THE APPLICATION POSSIBILITIES OF FLY ASH, SILICA FUME AND RECYCLED CONCRETE AGGREGATES IN SELF – COMPACTING CONCRETE

I.Despotović
Belgrade University College of Applied Studies in Civil Engineering and Geodesy
HajdukStankova 2, Belgrade
Serbia

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ABSTRACT
The concept of sustainable development, which besides social and economic aspects includes energy – saving, environmental protection and the conservation of exhaustible natural resources, impose the use of recycled aggregates as a solution of two significant problems in the civil engineering. There is a lack of natural aggregates in urban areas and increasing of the distance between the sources of natural aggregates and construction sites, as well as the problem of removal and disposal of large quantities of concrete waste. Self – compacting concrete, being innovation in the field of concrete technology, contains a certain amount of powdered materials – fillers. There are various possibilities of selecting this component. If we used any of the industrial by – products, such as fly ash or silica fume, we would solve the problem of depositing these materials, and thus made concrete ecological material. The research subject presented in this paper are properties and technology of self – compacting concrete made with various mineral additives: fly ash and silica fume, wherein the aggregates used, are both natural and recycled aggregates, obtained by demolition of retaining wall, whose amount is varied in the concrete.

INTRODUCTION
The construction industry uses vast amounts of natural resources, simultaneously producing significant amounts of debris, which has a large impacton the environment. Annual production of concrete in the world has reached 10 billion tons, which classifying it as the most widely used construction material. Regards to the fact that about 70% of concrete is actually an aggregate, it is clear the how much of the quantities of natural and crushed aggregates is required. The uncontrolled exploitation of aggregates from rivers seriously disrupts aquatic ecosystems and habitats, while production of crushed natural aggregates increases emission of harmful gases, primarilyCO_2, responsible for the greenhouse effect. These gases are produced during rock mining and also transportation of aggregates to the usually distant urban areas.
On the other hand, the amount of construction waste generated during construction and demolition process is growing rapidly (Figure 1), deepening problem of waste disposal, whichis usually resolves by established (which are occupying large areas and waste disposalis expensive) or "wild" – illegal dumps. One of the solutions of mentioned problems is recycling of deposited building, primarily concrete.
The ambition of reducing the use of natural materials in construction and the aim of reducing the environmental impact of the concrete industry has recently driven Europe to adopt a policy that strongly promotes the use of recycled aggregates in concrete production. The European Directive n.98 of 19/11/2008 calls on member states to take ‘‘the necessary measures to promote the reuse of products and the preparing measures for re-use activities, particularly by promoting the establishment of economic tools and criteria about tenders, quantitative targets or other measures’’. Particularly, it specifies that preparations for re-use, recycling and other types of recovery of material, including construction and demolition waste, shall be increased up to at least 70% (by weight) by 2020 (Pepe et. al., 2014).

Fig.1 Typical construction waste (www.hawersrecycling.co.uk)

FLY ASH, SILICA FUME AND RECYCLED CONCRETE AGGREGATE AS CONCRETE COMPONENTS

The initiators of the idea of applying fly ash, resulted from coal burning, in concrete were McMillan and Powers (1934). At the end of 40s the experiments carried out in the UK (by Fulton and Marshal) led to the construction of dams Lednock, Clatworthy and Lubreoch, with fly ash as a cement additive. All these structures are after 60 years in excellent condition (Newman and Chao, 2003).

During the combustion of coal in a furnace at temperatures between 1250˚C and 1600˚C, non-combustible particles combine to form spherical glassy droplets of silicate (SiO_2), aluminate (Al_2O_3), iron oxide (Fe_2O_3) and other less important constituents. When fly ash is added to concrete, pozzollanic reaction starts between silicon dioxide (SiO_2) and calcium hydroxide ($CaOH_2$) or lime, which is a by-product of hydration of Portland cement. The resulting products of hydration fill pores reducing the porosity of the matrix. These products differ from the products formed in concrete containing only Portland cement. In the reactions of Portland cement and water, hydrated lime ($CaOH_2$) is formed first, in the space between particles, because of its limited solubility. In the presence of water, lime reacts pozzollanic with fly ash to form new hydration products with fine pore structures.

Silica fume is formed during melting quartz at high temperature in an electric arc furnace, wherein silicon or ferrosilicon occurs. High purity quartz is heated to 2000˚C using coal, coke or wood chips as fuel and then electric arc is introduced in order to remove metals. By melting quartz, silicon oxide is released in gaseous state, and it is mixed with oxygen in the upper parts of the furnace, where it oxidizes turning into tiny particles of amorphous silicon dioxide. Particles are carried out from the furnace through the collector and cyclone, where the unburned parts of coal are removed, and then "blown" into the special filter bags.

