ACHIEVEMENT OF SPECIAL PROPERTIES OF CONCRETE WITH WASTE MATERIALS

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ABSTRACT

Large numbers of waste materials or industrial by-products, respectively have been in use in recent concrete technology for many years past. They can be use as mineral admixtures or as a filler – aggregates, which replace natural stone aggregate partially or on the whole. We can achieve high performance concrete by use of the mineral admixtures (fly ash, silica fume and slag). But, the quality of those admixtures have to be constant enough to ensure homogeneous concrete production, as we shall show it in the case of use of fly ash. Furthermore, we shall give and discuss the results of investigations of concrete with slag aggregate (which is waste from ferrochromium production). We achieve with it high strengths, toughness and resistance of concrete against wear with grinding. Very interesting concrete in regard to obtained properties originates with addition of granulated rubber, made by crumbing of waste car tires. We established significant influence of added granulated rubber on increase of underwater abrasion resistance of concrete. Average abrasion depth has been decrease for three time.

Key words: mineral admixtures, silica fume, fly ash, carbure slag aggregate, granulated rubber.

INTRODUCTION

Industrial by-products are widely used as supplementary cementitious materials (for example: silica fume, fly ash and slag) in modern construction practices involving concrete. They replace appointed part of cement in concrete: (1) to contribute to the energy conservation (cement is one of the most energy intensive materials) and (2) to help towards the solving of the disposal problem of the by-product materials [Jeffery 1987]. Mineral admixtures type II: fly ash, conformable to SIST EN 450, silica fume, conformable to SIST EN 13263 and slag, conformable to SIST EN 15167-1 valid as appropriate in generally for use in concrete in accordance with SIST EN 206-1:2003, item 5.1.6. The standards for fly ash and silica fume are harmonize, already. Conformity of mineral admixtures is verified by control tests of the supervisor on the samples taken in the plant in accordance with system 1+ regulated in the directive 89/106/EEC.

The use of fly ash or slag as a partial replacement for Portland cement may actually result in lower cost. But, only 6 % of the total available fly ash was being used as a pozzolan in blended Portland cements or in concrete mixtures [Mehta, 1999]. In order to eliminate or reduce corrosion of steel reinforcement, concrete should be so proportioned that the ingress of chloride ions into concrete is reduced to a minimum. One of the most economical ways to achieve this is to incorporate supplementary cementitious materials in concrete [Malhotra et al. 1999]. The successful use of fly ash in concrete depends not only on the mineralogical and chemical composition of fly ash, but also on its grading, particle shape and impurities, and most importantly, on the compatibility of properties of fly ash with the corresponding properties of Portland cement and sand used in the concrete mix [Samarian, 1999].

The resources of eruptive stone and appurtenant productions of crushed eruptive aggregates are too small so that they can not content all needs of construction practice in Slovenia [Zatler-Zupančič, 1991], [Grimšičar, 1984]. Major part of used eruptive aggregates are imported. Appointed part should be replaced with an artificial (slag) aggregate. Steel slag aggregate as waste of production in three Slovenian iron-works remained in dumping-places in content of 60000 t per years up to 1992 [Zatler-Zupančič, 1992]. In our research program the used artificial aggregate was FeCr carbure slag aggregate. It is industrial waste of ferrochromium production in TDR (Factory of Nitrogen Ruše). The slag aggregate in content of 10000 to 20000 t is arisen every year by this production.

Waste car tires have become a world-wide environmental problem. Recycling processes make shredded, chipped, granulated, or crumb rubber which has been evaluated for possible replacement of a part of the aggregate in concrete. The concrete prepared with crumb rubber has shown better resistance to cracking, noise reduction, low heat conductivity and flexibility during thermal expansion and contraction due to its ductile behavior. This has been reportedly useful for different applications (Eldin and Senouci, 1993), (Toutanji, 1996), (Lee et al, 1998).

