International Scientific Conference

SCIENCE , EDUCATION, TECHNOLOGY AND INNOVATION

S E T I IV

BOOK OF ABSTRACTS

Un pour tous, et tous pour un !

Belgrade , 2022

МЕЂУНАРОДНА ИСТРАЖИВАЧКА
АКАДЕМИЈА НАУКА И УМЕТНОСТИ - МИАНУ
INTERNATIONAL RESEARCH ACADEMY OF
SCIENCE AND ART – IRASA

IRASA
International Scientific Conference

SCIENCE, EDUCATION, TECHNOLOGY AND INNOVATION

SETI IV 2022

Book of Proceedings

Belgrade,

October 1, 2022

Publisher
IRASA – International Research Academy of Science and Art
Belgrade

For the Publisher
Academician Prof. Vladica Ristić, PhD

Editors
Academician Prof. Vladica Ristić, PhD
Academician Prof. Marija Maksin, PhD
Academician Prof. Jelena Bošković, PhD

Reviewers
Academician Prof. Vladica Ristić, PhD;
Academician Prof. Dušan Minić, PhD
Academician Prof. Jelena Bošković, PhD
Academician Prof. Marija Maksin, PhD
Academician Prof. Juan Sánchez Monroe, PhD
Academician Slavka Zeković, PhD
Academician Ana Perić Momčilović, PhD
Academician Prof. Mirko Smoljić, PhD
Academician Prof. Slobodanka Đolić, PhD
Academician Prof. Slavko Vukša, PhD
Academician Prof. Hadžib Salkić, PhD
Academician Prof. Enes Huseinagić, PhD
Academician Prof. Vjekoslav Budimirović, PhD
Academician Prof. Dobrica Vesić, PhD
Academician Prof. Radivoj Prodanović, PhD

Print run
150

Printed by
Instant system, Belgrade
2022

ISBN 978-86-81512-07-4

Publication of the Book of Proceedings has been co-financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

Scientific Committee

- Academician Prof. Jelena Bošković, PhD, University Metropolitan, Belgrade, Republic of Serbia, President of the Scientific Committee
- Academician Prof. Yong Du, PhD, State Key Lab of Powder Metallurgy, Central South University Changsha, Hunan, People's Republic of China
- Academician Andy Watson, PhD, School of Process, Environmental and Materials Engineering, University of Leeds, UK
- Academician Prof. Juan Sanchez Monroe, PhD, Instituto Superior de Relaciones Internacionales "Raúl Roa Garcia", Universidad de La Habana, Republic of Cuba
- Academician Prof. Wolfgang Rohrbach, PhD PhD.habil, European Academy of Sciences and Arts, Salzburg, Austria
- Academician Prof. Tariq Javed, PhD, Chairman of the Department of Pathology, Faculty of Veterinary Science, University of Agriculture, Faisalabad, Islamic Republic of Pakistan
- Academician Prof. Alina-Mihaela Stoica, PhD, Director of the Department of Physical Education and Sport, University of Bucharest, Republic of Romania
- Prof. Božidar Mitrović, PhD, Head of the Department, Moscow University of Finance and Law, (MFUA), Moscow, Russian Federation
- Prof. Giancarlo Cotella, PhD, Interuniversity Department of Regional and Urban Studies and Planning, Politechnico di Torino, Republic of Italia
- Academician Prof. Miodrag Ivanović, PhD, Oaklands College, Associate College of the University of Hertfordshire, UK
- Academician Prof. Aleksandar Slaev, PhD, Department of Architecture and Urban Studies, Varna Free Univeristy "Chernorizets Hrabar", Varna, Republic of Bulgaria
- Academician Prof. Andrea Carolina Schvartz Peres, PhD, Faculty of Philosophy and Human Sciences, State University of Campinas, Federative Republic of Brazil
- Academician Prof. Mirko Smoljić, PhD, University „Sjever", Varaždin, Republic of Croatia
- Academician Prof. Enes Huseinagić, PhD, International University Travnik (IUT), Travnik, Bosnia and Hercegovina Federation
- Prof. Atanas Kozarev, PhD, Faculty of Detectives and Criminology, European University, Skopje, Republic of Northern Macedonia
- Academician Prof. Vladica Ristić, PhD, Faculty of Applied Ecology Futura, University Metropoliten, Belgrade, Republic of Serbia
- Academician Prof. Marija Maksin, PhD, Institute of Architecture and Urban & Spatial Planning of Serbia, Belgrade, Republic of Serbia
- Academician Prof. Slobodanka Đolić, PhD, Slobomir P University, Bijeljina, Republic of Srpska

- Academician Prof. Duško Minić, PhD, Department of Materials and Metallurgy, Institute of Chemistry, Technology and Metallurgy, University of Prishtina, Kosovska Mitrovica, Republic of Serbia
- Academician Slavka Zeković, PhD, Scientific Advisor, Institute of Architecture and Urban & Spatial Planning of Serbia, Belgrade, Republic of Serbia
- Academician Prof. Gordana Dražić, PhD, University Singidunum, Belgrade, Republic of Serbia
- Academician Prof. Dragana Spasić, PhD, Faculty of Philology, University of Prishtina, Kosovska Mitrovica, Republic of Serbia
- Academician Prof. Dragan Manasijević, PhD, Department of Metallurgy Engineering, Technical Faculty Bor, University of Belgrade, Republic of Serbia
- Academician Vladan Ćosović, PhD, Scientific Advisor, Department of Materials and Metallurgy, Institute of Chemistry, Technology and Metallurgy, University of Belgrade, Belgrade, Republic of Serbia
- Academician Prof. Krešimir Buntak, PhD, University „Sjever", Varaždin, Republic of Croatia
- Nikola Krunić, PhD, Senior Research Associate, Institute of Architecture and Urban & Spatial Planning of Serbia, Belgrade, Republic of Serbia
- Marina Nenković-Riznić, PhD, Senior Research Associate, Institute of Architecture and Urban & Spatial Planning of Serbia, Belgrade, Republic of Serbia
- Academician Associate Prof. Milena Premović, PhD, Department of Technological Engineering, Faculty of Technical sciences, University of Prishtina, Kosovska Mitrovica, Republic of Serbia
- Assistant Prof. Ljubiša Balanović, PhD, Department of Metallurgy Engineering, Technical Faculty Bor, University of Belgrade, Republic of Serbia
- Associate Prof. Lidija Beko, Faculty of Mining and Geology, University of Belgrade, Republic of Serbia
- Dragana Vukašinović, PhD, Fauna Smart Technologies, Copenhagen, Kingdom of Denmark

Organizing Committee

- Academician Assistant Prof. Aleksandra Pavić Panić
- Academician Ivana Jelić, PhD
- Academician Assistant Prof. Mirza Totić, PhD
- MA Amit Vujić, Innovator of Academy
- MA Sergej Vukša, Candidate for Academician
- MA Slobodan Milić, Candidate for Academician

TABLE OF CONTENT

KEYNOTE PAPERS

A SCIENCE, TECHNOLOGY AND INNOVATION

GREEN CONCRETE AND MORTAR MADE WITH RECYCLED AGGREGATE – A STEP TOWARDS SUSTAINABILITY IN CIVIL ENGINEERING

Aleksandar Savić[27]; Gordana Broćeta[28]; Ivana Jelić[29]; Marina Aškrabić[30]

Abstract

The testing of physical and mechanical properties has always been the starting point for production of adequate cement composites, such as concrete and mortar. The need to preserve the environment by recycling materials, among other means, has found its recognition in production of mortars and concretes made with recycled aggregate. The paper deals with the specific aspects regarding the use of aggregate based on the recycled rubber, recycled brick and recycled concrete in mortar and concrete mixtures, with respect to the advantages and disadvantages of these aggregates. Properties such as density and consistency of fresh mixtures, as well as hardened state density, and hardened state compressive, flexural and bond strength will be used to quantify and assess the effect of the recycled materials on cement properties, in order to provide their practical use. The testing was conducted on the composites with local materials and in local laboratory conditions. A special part relates to the use of these materials in Self-Compacting Concrete mixtures, where the extreme attention to the component testing, mix proportioning, and production technology has to be paid.

