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STEEL SLAG AS A VALUABLE MATERIAL FOR CONCRETE PRODUCTION

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Original scientific paper
This paper aims to investigate the possibility of utilizing steel slags locally produced in Croatian plants as a concrete aggregate. Therefore, eight concrete mixtures were prepared with coarse slag fractions and different binders whose hardened state properties (compressive strength, static modulus of elasticity, volume changes and corrosion susceptibility) were then compared with the properties of reference concrete made of commonly used natural aggregate materials, dolomite. According to the obtained test results it can be concluded that concrete containing slag possesses acceptable mechanical properties and volume changes for its structural use but could represent a risk in terms of corrosion of reinforcement in case of slag with higher amount of sulphur in its chemical composition.

Keywords: *concrete, compressive strength, corrosion susceptibility, static modulus of elasticity, steel slag aggregate, volume changes, waste management*

Čeličanska zgura kao koristan materijal za proizvodnju betona

Izvorni znanstveni članak
U radu se istražuje mogućnost uporabe čeličanske zgure nastale u hrvatskim željezarama kao agregata u betonu. Pripremljeno je osam mješavina betona sa zgurom kao krupnom frakcijom i različitim vezivima te ispitana svojstva takvog betona u očvrslom stanju (tlačna čvrstoća, statički modul elastičnosti, volumne promjene i sklonost ka koroziji) i uspoređena sa svojstvima referentnog betona pripremljenog sa uobičajeno korištenim agregatom, dolomitom. Prema ostvarenim rezultatima ispitivanja može se zaključiti da beton sa zgurom u sastavu svojim mehaničkim svojstvima i volumnim promjenama zadovoljava uvjete za primjenu u konstrukciji ali može djelovati korozivno na armaturni čelik ukoliko zgura sadrži veći udio sumpora u kemijskom sastavu.

***Ključne riječi**: beton, čeličanska zgura kao agregat, sklonost ka koroziji, statički modul elastičnosti, tlačna čvrstoća, volumne promjene, zbrinjavanje otpada*

1 Introduction

The Republic of Croatia has two slag landfills, both containing air-cooled steel slag, which originates from steel production in electric-arc furnaces. Slag disposed in the first landfill (slag 1) covers an area of approximately 25 ha, accounting for an estimated 1,5 million tonnes of disposed material. This type of slag is currently utilised in road construction as a stabilisation layer, and fine fractions of the slag are used for improving soil quality in agriculture. The second landfill (slag 2) contains an estimated 30 000 tonnes of slag, which has not been exploited till now. However, the high price of slag disposal imposes the need to develop new slag applications. Due to its high density, steel slag has long been extensively used as protective armour stone for river, sea and coastal erosion prevention schemes and in various land reclamation projects, but some slag is still dumped [1]. Steel slag has already been evaluated as an aggregate in concrete, and the results affirmed its suitability [2, 3]. Maslehudin et al. [4] found that concrete prepared with steel slag partially replacing coarse aggregate has better mechanical and durability properties compared to concrete with dolomite aggregate.

The use of steel slag as a concrete aggregate is likely to be more economically acceptable than its use as a concrete binder. In addition, since aggregates account for more than three quarters of concrete volume, greater amounts of steel slag could be used as an aggregate than as a binder.

The mechanical properties of structural concrete are critical because it is a load-bearing material. However, concrete also provides physical and chemical protection to reinforcing steel. Therefore, it is essential that concrete components do not increase the susceptibility of reinforcement to corrosion. Because it contains a small amount of sulphur, however, slag may be corrosive to embedded steel [1]. A high rate of slag expansion, attributable to free CaO and MgO in the slag [5, 6], raises concern because it could cause structural deterioration.

As a part of wider research on using steel slag from Croatian steel plants as an aggregate in structural concrete, this paper investigates the mechanical and durability properties of resultant concrete in terms of compressive strength, static modulus of elasticity, volume changes and corrosion susceptibility. The results are compared to those from reference concrete made with dolomite aggregate. In addition, different types of binders (various combinations of Portland cement and fly ash) and polypropylene fibres were used in steel slag–based mixtures to investigate potential interactions.

2 Experimental design
2.1 Concrete constituting materials

CEM I 52,5N, according to the European standards, was used with the density of 3010 kg/m^3. In some mixtures, part of the cement were replaced with the fly ash with density of 1940 kg/m^3 with the aim to ensure reduction of heat of hydration, higher strength at later concrete age by pozzolanic reactivity [7] and to reduce the crack propagation caused by possible slag expansion in concrete [8].

In reference mixtures dolomite was used as a fine (0-4 mm) and coarse fractions (4 ÷ 8 mm, 8 ÷ 16 mm) of aggregate. In mixtures with slags, dolomite was used as a fine fraction (0 ÷ 4 mm) and two types of slag were used as a substitution of a coarse aggregate (4 ÷ 8 mm, 8 ÷ 16 mm).