OPTIMIZATION OF USE OF FLY ASH IN THE CONCRETE PRODUCTION

In this item, use of fly ash from Šoštanj steam power station in the concrete production are discussed. This power station use lignite from Velenje lignite mine, which is positioned in the neighborhood of the station. Fly ash is used already in form of slurry for filling empty spaces in the main. Mortars with fly ash are used too for fire protection of wooden lining. Different types of concrete, which are used in the mine and for outside constructions, are prepared in the concrete plant close by the steam power station. Therefore, use of fly ash in this concrete production was a sensible decision. But, there have been still question in regard to optimal use of fly ash in production of different types of concrete. Fly ashes with very different compositions are coming from Šoštanj steam power station, which depend upon regime of operation of the station as well as continuity of its operation. Some results of initial production control tests are discussed. Compressive strength of concrete were taken into account to evaluate the influence of fly ash on the concrete production.

Fly ash slurry and mortar with the fly ash are used permanent in the mine long before. Some properties of the fly ash and its composites are controlled constantly in the concrete plant laboratory. On the base of obtained results by quality control tests in 1999, there was found out that there are no correlation of the density and water for standard consistence of the fly ash and compressive strength of fly ash slurry. These can be seen in Figures 1 and 2.

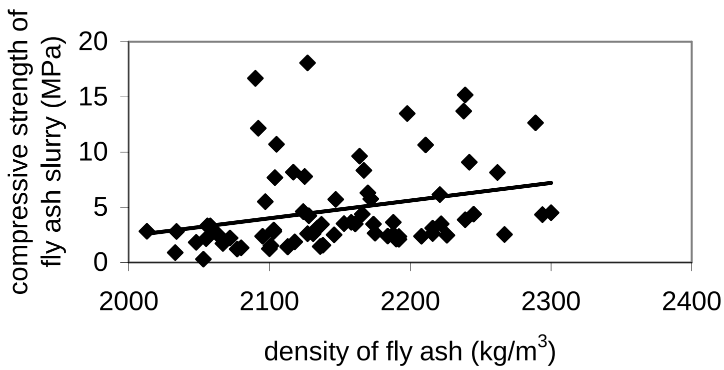

Figure 1.: Relationship of quality control test results of fly ash density and compressive strength of fly ash slurry, obtained in 1999.

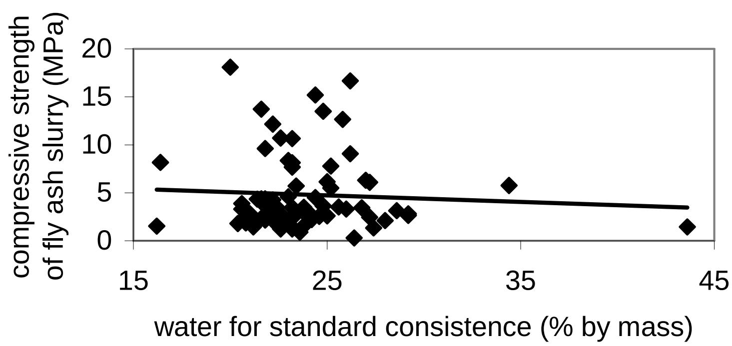

Figure 2.: Relationship of quality control test results of water for standard consistence and compressive strength of fly ash slurry, obtained in 1999.

The same very poor correlation of other measured physical properties of the fly ash and compressive strength of fly ash slurry were obtained. All these results show, that not only physical properties of fly ash varied so much, but chemical properties varied as well. The main reason for such high variation in the fly ash quality in 1999 should be in operation of the steam power plant, which was not constant. Furthermore, the plant had to stop with operation several times in year before, because of installation of new equipment.

Initial concrete production with fly ash in the plant started in October 1999. Test results of concrete quality control in October up to the end of December 1999 are discussed. Five mix proportions of concrete were modified with replacement of cement with fly ash in contents of 50 and 60 kg/m^3. Those five concrete are permanent produced in the concrete plant. Workability of all tested fresh concrete was the same, approximately. Compressive strengths were tested on the 28-day-old concrete cubes with edge length of 15 cm. All obtained compressive strengths of concrete with D_{max} = 16 mm are shown in Figure 3 in correlation with w/c and w/(c + FA) ratio, respectively.