Due to its nature, even a small addition of silica fume significantly changes physical and chemical properties of concrete. The customary dosage of 8- 10% by weight of cement means between 50 000 and 100 000 microspheres of dust per cement grain, which directly increases the cohesion of concrete. If silica fume is used in the powder form, there will be a need for a greater amount of water to allow mixing and placement of concrete so it is necessary to apply plasticizers and superplasticizers. In terms of placeability,it should be noted that fresh concrete with silica fume has less spreading(slump values) because of greater cohesion. Very fine silica fume particles will provide considerably larger contact area of fresh concrete and reinforcement and thus make better bonding of hardened concrete with reinforcement. Besides the lack of segregation and filling the main cavities, inconcretewithsilicafume,thereis no separation of water. That is why, immediately after placement,itisnecessarytobeginwith appropriate curing. Silica fume is pozzolan and it requires the presence of calcium hydroxide to be activated. Calcium hydroxide is formed in the cement hydration process, so that silica fume can be activated only when the cement begins to react. Setting time of concrete with silica fume is the same as in plain concrete. As concrete begins to set and harden, pozzolanic activity of silica fume becomes dominant reaction. Silica fume reacts with free calcium hydroxide, thus forming calcium silicate and hydrates of aluminium. These compounds increase the strength and reduce permeability, thickening the cement matrix.

Recycled Concrete Aggregate (RCA), derived from Concrete & Demolition waste generally consists of natural coarse aggregate and adhered mortar which makes it porous due to high mortar content,inhomogeneous and less dense (Hansen, 1986; Katz, 2003). The volume of the residual mortar in RA varies from 25% to 60% according tothe size of aggregate (Corinaldesi, 2010). Some researchers have reported in their studies that around 20% of cement paste is found attached to the surface of RA for particle size range from 20 to 30 mm (Nassar and Soroushian, 2012; Rahal, 2007).The water absorption of RCA ranges 3 - 12 % compared with 1 – 5 % for natural aggregate (Katz, 2003). The density and absorption of RCA depend upon the W/C ratio of the original concrete (Etxeberria et al., 2007) and the amount of adhered mortar. Also, the crushing process and the dimension of RCA affect the amount of adhered mortar (Ajdukiewicz and Kliszczewicz, 2002). What is specific for RCA is a presence of several types of interfacial transition zone (ITZ) - between the ''old'' and ''new'' compounds, that may play a key role in the internal microstructure of a concrete (Figure 2). Therefore, it will facilitate the applications of RCA if the adhered cement mortar can be enhanced. Removing and strengthening the adhered mortar are the two main methods for enhancing the properties of RCA.

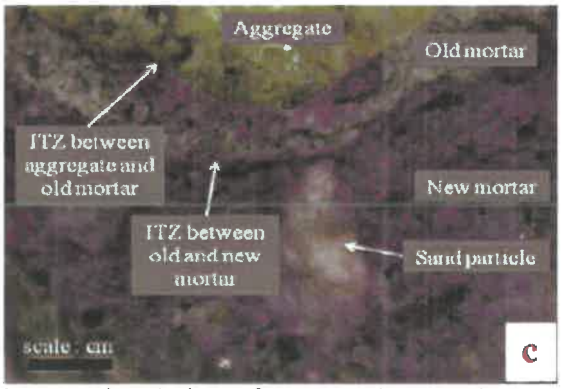


Fig.2 Sectional view of RCA (Behera et al., 2014)

LABORATORY TESTING

For the purpose of the experimental part of the work, it was made six different three-sized fracture concrete mixtures, with fly ash and silica fume; control concrete (CF – with fly ash, CS – with silica fume) are made with river aggregate; in mixtures of F50 and S50 is the fraction 8/16 mm replaced by recycled aggregate (crushed retaining wall), and in mixtures of F100 and S100 are both coarse fraction (4/8 and 8/16 mm) replaced with recycled. In all mixtures is used super plasticizer ViscoCrete 5380 (SIKA) which is dosed according to the manufacturer's recommendations. The criteria in the mixture design was achieving of the same concrete consistency, i.e. slump - flow class SF2, which includes the usual application of concrete and involves diffusion from 66 to 75 cm. By preparing of concrete mixture is the aggregate mixed with half the required water for about 30 seconds first, and then the other components were added. By case of recycled aggregate usage, it was added the amount of water absorbed by the unit in 30 minutes (fraction II 22.2%, fraction III of 1.5%), although this principle could not be applied consistently.The compositions of concrete mixtures are shown in Table 1.

Concrete mixture	CF	CS	F50	S50	F100	S100
Cement (kg/m^3)	400	400	400	400	400	400
Fly ash (kg/m^3)	120	0	120	0	120	0
Silica fume (kg/m^3)	0	52	0	52	0	52
0 – 4 mm (kg/m^3)	770.86	770.86	809.14	809.14	809.14	809.14
4- 8 mm(kg/m^3)	306.28	306.28	306.28	306.28	306.28	306.28
8 – 16 mm (kg/m^3)	532	532	505.43	505.43	505.43	505.43
Water (kg/m^3)	192.66	185.71	214.28	197.14	221	228.6
VSC5380 (kg/m^3)	4.94	4.94	5.08	5.08	5.08	5.08