Considering the fact that slag properties depend on its origin, the possibility of using domestic slag as a concrete aggregate had to be previously verified by a number of tests. Aggregates properties considered to be important for concrete, were determined in accordance with the standard HRN EN 12620/AC:2006 [9], because preliminary testing on fine fractions showed negative behaviour in terms of volume expansions. That is why fine fractions were avoided for production of concrete mixtures. According to the test results, it was concluded that coarse fractions of this type of slag satisfy requirements of standard HRN EN 206-1 [10] and national technical requirements for reinforced concrete structures [11] and could be used as a substitute for commonly used natural aggregates. The results of aggregate testing are presented in detail by the authors in [12, 13].

Particle density on a saturated and surface-dried basis for dolomite was 2750 kg/m^3, for slag 1 - 3210 kg/m^3 and for slag 2 - 3070 kg/m^3. Aggregates used for preparing concrete, were firstly saturated and then surface-dried. This was achieved in an artificial way, namely by dipping aggregates into a water tank for 24 hours, taking them out and then wiping their surface of excess water. The chemical characteristics of cement, fly ash and aggregates are presented in Tab. 1. The composition of free CaO and MgO in slags is shown in Tab. 2.

Table 1 Chemical properties of materials (% of mass)

Compound / material	Cement	Fly ash	Aggregates		
			dolomite	slag 1	slag 2
SiO_2	19,74	55,8	0,49	17,08	14,24
CaO	63,35	5,29	31,78	24,98	31,52
Al_2O_3	5,33	19,2	0,10	5,40	7,60
Fe_2O_3	2,25	8,85	0,10	25,45	25,74
MgO	2,72	2,88	20,85	10,58	7,42
MnO	0,18		-	8,91	3,80
Na_2O	0,3		0,01	0,12	0,13
K_2O	0,84		0,01	0,13	0,08
SO_3^{2-}	3,30		-	0,25	0,44
S^{2-}	-		-	0,05	0,04

Table 2 Content of free CaO and MgO in slags

Applied method	Analyzed property	Property value (% of mass)	
		slag 1	slag 2
combination of complexometric method (described in HRN EN 1744-1) and X-ray diffraction	content of free CaO	0,28	0,22
X-ray diffraction	content of free MgO	4,82	4,21

The cumulative sieving curve (C) of aggregates, obtained by combining different aggregate fractions in precisely prescribed proportions, was the same for all mixtures (Fig. 1). A suitable overall grading of the aggregate (C) was determined as a middle curve between two recommended curves which provide good aggregate packing and good properties of concrete - Fuller and EMPA curves [14].

The water used in mixtures was taken from the general city supply-drinking water with a negligible proportion of chloride substances.

Superplasticizer based on modified polycarboxylic ether (PCE) polymers, with relative density of 1100 kg/m^3, was added during the concrete production to achieve targeted workability. In some mixtures polypropylene fibers (12 mm of cut length, 18 µm of nominal diameter and 557 MPa of tensile strength) were added with the aim to reduce possible volume expansion of slag caused by free CaO and MgO in slag.

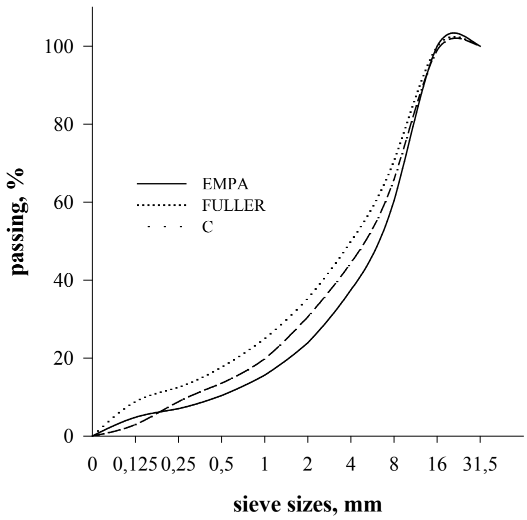


Figure 1 The cumulative sieving curve of aggregates

2.2 Mixture design

Nine groups of concrete specimens were formed with regard to nine different concrete mixtures. The mixtures were prepared with the same binder content (400 kg/m^3), the same the water to binder ratio (w/b=0,43). The reference mixture (M1) was completely prepared with dolomite (fractions 0 ÷ 4 mm, 4 ÷ 8 mm and 8 ÷ 16 mm). The other eight mixtures, M2 to M9, were made of two types of slags (mixtures M2 to M5 were prepared with slag 1, mixtures M6 to M9 were prepared with slag 2) used as a coarse aggregate (4 ÷ 8 mm and 8 ÷ 16 mm) and dolomite as a fine aggregate (0 ÷ 4 mm). Cement matrices for reference mixture were made of pure Portland cement, while cement matrices for slag based mixtures were made of:

1) Portland cement (M2 and M6)
2) Portland cement and polypropylene fibres (M3 and M7)
3) Portland cement and fly ash (M4 and M8)
4) Portland cement, fly ash and polypropylene fibres (M5 and M9).

In mixtures M4, M5, M8 and M9 fly ash was added as 20 % replacement for Portland cement, while polypropylene fibres were added in amount of 1 % by volume in mixtures M3, M5, M7 and M9.

