Hematite; G – Gypsum; B – Brownmillerite; H – Hatrurite; L – Larnite; C – Calcite).

Table 1. Phase composition of used materials.

Silica Sand	Quartz (Q)						
Brick rec.	Amorphous						
CEM I 42.5 R	Hatrurite (H)	Quartz (Q)	Hematite (He)	Albite (Al)	Orthoclase (O)	Åkermanite	Muscovite

The particle size distribution of crushed bricks recycle was analyzed by six sieves with sieve size 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm and the results are shown in figure 2. The morphology of crushed bricks was observed by Scanning electron microscopy (SEM, Zeiss LS Evo 10), see figure 3.

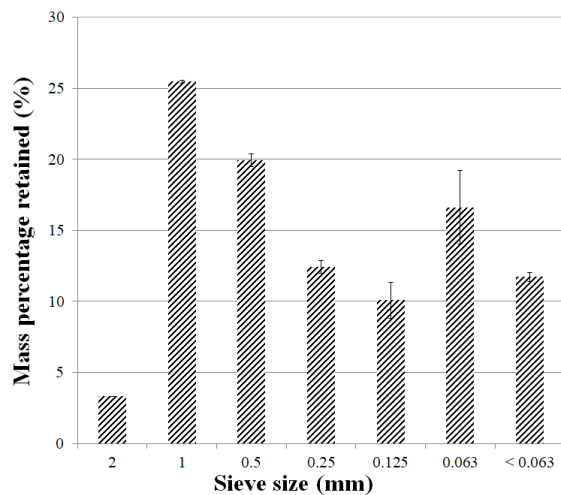


Figure 2. Particle size of crushed brick recycle.

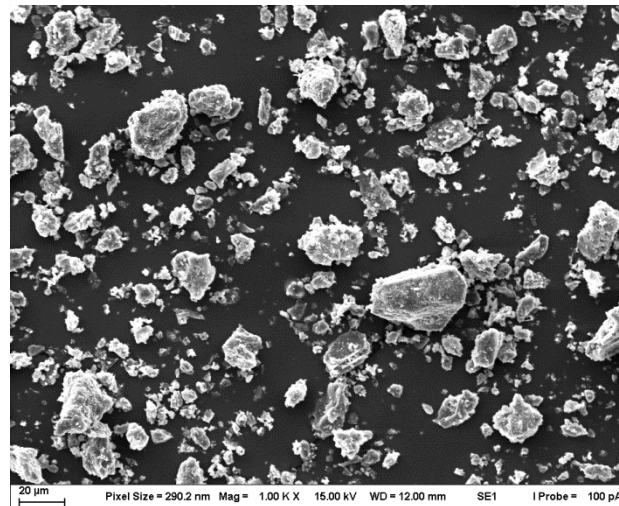


Figure 3. Morphology of crushed brick (SEM, mag. 10 000×).

The samples were prepared in such way that the standard sand was gradually replaced by crushed brick recycle. As a reference the sample without the brick recycle was prepared. The reference contains only normalized sand, cement and tap water. All samples were prepared according to the ČSN EN 196-1 standard.

The composition of prepared samples is shown in table 2. The water/cement ratio is marked w/c. Three test specimens (40 × 40 × 160 mm) were used for each testing of mechanical properties. The equipment for testing was DESTTEST and BETONSYSTEM. Prepared samples were cured for 1, 7 and 28 days in humidity chamber at laboratory temperature. The average values of flexural and compressive strengths are shown in figure 4 and figure 5. Parts of samples were milled and analyzed by XRD in order to determine the phase composition (figure 8). After 28 days the microstructure of sample was observed by SEM (figure 9 and figure 10).

Table 2. Composition of prepared samples.