Table 1 The compositions of concrete mixtures

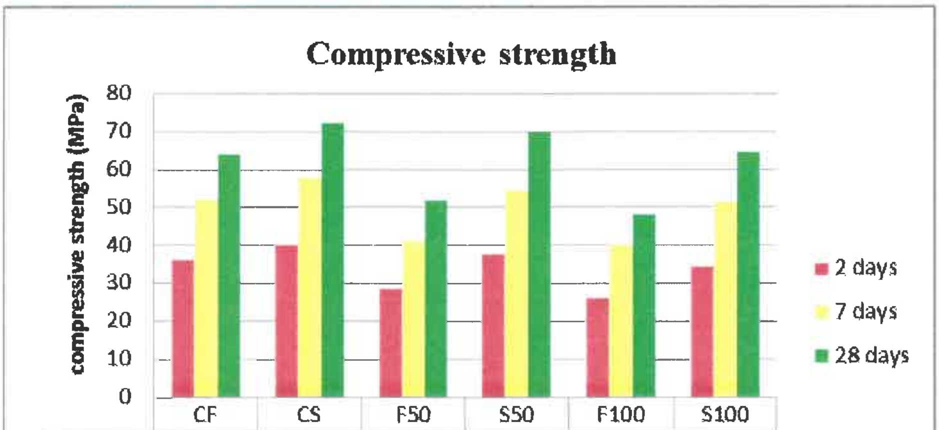
The fresh concrete tests (Table 2) were conducted on the following: density, flowability - Slump flow test according to EN 12350-8, viscosity - T500 test according to EN 12350-8, the passage ability between reinforcing bars - L box test according to EN 12350-10, segregation resistance - Sieve segregation test according to EN 12350-11. On hardened concrete tests were conductedon the following: density, compressive strength (Fig 2), tensile strength by bending, drying shrinkage(Fig 3), water - impermeability, water absorption and SEM analysis (Fig 5, 6).

Concrete mixture	CF	CS	F50	S50	F100	S100
Density (kg/m^3)	2288	2416	2279	2324	2298	2359
Slump – flow (cm)	70	66	70	67	66	66
T500 (s)	4	6	5	5	6	6
L box (H1/H2)	0.94	0.91	0.95	0.94	0.91	0.92
Sieve segreg. (%)	11	6.8	7.8	5.2	5.5	7.5

Table 2 Test results for concrete in the fresh state

Property	CF	CS	F50	S50	F100	S100
Density (kg/m^3)	2306	2376	2314	2325	2303	2333
Tens. strength(MPa)	8.98	10.31	8.2	8.91	7.97	8.28
Water absorp. (%)	2.12	0.9	1.95	0.85	1.93	0.86
Water imperm.	permeable	imperm.	permeable	imperm.	permeable	imperm.

Table 3 Test results for concrete in the hardened state (after 28 days)



	CF	CS	F50	S50	F100	S100
2 days	36.34	40.4	28.68	37.75	26.2	34.38
7 days	52.18	58.05	41.24	54.67	40.18	51.59
28 days	64	72.31	51.7	69.7	48.2	64.5