All mixtures were planned to have the same consistency – S4 class according to the Slump test (160 ÷ 210 mm). It was achieved using superplasticizer. Since it is well-known that fly ash [14, 15], improves concrete workability, the concrete mixtures with fly ash (M4, M5, M8 and M9) were prepared with a lower amount of superplasticizer than all the other mixtures (0,75 % to the binder content compared to 0,8 % in mixtures M1, M2, M3, M6 and M7).

Mixture details are given in Tab. 3 and properties of prepared concrete mixtures in their fresh state are given in Tab. 4. Fresh concrete properties were performed according to the relevant European Standards; density was measured according to the HRN EN 12350-6:2009 [16], air content according to the HRN EN 12350-7:2000 [17] and consistency according to the HRN EN 12350-2:2000 [18].

All specimens were demoulded 24 h after casting, dipped into a water tank for 7 days, placed in the chamber (with temperature of about 20±2 °C and humidity level of 95±5 %) and kept there for another 27 days. After 28 days, the prisms were left in the laboratory room until the age of 56 days. The prisms for volume changes testing were in the chamber until the end of the testing.

Table 3 Mixtures composition, per 1 m^3

Mixture	*w/b*	Superplasticizer (kg)	Cement (kg)	Fly ash (kg)	Polypro. fibres (kg)	Aggregate (kg)						
						dolomite, fraction 0 ÷ 4 mm	dolomite, fraction 4 ÷ 8 mm	dolomite, fraction 8 ÷ 16 mm	slag 1, fraction 4 ÷ 8 mm	slag 1, fraction 8 ÷ 16 mm	slag 2, fraction 4 ÷ 8 mm	slag 2, fraction 8 ÷ 16 mm
M1		3,20	400	-	-	807	367	661	-	-	-	-
M2		3,20	400	-	-	864	-	-	422	723	-	-
M3		3,20	400	-	0,910	864	-	-	422	723	-	-
M4		3,00	320	80	-	864	-	-	422	723	-	-
M5	0,43	3,00	320	80	0,910	864	-	-	422	723	-	-
M6		3,20	400	-	-	841	-	-	-	-	411	704
M7		3,20	400	-	0,910	841	-	-	-	-	411	704
M8		3,00	320	80	-	841	-	-	-	-	411	704
M9		3,00	320	80	0,910	841	-	-	-	-	411	704

Table 4 Properties of fresh concrete mixtures

Mixture	Density of fresh concrete (kg/m^3)	Air content (%)	Consistency by Slump test (cm)
M1	2530	0,9	20
M2	2643	2,0	20
M3	2637	3,5	19
M4	2615	2,4	20
M5	2563	2,8	19
M6	2574	2,3	20
M7	2538	3,3	20
M8	2504	2,4	20
M9	2472	3,5	19

2.3 Test methods
2.3.1 Mechanical properties

Compressive strength testing was performed according to the HRN EN 12390-3:2002 [19] on 10×10×10 cubes. Static modulus of elasticity was performed according to the HRN EN 12390-13:2013 [20] on 10×10×40 cm prisms. Three loading-unloading cycles between 0,5 MPa and the third of the compressive strength, obtained previously, were performed. Modulus of elasticity corresponds to the mean value of secant modulus obtained within the last cycle. Mechanical properties were examined on three specimens for each concrete mixture.

2.3.2 Corrosion testing

Possible corrosive effects of such concrete on the reinforcement within reinforced concrete elements were estimated by testing pH value of filtrate prepared with concrete powder and distilled water [21]. Concrete specimen in fresh state was placed into a closed mould and kept there for 28 days with no air or water to avoid carbonation. After 28 days, concrete was ground into fine powder, and diluted with distilled water in 1:10 ratio. After 24 h solution was filtrated through filter paper. pH value of such a prepared filtrate was measured by pH-meter. In addition, the corrosion susceptibility was observed on samples exposed to aggressive environment for 500 days. For long term exposure to simulated aggressive environment concrete "lollipops" with embedded reinforcement were prepared. Steel rebar was placed in the middle of concrete specimen, covered with concrete on all sides. On one side of reinforcing bar an insulated copper wire was glued, which served as connection for measurement of corrosion parameters. These specimens were left in humidity chamber until the age of 28 days.

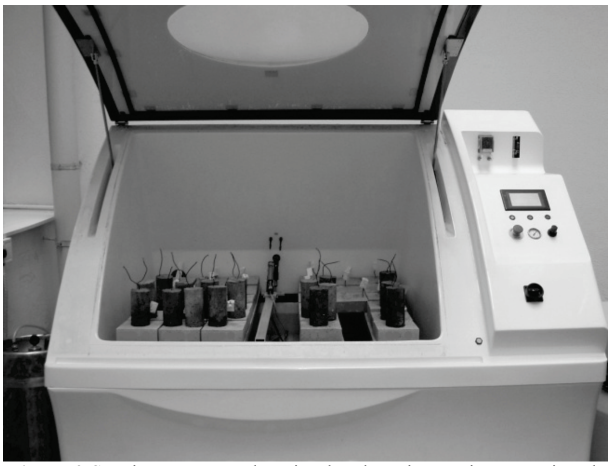


Figure 2 Specimens exposed to simulated marine environment in salt spray chamber

After curing "lollipops" were placed into salt spray chamber (Fig. 2). In salt spray chamber specimens were exposed to simulated marine environment with cycles of wetting, drying and spraying with 3,5 % NaCl solution, under controlled temperature and humidity. Corrosion parameters (potential and current) and concrete resistivity are measured periodically during exposure in the salt spray chamber using galvanostatic pulse method with suitable reference electrode (Ag/AgCl) placed on concrete surface. Corrosive effects were examined on three specimens for each concrete mixture.