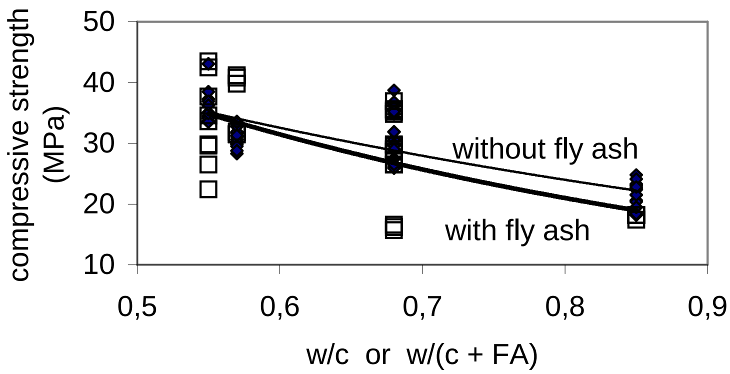

Figure 3.: Correlation of compressive strength of concrete with D_{max} = 16 mm (with and without fly ash) and w/c and w/(c + FA) ratio.

Compressive strengths of concrete with fly ash are lower, moderate when they are compared with those of concrete without fly ash (Figure 3). Higher differences between compressive strengths are achieved at the higher w/c and w/(c + FA) ratio, respectively, because of replacements of cement with fly ash are higher in these concrete. But, significant dispersion of compressive strength test results can be seen in Figure 3, too. It is more significant in the case of concrete with fly ash. Coefficients of variation, V (derived from equation (3-3) in the Recommended Practice of ACI 214-77) of these concrete are much higher, when they are compared with the coefficients of concrete without fly ash.

Influence of replaced content of cement with fly ash was evaluate with compressive strength test results of concrete with D_{max} = 32 mm. High dispersion of test results can be seen in Figure 4. However, moderate tendency to decreasing of compressive strength are achieved when higher content of cement have been replaced with fly ash.

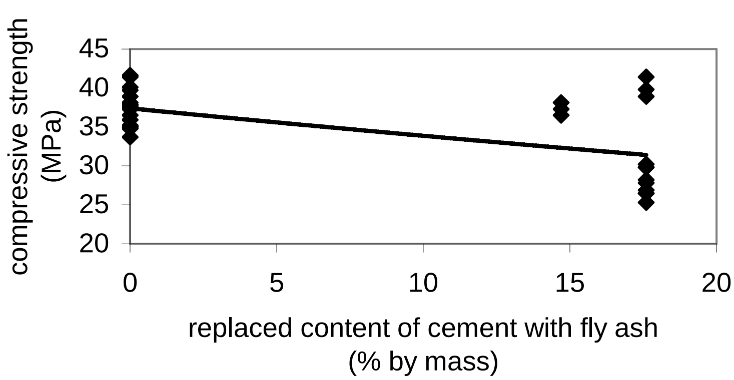

Figure 4.: Relationship of compressive strength of concrete with D_{max} = 32 mm and replaced content of cement with fly ash.

HIGH PERFORMANCE CONCRETE WITH CARBURE SLAG AGGREGATE

The compounds and their contents in the carbure slag aggregate identified by petrographic examination are: forsterite (Mg_2SiO_4) – 62,8 vol.%, enstantite ($MgSiO_3$) – 2,4 vol.%, spinel ($(Mg,Fe)(Al,Cr)_2O_4$) – 11,8 vol.%, glass content – 15,0 vol.%, monticellite ($CaMgSiO_4$) – 6,7 vol.%, and metallic ingredients – 1,3 vol.%.

Portland cement with 15% of blast-furnace slag, silica fume, high-range water-reducing admixture and air-entraining admixture were used in all concretes. Three concrete mixtures were prepared with carbure slag aggregate in grading of 0/16 mm (with cement contents within range of 439 to 466 kg/m^3 of concrete) and other three were prepared with natural aggregate (crushed river sand in grading of 0/4 mm and eruptive aggregate - crushed quartzose amphibolite in grading of 4/8, 8/11 and 8/16 mm, and with cement contents within range of 320 to 375 kg/m^3 of concrete). Hooked steel fibers with contents of 0, 1,0 and 1,5 vol.% were used. The length of fibers was l = 32 mm, and their diameters were d_1 = 0.50 mm and d_2 = 0.32 mm. Thus, the aspect ratios of the fibers were $l/d_1 = 64$ and l/d_2 = 100. All mixtures had the same parameters as follows: w/c = 0.35, silica fume = 8,5 mass % of cement content, D_{max} = 16 mm and contents of chemical admixtures.