Sample	a	b	c	d	e	f
crushed bricks [%]	0	20	40	60	80	100
crushed bricks [g]	0	270	1080	1620	2160	2700
sand [g]	2700	2430	1620	1080	540	0
sand [%]	100	80	60	40	20	0
CEM I 42,5 R [g]	900	900	900	900	900	900
water [g]	450	490	590	730	830	980
w/c	0.50	0.54	0.66	0.81	0.92	1.09

3. Results and discussion

3.1. Mechanical properties

Flexural strength of prepared samples after 1 day decreased with rising amount of crushed bricks. After 7 and 28 days the strength of samples b, c and d was higher than that of reference sample a. It should be caused by angular shape of brick particles that arises during crushing. The surface of brick particles causes good bond between cement paste and brick aggregate which could increase the flexural strength performance [7]. As for compressive strength, the trend here is approximately similar. The reference sample a has about 3 MPa less compressive strength than sample b with 20% compensation of sand by crushed bricks after 28 days. Sample c with 40% compensation has only about 2 MPa less strength than the reference sample. The flexural tensile strengths are significantly lower after 28 days for the addition of 60% (sample d) and more. In the case of compressive strengths, there is a significant decrease of values for samples that contain more than 40% (c) of sand substitution with brick recycled material. The improvement of mechanical properties with the addition of brick aggregate is described in the literature rather rarely [10]. More often, a deterioration of the properties of about 15% to 22% by the brick pulp content is observed [6, 8, 11, 12]. The improvement of mechanical properties can be influenced by many factors. One of the most important factors is the use of pure brick recycled material compared to the use of pulp from demolition, which may contain impurities such as plaster, wood, clay and others. Another factor is the fine fraction content and the absence of aggregate greater than 2 mm. This can result in lower content of large defects in the brick aggregate and also reduce the potential for crack formation in the aggregate. On the other hand, with finer proportion of brick recycled material, its specific surface area and water absorption increase, thereby increasing the demand for mixing water content and the brick recycled material should be pre-saturated [13].

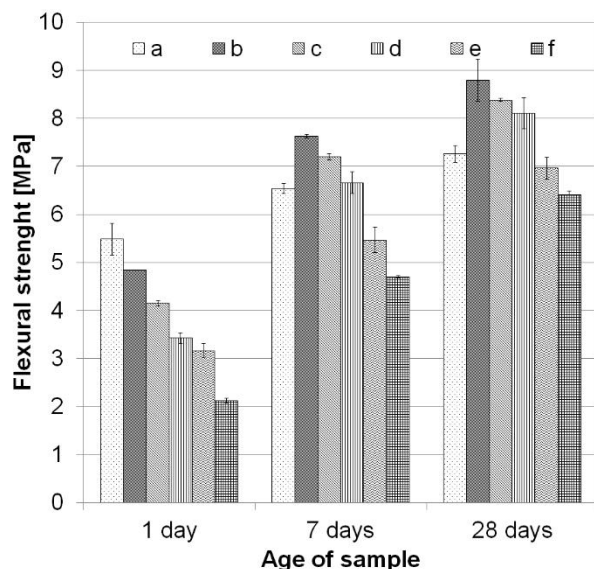


Figure 4. Development of flexural strength of prepared samples in time.

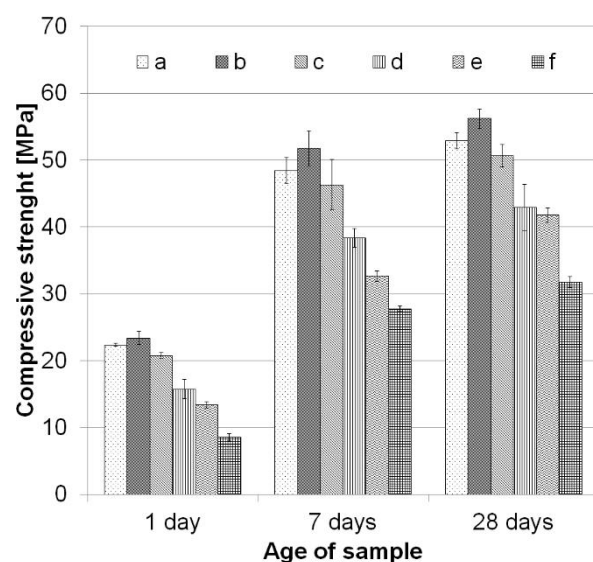


Figure 5. Development of compressive strength of prepared samples.

High water absorption can be an advantage. Water contained in the aggregate may later be provided for hydration, which may run to a higher degree. This phenomenon is described as the effect of internal curing effect and may be one of the reasons for achieving higher strengths [6].

Another effect may be the effect of the shape and surface of the brick aggregate, which is produced by crushing and promotes good mechanical bond between cement paste and aggregate.