Fig. 3 Compressive strength

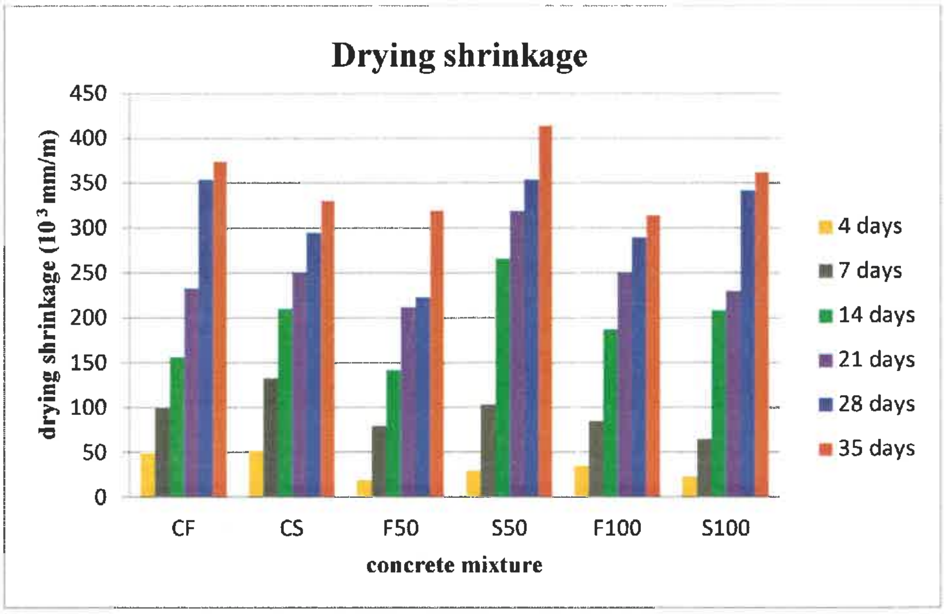


Fig. 4 Drying shrinkage

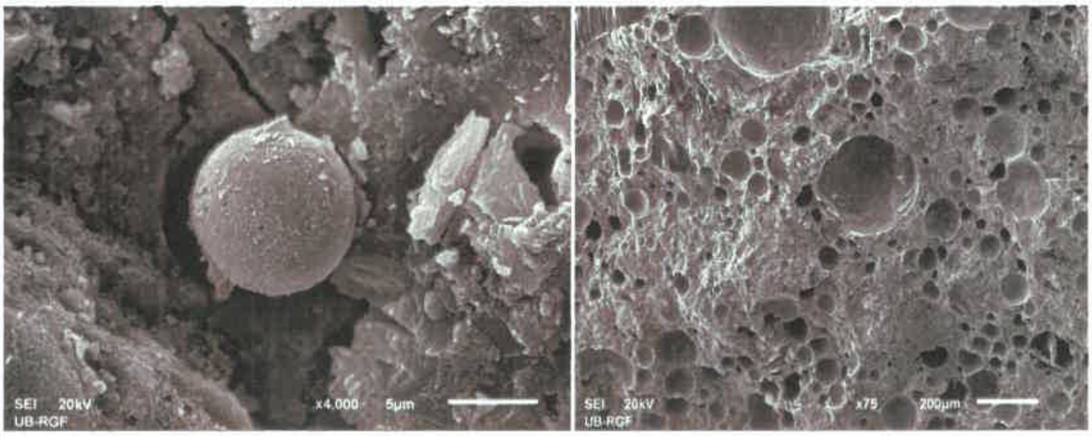


Fig.5 Microstructure of the concrete with fly ash

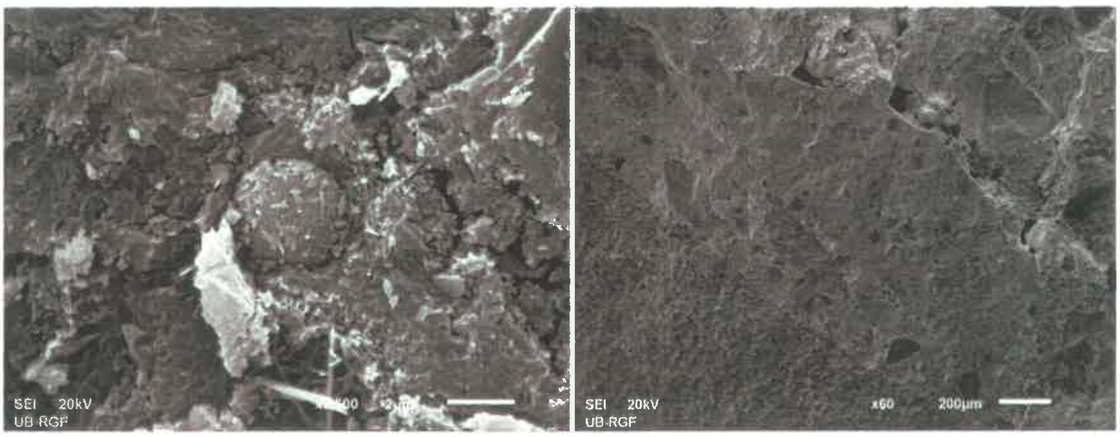


Fig.6 Microstructure of the concrete with silica fume

RESULTS ANALYSIS

By designing the concrete mix, and in order to achieve the same consistency, due to the application of recycled aggregates, it was necessary to intervene in two directions: to increase the amount of water and at the same time to reduce the amount of fraction III by 5% while increasing the amount of sand for 5%. Without these interventions in the composition, it was not possible to achieve self-compacting mixture; by reason of sharpedged form of recycled aggregate grain and its particle size distribution (recycled aggregate had a 7% of oversized grains).Spreadingwas between66 to73 cm,and it ranked allthe projectedmixturesin classSF2,corresponding to themost commonuse of concretein construction.Lowermobilitywas byconcrete mixtureswithsilica fume, as well asmixtureswith recycledaggregate, because this kind of sharpedged grain is harder to"move" during concrete pouring. T500 represents checking of themixture viscosity; for classSF2 is recommendedintervalof3.5-6.0s,inwhichallmixtures"fit". Also, allmixturesmeet thecriterionforthe relative height ofthe concreteat the ends ofL-box is at least0.8; and how thetestingwas donewiththreereinforcing bars(which isa requirementfordenselyreinforcedstructures) their class is PA2. The results show thatallblends/mixturesareresistant tosegregation andbelong to the classSR2(<15%).

Concretes with silica fume had higher density, which is in accordance with obtained microstructure. After 28 days, control concrete with silica fume had the highest density, for 27 kg/m^3 (1.2 %) higher than the mixturewith fly ashand both coarse recycled factions.

The highest value of compressive strength after two days had control concrete with silica fume, CS, and the lowest mixture with fly ash and recycled both coarse fractions - F100. The difference was 14.2 MPa (35%). After 7 days control concretesF50 and F100 had almost the same compressive strength (41 and 40MPa) while the mixture of CS reached 58 MPa (difference of 18 MPa, i.e. 31%). After 28 days, the maximum value of compressive strength is was reached bycontrol concretewith silica fume - 72.31 MPa, while the lowest mixture of F100, 47.2 MPa (difference of 25.11 MPa, i.e. 34.7%). Observing mixtures with silica fume, it can be concluded that the differences in achieved compressive strength by the use of natural and recycled aggregates are relatively small – 2.6 MPa (3.6%) and 7.8 MPa (10.8%) - comparison with standards mixtures with replaced one or both coarse fractions. By mixtures with fly ashes difference is 12.3 MPa (19.2%) and 16.8 MPa (26.2%). The bigger difference in compressive strength within the mixtures with the fly ashes can be explained by the uneven quality of recycled aggregates, which represents a major problem within its application.Also, faster increase of strength had mixtures with silica fume.

The differences in the results of tensile strength by bending are not significant. The values of tensile strength by bending are in the range from7.97 MPa (F100) to 10.31 MPa (CS).

The available data from the literature as well as proper previous research (Grdic et.al., 2010) shows that it is difficult to foreseen or find some rule when it comes to shrinkage of concrete. The measurements show the largest shrinkage of concrete (after 35 days), had mixtures with silica fume and III recycled fraction, S50, but the lowest concrete F100, with difference of 24%. It is not possible to draw any regularity in these results: mixtures with III recycled fraction had greater shrinkage of the mixtures with II and III recycled fraction, whereby the differences in silica fume were more pronounced than in concrete with fly ash.