Higher cement contents had to be added in the concrete with carbure slag aggregate than in the concrete with natural aggregate, if workability of fresh concretes would be maintained constant (Webe indices were 7 to 9 approximately). Obtained porosity of these concretes after mixing varied from 1.7 to 2.6 vol.%. Densities of fresh concretes with carbure slag aggregate were higher than those of concretes with natural aggregate. The slag aggregate has density of 3300 kg/m^3 approximately, while used natural aggregates have density from 2690 to 2940 kg/m^3. Density of concrete have been increased moderately by addition of steel fibers.

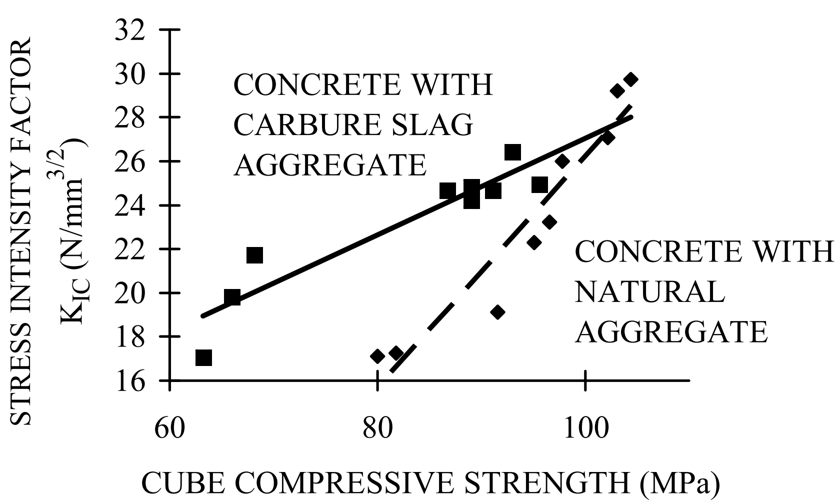

Figure 5.: Relationship between stress intensity factor K_{IC} and compressive strength.

The compact compressive test was carried out on the concrete specimens without fibers to obtain stress intensity factor K_{IC} [Barr et al, 1981], [Barr et al, 1985] . Fracture toughness, as measured by the stress intensity factor K_{IC}, express , more or less, elastically behavior of concrete specimen. Fibers haven't significant effect on the elastically behavior.

Test results of K_{IC} of 28-day-old concrete specimens (with artificial - carbure slag aggregate and with natural - river sand and eruptive coarse aggregate) are presented in Figure 5.

It can be seen, that the fracture toughness increases with increasing compressive strength of concretes with artificial and natural aggregate. The obtained results of compressive strength are very high (within the range from over 60 MPa to over 100 MPa). Although, the values of K_{IC} of concrete with slag aggregate are higher than those of concrete with natural aggregate, almost on the all observed range, the increase of fracture toughness of concrete with natural aggregate is faster so that the values of K_{IC} of this concrete become higher then those of concrete with slag aggregate at the highest compressive strength (100 MPa approximately). If these results are compared with the results of the same tests of concretes with instant-chilled steel slag aggregate and with limestone aggregate [Montgomery and Wang, 1992], almost adequate relationship is evidenced. But, the values of K_{IC} and compressive strength of these concretes ($K_{IC} \approx 5$ - 10 $N/mm^{3/2}$, compressive strength ≈ 20 - 40 MPa) are much lower than those of concretes discussed in this paper.

Abrasion resistance test method (Böhme test method) is included in the German National Standard: DIN 52108. The entire surface (with area of 50 cm^2) of the specimen was abraded by the action of a horizontally rotating steel grinding wheel against which the specimen was pressed. Speed of rotation and contact pressure was controlled. Abrasive grit was used. No high stresses or impact were applied.