The demonstration of good bonding of cement paste and aggregates is also the fracture of test specimens through brick aggregates (figure 7). But this is also given due to low mechanical strength of bricks (about 20 MPa depending on the type of bricks) [7].

In figure 6, significant reduction in the bulk density of prepared test specimens with the addition of brick aggregate can be observed. While maintaining the compressive strength of approximately 50 MPa, the bulk density can be reduced by $180 \text{ kg}\cdot\text{m}^{-3}$ (sample c). When quartz sand is completely replaced, the density after 28 days is reduced by approximately $430 \text{ kg}\cdot\text{m}^{-3}$. In figure 7, an increasing depth of carbonation can be observed with the increase of the amount of brick recycled material. This is probably due to its porosity, as well as the effect of volume density reduction.

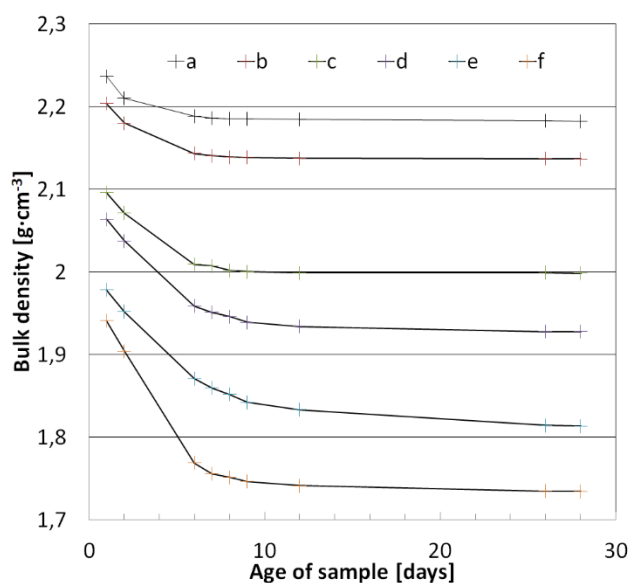


Figure 6. Development of bulk density in 28 days.



Figure 7. Carbonation line after 28 days (from the left top sample a to bottom left sample f) showed by phenolphthalein solution.

3.2. Phase composition and microstructure

In figure 8, the intense main diffraction peak of quartz corresponding to the plane (001) of 26.7° is omitted for better comparison of the intensities of other phases. The XRD analysis shows that replacing quartz sand with recycled brick in a Portland cement system does not give rise to any new crystalline phase. In the mixture b with 20% of the brick content, the quartz content increases. Quartz is the main phase of silica sand, but bricks also contain it. Furthermore, the intensity of quartz decreases as sand content is reduced. On the contrary, the content of other phases occurring in the brick (Albite, Orthoclase, Muscovite and Hematite) increases. The amount of unreacted clinker minerals (Larnite, Hatrurite) decreases with increasing content of brick recycled material, as does the amount of Portlandite. The principle is similar to that described by El-Didamony et al [14].

They used refractory bricks. These bricks contain phases formed at higher temperatures than ordinary bricks for building. The loss of clinker minerals may be due to better conditions of internal curing and filler effect [5, 6]. The loss of Portlandite with the addition of brick aggregate can be attributed to the pozzolan reaction [15]. On the other hand, the Calcite peaks can be observed and the reason of Portlandite reduction may be due to porous structure of brick aggregate and easier diffusion of CO_2 into the sample matrix.

