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RECYCLED CLAY BRICK AS AN AGGREGATE FOR CONCRETE: OVERVIEW

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Subject review

One of the significant problems nowadays is the accumulation and management of construction and demolition waste, which increases along with continuous spreading of urbanization and industrialization. Construction and demolition waste can be recycled and used as a raw material for new applications. Recycled brick aggregates recovered from demolished masonry structures can be utilized in the manufacture of new concrete mixtures. In order to ensure a sustainable waste management it is necessary to predict its properties and to specify its utilization. An overview of previous investigation of possibilities of using recycled clay brick as an aggregate in production of new concrete is presented in this paper.

Keywords: *aggregate, concrete, construction and demolition waste, recycled brick, waste management*

Reciklirana glinena opeka kao agregat za beton: pregled

Pregledni članak

Jedan od sve značajnijih problema današnjice jest nagomilavanje i zbrinjavanje građevinskog otpada, koji neprestanom urbanizacijom i industrijalizacijom poprima sve veće razmjere. Građevinski se otpad može reciklirati i upotrijebiti kao sirovina za novu primjenu. Reciklirana opeka dobivena iz srušenih zidanih konstrukcija može biti primijenjena kao agregat u proizvodnji novih betonskih mješavina. Kako bismo osigurali održivo gospodarenje građevinskim otpadom, nužno je predvidjeti njegova svojstva i odrediti njegovu primjenu. U radu je prikazan pregled dosadašnjih istraživanja mogućnosti uporabe reciklirane opeke kao agregata u proizvodnji novog betona.

Ključne riječi: *agregat, beton, građevinski otpad, reciklirana opeka, gospodarenje otpadom*

1 Introduction
Uvod

During the last decades, it has been recognized with growing concern that wastes from a construction are of large volume and that this volume is increasing year by year. The problem of waste accumulation exists worldwide. Most of waste materials are left as a landfill material or illegally dumped. Environmental impact can be reduced by making more sustainable use of this waste [1].

Waste management is one of the priorities of every community and it has become evident that good waste management can enhance the quality of life. The main principle of a quality waste management is in lowering the mass production of new, finding ways to recycle and reuse existing, and safe and ecologically acceptable depositing of unused waste [2].

Recycling is the reprocessing of old materials into the new products, in order to prevent the waste of potentially useful materials, reducing the consumption of raw materials. Recycling or re-using of bricks is an environmentally friendly way of eliminating it from the waste stream. Fine recycled brick aggregates recovered from demolished masonry structures can be utilized in the manufacture of new concrete mixtures. At this way, it is possible to reduce the problem of construction and demolition waste storage, and to reduce the consumption of natural materials. The utilization of masonry waste and of crushed brick as an aggregate in mortar and concrete would have a positive effect on the economy also. Namely, a preservation of natural materials is significant for an ecologically responsible and sustainable building that would be cost effective also. This kind of building implies a usage of low-cost materials that can be used without any negative impact on the environment.

This paper presents an overview of results of research that is carried out on a concrete made with recycled clay brick as an aggregate. Ecologically responsible and sustainable building implies that the material cycle will be completely closed, and the original constituents (clay brick and tiles, gravel, sand, cement stone) are recovered in thermal process. This concept of recycling and reuse of masonry waste is shown in Figure 1.

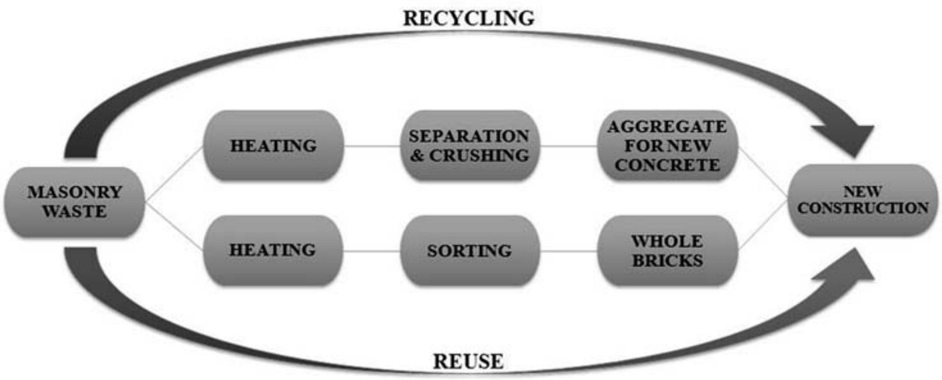

Figure 1. Concept of recycling and reuse of masonry waste
Slika 2. Koncept recikliranja i ponovne uporabe građevinskog otpada

2
Literature overview
Pregled literature

The overview of the subject revealed that there is more information available on the use of recycled concrete as an aggregate in new concrete, than on the same use of recycled brick.