2.3.3 Volume changes

In order to estimate the possibly high rate of slag expansion (due to the presence of free CaO and MgO), volume changes of the slag concrete were compared with volume changes of the reference concrete made of commonly used natural aggregate - dolomite. Concrete volume changes were measured on 10×10×40 cm prisms according to the HRN U.M1.029:1983 [22]. At the age of three days, metal stamps are fixed to the specimens and the deformation was measured mechanically for the first time. Measuring of deformation was continued up to 91 days of prisms age. Volume changes were examined on three prisms made from the same mixture and two measuring lines on each prism.

4 Results and discussion
4.1 Mechanical properties

The results of compressive strength development at the age of 2, 28 and 56 days, are given in Fig. 3, while the values of modulus of elasticity at the age of 56 days are shown in Fig. 4. Each of the results has been obtained upon testing of three specimens for each property.

Because of the same amount of binder used in all mixtures, the same water to binder ratio, the same amount of superplasticizer and the same cumulative sieving curve of aggregates, the obtained results for mixtures M1, M2 and M6 show crucial impact of an aggregate type on concrete mechanical properties. Increase in compressive strength (Fig. 3) in mixtures with slags was more prominent than in reference mixture. At the age of 2 days, the mixture M2 achieved 77 % of compressive strength of the reference mixture, while the mixture M6 achieved 64 % of compressive strength of the M1 mixture. The 28 days old mixture M2 achieved 83 % of compressive strength of the reference mixture (M1) while mixture M6 developed 70 % of compressive strength of the M1 mixture (Fig. 3). At the end of the observed period (after 56 days), the mixtures M2 and M6 achieved 85 % and 81 % of compressive strength of the M1 mixture, respectively. Contrary to those presented in [4] and [23], all the mixtures with slag in their composition achieved lower compressive strength than the reference mixture which can be explained by lower quality of slag as an aggregate in comparison with dolomite. From the results it can also be seen that concrete mixtures with slag 1 have higher strength than mixtures with slag 2. Addition of polypropylene fibres did not influence significantly compressive strength of specimens at any observed age. Fly ash and polypropylene fibers-fly ash combination improved compressive strength at the age of 56 days in case of mixtures with slag 2. However, this effect is not observed in case of mixtures with slag 1.

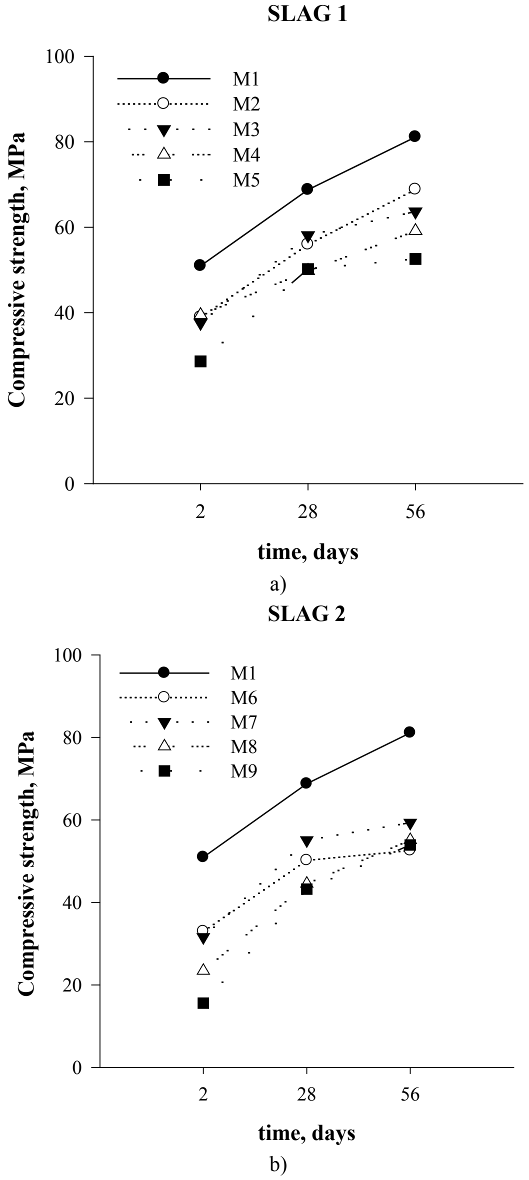


Figure 3 Compressive strength development during the time of reference mixture and a) mixtures with slag 1 and b) mixtures with slag 2