Water absorption goes in the range of 0.85% (mixture S50) to2.12% (mixture CF).Higherwater absorptionwereat mixturesof fly ashes,which is entirely in accordance with the achieved structure of concrete, and how was showed in SEM analysis, it was at most porous at concrete mixtures with fly ash. This structure explains decrease of concrete impermeability. Some authors (Ponikiewski and Golaszewski, 2014) connect this with fly ash with high content of CaO, a kind of which is used in laboratory testing.

By testing of water-impermeability, ingress of water to concrete with silica fume was very low, about 2cm, which defines these mixtures as impermeable, while by the mixtures with fly ashes there was higher penetration of water, about 10cm, due tothe increased porosity of these concrete mixtures. According to the criteria the penetration of water should not be higher than 4cm (Grdic et.al., 2008), which implies that concrete mixtures with fly ash could consider permeable.

CONCLUSIONS

- The impact on the properties of fresh self-compacting concrete have mineral addition types and type of applied aggregates. Mixtures with fly ashes had better ratio of fluidity and resistance to segregation. Due to their small proportion (about 100 times smaller than a grain of cement or fly ash) with a very large grain surface (15000 - 20000 m^2/kg), powder of silica fume significantly increase the cohesion of concrete and adversely affect self-compacting of fresh concrete. Mixtures with silica fume were with severe mobility, had lower spreading diameters, but also the greater resistance to segregation. The use of recycled aggregates, due to particle sharp edged grain shape, which increases friction, also adversely affect the properties of self-compacting concrete. It was necessary to intervene in terms of III fraction reduction and increase of III fraction for 5%, to achieve the desired consistency.
- Silica fume influence in concrete compressive strength: silica fume is pozzolana and for its activation presence of calcium hydroxide is necessary. Calcium hydroxide is formed in the process of cement hydration; therefor silica fume can be activated only after the cement begins with reaction. As concrete starts with setting and strengthening, activity of pozzolanic in silica fume becomes the dominant reaction. Due to the high specific surface area and a higher content of siliciumdioxide, silica fume is much more reactive than the fly ash. This increasedreaction will initially enhance the speed of C_3S hydration of cement fraction, but after two days the process is normalized. By reaction of silica fume and forming of calcium silicate hydrates, which results with filling of pores and voids. At the same time formed crystals made connection within the space between cement particles and aggregate grains. With only the physical presence of silica fume in the mix, the concrete matrix will be very homogeneous and dense, resulting in improved strength and impermeability. Clearly represented in the SEM images. Additionally, the particles of silica fume, due to their size, could cause "micro filer" effect, with filling the transit area in concrete.
- Influence of fly ash on concrete compressive strength: when fly ash is added to concrete begins pozzolanic reaction between silicon dioxide (SiO_2) and calcium hydroxide ($Ca(OH)_2$) i.e. lime, which is a by-product of Portland cement hydration. Light pozzolanic reaction takes place during the first 24 hours at 20°C. Therefore, given amount of cement with increased fly ash results in lower early strength. The presence of fly ash slows reaction of alite within the Portland cement in the early stage. However, the production of alite would later accelerate thanks to the formation of hydration core on the surface of fly ash particles. Calcium hydroxide is imprinted on the surface of the glassy particles having its reaction with SiO_2 or SiO_2 Al_2O_3- grid. Slower growth of concrete strength with fly ash prevents its application, at the expected high early strength, which can be solved by applying the accelerator. At the available literature sources has been recommended process of the design and monitoring of the 90 - day long concrete strength. SEM analysis clearly shows an extremely spongy, i.e. porous concrete structure with fly ash, due to fly ash properties (high content of CaO).
- Compressive strength differences between concrete with fly ash and with silica fume are in range from 13% (forstandards) to 37% in concrete with recycled coarse aggregate, while concrete mixtures with fly ash have greater ecological value, because it solves the problem of depositing huge quantities of fly ash.
- Results of tensile strength by bending are consistent and show that kind of mineral addition and aggregate does not affect the value of this strength.
- Shrinkageat thecement pasteisincreasedby usage of silica fume, which should be specifically taken into account, according to the available data. Rule of shrinkage is not possible to determine as well some generalconclusion, which means careful monitoring of shrinkage process for each concrete mixture.
- Minimum water absorption is recorded in concrete mixtures with silica fume, and larger is in concrete with fly ash. However, this difference is not too significant (about 1%) regarding to the spongy structure of concrete with fly ash, which could be explained by a lower content of open

pores with 1-10 μm; water flow through them is the fastest, which is also related to the pozzolanic activity of fly ash to participate in the CSH formation sand fills the pores. Only concretes with silica fume had a good water-impermeability, which is in accordance with the achieved microstructure.

- The main problem regarding the application of recycled aggregates is increased porosity, which is caused by old cement paste at aggregate grains. Cement paste is also responsible for unequal quality of the aggregate sand it leads to a reduction incompressive strength of concrete. There are method sof aggregates "purifying", which increase the cost of concrete, but the environmental benefits are significant.
- Applying both of all mineral additions, opens possibility for obtaining self-compacting concretes of high performances. Better results are for concretes with silica fume,but having in mind economic and environmental components of fly ash, as well as the slight difference in obtained results, it should certainly be taken into account. Due to the use of recycled aggregates, these concrete types could be classified as ecological.