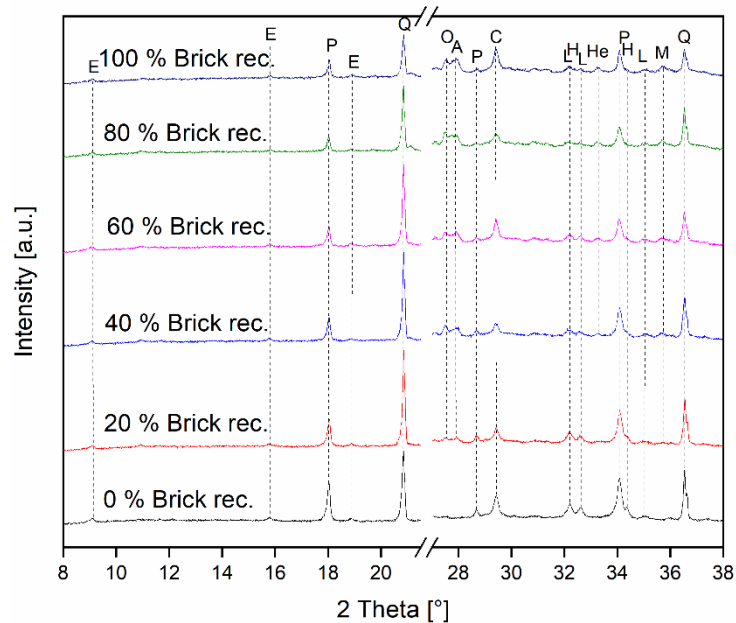


Figure 8. XRD analysis of prepared samples after 28 days (E – Ettringite; P – Portlandite, Q – Quartz; O – Orthoclase; A – Albite; C – Calcite; L – Larnite; H – Hatrurite; He – Hematite; M – Muscovite).

The microstructure of the samples was observed on the fracture area after 28 days in secondary electron mode at a magnification of 10 000 \times . The samples were gilded prior to observation. Only two samples were selected for the comparison in the paper – sample a (figure 9) without brick aggregate and sample f with 100% brick aggregate (figure 10) without sand. Both samples contain plate-like Portlandite crystals up to 1 micron thick. The sample containing brick aggregate exhibits finer CSH phase needle structure compared to sample a. The porosity of the sample is not comparable due to the fracture surface.

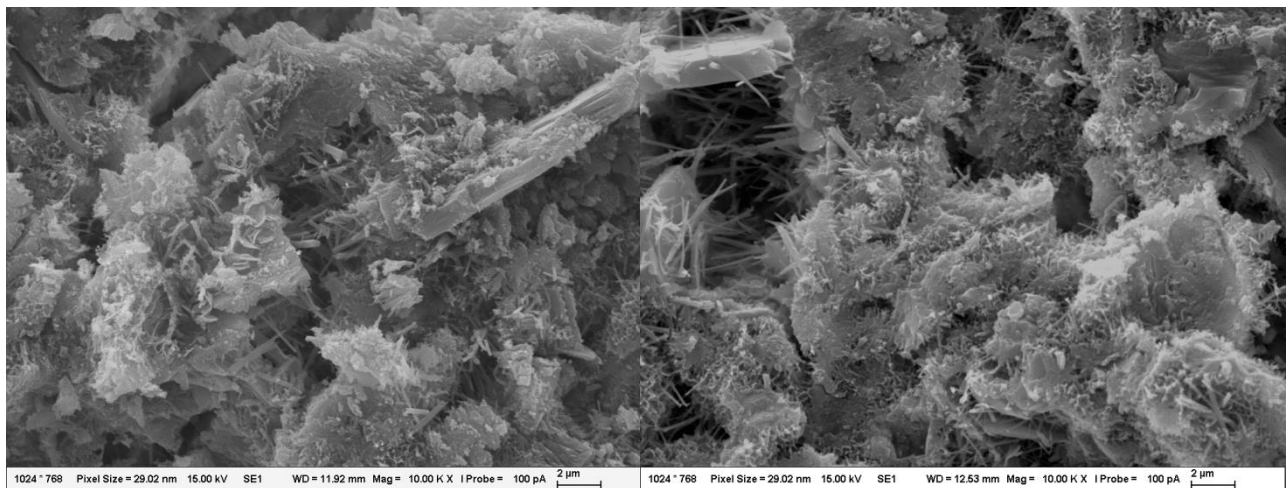


Figure 9. SEM image of sample a (0% brick agg.), magnification 10 000 \times .

Figure 10. SEM image of sample f (100% brick agg.), magnification 10 000 \times .

4. Conclusion

Partial replacement of quartz sand with recycled brick (up to about 40%) has positive effect on flexural and compressive strength. In addition, there is a decrease in bulk density. Brick aggregate has lower strengths than quartz sand, but compressive strengths of prepared samples with crushed bricks content are higher than reference without bricks. It means that the surface of brick aggregate probably reacts with the cement paste and contributes to the increase of strength. Or the fine fractions react with the cement as pozzolan or filler. Another positive feature is the so-called internal curing effect provided by the brick aggregate. The XRD results showed no new phases of hydration products. If any new phase was formed, it would be X-ray amorphous. The SEM results from the fracture surface suggest that the CSH phase formed in the case of brick aggregate is finer than in that with sand.

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