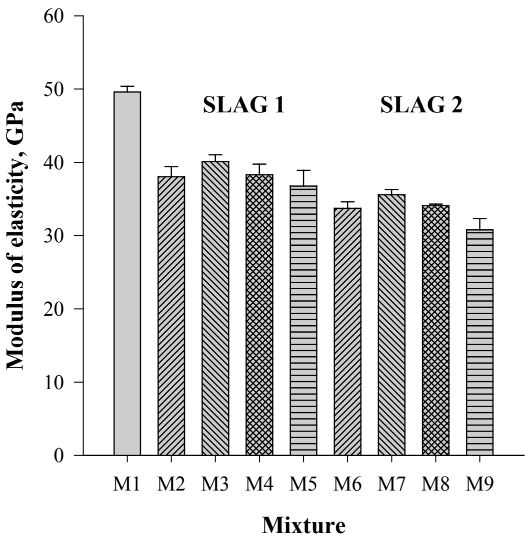


Figure 4 Static modulus of elasticity of all mixtures at age of 56 days

As for the modulus of elasticity (Fig. 4), the mixture M2 developed 77 % of the value of the reference mixture while for the M6 mixture this percentage amounts to 67 %. Just for comparison, the slag and limestone mixtures studied in [23] show similar values of the modulus of elasticity. When separately in concrete, fly ash and polypropylene fibres slightly improved modulus of elasticity of concrete with slags. Even expected, an increase in modulus of elasticity in case of concrete with polypropylene fibres-fly ash combination was not recorded.

It is obvious that both types of slags give concrete (M2 to M9) lower mechanical properties comparing to the reference concrete (M1) made with dolomite aggregate. Since all the aggregates were in a saturated and surface-dry condition, obtained lower values of mechanical properties of slag concrete cannot be explained by higher absorption of slag as an aggregate. After examining the fracture lines of the test samples remained after strength testing, it can be concluded that fracture of all the samples occurs evenly throughout the cement paste and aggregate. Therefore, lower values of mechanical properties of the slag concrete can be explained by lower quality of slag as an aggregate in comparison with dolomite.

However, considering the mechanical properties of the concrete with both slags it may be concluded that these by-products might be used as a replacement for a commonly used natural aggregate in structural concrete.

4.2 Corrosion susceptibility

The pH values of the above described filtrates are given in Fig. 5.

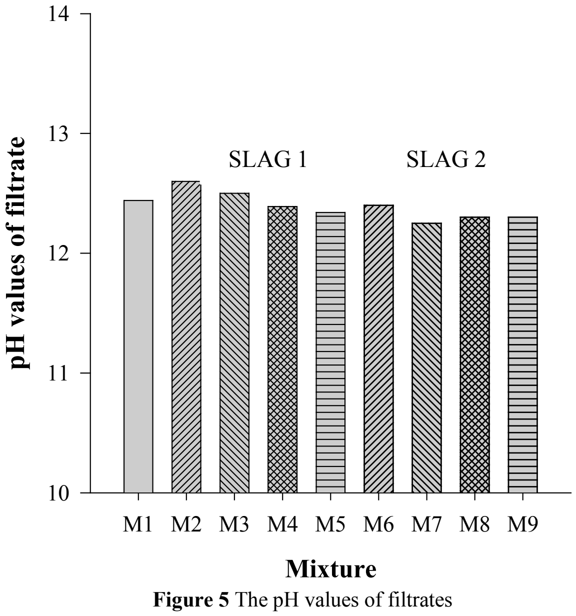


Figure 5 The pH values of filtrates

Given that all the basic mixtures contain the same volume fraction of aggregates, higher filtrate alkalinity at mixture M2 compared to mixture M1 can be attributed solely to an aggregate. The ratio of alkaline and acidic components in the chemical composition of the slag 1 is (CaO + MgO) / (SiO_2 + Al_2O_3) = 1,56 while the same ratio in slag 2 is 1,78 and it is expected that the filtrate of mixture M2 will have a lower pH value than the filtrate of mixture M6. Obtained differences between pH values obtained for mixtures M1, M2 and M6 are not significant. Against expectations, slightly higher pH values of the filtrate were measured for M2 than for M6 mixture. This could be due to the fact that in M6 lower amount of aggregate (measured by mass) was used, compared to M2. In any case, substitution of dolomite aggregate with slag did not show negative effect on pH value of the filtrate, opposite to the influence slag has when used as substitution of cement [21]. In M4 and M5, where part of the cement was substituted with fly ash, a slight decrease in pH value, compared with M2, can be seen. The same trend can be observed with M8 and M9, where part of the cement was also substituted by fly ash, compared to M6. According to [24], the pH value above 9,5 is considered an alkaline medium, in which a passive (protective) layer of iron oxide on the surface of the reinforcement, which is very dense and impervious to corrosion reactants (O_2, H_2O) and thus it protects the reinforcement from corrosion in a "normal"/ non-aggressive environment. In addition, the pH filtrate value of all the mixtures with both slag concrete 1 and 2 only slightly differs from the pH filtrate values of the concrete with dolomite, indicating that the use of slag as a concrete aggregate is equally appropriate regarding the danger of corrosive action as dolomite. However, the difference in pH values of all mixtures is quite small and the environment that is created in all mixtures is highly alkaline.