Key words: *Recycled aggregates, physical and mechanical properties, concrete, mortar.*

Introduction

In chorus with the uprise of the civilization, the awareness of our identity, the world around us, the general laws of existence and events, and therefore the awareness of the interaction of us and nature, in the broadest sense, developed. The current universal awareness through the platform of sustainable development should enable the survival of our species and our culture, as we know it [1].

[27]Aleksandar Savić, Associate Professor, PhD, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Beograd, Republic of Serbia, sasha@grf.bg.ac.rs
[28]Gordana Broćeta, Associate Professor, PhD, University of Banja Luka Faculty for Architecture, Civil Engineering and Geodesy, Bulevar vojvode Petra Bojovića 1a, 78000 Banja Luka, Republic of Srpska, gordana.broceta@aggf.unibl.org
[29]Ivana Jelić, Research Associate, PhD, Academician of IRASA, Vinča Institute of Nuclear Sciencies, Mike Petrovića Alasa 12-14, 11351 Vinča, Beograd, Republic of Serbia, ivana.jelic@vin.bg.ac.rs
[30]Marina Aškrabić, Assistant Professor, PhD, University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Beograd, Republic of Serbia, amarina@grf.bg.ac.rs

Construction, as an economic branch with a significant impact on the environment, is changing, among other things, in accordance with the trends that guide the sustainable development. In this sense, all aspects of construction (planning, designing, implementation, functioning, duration, i.e. structure lifespan, etc.) are critically looked at, re-examined and, in case it is possible and expedient, modernized by implementing the philosophy of sustainable development. Sustainable use of resources, energy efficiency and durability of civil engineering structures (with reference to the possibility of material recycling and minimization of waste material and impact on the environment), represent the basic aspects of the evident determination for sustainable development in construction today [2]. Based on the estimations, the size of the construction market ranged between values 6.4 trillion and over 12.6 trillion dollars in 2020. In 2030, it is projected to be more than twice as big as it was in 2020 [3, 4].
On the basis of statistical research, industry is accounted for 33-35% energy consumption [5] (where transportation, residential and commercials sectors complement this amount), but based on different type of research, the buildings and construction sector alone can be held responsible for approximately 36% of final energy use [6]. With broader picture in mind, up to 39% of energy and process-related carbon dioxide (CO2) emissions also take place in the buildings and construction sector, 11% of which results from manufacturing building materials and products such as steel, cement and glass [6]. Nevertheless, there is also a lower bound estimation of 24% greenhouse gas emissions by the industry sector, calculated for the year of 2020 [7].
Therefore, it occurs to be quite realistic to estimate that the most prominent themes that would aid circular economy, improve the building industry sector and enable better effect on the environment are the following: switching to renewable energy sources and energy efficient approaches, improving building design, use of nature-based and traditional solutions, and improvement in materials in terms of their environmental impact. The use of recyclable and recycled materials is a very important segment in this approach. Following the Sofia Declaration [8] on the Green Agenda for Western Balkan 2021—2030 that endorses the EU's Green Deal strategy and the New Circular Economy, the legislation is being taken from EU on waste management (National Assembly of the Republic of Serbia 2018) and landfill disposal (Government of the Republic of Serbia 2010), waste categories, (Government of the Republic of Serbia Ministry of Environmental Protection 2021) and waste statistics.
Sustainable development of construction industry has become a growing concern. It is estimated that the worldwide annual production of concrete, as the most prominent construction material, is approximately 20 billion tones [9]. On a global scale, the estimated annual consumption of natural resources surpassed 40% of raw stone, gravel and sand, 25% of virgin wood, 16% of water, and 40% of total energy [10]. Furthermore, total world production of cement hit 4.1 billion tones in 2019 [11], and it was estimated that it will exceed 6 billion tones till 2025 [12]. Given that production of cement itself yields approximately 7% of the total CO2 emission worldwide, it is recognized as one of the major environmental concerns [12]. On the other hand, significant increase in construction and demolition waste discarded in landfills is

recorded, leading to other environmental hazards. In the EU alone, 850 million tonnes of construction and demolition waste are generated, accounting for around 30% of total waste [13]. One of the ways of solving this problem can be sought in the application of recycled aggregates, as well as partial replacement of cement with waste or supplementary cementitious materials, such as fly ash.

Based on the insight in the composition of concrete, the production of 1 m3 of this building materials means consumption of almost 1 m3 of aggregate [14], and many researchers agree that a reduction in natural aggregate utilisation can only be sustainably achieved through the C&D (construction and demolition) waste, in a role of a recycled aggregate.

The aim of this paper is to show and address the properties of different kinds of recycled aggregates: recycled rubber aggregate, recycled brick aggregate and recycled concrete aggregate that have been studied for decades in the Laboratory for materials of the University of Belgrade Faculty of Civil Engineering on mortar (aggregate grains up to 4 mm – fine aggregate) and concrete (aggregate grains including fine and aggregate regarded as coarse – size from 4 mm up to 32 mm). Also, based on the results and findings of these studies, and described production techniques, the concrete technology practitioners can learn to produce such "green" concretes that incorporate sustainability component.

The use of aggregate based on recycled rubber

The problem of the used and worn tires is persistent for decades. The rise in the number of vehicles, together with the arrangement of legal regulations regarding the worn tires resulted in high quantities of such material discarded of on legal and illegal landfills. Followed by the problem of the environment pollution, there is a present threat of pests who got used to such places as habitats. Although there are no precise data, it is estimated that in Serbia about 28,000 tons of waste tires are ”generated” annually, of which 7000 tons are used by cement factories as fuel. Although there is a non-negligeable effect of using such waste rubber materials for combustion processes in cement kilns, a number of studies were done in the area of using them in asphalt and cement composites. For instance, recycled rubber can be used in asphalt composites in two ways: as a modifier of bituminous binder, and as aggregate. Also, significant quantities of rubber are made and used as polymer bound composites for sports facilities, children playgrounds, for other paving applications etc.

A mass of recycled rubber granules represents 55-65% of the tire weight. Secondary product of tire fragmentation process is steel wire (25-30% of the mass), and a tertiary product are textile fibers, which make up about 10% of the tire weight. All of these components can be successfully recycled, after the process of their separation. In the case of the rubber component, it is cut, shredded, ground and sieved in different size classes i.e. fractions. The size of the fractions is given in the Table 1, as an illustration of the possibilities, but not as a limitation. For mortar the fine fraction I (0/4) is used most often, and for concrete, beside this fraction a fraction II (4/8), III (8/16) and IV

(16/31.5) are most often used. Naturally, depending of the specific application, some subfractions can be made, as well as different convenient size limits can be applied.