2.1
Properties of recycled clay brick as an aggregate for new concrete
Svojstva reciklirane glinene opeke kao agregata za novi beton

By producing concrete the intention is to use as much aggregate as possible, as this material is cheaper than the cement binder. This means that the maximum possible aggregate size should be used, with continuous grading of particle sizes from fine sand up to the coarse aggregate. Aggregate occupies between 70 % and 80 % of the total concrete volume, and because of that the strength of aggregate is very important for the final strength of the concrete.

2.1.1
Porosity and absorption of recycled clay brick
Poroznost i apsorpcija reciklirane glinene opeke

Porosity is a measure of the void spaces in a material. Absorption is a measure of the water content in a surface dry material that is water saturated. These two properties of the aggregate are very important factors in influencing aggregate properties such as the bond between it and the cement paste, the resistance of concrete to freezing and thawing, as well as its chemical stability and resistance to abrasion. The specific gravity of the aggregate also depends on its porosity.

Water absorption and void content of crushed-brick aggregate were several times higher than those of crushed-stone aggregate [3]. The porosity of most common natural aggregates such as granite has been looked into, but very little is known about the porosity of recycled brick aggregate except that it has a relatively high value.

2.1.2
Contaminants in recycled brick aggregate
Štetne primjese u recikliranom agregatu od opeke

The need for predictable and consistent performance of the final product is one of the limiting factors in expanding the reuse and recycling of construction waste. For instance, the contaminants in the recycled brick aggregate could pass into the new concrete and have harmful effects on strength and durability.

The presence of asphalt in aggregates reduces the strength of the concrete. For instance, the addition of 30 % by volume of asphalt to recycled aggregate reduces the concrete compressive strength by approximately 30 % [4].

The lime mortar can be easily removed from the surface of the bricks, and because of that it is possible to reuse the whole bricks for the new brickwork. On the other side cement containing mortar is much more difficult to remove than lime mortar, so bricks that have this mortar adhered to them are usually crushed to aggregate [5].

From the studies of deleterious effects of gypsum plaster in recycled aggregate concrete due, to sulfate expansion it was concluded that standard specifications for recycled aggregates should include limits on the gypsum content [4]. For production of concrete where the recycled aggregate may be contaminated with gypsum, it is recommended that sulphate resistant Portland cement should be used.

Organic substances such as paper, wood, textile and other polymeric materials are unstable in concrete when it is subjected to drying/wetting or freezing/thawing cycles. Other types of organic substances, like paint, may entrain large amounts of air in the concrete [6].

The presence of chlorides, sulphates and other salts in reinforced concrete can causes corrosion of steel reinforcement. It has been found through previous experience that recycled masonry aggregates have lower chloride and sulphate contents than recycled concrete aggregates [4].

2.2
Concrete mix design
Projektiranje sastava betona

By using the recycled clay brick as an aggregate in concrete, it is possible to design concrete mixtures in the same way as the design mixtures for commonly used aggregates. The use of above mentioned aggregate for concrete couses high porosity and water absorption of the material. Consequently, that can affect workability of the fresh concrete made with that aggregate. *Workability* is the ability of a fresh concrete mix to fill the form/mold properly with the desired work and without reducing the concrete's quality.

The absorption of recycled crushed brick is estimated to a value between 22 % and 25 % by weight in relation to the material in its dry state. From the studies of absorption recycled bricks aggregates, it was concluded that recycled crushed brick becomes almost totally saturated with water after just 30 min of submersion in water. Submersion for a further 24 h produces only an increase of about 2 % water absorption [4]. Prewetting can be also avoided by designing a mixture with a very high workability levels or by adding a superplasticiser admixture. The effects of the super-plasticiser last for only about 15 min, and after that the concrete becomes difficult to work with. Thus, the recommendation is that the prewetting is the best solution to the problem of such porous aggregates [7]. It is generally accepted that concrete with crushed brick as an aggregate can be made with all demanded concrete consistencies without any limitation.