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Masonry Arch Bridge Conservation		
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Masonry		
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	INTERNAL VISUALIZATION OF DETERIORATED RC PIERS DUE TO ASR USING 3D ELASTIC WAVE TOMOGRAPHY	T Shiotani, T Nishda, CW Huang, H Asaue, T Miyagawa, Kyoto Univ, S Furuno, K Hirano, New Nippon Consultants

1741		Co., Ltd., Toyama, Y Kobayashi, Nihon Univ, Tokyo, Japan
1742	TWO-DIMENSIONAL Q VALUE TOMOGRAPHY & ITS VERIFICATION BASED ON NUMERICAL INVESTIGATIONS	Y Kobayashi, Nihon University, T Shiotani, Kyoto Univ, Japan
1662	NUMERICAL SIMULATION & CASE STUDIES FOR REBAR DETECTION IN R.C. STRUCTURES USING GROUND PENETRATING RADAR	M Al-Soudani, G Klysz, J-P Balayssac, Univ de Toulouse III, France.
1686	DETECTION OF LOCAL CRACKING DAMAGE OF IN-SERVICE CONCRETE BY AE & X-RAY CT	T Suzuki, Niigata Univ, Japan, MC Forde, Univ of Edinburgh, UK, M Ohtsu, Kyoto Univ, Japan
1680	ACOUSTIC EMISSION & DIGITAL IMAGE CORRELATION FOR MONITORING OF FRACTURE OF COMPOSITE-CONCRETE BEAMS	S Verbruggen, S De Sutter, S Iliopoulos, T Tysmans, D G Aggelis, Vrije Univ Brussel, Belgium
1688	DEVELOPMENT OF NDT METHOD FOR DETECTION OF CORRODED CONDITIONS IN STEEL DRAINAGE WELL LAND SLIDE PROTECTION INFRASTRUCTURE	K Inaba, T Suzuki, Niigata Univ, Japan
1702	EARLY AGE ULTRASONIC TESTING OF CONCRETE COMPOSED OF GLASS SPHERES AS AGGREGATES	SN Iliopoulos, R Neves, A Chenu, DG Aggelis, Vrije Universiteit Brussel, Belgium
1663	COMBINATION OF ULTRASONIC PULSE VELOCITY & GPR FOR DETECTION OF DEFECTS & THICKNESS IN LAYERED UNREINFORCED CONCRETE: CASE OF A ROLLER COMPACTED CONCRETE (RCC) DAM IN STATE OF PAHANG (MALAYSIA)	M Di Tommaso, Istituto Meccanica dei Materiali SA, Montagnola, Switzerland, P Tudori, IMM SOIL Sdn. Bhd., Selangor Darul Ehshan, Malaysia
1739	CHARACTERISING CARBONATION IN PORTLAND CEMENT PASTE WITH OPTICAL FIBRE EXCITATION RAMAN SPECTROSCOPY	Y Yue, Y Bai, Univ College London, JJ Wang, JJ Boland, CRANN, Trinity College Dublin, PAM Basheer, Univ of Leeds , UK
1740	EARLY DETECTION OF CRACK & REBAR CORROSION DUE TO CHLORIDE DAMAGE BY UT	T Watanabe, KI Miyazaki, H Fukutomi, C Hashimoto, Tokushima Univ, Japan
1659	IMPLICATIONS OF ACI 288 ON INSITU NDT OF CONCRETE COMPRESSIVE STRENGTH	N Dimova, J Kwong, H Al-Abed, R De Bold, & MC Forde, University of Edinburgh, UK & K Pareemamun Mauritius Standards Board
Concrete & Concrete Repair		
1749	MODERN TECHNIQUES & CONCRETE TECHNOLOGY USED TO CONSERVE A UNIQUE HERITAGE BREAKWATER	S Hold, Steve Hold Consulting Civil Engineering Ltd, Cowbridge, UK
1677	EXAMINATION ABOUT LONG-TERM CARBONATION CONTROL EFFECT OF ELASTIC PAINT FOR HOUSING BASE CONCRETE IN JAPAN	M Sugiyama, Hokkai Gakuen Univ, Sapporo, Japan
1716	EXTENDING LIFE OF CONCRETE STRUCTURES WITH POST-INSTALLED PUNCHING SHEAR REINFORCEMENT	J Kunz, Hilti Corp, Schaan, Liechtenstein, P Sleep & L Giulietti, Hilti (GB) Ltd, Manchester, UK
1691	LEVEE WIDENING & RAISING OF EXISTING BREAKWATER & QUAY OF FISHING PORTS USING PRECAST CONCRETE FORM	M Kawakami, Akita Univ, A Nagano, All Japan Fishing Port Construction, H Ushida, Kyowa Concrete Industry Co., Ltd., M Nasu, Maruei Concrete Industry Co., Ltd & Y Komori, Landes Co., Ltd., Okayama, Japan
1733	PROTECTING CRACKED CONCRETE STRUCTURES AGAINST ADVERSE EFFECTS OF ASR, DEF & CHLORIDE PENETRATION	J Mander, Texas A&M Univ, College Station, TX, USA, MG Gilbertson, G-Group Consulting, Hastings, New Zealand
Concrete & FRP & Repair		
1676	EVALUATION OF RC BEAMS STRENGTHENED WITH SPLICED CFRP ROD PANELS	A Jawdhari, I Harik, Univ of Kentucky, Lexington, KY, USA
1730	HYBRID GFRP-STEEL CONTINUOUS REINFORCED CONCRETE BEAMS	A M Araba, A Ashour, D Lam, Univ of Bradford, UK
1757	THE SHEAR CAPACITY OF REINFORCED CONCRETE MEMBERS WITH PLAIN BARS	Y Yang, Cor van der Veen & D Hordijk, Delft Univ of Technology, Ane de Boer, Dutch Ministry of Infrastructure & the Environment, Utrecht, The Netherlands
1773	EXPERIMENTAL STUDY ON FIBER REINFORCED SELF-CONSOLIDATING CONCRETE WITH POLYETHYLENE WASTES	DDG Tokgoz, NG Ozerkan, OS Kowita, Qatar Univ, SJ Antony, Univ of Leeds, UK
1665	SHEAR RESISTANCE OF GFRP COMPOSITE BARS FOR REPAIR OF CONCRETE PAVEMENT CONTROL & CONSTRUCTION JOINTS	J Xu, C Tan, RS Aboutaha, Syracuse Univ, Syracuse, NY, USA
	LIMITATIONS OF SAFETY FORMATS USED IN DESIGN FOR FRP-BASED STRENGTHENING OF CONCRETE	K D Kansara, XEIAD, Tiverton, T Ibell, A Darby, M Evernden, Univ of Bath, UK