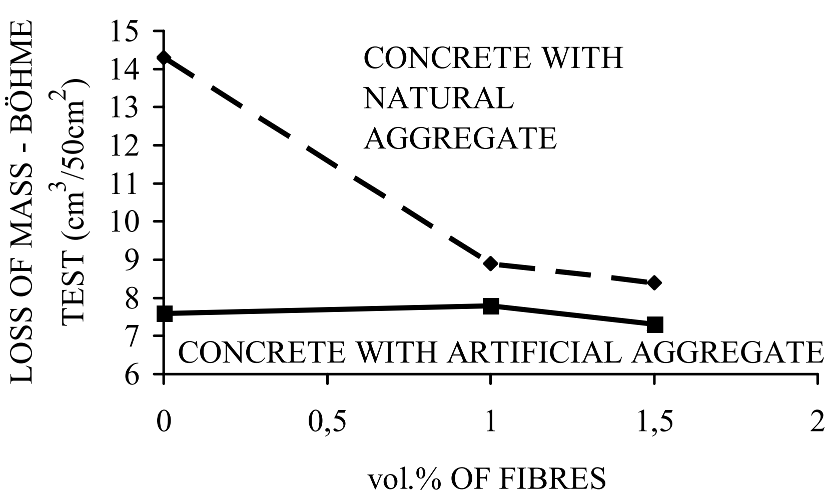

Figure 6.: Influence of the aggregates and steel fibers on the loss of concrete mass.

Very high abrasion resistance of concrete with carbure slag aggregate according to the used test method was obtained on the 90-day-old specimens (Figure 6). These results have been expected, because loss of mass of carbure slag aggregate is very low (7,3 $cm^3/50cm^2$). Steel fibers have the evident influence on the abrasion resistance of SFRC [Šušteršič et al, 1991], but only in the SFRC with natural aggregate (Figure 6). There is no influence of the fibers on the abrasion resistance of SFRC with the slag aggregate.

UNDERWATER ABRASION RESISTANT LININGS MADE BY PMC WITH GRANULATED RUBBER

Underwater abrasion resistance is the ability of concrete to withstand abrasion loads which are caused by water flow containing solid water borne particles. The effects of water borne abrasion is well demonstrated with the experimental method which is similar to standard ASTM C 1138. In this item, some results of our previous and the current research works of underwater abrasion resistance are shown and discussed [Šušteršič et al, 2005].

In all mix proportions, following materials are used: Portland cement CEM II/A-S 42.5 R, Styrene-butadiene copolymer latex (SBR) was added at a rate of 10 mass% of solid particles with regard to cement content, fractions of gravel aggregate with a grading of 0 - 4, 4 – 8, and 8 - 16 mm, granulated rubber made from waste car tires in grading of 0 – 4 mm [Zajc et al, 2001], hooked steel fibers with length of 16 mm and with diameter of 0.5 mm, and polypropylene fibers with length of 10 and 30 mm. A high-range superplasticizer is added in the mixtures, in which silica fume is added too. The results from underwater abrasion measurement of concrete at the ages of 90 days are shown in Figures 7. They show dependence of average depth of abrasion (ADA_t) from the time of test which last up to 72 hours. The smallest ADA_t were ascertained at PMC2 (PMC –polymer modified concrete with granulated rubber). Values of ADA_t of all other concrete, obtained after 72 hours, are much higher and they lie in relative small range.

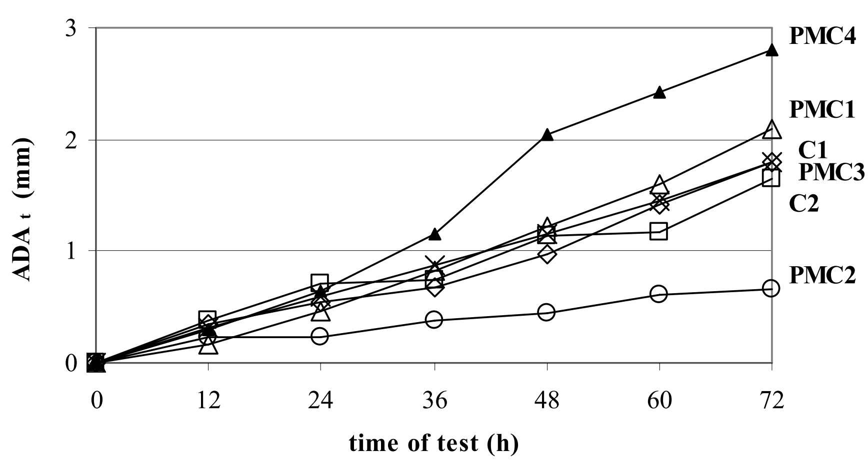

Figure 7.: Interdependence of average depth of abrasion (ADA_t) of the 90-days-old laboratory concrete and the time (length) of the experiment.