By using recycled aggregates, the dust content must be taken into consideration because it can cause a reduction in workability. In that case, if extra water has to be added to the concrete mix to increase the workability, the loss of strength will be evident. If the reduction in strength is limited to around 5 %, the maximum amount of dust should be limited also. That limitation could be in ranges from 5 % of the total aggregate content for low workability with a coarse grading, 10 % for low workability with fine grading and 20 % for a high workability with fine grading [6].

The cement content in concrete with crushed masonry aggregate might be up to 20 % higher than in a normal concrete containing natural aggregate, depending on the type and composition of the above mentioned aggregate. By using recycled masonry for the fine aggregate fraction as well as the coarse aggregate it is concluded that the cement content will be higher [4]. It was found that the density of recycled brick concrete is lower 8-17 % than the one of the commonly used concrete. With the increasing of a percentage of substitution of natural aggregate with crushed brick aggregate, the percentage of entrained air increases also [8]. Because of a lower density of the brick aggregate, concrete made with it should have a lower density than the one with commonly used natural aggregate for concrete.

2.3 Properties of concrete with recycled brick as an aggregate

Svojstva betona s recikliranom opekom kao agregatom

2.3.1 Compressive strength

Tlačna čvrstoća

Compressive strength is the capacity of a material to withstand axially directed pushing forces. Generally, concrete with recycled brick as an aggregate has a relatively lower strength than a normal aggregate concrete. This characteristic can be attributed to the higher water absorption of recycled crushed brick aggregate compared to natural aggregate. Increasing of the rate of substitution natural aggregate with brick decreases the compressive strength. After 28 days of, the decreasing in compressive strength was in the order of 10-35 % for the recycled coarse aggregates concrete in comparison with an ordinary concrete [8]. From the studies, it can be concluded also that the compressive strength of concrete with recycled clay brick as an aggregate is between 20 and 40 MPa (after 28 days).

However, the strength of the concrete with recycled brick as an aggregate depends on the strength of the original brick. For instance, the use of crushed brick aggregates, obtained from brick with higher initial strength, may exceed the compressive strengths reached using granite aggregate, even allowing for the production of high strength concrete [6, 7]. Generally, it is possible to estimate the strength of the concrete with the brick as the coarse aggregate from the strength of the original brick [7]. This estimation of the compressive strength could be important when recycled bricks from a construction waste are used as an aggregate for a new concrete. On this way it would be possible to determine whether or not that brick type, in a particular condition, is suitable for use as the aggregate for a new concrete with demanded strength. Air-entrained concrete can be successfully produced using crushed brick aggregate. The compressive strengths of that concrete are close to the target strengths designed for and close to the strength of the concrete produced with the granite aggregate [7].

2.3.2 Flexural strength

Čvrstoća na savijanje

Flexural strength is the stress at which a material breaks or permanently deforms. The angular shape of the crushed brick and its surface roughness are generally beneficial for a good bond between the aggregates and the cement paste which could hence increase the flexural strength performances. In spite of that assumption, flexural strength of the concrete with crushed brick as an aggregate is about 8 % - 15 % lower than the one of the ordinary concrete [6]. During the studies of correlation between flexural and compressive strength of concrete with recycled crushed brick aggregate, it was observed that a decrease in flexural strength has a similar pattern as the one observed for compressive strength [8].

2.3.3 Modulus of elasticity

Modul elastičnosti

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete with crushed brick as an aggregate is about 30-40 % lower than the one of a normal concrete [9]. With the increasing of a percentage of substitution of natural aggregate with crushed brick aggregate, the modulus of elasticity decreases. It is also concluded that the modulus of elasticity of fine and both fine and coarse crushed bricks concrete is lower up to 30 %, 40 % and 50 % in a comparison with the modulus of elasticity of a natural aggregates concrete [8]. By using recycled brick for concrete aggregate an increasing of deformation has to be taken into account. Replacing 100 % of the natural aggregate with recycled brick increases the deformations about 30 % [10]. That means that in constructions, in which deformations should be considered, the smaller elasticity modulus resulted from the use of recycled brick aggregate.

2.3.4 Shrinkage

Skupljanje

The shrinkage are volumetric changes as a result of drying of the material. The drying shrinkage in a concrete with recycled crushed brick as an aggregate is higher than the shrinkage in a normal commonly used concrete [6]. The shrinkage is in correlation with the size of aggregate particles used in concrete production.