1704	STRUCTURES	
1666	PARAMETERS AFFECTING DUCTILITY OF CFRP STRENGTHENED RC MEMBERS	C Tan, J Xu, RS Aboutaha, Syracuse Univ, NY, USA
1674	ANALYTICAL MODEL FOR SHEAR REHABILITATION OF R.C. BEAMS USING NEAR-SURFACE MOUNTED FRP COMPOSITES	A Mofidi & Y Shao, McGill Univ, Montreal, O Chaallal, University of Quebec, Canada, L Cheng, University of California, Davis, USA
Concrete Behaviour & Repair		
1695	USING RECYCLED CONCRETE AGGREGATES IN CRCP	H De Backer, A Outtier & P De Winne, Ghent Univ, Belgium
1780	CHARACTERIZATION OF LOW CALCIUM FLY ASH FOR GEOPOLYMER PASTE	Y Tajunnisa, M Sugimoto, T Sato, M Shigeishi, Kumamoto Univ, Japan & JJ Ekaputri, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
1737	CONCRETE STRUCTURE RAPID REPAIR MATERIAL - MAGNESIUM PHOSPHATE CEMENT (MPC)	C You, J Qin, Y Haung, Y Fan, J Qian, Chongqing Univ, China
1719	STUDY ON ESTIMATION OF THE DETERIORATION OF REINFORCING BAR IN R.C.	Watanabe Ruiko & Mizobuchi Toshiaki, Hosei Univ, Japan
1750	INFLUENCE OF A PROTEINIC BIOFLUIDIFICATION OF CEMENTITIOUS MORTARS ON MECHANICAL PROPERTIES IN HARDENED STATE	A Chikhi, RM Dheilly, M Quéneudec, Univ of Picardie Jules Verne, Amiens, France
Timber Structures		
1669	INVESTIGATION & REPAIR OF FIRST WORLD WAR TIMBER BELFAST TRUSSES AT FILTON AIRFIELD, BRISTOL	F Gamble, A Wylie, Buro Happold, Bath, UK
1682	STRUCTURAL PROBLEMS OF ADAPTIVE REUSE OF EXISTING TIMBER & STONE MASONRY STRUCTURE	MD Traykova & T Chardakova, Univ of Arch, Civil Eng & Geodesy (UACEG), Sofia, Bulgaria
1675	NON-DESTRUCTIVE TESTING METHODS FOR DETERMINING MATERIAL CHARACTERISTIC VALUES OF HISTORIC TIMBER STRUCTURES	J Maddox, P Kuklík, Czech Tech Univ in Prague, Czech Republic
Structural Performance		
1759	NEED FOR AN INTEGRATED APPROACH FOR RAPID CONDITION ASSESSMENT & EVALUATION OF RC BUILDING STOCKS	O Gunes, Sengul, C., Colak, C. & Asan, M., Istanbul Technical Univ, Turkey
1762	EXTENDING THE LIFE OF CONCRETE FROM INSIDE OUT	P Rhodes, J Tuerack, J Warburton-Pitt, F Wahab, Hycrete, Carlstadt NJ, USA
1752	TRACES OF EXPOSED SAMPLES UNDER SALT ATTACK FOR TEN YEARS	T Sonoda, Nippon Koei Co, Tokyo, M Sato, MLIT Hokuriku Regional Development Bureau, Niigata, Japan, K. Maruyama, Nagaoka University of Technology, Japan
1701	STUDY ON PREDICTION OF PERFORMANCE OF RC STRUCTURES DUE TO COMPLEX DETERIORATION	H Ito, T Mizobuchi, Hosei Univ, Japan
1748	WWII GERMAN CONCRETE DEFENCE WALLS IN JERSEY, CHANNEL ISLANDS	S Hold, Steve Hold Consulting Civil Engineering Ltd, Cowbridge, UK
1678	RELIABILITY-BASED LONG-TERM MAINTENANCE ACTIVITIES FOR GAS TRANSMISSION PIPELINE SYSTEM	K Pesinis, KF Tee, Univ of Greenwich, UK
1782	CYCLIC PERFORMANCE ASSESSMENT OF SEISMICALLY DEFICIENT SRC COMPOSITE COLUMNS	W M Hassan & M G Farag, American University in Cairo, Egypt
1751	VEGETABLE MULTILAYER WALLS FOR RENOVATION OF BUILT HERITAGE	N El-Hajj, LB Mboumba-Mamboundou, RM Dheilly & M Quéneudec, Univ of Picardie Jules Verne, Amiens, Z Avoura, Univ of Technology of Compiègne, France
1767	EFFECT OF THE SATURATION STATE OF THE RECYCLED AGGREGATES ON FRESH & HARDENED PROPERTIES OF MORTAR	A Yacoub, A D Tegguer, T Fen-Chong, Univ Paris-Est/IFFSTAR, Marne la Vallee, France
1768	APPLICATION POSSIBILITIES OF FLY ASH, SILICA FUME & RECYCLED CONCRETE AGGREGATES IN SELF-COMPACTING CONCRETE	I Despotovic, Belgrade Univ College of Applied Studies in Civil Engineering and Geodesy, Belgrade, Serbia