Table 1: Sizes and application of the rubber granulates

Size	Name and production method	Application
Whole or cut tires	Whole tires can be recycled by cutting in halves, quarters, etc.	building stocks, artificial reefs, sound barriers, temporary roads etc.
50-300 mm	Shred is made from mechanically cut pneumatics, which can be split in different sizes	light fillings for road bases, embankments, drainages, thermal insulation in roads and buildings, sound ramps, construction of landfill fences
10-50 mm	Pieces that have been mechanically cut, split in smaller parts	light fills for general construction, drainage, construction pavements, construction and maintenance of landfills, bridge pillars and agricultural elements
1-10 mm	Granulate, as a result of further processing in fine particles	cattle mats, floor tiles, roofing materials, sports field coverings, rubber asphalt, roadside guardrails, speed reduction bumpers
0-0.5 mm	Dust and powder can be result of processing of rubber under 1 mm in size	soles for shoes, sports equipment, insulating materials for covering cables, automotive parts, pigments, inks, porous bituminous binders, protective layers, sealing compounds

The properties of the fractions are usually inherited from the rubber tire, and provide a base for explanation regarding the properties of the cement composites they are incorporated. Orientation values of the physical and mechanical properties of rubber aggregate important for this application are given in Table 2.

Table 2. Relevant physical and mechanical properties of recycled rubber aggregate

Property	Value
Specific gravity	0.9-1.1
Granulate density	300-600 kg/m^3
Water absorption	≈0%
Compressive strength	10-30 MPa
Tensile strength	2.3-5.6 MPa

The results of mortar and concrete studies shown here are based on the own studies performed in the Laboratory for materials. Although there were certain concerns regarding the adhesion (or bond) between rubber aggregate and cement matrix, the studies show that this should not be considered a problem. Also, production or mixing technology of the concrete and mortar can be similar to that of conventional concrete. Some studies incorporated mixing process where aggregate was poured in the already mixed paste of cement and water, in order to provide better adhesion, but most of the studies were conducted in an usual manner, meaning that aggregate (a mix of natural and recycled rubber aggregate) was first mixed with cement in a dry mix, and then water and other optional fluids were introduced.

Most studies were made with moderate replacement percentages of natural aggregate with recycled rubber (up to 30%), but also with the replacement percentages of up to 60%. Having in mind the fact that recycled rubber aggregate has a lower density than the natural river or crushed aggregate, volume percentage replacement of natural aggregate by rubber should be given advance in favour of mass percentages. The most replaced fraction of aggregate in these studies was fraction 0/2 mm. The change in most of the physical and mechanical properties with the rise in rubber content is substantial, due to the substantial differences between natural aggregate and recycled rubber properties.

When fresh properties of mortar with rubber aggregate are concerned, density is influenced the least, decreasing up to approximately 10% with the incorporation of rubber aggregate up to 30% by volume. Slump and air content slightly increased, with no visible trend with the rubber content. A certain increase in superplasticizer needed in order to achieve a certain consistency was also recorded with the increase in rubber content [15].

Studies conducted on hardened mortar series showed decrease in mechanical properties, such as compressive, flexural and pull off strength. The reduction in compressive strength at the age of 28 days reached 37% with incorporation of 30% vol replacement of sand with recycled rubber aggregate, and even 75% for 60% incorporation, and the flexural strength was reduced to up to 16%. The pull-off or bond strength reduced 22% with incorporation of 30% vol replacement of sand with recycled rubber aggregate, and it achieved 28.4% decrease for the series with 60% rubber.

It is important to stress out that for the mortars the ratio between flexural and compressive strength increases from 0.15 to 0.20 providing the more favourable internal stresses, so in the light of energy efficiency and sustainability, more robust structures made of rubberized concrete have better internal stresses arrangement, higher durability, and overall better impact on the environment (Figure 1). Freeze thaw effect is lower than that of the superplasticizer.

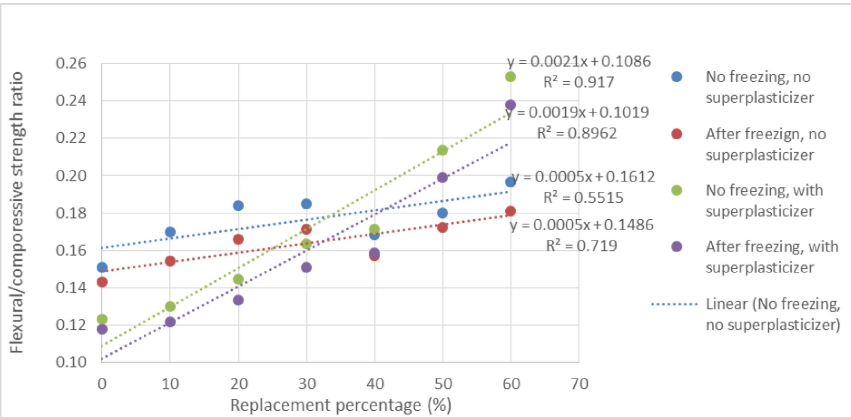

Figure 1. Trends of ratio flexural/compressive strength with respect to rubber content, superplasticizer and freeze thaw effect

Modulus of elasticity for rubberized mortars reduced 16% for the incorporation of up to 30% of mortar, and up to 25% for the 60% (by volume) replacement. In the case of ultrasonic pulse velocity, it declined with the presence of rubber aggregate. This property showed a decrease from the reference mortar in the amount of 11.7- 20.6%.
The freeze-thaw resistance test showed increased resistance of rubberized mortar. The increment varied with the percentage of used rubber aggregate, amounting to 3.4-17.0% in comparison to the reference mortar [16]. The appearance of the samples after the flexural testing is shown in Figure 2 (little black areas are rubber granulate).