If the fine crushed brick was used as an aggregate for a new concrete, the shrinkage at early age is almost six times higher than for the natural aggregates concrete and continues with the same rate of increase up to 90 days [8]. The incorporation of fine crushed brick aggregates significantly increases the shrinkage. When coarse and fine crushed brick are used together as aggregates, the shrinkage is stabilized at early age and becomes comparable with the one of the normal concrete. At later age, the shrinkage of concrete with fine and coarse recycled brick aggregate is higher than the one of the normal concrete with natural aggregate [8].

2.3.5 Water absorption

Apsorpcija vode

The main problem of using the recycled brick as an aggregate for concrete is its high water absorption. The water absorption of recycled crushed brick aggregate concrete is significantly greater than the one of the natural aggregate concrete [8].

Water is necessary for the corrosion of embedded steel, as it can carry chlorides and sulphates as well as other harmful ions. The presence of water can also cause freeze-thaw damage to concrete. The durability of concrete with recycled brick aggregate may turn to be its major insufficiency, since the water absorption increases very significantly with the proportion of the crushed brick aggregate on the concrete mix. The use of a plasticizer admixture has a positive effect by decreasing the water absorption. The high water absorption problem may be partially solved by using a pre-saturation method of the aggregates [9].

2.3.6 Abrasion resistance
Otpornost na habanje

The abrasion resistance is the ability of material to resist wearing, grinding, or rubbing away by friction. The abrasion resistance is important in order to evaluate the durability of the concrete produced with recycled brick coarse aggregate. It can be observed especially in elements such as pavement slabs which are subjected to abrasion degradation. Concrete produced with recycled brick aggregates shows a good performance, even better than the limestone aggregates concrete. This can be explained by the better adhesion between the mortar paste and the recycled brick aggregates, caused by their greater porosity as compared with the limestone aggregates [9].

2.3.7 Thermal conductivity
Toplinska provodljivost

Thermal conductivity is the property of a material that indicates its ability to conduct heat. The thermal performance of concrete is expressed in terms of the thermal conductivity. Crushed brick aggregate concrete had a lower coefficient of thermal conductivity than a normal aggregate concrete. Coefficient of thermal conductivity of crushed brick aggregate concrete is in a range of 0,5-0,75 W/(m·K), and for a concrete with natural aggregate the coefficient is about 1,75 W/(m·K) [11].

From the studies of thermal conductivity of concrete with recycled bricks as an aggregate it can be concluded that cement and polymer content have an influence on the thermal conductivity of concrete. By reduction of cement content or by increasing of polymer content, there was a reduction in thermal conductivity [12].

2.3.8 Fire resistance
Otpornost na požar

Recycled crushed clay brick is one of the best aggregates for concrete that may have to resist fire, and it performs much better than similar concrete containing granite aggregate [13]. Brick aggregate is a thermally stable aggregate. It is probably why it performs well when used as an aggregate in concrete subjected to high temperatures. Fire resistance of clay brickwork is an important characteristic, since it has been recognized that brickwork masonry is a very effective material for resisting and preventing the spread of fire. When brick material is used as the aggregate in concrete, there should be no lowering of the concrete's ability to resist the fire.

To ensure very good fire resistance of the crushed brick aggregate concrete, it should be kept dry. If the crushed brick aggregate concrete is wet, then the internal steam pressure, created in a case of fire, can cause spalling [4]. Low thermal conductivity of concrete also improves its fire resistance. Because of a lower thermal conductivity, reinforced concrete is much better protected against early heating. Concrete with recycled brick as an aggregate keeps its structural integrity under fire for a much longer period than commonly used ordinary concrete.

3 Experimental investigation
Eksperimentalno istraživanje

The preliminary experimental investigation of some physical and mechanical properties is carried out on micro-concrete with three different types of aggregates. Results of the investigation are presented in order to compare properties of these three types of micro-concrete in their fresh and hardened state.

Testing was performed on three different micro-concrete mix designs made with different types of aggregate. All mixtures are made with Portland cement CEM I 52,5 N. The mixtures are of the same cement percentage (450 kg/m^3); they were made by the same water-cement factor (v/c=0,5) as well as properties of the fresh state. River aggregate is used in a reference control mixture (MC1). Crushed brick and crushed tiles are used as the aggregate in MC2 and MC3 mixtures.

Crushed brick and crushed tiles aggregate was submitted to a pre-saturation process, i.e. to water submersion during 30 min. River aggregate grading curve is the same as the grading curve of crushed brick and crushed tiles aggregate that is obtained by sieving on the standardized sieves. Proportions of particles of crushed brick and crushed tiles aggregates are adapted to a content of certain size particles of the river aggregate. An influence of different particle size of aggregates on properties of concrete is avoided in this way. Furthermore, a mutual comparison of obtained micro-concretes is simplified.