Concrete with silica fume and without polymer reach higher strength than PMC at all ages. PMC2 (PMC with granulated rubber) has the smallest compressive strength in comparison with all other laboratory concrete. Very good correlation between compressive strength of 90-days-old specimens and modulus of elasticity, obtained at the same age of concrete was found. If we calculate the ranges between compressive strength and modulus of elasticity (E/f_{fc}), and compare them with ADA_t, very good correlation is achieved. This correlation shows that concrete will resist an abrasive action of solid water borne particles, ADA_t will be smaller, respectively, if E/f_{fc} ratio will be higher, independent of compressive strength level. Concrete with higher E/f_{fc} have capacity to deform elastically when solid water borne particles cause abrasion loading to the concrete surface and therefore, loss of concrete mass is smaller.

The first field tests were carried out 3 years after construction of test sections. In the frame of these tests, average depth of abrasion of test sections ($ADA_{t,ts}$) were obtained. If these results are compared with the results of laboratory tests good correlation is achieved (Figure 12).

CONCLUSIONS

Following main conclusions should be done on the base of obtained results of initial production of concrete with fly ash in the concrete plant: (1) there will be able to establish homogeneous, as well as permanent production of concrete with fly ash, when fly ash quality will be constant enough to ensure it, (2) concrete with not enough constant quality of fly ash can be produced only when lower compressive strengths should be required and lower content of cement should be replaced with such fly ash, (3) the optimal use of the fly ash in concrete will be reached by such production process in which the use of the fly ash with required properties will be possible.

The results of investigation in to the properties of high-performance concrete with artificial - carbure slag aggregate show that such aggregate is useful in concreting practice. It can replace natural - eruptive aggregate. The highest benefit is achieved, if it should be used to improve abrasion resistance of concrete.

The laboratory investigations of concrete which are diverse in regard to their ingredients and properties shows that concrete will resist an abrasive action of solid water borne particles more, if ratio between modulus of elasticity and compressive strength will be higher. The best resistance to underwater abrasion loading is reached by PMC with granulated rubber. The first field test measurements confirm the laboratory test results.

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DOSEGANJE POSEBNIH LASTNOSTI BETONOV Z ODPADNIMI MATERIALI

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POVZETEK

Veliko število odpadnih materialov, oziroma stranskih industrijskih produktov se že vrsto let uporablja v sodobni tehnologiji betona, kot mineralni dodatki ali kot polnila – agregati, ki delno ali v celoti nadomestijo naravni kameni agregat. Z uporabo mineralnih dodatkov (elektro-filtrski pepel (EFP), mikrosilika in žlindra) lahko dosežemo betone visokih zmogljivosti. Toda kakovost teh dodatkov mora biti konstantna, da zagotovi enakomerno proizvodnjo betona, kot bomo prikazali na primeru uporabe EFP. Poleg tega bomo podali in obravnavali rezultate preiskav betonov z agregatom iz žlindre (ki je industrijski odpad iz proizvodnje ferokroma), s katerim dosegamo visoke trdnosti, žilavost in odpornost betonov proti obrabi z obrusom. Zelo zanimiv beton glede na dobljene lastnosti nastane z dodajanjem granulirane gume, pridobljenega z drobljenjem starih avtomobilskih gum. Ugotovili smo precej velik vpliv dodane granulirane gume na povečanje podvodne abrazijske odpornosti betona. Povprečna globina abrazije se je zmanjšala za trikrat.

Ključne besede: mineralni dodatki, mikrosilika, elektro-filtrski pepel, agregat iz žlindre carbure, granulirana guma.