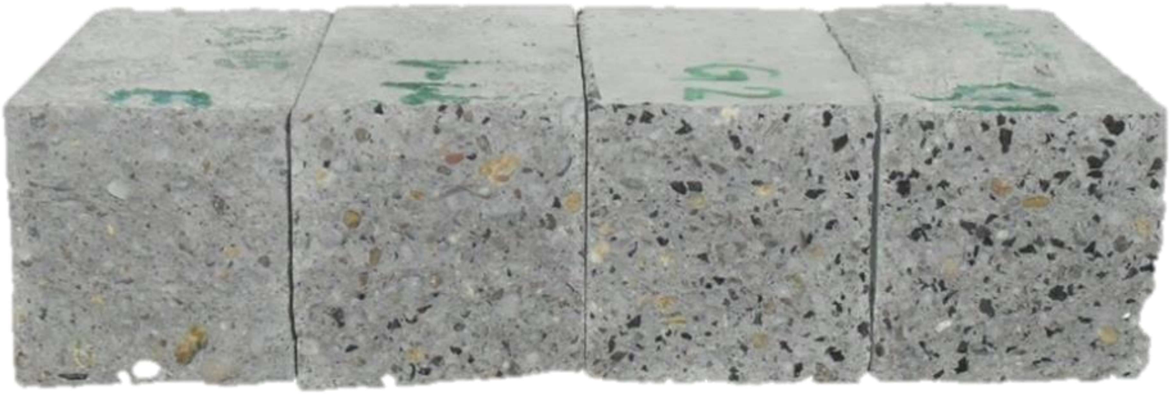

Figure 2. Appearance of the mortar samples after the flexural testing

In the case of conventional concrete mixtures, the usual amounts of component materials were used (quantity of cement 350 kg/m3, the water/cement ratio was constant and it amounted to 0.50, with addition of 0.5% superplasticizer in the form of modified polycarboxilate related to the mass of cement to achieve the projected consistency of all mixtures in the laboratory studies. These testing results indicate that the density of fresh concrete decreases 27% with the increment of rubber content up to 20% mass replacement of aggregate with recycled rubber - almost with linear rate. When it comes to entrained air content, the results show significant increase of almost 100%. Nevertheless, this is the effect of the aperture, which is designed with the premise of incompressible aggregate and water. The 28 days compressive strength decrease is 84% with 20% mass replacement of aggregate with recycled rubber. The decrease of tensile and splitting tensile strength was as close as 78%, which is also a noticeable effect [17].
The testing of simultaneous action of frost and de-icing salts consisted of cyclic frost/thaw periods (25 cycles), using three concrete specimens per each mixture, with upper surface subjected to the NaCl water solution – according to the Serbian standard SRPS U.M1.055:1984. After the prescribed treatment, the visual evaluation of concrete surface degradation was performed. This procedure showed that there were no visible traces of degradation on any of the concrete specimens [18].
In the case of Self-Compacting Concrete (SCC - a special type of concrete that can be placed without vibration equipment, flowing through the dense reinforcement and filling the formwork only by its own weight) with the addition of rubber aggregate,

performed laboratory tests showed that fresh mixes had similar consistency and workability as reference concrete (made without rubber granulate). Due to the fact that the rubber replacement took place only for sand and only in the amount of 30%, the effect was not so high decrease of density of 6%.
For the hardened properties, there was a decrease in 28 days compressive strength of 32.5% (from 40.8 MPa for reference concrete, to 27.8 MPa for series with 30% replacement of sand with rubber aggregate) [19].
"Drop weight" dynamic toughness test was conducted on RSCC series, with the aim of estimating the impact energy absorption of rubberized series. The results showed that the energy consumed by the specimen before fracture of the specimen doubled for series with 30% replacement of sand with rubber aggregate [20].

The use of aggregate based on recycled brick

The use of the ceramic materials has been present in building industry for ages. It enabled the development of building brick, block and roof tile industry, which also resulted in precise qualification and standardization of such material. Although the current production technologies minimize waste and even enable a high rate of recycling of such material, there is still a vast majority of brick and block made structures, dating from different ages, even centuries. In Serbia, about 80% of buildings are completely or partially brick, so this material has a future in the field of recycling. According to the available data regarding construction materials, bricks have the highest percentage of recycling (35%), followed by concrete (20%) and wood (12%), etc.
With the assumption that the present ceramic material can be successfully separated from the other present materials, ceramic waste materials offer solid opportunities in the sphere of sustainable construction. Similar to rubber aggregate, brick can be easily crushed and ground and separated into fraction for the use in mortar and concrete as aggregate. Fines also have pozzolanic effect. Basic physical and mechanical properties of brick aggregate are given in the Table 3. Due to the nature of the material, the recycled brick grains obtained by crushing are often flat or needle-shaped, Therefore the shape coefficient of crushed brick aggregate is often very low, which is a limiting factor for its application. Compressive strength of brick is 5-10 times higher than the tensile strength. This is a property of brittle materials, and this brittleness is visible also in the fracture of the cement composites made with recycled brick aggregate (Figure 3).

Table 3. Basic physical and mechanical properties of the brick aggregate [21, 22]

	Shape coeff.	Water absorption (%)	Density (kg/m^3)	Specific gravity	Compressive strength (MPa)	Tensile strength (MPa)
Fraction I	not applicable	12.3	1081	2.4	7.5-30.0	1.5-2.5
Fraction II	0.23	16.1	816	2.4	7.5-30.0	1.5-2.5
Fraction III	0.11	16.3	811	2.4	7.5-30.0	1.5-2.5

Lime based mortars made with crushed brick aggregate (0/5 mm in size) were made in order to study the physical and mechanical properties in hardened state [21]. As expected, given the higher porosity of crushed brick aggregates compared to aggregates of river origin, with an increase in the percentage of aggregate replacement, the final absorption values for all three types of mixtures also increase from 11% to 23% (for the mortar with 75% of crushed brick aggregate by volume replacement of river sand). Although most mortars with added crushed brick aggregates achieved a lower compressive strength value compared to the corresponding reference mix, all results at 56 days of age met the minimum requirements for plastering mortars. On the other hand, adhesion was in most cases higher with mortars with crushed bricks compared to the reference mixtures. This way the point of view that the connection between mortar and brick depends primarily on the quality of the contact zone, and less on the mechanical characteristics of the mortar itself, was confirmed.

Figure 3. The appearance of the fracture surface of the concrete with different content of recycled brick aggregate

Research done on Self-Compacting Mortars (SCM), suitable for some levelling or even repair applications in structures showed that the incorporation of crushed brick powder (finer than 0.125 mm) and crushed brick aggregate (0.09/2 mm) didn't affect much the consistency of mortars (measured by slump flow) with deviations of ±30% from the reference mixture made with limestone filler and river aggregate [23]. These deviations were not only the effect of crushed brick powder and crushed brick aggregate presence, but the combined effect of these materials with fly ash and recycled concrete aggregate. Crushed brick powder presence in the amount of 50% of total filler mass even reduced the value of slump flow diameter of SCM.

As for the hardened SCM, measured density was reduced approximately 1% due to replacement of limestone powder filler with crushed brick powder, while the replacement of river aggregate with crushed brick aggregate resulted in decrease of 15% in mortar density. Compressive strength at the age of 28 days of SCM was adversely affected by the presence of crushed brick powder (decrease of 6%) and crushed brick aggregate (further decrease of 17%). Flexural strength of SCM at the age of 28 days of SCM showed decrease of 4% for crushed brick powder use, and further decrease of 27% for crushed brick aggregate. A note has to be made here that after 90 days these changes were closer to the reference mixture (but didn't reach it), based on the pozzolanic effect of the crushed brick powder. Pull off was also studied, with high decrease of 26% for crushed brick powder use, and further decrease of 50% for crushed brick aggregate. In these formulations, final value of pull off strength for the series with recycled brick aggregate was 1.2 MPa, which is even lower than the lowest value requirement of 1.5 MPa.

Along with the density decrease due to use of lighter components, and proving the correlation with strength, values of ultrasonic pulse velocity were 12% lower for crushed brick powder use, and further 34% for crushed brick aggregate use, at the age of 28 days.

Durability of SCM's was evaluated through the freeze and thaw test, where the series with crushed brick powder showed 35% better performance in comparison to the reference series, and the series with crushed brick aggregate showed substantially worse behaviour, even failing to withstand the whole procedure of 25 freeze and thaw cycles.

Strong correlation between dynamic modulus of elasticity and compressive strength was established for all of the series. It was confirmed that coefficient in these correlations depended mostly on the overall mortar composition (through bulk densities of the series) [24].