Corrosion susceptibility was further measured by exposing reinforced concrete samples to simulated marine environment in salt spray chamber during period of more than 1 year. Results of monitoring of corrosion potential are shown in Fig. 6a for slag 1 and Fig. 6b for slag 2.

From continuous monitoring of corrosion potential, it is possible to estimate a tendency of steel towards corrosion. Lower and decreasing values of corrosion potential during time, indicate corrosion susceptibility or high probability of corrosion occurrence. Higher, stable or increasing values of corrosion potential indicate corrosion passivity and low probability of corrosion occurrence. From the corrosion potential monitoring, it can be observed that corrosion potential significantly decreased after 200 days of exposure to simulated aggressive marine environment in salt spray chamber for all concrete mixtures. This decrease can be taken as an indication of initiation of corrosion process. Comparing half-cell potential values of samples with dolomite aggregate (M1) and slag aggregate (M2 and M6), it can be seen that the corrosion potential values of slag aggregate concrete are significantly lower than those for concrete with dolomite aggregate. Moreover, the influence of the substitution of cement with fly ash is seen only in the case of concrete with slag 1. In concrete with slag 2 samples with slag aggregate and fly ash as part of the binder corroded with the same intensity as those with slag aggregate and cement as binder.

Beside corrosion potential, corrosion current was also measured during exposure to simulated aggressive environment. From corrosion current, depth of corrosion can be calculated using Faraday's law [25]. Depth of corrosion is defined as a thickness of reinforcement cross section lost during corrosion. Calculated depth of corrosion is presented in Fig. 7a for concrete prepared with slag 1 and b) for concrete prepared with slag 2.

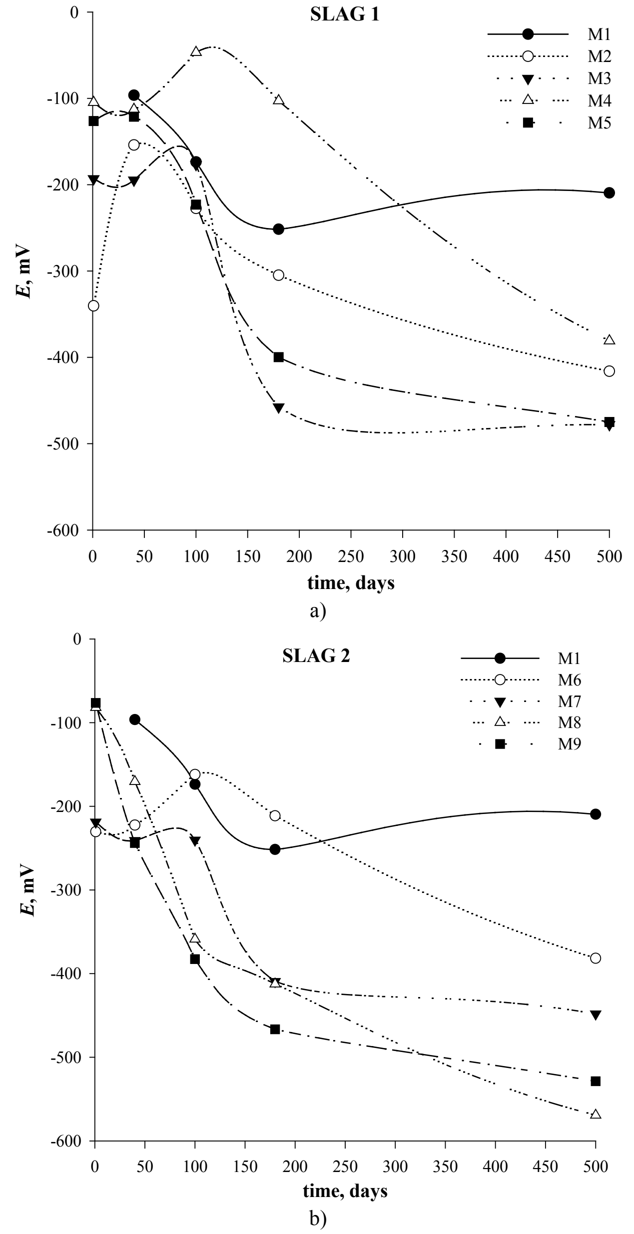


Figure 6 Monitoring corrosion potential of reinforced concrete samples during exposure to simulated marine environment of reference mixture and a) mixtures with slag 1 and b) mixtures with slag 2

From Fig. 7 it can be seen that in the case of slag 1 the loss of reinforcement due to corrosion is similar to that of dolomite aggregate concrete. Furthermore, in the case of slag 1 aggregate a decrease in the corrosion penetration depth is achieved when fly ash is added as a substitute of part of the cement (M4). On the other side, an increase of corrosion penetration depth in time is obtained with all mixtures containing slag 2 aggregate. This could be attributed to bigger amount of sulphur in slag 2 in comparison with slag 1.