1677	EXAMINATION ABOUT LONG-TERM CARBONATION CONTROL EFFECT OF ELASTIC PAINT FOR HOUSING BASE CONCRETE IN JAPAN	M Sugiyama, Hokkai Gakuen Univ, Sapporo, Japan
1720	RETROFITTING ONE PRECAST R.C. WALL PANEL WITH ENLARGED OPENING SUBJECTED TO SEISMIC ACTIONS	M Fofiu, V Stoian, "Politehnica" Univ of Timisoara, Romania
1755	COLLAPSE OF STEEL CONSTRUCTION HALL IN DANILOVGRAD & ITS REPARATION	M Taric, E Maslak, B Stipanic, Faculty of Tech Sci, Kosovska Mitrovic, Serbia & Montenegro
Conservation of Heritage Structures		
1703	180 YEARS OLD STONE HOUSE REPAIR	I Soric, Geotehnicki studio d.o.o, Zagreb, Croatia
1731	CONTINUOUS DYNAMIC MONITORING OF AN ANCIENT TOWER: IDENTIFYING DAMAGE UNDER CHANGING ENVIRONMENT	M Guidobaldi, C Gentile, A Saisi, Politecnico di Milano, Italy
Civil Engineering Structures		
1696	SOUTH EUROPEAN PIPELINE NEW LIFE FOR A 1960'S PIPELINE	C Chanonier & C Raulet, Setec Diades, Vitrolles, F Martin & C Carde, Setec LERM, Arles, France
1712	STRUCTURAL COATING OF SEWERS & MANHOLES BENEFITING SLUDGE RECYCLE	M Kurozumi, Japan Sewage Works Assoc, Tokyo, Y Iwasa, Tokyo Metro Sewerage Service Corp, Y Hosaka, Maithick Co., Ltd, Tokyo, M Ito, Nippon Koei Co. Ltd, Tokyo, K Uji, Tokyo Metro Univ, Japan
1781	ASSESSMENT AND REPAIR OF RC STRUCTURE OF AN INDUSTRIAL COMPENSATION TANK	V Radonjanin, M Malesev, I Lukic & S Supic, University of Novi Sad, Serbia
1779	INSPECTION & MONITORING OF FOUNDATION UNDER DYNAMIC LOAD	N Vilchinska, LAA, Riga, Latvia
Building Structures		
1784	IMPORTANCE OF CONSTRUCTION SEQUENCES IN STRUCTURAL BUILDING DESIGN – CASE STUDIES	M Maier, CJ Schulte, Leonhardt, Andrä & Partner Beratende Ingenieure VBI AG, Stuttgart & Berlin, Germany
1776	EFFECT OF REINFORCEMENT DETAILING ON PROGRESSIVE COLLAPSE RESISTANCE	O Harry & Yong Lu, University of Edinburgh, UK
1722	A DIAGNOSTIC METHOD FOR EXTERIOR TILE DEBONDING	T Mikami & T Hamada, Tokyo Inst of Tech, T Soeta & T Fujinuma, Fujita Corp, Kanagawa, Japan
1710	RETROFIT OF DEFICIENT LAP SPLICES	K S Beiter, GA Martinez, O Bayrak, Univ of Texas at Austin, USA
1775	COMPOSITE BEAM-FLOOR SYSTEM AGAINST PROGRESSIVE COLLAPSE	X Cheng & Yong Lu, University of Edinburgh, UK
1714	IN-SITU DIAGNOSTICS OF HISTORICAL BRICK & STONEWORK BUILDINGS IN MOSCOW	A Shilin, A Kirilenko, P Znajchenko, ZAO "Triada-Holding", Moscow, Russia
1756	ANALYSIS OF VULNERABILITY OF BUILDINGS DAMAGED AS A RESULT OF TERRORIST ATTACK: SCENARIO OF NONLINEAR ANALYSES & MULTI-CRITERIA OPTIMIZATIONS	R Folic, Univ of Novi Sad & Dr M Cosic, Institute for testing of materials, Belgrade, Serbia