The SCC mixtures with moderate amount of 360 kg/m3 of cement, 160 kg/m3 of filler (fly ash in three and ground recycled brick in the fourth mixture) as well as partial replacement of 75% and 25% of river coarse aggregate with crushed brick aggregate, with 233-370 kg/m3 of water (depending on the absorption of aggregate) and superplasticizer (4-6 kg/m3) were made in order to assess the effects of brick aggregate in SCC. Fresh concrete densities ranged from 2096 to 2252 kg/m3, and slump flow values ranged between 590 mm and 660 mm. Slump flow time increased with the increase of recycled brick aggregate share. Due to different water absorption mechanism, bleeding was noticed for the mixtures with recycled brick, but the workability decreased rapidly for the mixtures with recycled brick aggregate. The mixture with the highest content of recycled brick aggregate had the lowest, and the mixture with natural river aggregate and brick as a filler had the highest value of hardened density. Compressive strength of the mixtures made with fly ash as a filler all reached similar values of compressive strength of approximately 44 MPa, while the mixture made with river aggregate and ground brick as a filler showed 53 MPa, at the age of 90 days [22].

The use of aggregate based on recycled concrete

Depending on the considered region or country, the structure of construction waste also varies, but research shows that a significant part is concrete waste (Japan 42%, Europe 50% [25]), which is disposed of in planned or ad-hoc landfills. The main reasons for the limited use of recycled aggregate obtained by crushing old concrete (recycled concrete aggregate – RCA) are related to the quality of recycled aggregate (water absorption, density, impurities), the technology of producing concrete with recycled aggregate and certain properties of concrete made with it (rheology, durability) [26,27].

Regarding physical and mechanical properties of RCA, tests have shown that recycled aggregate, compared to natural aggregate, has 2-5 times higher water absorption, 5-15% lower density, 5-10% higher content of fines, in certain cases 1-2% higher content of organic and possibly other harmful substances, 5-15% higher crushability, 10-30% lower resistance to wear and frost [26]. Comparative laboratory testing organic matter in fine recycled and fine river aggregate with 3% NaOH showed substantially better quality of recycled aggregate obtained by crushing laboratory cubes (Figure 4).

Figure 4. Organic content testing of fine aggregates – transparent solution for recycled (left) and colored for river (right) aggregate

The presence of old cement mortar in the grain of the recycled aggregate (Figure 5) is a factor that adversely affects most of the stated physical and mechanical properties of RCA, together with the crack formations induced by production i.e., by crushing concrete. The possible improvement of RCA quality is always based on the procedures for partial or complete removal of cement mortar from aggregate grains (either completely mechanical removal of cement mortar or mechanical removal after pre-treated aggregate by heating, wetting or chemical agents). It should be emphasized that all procedures for removing cement mortar from recycled aggregate are very expensive (high consumption of electricity, chemicals, etc.). One of the implications of these aggregate properties is the very limited use of the fine fraction of RCA (due to high content of the attached cement paste) in recycled aggregate concrete (RAC) production (fraction 0/4 mm). Therefore, the choice of fractions used and their ratio represent a very important aspect when designing a concrete mix.

Figure 5. The characteristic appearance of the recycled concrete grain

One of the methods for improvement of recycled concrete aggregate is suggested to be carbonation (naturally or artificially made reaction of the atmospheric CO2 with the Ca(OH)2 present in cement paste of the recycled aggregate, with CaCO3 as a product). Regarding that, in the laboratory, the absorption measuring method was studied both on NA and RCA (with and without carbonation) using a hydrostatic weighing technique enabling continuous measurement, where different drying temperatures were analysed. The studies have shown that the carbonation modification of RCA can significantly change water absorption values, ranging from 33.9% decrease in the case of fraction III (8/16 mm) dried at 110ºC, to an increase of 1.2% in the case of fraction II (4/8 mm) dried at 45ºC [28].
On the other hand, the possible improvement of its' properties is sought in the production method, or the technology of RAC. First of all, most researchers agree that the water needed for mixing process should be increased by the absorption values of RCA. Second, pre-soaking of aggregate, sometimes aided by sodium silicate solution and silica fume or fly ash was considered a method for improvement of the aggregate and the RAC consequently. Also, the so called "Two-Stage Mixing Approach (TSMA)" was suggested (Figure 6), where half of the water is being introduced to the mixture in the first phase, after the dry mixing of aggregate, filling the pores and cracks and improving transition zones around the recycled aggregate (ITZ), and after that the rest of the water and cement are mixed [29].
All of the researchers notice that the workability of such concretes have to be periodically checked, and because of this most researchers suggest slump test to be performed 30 minutes after the concrete was mixed.
With the aim of improving the quality of recycled aggregate concrete and expanding its application, Tam et al. first proposed the mentioned method for concrete with recycled aggregate – "Two-Stage Mixing Approach (TSMA)". Experimental research in their work, based on SEM microscopy and mechanical tests, has shown improvements in the strength of concrete made this way. The effect is explained by the fact that, due to the high porosity of the recycled aggregate grains, the "pre-

mixing" process of the first stage helps filling pores and cracks, leading to concrete with higher bulk density, improved interfacial transition zone around the recycled aggregate (ITZ), and thus greater strength compared to the traditional mixing approach [30]. Lee (2012) investigated the ITZ and the influence of the mixing method, reaching the conclusion that a two-phase approach gives a denser and more homogeneous microstructure, and thus better mechanical properties of concrete with recycled aggregate [31]. Brand (2015) examined the impact of a two-phase mixing approach on high-quality recycled aggregate at different degrees of water saturation (completely dry, partially saturated, fully saturated) and the results showed that the two-phase approach contributed to the workability of the concrete mix and that lead to an improvement in the strength of concrete, when using a partially saturated recycled aggregate [32].

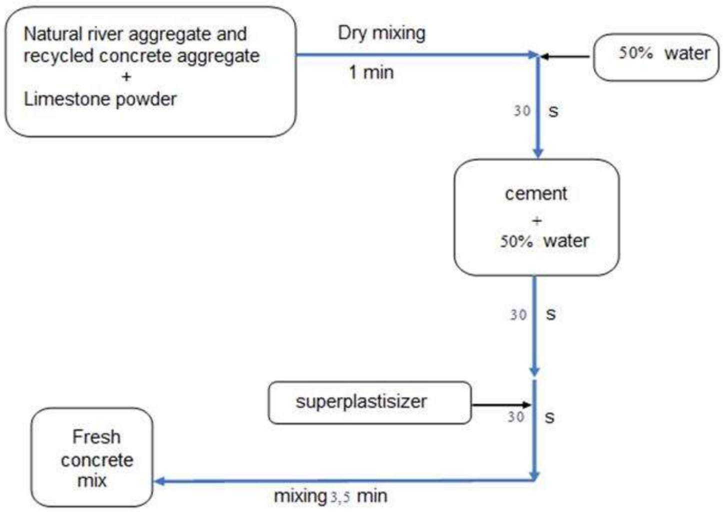

Figure 6. Two stage mixing approach used for the SCC RCA production [33, 34]

The most of the studies in the Belgrade laboratory were focused on the investigation of fresh and hardened concrete with coarse RCA, but some of them investigated also the use of fine RCA, production technology, properties of mortars with RCA, and structural properties of reinforced concrete elements - such as beams (flexural strength, creep and durability).

The use of fine fraction (size of grains under 4 mm) of recycled concrete aggregate in mortars, although rare as previously explained, was studied on cement-based mixtures with the similar compressive strengths of 30-33 MPa at the age of 2 days, which governed their composition (Table 4) [35]. Namely, in the case of recycled aggregate use, both cement and water content had to be increased (4% and 32% respectively by mass) to achieve the same target compressive strength, but in the case of silica fume use (approximately 10% by mass of cement) and water solution of sodium silicate, a reduction in cement content of 3.5% by mass was done. Also, for the same target compressive strength at 2 days, increase of 31% by mass of water was approximately similar (in comparison to the reference mixture) for all three mortar mixtures: (i) with recycled aggregate, (ii) with recycled aggregate and silica fume, and (iii) with recycled aggregate, sodium silicate and silica fume.