On both graphs in Fig. 7, straight line is indicating 5 μm corrosion penetration depth, which can be taken as a limiting value indicating corrosion initiation and beginning of accumulation of corrosion products [26]. Factor of acceleration is defining the acceleration of degradation process using exposure in salt spray chamber, compared to exposure in natural environment. For concrete with concrete cover 25 mm, factor of acceleration can be taken as 44 days per cycle, meaning that during exposure in salt spray chamber the same level of corrosion activity is obtained 44 times more quickly than when the same concrete is exposed to natural marine environment [27]. If these assumptions are taken into account, time necessary for a critical corrosion depth of 5 μm to occur in real aggressive marine environment for concrete prepared with dolomite aggregate would be 9,3 years. The same time would be necessary for concrete prepared with slag 1 to achieve the same corrosion level. For concrete prepared with slag 1 and fly ash as addition to cement, prolong time of corrosion initiation is achieved and is 18 years. At the same time, for concrete prepared with slag 2 to achieve the same level of corrosion penetration 5,1 years would be necessary.

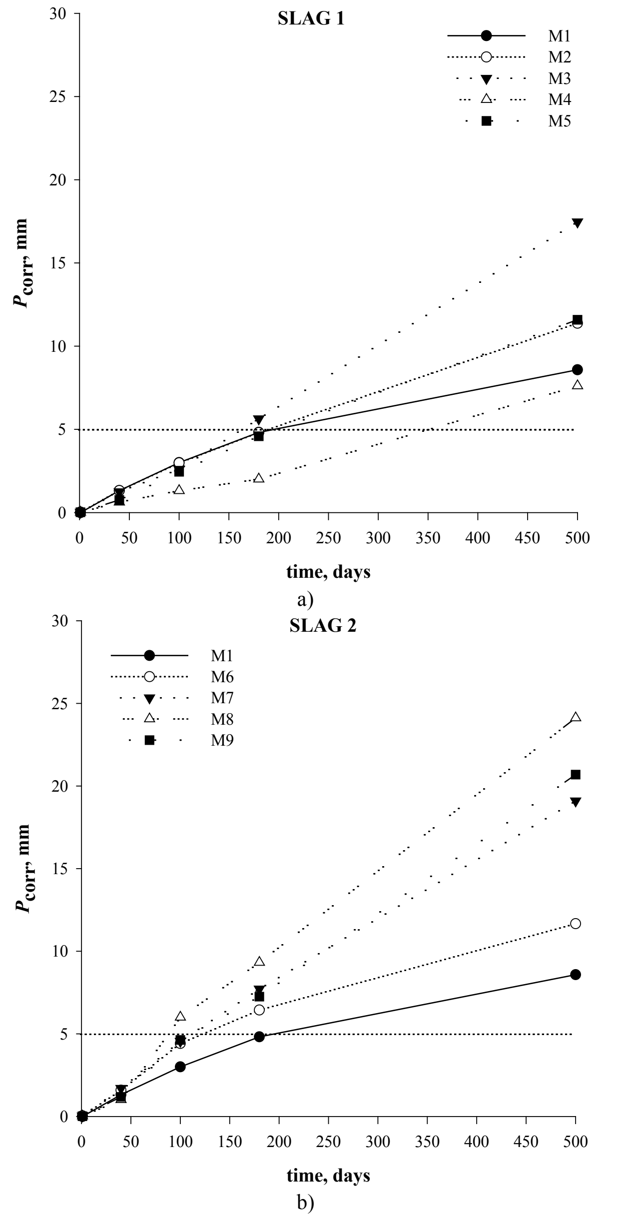
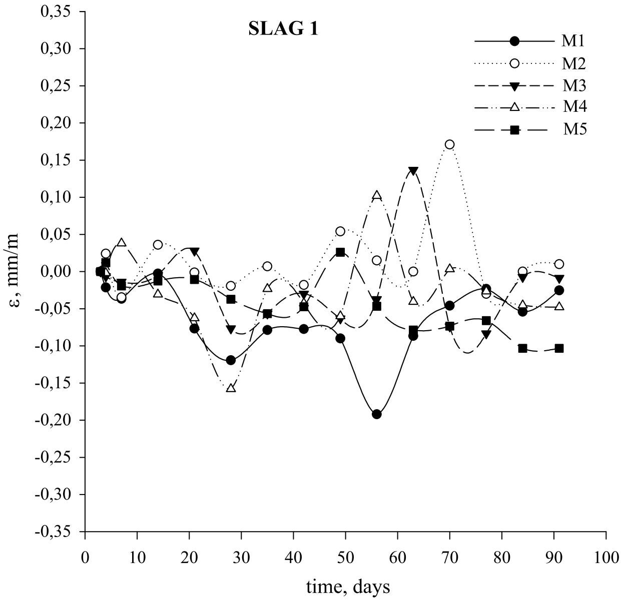
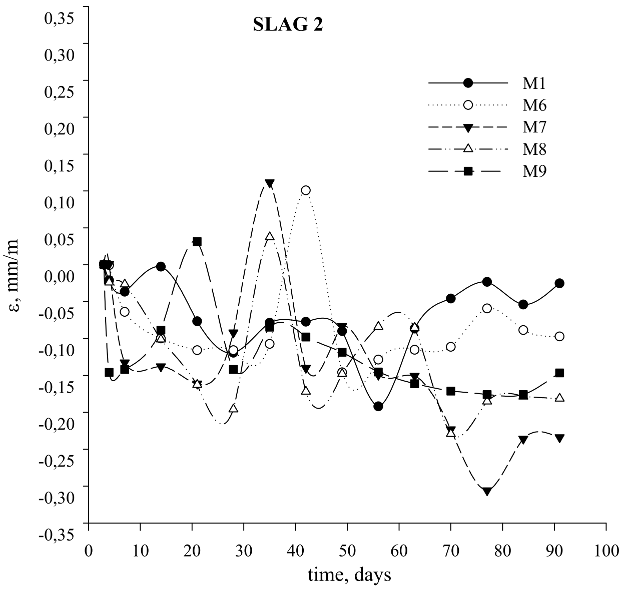