Table 1 Properties of fresh micro-concrete
Tablica 1 Svojstva svježeg mikro-betona

	Density of fresh micro-concrete, kg/m^3	Air content, %	Consistency, cm
Control mixture MC1 River aggregate	2228	3	16
Mixture MC2 Crushed brick aggregate	1862	10,5	15,8
Mixture MC3 Crushed tiles aggregate	1944	4,4	15

For each mixture 3 prisms of 40×40×160 mm were cast in steel moulds. All the moulds were covered by plastic sheets and stored for 24 h in the laboratory. After demoulding samples were placed in water at the room temperature for a total curing period of 28 days. All measurements were carried out on 28 days old specimens.

The following properties of the fresh micro-concrete were determined: workability, specific density and air content. The average values of measured properties of fresh micro-concrete are presented in Table 1 for produced three types of micro-concrete mixtures (MC1, MC2, and Mc3).

At the water/cement ratio of 0,5, both concretes exhibit very good workability without the use of admixtures. From the results presented in Table 1 it can be concluded that micro-concretes MC2 and MC3 have a lower density than the river aggregate concrete. Density of crushed brick aggregate micro-concrete was found to be lower by 16,4 %, and the density of crushed tiles aggregate micro-concrete was found to be lower by 12,7 % than the one of control micro-concrete.

Test results of flexural and compressive strength of 28 days old specimens of recycled crushed brick, crushed tiles and river aggregate micro-concrete are presented in Table 2. After 28 days, the compressive strength of micro-concrete with recycled crushed brick aggregate was about 23,8 %, and with crushed tiles about 32,7 % lower than the one of river aggregate micro-concrete. Micro-concrete produced with these aggregates does not perform as well as concrete produced with regular river aggregates in terms of strength. However, the concrete still has a strength that would make it suitable for some applications, with the added benefit that density values are much lower; making it suitable in situations where self-weight is a problem.

Table 2 Properties of hardened concrete
Tablica 2 Svojstva očvrsnutog betona

	Compressive strength, MPa	Flexural strength, MPa
Control mixture MC1	46,88	10,10
Mixture MC2	35,73	6,63
Mixture MC3	31,56	6,01

After 28 days, the flexural strength of micro-concrete with recycled crushed brick aggregate was about 34,4 %, and with crushed tiles about 40,5 % lower than the one of river aggregate micro-concrete. From these preliminary results it could be concluded that there was a reduction in flexural strength when crushed brick or tiles aggregates was used instead of river aggregate.

4 Conclusion
Zaključak

An overview of important properties of concrete made with crushed clay brick and tiles as an aggregate is presented in this paper. The overview showed that concrete can be successfully produced using recycled aggregates that have been produced from demolition and construction waste. Thereby, it is necessary to take into account that the normal concrete with regular aggregate has better physico-mechanical properties, e.g. compressive and flexural strength, than the concrete with crushed brick as an aggregate. However, the concrete made with crushed brick aggregate has better thermal properties.

According to results of experimental investigation that are presented in the paper, following conclusions are obtained:

- Density of crushed brick micro-concrete and crushed tiles micro-concrete was found to be lower, and the percentage of entrained air is higher than the one of river aggregate micro-concrete. Because of the lower density, micro-concrete with recycled crushed brick aggregate can be suitable for applications where self-weight is a problem.
- The compressive and flexural strengths of the crushed brick micro-concrete and crushed tiles micro-concrete are lower than the strengths of river aggregate micro-concrete. This conclusion corresponds to the results of previous investigations of concrete strength. The concrete with recycled crushed brick aggregate still has a strength that would make it suitable for applications in which the high strength is not necessary.

The aim of experimental investigation presented in this paper was the investigation of possibilities of utilization of waste brick and tiles as an aggregate in micro-concrete. This investigation is preliminary and the future work will address extensive investigation of physical, mechanical and thermal properties of concrete made with recycled brick aggregate in order to obtain final conclusions about the possibilities of application of recycled brick as aggregate for concrete.

The principles of sustainable development require the prudent use of natural resources and maximum use of recycling of construction waste. Recycling of bricks and tiles provides environmental benefits, conserving landfill space and use as aggregate reduces the need for river aggregate mining.

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