Table 4. Mortar mixtures with fine river and recycled aggregate

	Aggregate [g]		Cement [g]	Silica fume (SF) [g]	Water solution of sodium silicate (SS) [ml]	Water [ml]
	River (RI)	Recycled (RE)				
RI-REF	1300	/	433	/	/	216.7
RE	/	1300	452	/	/	285.5
RI-SF	1300	/	433	43	/	231.1
RE-SF	/	1300	438	43	/	282.8
RE-SF-SS	/	1300	418	43	245	46.1
RE-SS	/	1300	437	/	295	/

Density of fresh mortars made with recycled concrete aggregate was 3-4% lower than the reference (made with river aggregate). The use of silica fume and sodium silicate (because sodium silicate penetrates the aggregate structure, promotes self-healing and reacts with calcium hydroxide) resulted with higher fresh mortar density of the series with recycled concrete aggregate, which was less than 1% lower in comparison to the reference. Adversely, all of the mortar mixtures had very stiff consistency, with values of flow on the flow table between 102 mm and 126 mm, the values for mixtures with recycled concrete aggregate being on lower end.
Density of the hardened mortar mixtures was again higher for the mixtures made with river aggregate (approximately 2200-2300 kg/m3), and lower for the mixtures with recycled concrete aggregate (2150-2250 kg/m3), with silica fume and sodium silicate improving the compactness.

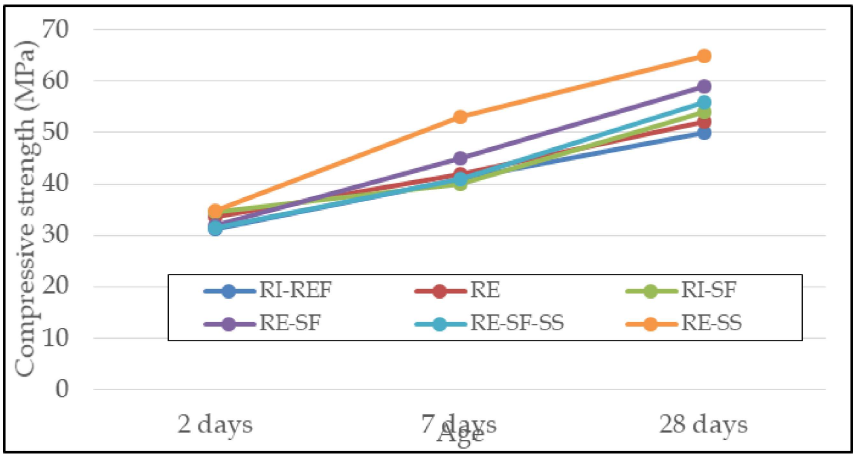

Figure 7: Development of compressive strength in time for mortars

Although the values of compressive strength at the age of 2 days were similar, there was a development of these values over time, up to the age of 28 days (Figure 7). The most moderate development of mortar mixtures was recorded for the series without improvement in the form of sodium silicate and silica fume, achieving 50 MPa at the age of 28 days. The fastest development of compressive strength was recorded for the mixture RE-SS with recycled aggregate and sodium silicate (65 MPa at the age of 28 days) and for the mixture RE-SF with recycled aggregate and silica fume (59 MPa at the age of 28 days). Last two trends justify the use of sodium silicate and silica fume for improving the properties of mortars with recycled concrete aggregate.

Flexural strength of the series at the age of 28 days ranged from 7.1 MPa up to 9.6 MPa, being the lowest for the RI-SF mixture, and highest for the RE-SS (with recycled aggregate and sodium silicate solution). Bond strength for all the mixtures ranged between 1.71 MPa (with recycled aggregate and sodium silicate solution) and 2.34 MPa (for the reference mixture, made with river aggregate).

Ultrasonic pulse velocity was similar for the mixtures, ranging between 3900 m/s for mixture with recycled aggregate, silica fume and sodium silicate solution and 4100 m/s for the reference mixture. Therefore, the finding was that treatment with sodium silicate and silica fume had certain improving effect on compactness of mortars.

There was an extensive study of the recycled aggregate concrete (RAC) with RCA in the Laboratory for materials, University of Belgrade Faculty of Civil engineering and over several decades, with the use of RCA (obtained by laboratory crusher) mostly from destroyed concrete test cubes as previously stated, but also from the concrete originated from structures, and some general findings have been made. First, density values of recycled concrete aggregate are 5-10% lower than the same values for natural aggregate, water absorption is around 4% (which is 4 times higher than that of natural aggregate), and crush test values are lower than 30%. The water absorption, and the development of that process in the case of the recycled aggregate is one of the main obstacles for the use of this aggregate more often. Namely, like in the case of the recycled brick aggregate, the needed high quantities of water and the absorption of recycled aggregate make it very hard for the water to cement factor to be held lower, for the consistency to be optimal, and also to be retained for a longer period of time. Therefore, the decrease in density is up to 4% in comparison to the concrete made with natural aggregate [27]. The concrete mixtures made with crushed aggregate showed significantly higher slump and flow, i.e. more fluid consistencies, than the target. The higher consistency of the fresh concrete mixtures made with natural crushed aggregate did not have a negative effect on the compressive strength of the hardened concrete. Small differences of the slump, flow and even density of concrete mixtures produced by normal and TSMA approaches can be attributed to the reproducibility of the tests. Based on the obtained results, concrete preparation technology does not have a major impact on the consistency of fresh concrete [29].

The compressive strength values of the RAC were 6% lower, in the case of complete substitution of coarse natural aggregate with recycled concrete aggregate. Although (as reported by other researchers) the shape of the recycled concrete aggregate (irregular, husky, and crackly) should aid the tensile strength, the results of splitting tensile tests of the concrete with recycled aggregate were in the range of ±7.5% of the values recorded for natural river aggregate [27].

In the case of concrete made with three types of aggregate – natural (river and crushed) and recycled concrete aggregate of up to 8 mm, there was no significant increase in compressive strength for the mixtures with river and crushed aggregate,