Figure 7 Monitoring depth of corrosion in time of reference mixture and a) mixtures with slag 1 and b) mixtures with slag 2

Taking into account results of pH values of filtrate of concrete prepared with different type of slag aggregate and the results of corrosion process monitoring during exposure to simulated aggressive environment in salt spray chamber, it can be concluded that slag 1 does not increase the risk of reinforcement corrosion, when used for preparation of concrete that will be exposed to aggressive marine environment. Moreover, prolongation of service life could be obtained if fly ash is used as substitution of part of the cement, together with slag 1 as aggregate. Opposite to that, when slag 2 is used, negative influence on corrosion is obtained. This is potentially indicating that there is an increased risk that corrosion of reinforcement will occur, when slag 2 is used to prepare concrete that will be exposed to aggressive marine environment. In that case, it is recommended to design further corrosion protection of steel in concrete, by increasing concrete resistivity to penetration of chlorides (e.g. addition of mineral and chemical admixtures, impermeable coatings) or by directly increasing corrosion resistance of reinforcement (e.g. protective coatings, alloyed steel, corrosion inhibitors).



a)



b)

Figure 8 Average volume changes of reference mixture and a) mixtures with slag 1 and b) mixtures with slag 2

4.3 Volume changes

Fig. 8 shows the comparison of average values of deformation measured for the reference concrete mixture (M1), mixtures with slag 1 (M2, M3, M4, M5) and slag 2 (M6, M7, M8, M9). Each of here shown curves presents a mean line of 6 measurement lines (3 prisms x 2 measuring lines per prism = 6 measurement lines).

In Fig. 8, the declining curve indicates the shrinkage of concrete specimens and the increasing curve indicates their expansion. Despite the fact that the slag 1 contains a greater amount of free CaO and MgO, which might lead to the conclusion that the mixtures M2 to M5 might have larger volume changes, the authors observed that volume changes were more expressed in mixtures with slag 2 (M6 to M9).

The presented test results do not indicate significantly different volume changes of slag concrete M2 to M5 in relation to the reference concrete (M1) which means that slags did not show their expansive nature. Such a result was expected due to previous long-term exposure of the studied slags to the influence of atmospheric condition during the making of aggregate from the original slag sample (6 months). During this period, there was enough time for the reaction of free CaO and MgO. Although the results of the volume stability of the slag mixture are satisfying in this short reference period, testing of volume stability will be continued. In contrast, mixtures with slag 2 (M6 to M9) showed larger volume changes than reference mixture. Results like this should not exclude slag 2 as a valuable construction material - it is recommended to use one of the methods of accelerated slag aging in case of volume instability, such as steaming or steaming under pressure [28], which can effectively solve this problem. The use of accelerated aging methods will certainly increase the production costs of slag as an aggregate, but it will also enable its disposal as a waste material. Addition of polypropylene fibres and fly ash did not influence volume changes significantly.

5 Conclusion

This paper presents the possibility of utilisation of steel slags from local landfills as an aggregate in concrete according to the aggregates requirements to use them in concrete production. Therefore, mechanical properties, volume changes and corrosion susceptibility of concrete made with steel slag aggregates were experimentally tested and compared to the commonly used dolomite aggregate concrete. According to the hitherto explicit test results, the conclusion can be given that here observed slags used as coarse aggregate in concrete:

- result in mechanical properties of concrete acceptable for structural use.
- do not represent a risk in terms of corrosion of reinforcement in case of slag 1. However, if and when using slag 2 in concrete, it is recommended to ensure additional corrosion protection of reinforcing steel.
- do not possess the high rate of expansion which could cause deterioration of structure.

The presented results are affirmative and justify the application of locally produced steel slags as aggregates in structural concrete. However, additional corrosion protection of reinforcing steel could increase the price of slag based structure and in that case a cost benefit analysis is needed for widespread use of slag 2.

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