induced by two-stage mixing approach [29]. The improvement of compressive strength of the mixture by the two-stage mixing approach was 13.7% (when compared to the mixture with recycled concrete aggregate mixed by the usual approach). Concrete preparation technology had different effects on flexural strength depending of the aggregate used. Although there was no positive effect on flexural strength of concrete mixtures made with river aggregate, an increase in flexural strength of 4.5% in concrete with crushed, and 9.2% in concrete with recycled aggregate was recorded. As for the splitting tensile strength, the same conclusion can be drawn, with stronger effects: an increase in splitting tensile strength of 7.3% in concrete with crushed, and 14.3% in concrete with recycled aggregate was recorded.
Investigations on Self-Compacting Concrete made with recycled concrete aggregate were mainly focused on obtaining the needed fresh properties, so that the concrete can be characterised as SCC. Therefore, although carefully recorded and discussed, in most of the studies the properties in the hardened state stayed in the background. Although all of the mixtures were characterized as SCC with a slump-flow diameter of more than 650 mm, the introduction of recycled concrete aggregate induced challenges regarding the consistency, as expected. The consistency of the series with the recycled coarse aggregate was both more fluid and more rapidly thickening, in comparison to the series with river aggregate [33,34]. Suggestion was made for all the mixtures to be composed for the upper bond of slump flow values for SCC, reaching approximately 850 mm (lowest bond value being 550 mm) [33,34]. Having in mind that, in two-hour time slump flow value of this kind of concrete can drop fast from this upper to the lower bond, the study showed SCC mixtures with RCA to be adequate. All the other tests, done on fresh SCC mixtures (t500, tv, L-box), showed acceptable results. Bulk density of the fresh SCC mixtures displayed the expected trend of decrease of up to 5%, with the increase in recycled concrete aggregate content [34].
The early compressive strengths of the SCC mixtures with recycled concrete aggregate were found to be lower than reference, but after 28 days compressive strength was very similar for all the mixtures, with decrease of 3.9% when recycled coarse concrete was used for 50% mass replacement of the aggregate from 4 up to 16 mm [34, 36].
The SCC mixtures made with recycled aggregate and cured in ambient conditions (temperatures lower than 10˚C) were monitored in terms of physical and mechanical properties, after fresh concrete tests (regarding fluidity, workability, passing ability and segregation resistance of all mixtures were in line with the requirements for SCC. The results showed that concrete mixtures made with recycled aggregate had lower values of compressive strength at 1 day than the reference, but the differences in the compressive strengths decreased with the age [37].
Based on the studies, all tensile strengths achieved the values usual for conventional concretes, and similar values were obtained for all SCC mixtures. On the other hand, bond strength (determined by pull-off method) was highest for the mixture where river aggregate fraction II (4/8 mm) was replaced with recycled concrete aggregate, while the lowest bond strength (10% lower than the reference) was recorded for the mixture with 100% coarse recycled concrete aggregate [34].

The obtained values of static and dynamic moduli fall in quite narrow range. The decrease in static and dynamic moduli were up to 5%.
Concretes with recycled aggregate displayed the lowest test results of ultrasonic pulse velocity, in the range of 2-3% lower than for the concrete with natural aggregate. All concretes generally displayed high water absorption, but the production technology alteration induced no measurable effect on this property of concrete [29].
Studies on the SCC mixtures with recycled concrete aggregate of up to 32 mm and fly ash were performed in order to promote use of fly ash and coarse recycled aggregate in SCC (although due to the application of SCC – narrow reinforcement distances in the elements – usual size of the aggregate is limited to 16 mm). These studies showed that the differences in compressive strengths of the SCC series made with and without the recycled coarse aggregate were almost neglectable (2.6%) [38].
Studies have been conducted on SCC mixtures with both fine and coarse recycled concrete aggregate, with increase in the water based on the absorption, using TSMA and, as the dominant concept – particle packing density method. After experimentally obtaining ratios of fine and coarse aggregates on the basis of packing requirements and applying sufficient amount of proper paste component, it was shown that the optimal compositions of Self-Compacting Concrete could be provided with higher-than-average mechanical properties. Nevertheless, the use of recycled concrete aggregate and fly ash embodies challenges such as higher amount of needed water, fast decrease in workability, and decrease in mechanical properties in hardened state [39].

Conclusion

The conclusions will highlight the most important findings regarding: recycled rubber aggregate, recycled brick aggregate and recycled concrete aggregate, for the use in cement composites (mortar and concrete) in the same order as given in the paper.
Having in mind all the above-mentioned tests and the obtained results, although there is a sharp decrease in the important properties of rubberized cementitious composites with increase in rubber content, a general conclusion can be made that these composites can be successfully applied in many fields of engineering practice, due to their favourable properties such as: sustainability, toughness, elasticity and durability. The best results were obtained in the area of freeze-thaw resistance and impact properties. Reduction in density provides an option to achieve lightweight concrete and mortar.
In the case when recycled (crushed) brick was used for lime-based mortars, all results at 56 days of age met the minimum requirements for plastering mortars. Although the negative property of bleeding was noticed for the mixtures with recycled brick and the workability decreased rapidly for the mixtures with recycled brick aggregate, compressive strength of the mixture made with river aggregate and ground brick as a filler reached relatively high compressive strength of 53 MPa, at the age of 90 days.
When the properties of recycled concrete aggregate are addressed, and having in mind the fact that water to cement ratio is a very delicate aspect that governs the levels of

compressive strength and other properties, it is necessary to develop new standards for RCA water absorption tests that will take into account its specificities, paving a way to more accurate proportioning of RAC.
The strong suggestion of the sustainability improvement of Self-Compacting Concrete with recycled concrete aggregate was based on the use of RCA and fly ash, with respect to the reduction in cement and natural aggregate for concrete, also practicing the TSMA as a production technique, and higher water contents (due to the higher absorption of the RCA in comparison to the natural aggregate).
Regarding the compressive strength of SCC with RCA, it was shown that the values of 28d compressive strength can correspond to the higher than typical strength class C40/50, according to the SRPS EN 206, for all SCC mixtures, and that there was little negative effect on the mechanical properties due to the presence of additional water for absorption in the SCC. Similar properties of all mixtures were achieved for both coarse aggregate fractions replacement, showing no significant differences when aggregate size is taken as a parameter, and this can be explained by the fact that this study was conducted with recycled aggregate of good properties and in laboratory conditions. Having in mind the fact that in most of the studies the values of compressive strength of concrete mixtures with recycled aggregate were in line with the values for mixture with natural aggregate, industrial use of recycled aggregate in SCC in ambient conditions is expected.
Nevertheless, higher amount of water, fast decrease in workability, and decrease in mechanical properties in hardened state are expected properties of such concretes. These issues have to be regarded as main obstacles for wider application of compositions similar to the ones from this study, so the practical application always has to include the concrete technology techniques described in this paper.

Acknowledgements

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the funding of scientific research work at the University of Belgrade, Vinca Institute of Nuclear Sciences (Contract No. 451-03-68/2022-14/200017) and University of Belgrade, Faculty of Civil Engineering (No. 200092).

References

[1] *National Strategy of Sustainable Development of the Republic of Serbia*, Official Gazette of RS 57/08, 2008
[2] Savić A. *Investigation of the properties of fresh and hardened self-compacting concrete with mineral additives based on industrial by-products*. Doctoral dissertation, 2015
[3] Novicio, T. *5 Biggest Industries in the World in 2021*, https://www.insidermonkey.com/blog/5-biggest-industries-in-the-world-in-2021-925230/?singlepage=1, last accessed 12/09/2022

[4] Peysakhovich, R. *95+ Construction Industry Statistics & Facts*, https://www.getonedesk.com/blog/construction-industry-statistics, last accessed 12/09/2022
[5] *Monthly Energy Review*, U.S. Energy Information Administration April 2022
[6] Birol, F., Andersen, I. *2019 Global Status Report for Buildings and Construction*, International Energy Agency , https://www.worldgbc.org/news-media/2019-global-status-report-buildings-and-construction, last accessed 12/09/2022
[7] *Motive Power*, National Public Utilities Council, www. motivepower.com/ NPUC, last accessed 06/09/2022
[8] *Sofia declaration on the green agenda for the Western Balkans*, Regional Cooperation Council, 2020
[9] Mehta, P.K. Greening of the Concrete Industry for Sustainable Development, *Concrete International*, 24 (2002), pp. 23-28,
[10] Dixit, M.K., Fernández-Solís, J.L., Lavy, S., Culp, C.H. Identification of parameters for embodied energy measurement: A literature review, *Energy Build* 42 (2010), pp. 1238–1247, https://doi.org/10.1016/j.enbuild.2010.02.016,
[11] Statista, Chemicals & Resources, Mining, Metals & Minerals, https://www.statista.com/statistics/219343/cement-production-worldwide/, Accessed 12 / 09 / 2022
[12] Andrew, R.M. Global CO2 emissions from cement production, *Earth Syst. Sci. Data* 10 (2018), pp. 195–217, https://doi.org/10.5194/essd-10-195-2018
[13] Fischer, C., Werge, M. *EU as a Recycling Society: Present Recycling Levels of Municipal Waste and Construction & Demolition Waste in the EU*, European Topic Centre on Sustainable Consumption and Production, Copenhagen, 2009
[14] Radonjanin, V., Malešev, M., Marinković, S., Saed, A.M.A. Green recycled aggregate concrete, *Construction and Building Materials* 47 (2013), pp. 1503–1511
[15] Jevtić, D., Zakić, D., Savić, A., Application of recycled materials for production of sustainable cementitious composites, Plenary and Invitation Paper, 11th International Conference RaDMI, "Research and Development in Mechanical Industry", *RaDMI Proceedings*, pp. 110-121., 2011
[16] Jevtić, D., Zakić D., Savić, A. Investigation of cement based composites made with recycled rubber aggregate, *Hemijska industrija* (2012) OnLine-First (00):10-10, DOI:10.2298/HEMIND 111203010J
[17] Jevtić, D., Zakić, D., Savić, A., Radević, A. Experimental Investigation of "Green" Mortars With Recycled Rubber Aggregate, *2nd International scientific meeting GTZ 2012 and Conference GEO-EXPO 2012*, Proceedings, pp. 111-118, Tuzla, 2012
[18] Jevtić, D., Savić, A., Durability Investigation of Cement Mortars Made with Recycled Rubber Aggregate, *XIV YUCORR International conference*, ISBN 978-86-82343-16-5, Proceedings, pp. 302-307., Tara, 2012
[19] Jevtić, D., Zakić, D., Savić, A., Radević, A. Physical and mechanical properties of mortar and concrete made with the addition of recycled rubber, *II International Congress Engineering, Ecology and Materials in the Process Industry*, Proceedings, pp. 361-369, Jahorina, 2011
[20] Jevtić, D., Savić, A. Impact Strength Evaluation of Rubberized Fiber Reinforced SCC, Proceedings of the RILEM International workshop on performance-based

specification and control of concrete durability, *Proceeding PRO 89*, pp. 641-646, Zagreb, Croatia, 2014

[21] Aškrabić, M., Zakić, D., Savić, A., Jevtić, D., Mušović, E., Stanimirović, S., Lime plasters with the addition of recycled bricks intended for the restoration of historical buildings [In Serbian: Krečni malteri sa dodatkom reciklirane opeke namenjeni za restauraciju istorijskih objekata], *XV Congress, Association of Structural Engineers of Serbia*, Proceedings, pp. 180-189, 2018

[22] Purić, K. Influence of aggregates and fillers based on broken brick on the properties of self-compacting concrete, *8th International Conference "Science and Higher Education in Function of Sustainable Development"*, High Business Technical School, (proceedings of the student papers, mentor Aleksandar Savić), pp. 8-14, Užice, Serbia, 2015

[23] Savić, A., Aškrabić, M. Investigation of Self-compacting Mortars with Fly Ash and Crushed Brick, Athens Institute for Education and Research, *ATINER's Conference Paper Series CIV2016-2142*, pp. 1-17, Athens, Greece, 2016

[24] Savić, A., Aškrabić, M. Correlation between dynamic modulus of elasticity and compressive strength from self-compacting mortars, *Proceedings of The 6th International Congress of Serbian Society of Mechanics*, pp. S4A1-S4A8, Tara, 2017

[25] Luritzen, E. Recycling Concrete – An overview of development and challenges, *International RILEM Conference on the Use of Recycled Materials in Building and Structures*, pp. 297-305, Barcelona, 2004

[26] Jevtić, D., Zakić, D., Savić, A., Specific properties of recycled aggregate concrete production technology [In Serbian: Specifičnosti tehnologije spravljanja betona na bazi recikliranog agregata], *Building materials and structures*, Vol. 52−1 (2009) pp. 52−62.

[27] Ignjatović, I. Savić, A., Marinković, S. Experimental investigation of recycled aggregate concrete [In Serbian: Eksperimentalno ispitivanje betona od recikliranog agregata], *Građevinski kalendar* 2011, Vol. 43, 2010, pp. 101-147.

[28] Tošić, N., Savić, A., Carević, V. A method for the continuous measurement of water absorption of coarse recycled aggregates, *Association of Civil Engineers of Serbia*, Proceedings, pp. 1023-1030, Zlatibor, 2016

[29] Vidanović, Lj. *Investigation of composition and mixing approach on the properties of fine aggregate concrete with different aggregate types*, Master theses, Mentor Aleksandar Savić, Beograd, 2019

[30] Tam, V.W.Y., Gao, X., Tam, C.M. Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach, *Cement and Concrete Research* 35 (2005), pp. 1195-1203.

[31] Li, W., Xiao, J., Sun, Z., Kawashima, Shah, S., S.P. Interfacial transition zones in recycled aggregate concrete with different mixing approaches, *Construction and Building Materials* 35 (2012), pp. 1045–1055.

[32] Brand, A.S., Roesler, J.R., Salas, A. Initial moisture and mixing effects on higher quality recycled coarse aggregate concrete, *Construction and Building Materials* 79 (2015), pp. 83–89.

[33] Savić, A., Jelić, I., Aškrabić, M., Pavlović, D., Kovačević, B. Investigation of Green Self-Compacting Concrete Made with Recycled Concrete Aggregate,

International conference of Science, Education, Technology and Innovation SETI 2019, pp. 120-129., Belgrade, Serbia, 2019

[34] Savić, A., Aškrabić, M., Kovačević, B., Pavlović, D., Properties of SCC mixtures with coarse recycled aggregates, *ASES International Congress Proceedings*, pp. 265-274, Zlatibor, 2018

[35] Radojević, A. *The effect of the use of sodium silicate and silica fume on the improvement of the properties of the recycled aggregate in mortars*, mentor Aleksandar Savić

[36] Savić, A., Broćeta, G., Aškrabić, M., Gajić, A. Effect Of Aggregate Type And Fly Ash Content On Properties Of Self-Compacting Concrete, *XI International Scientific Conference Contemporary Materials*, Proceedings, pp. 23-31, Banja Luka, 2018

[37] Savić, A., Jelić, I., Šljivić-Ivanović, M., Dimović, D. Recycled concrete aggregate effect on Self-Compacting Concrete at low temperatures, *29th International Conference Ecological Truth and Environmental Research*, Bor, 2022, pp. 126-131

[38] Savić, A., Jelić, I., Sljivic-Ivanovic, M., Dimović, S., Pudar, N., Pfandler, A. Recycled Coarse Aggregate and Fly Ash Effect on Compressive Strength of Self-Compacting Concrete, *52nd International October Conference on Mining and Metallurgy*, pp. 173-176, Bor, 2021

[39] Vasić, M., Martinović, S., Vlahović, M., Volkov-Husović, T., Savić, A. Relevant Properties of Green Self-Compacting Concrete, *5th Conference of the Serbian Ceramic Materials*, Book of abstracts, pp. 11, Belgrade, 2019