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Influence of Surface Retarders on Texture Profile And Durability of Upper Layer of Exposed Aggregate Concrete Pavement

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ABSTRACT

Exposed aggregate concrete (EAC) pavement technology is used in Poland for construction of major highways and expressways. When properly executed, it is an efficient technique to provide desired friction for skid resistance without compromising the noise limitations. Concrete mix uniformity, proper dosing of retarding agent and optimal time to brush with a mechanical broom are supposed to have a major impact on the properties of the upper pavement layer. An experimental investigation was performed on exposed aggregate concrete specimens manufactured in the laboratory in a way to simulate the industrial production of two-layer concrete slab with exposed aggregate. The texture depth was determined using a laser profiler. The compressive strength of concrete, the water absorption rate, and permeability of chloride ions through concrete were also determined. The freeze-thaw resistance and surface scaling resistance were tested and analyzed with respect to air void characteristics. Results revealed an increase in surface scaling for EAC slabs with higher w/c ratio and slabs simulating local bleeding. The most efficient method to determine indirectly the durability of EAC slabs was the set of permeability tests comprised of measurements of chloride migration and rate of water absorption. The change of macrotexture depth with increase of w/c ratio and retarding admixture type was found.

Keywords: highway pavement, exposed aggregate concrete, surface retarder, durability, concrete preparation parameter, water absorption, chloride migration, surface scaling, macrotexture.

1.0 INTRODUCTION

The most detrimental exposure conditions on concrete pavements in temperate climate in Poland are freeze-thaw cycles in winter time. Additionally on the highways pavements deicing salts are used during the winter time. In this case very important is the salt scaling resistance of concrete, particulary in the upper surface of pavement.

The slip-form two-lift pavement technology with EAC has many benefits and has been used in many European countries, especially in Germany and Austria. Technical specifications used in Poland are similar to both mentioned countries (ZTV 2007), (RVS 2011). Exposed aggregate concrete, when properly executed, is considered as an efficient technique to provide desired friction for skid resistance without compromising the noise limitations. The greatest impact on the properties of final EAC pavement is concrete uniformity, proper dosing of retarding agent and optimal time to brush with a mechanical broom. The above technological processes are critical to achieve the designed performance and durability of pavements (Glinicki et al, 2016). The application rate of the retarder has to be established experimentally in regard to the cement setting and hardening rate in particular weather conditions (Hu *et al.*, 2014). The optimal time to brush with a mechanical broom is usually determined by a hand broom. Furthermore the penetration depth of retarder into concrete is variable depending on its chemical composition (Akkari and Izevbekha, 2012). Finally the significance impact on properties of two-lift pavement has curing condition of upper layer of pavement (Skarabis, 2012).

The investigation on the performance of EAC was performed to gain a better understanding of material, proposed technology and eventually to contribute to a performance-based materials selection. Research focused on macrotexture, water absorption, migration of chloride ions and durability of EAC with reference to amount of retarder/curing agents, type of retarder/curing, proportion of coarse aggregate, local bleeding of surface layer and bulk w/c ratio change.

2.0 EXPERIMENTAL PROGRAM

2.1 Materials

The specimens were manufactured in the laboratory in a way to mimic the EAC technique for texturing the surface of concrete pavements. The surface should be intentionally removed to leave the larger aggregates exposed, and thus to serve as the contact surface for traffic. To achieve that the top layer is covered with retarding compound that slows the cement hydration process in mortar near the surface and prevents it from adequately bonding with the aggregates. This allows for the mortar to be dry-brushed easily without removing aggregates from concrete.

Concrete mix design was chosen based of quality of the weakest concrete used for upper layer of two-lift EAC pavements in Poland (Table 1).

Table 1. Concrete mix design

		M40-1	M40-2	M45-1	M45-2
Cement CEM I 42.5 R (kg/m^3)		430	430	430	430
Water (kg/m^3)		172	172	193	193
River quartz sand (kg/m^3)	0-2 mm	500	500	484	484
Amfibolite coarse aggregate (kg/m^3)	2-4 mm	91	639	88	617
	4-8 mm	1186	639	1147	617
AEA[1)] (% c.m.)		0.15	0,15	0.18	0.18
Compressive strength – 28 days (MPa)		52.4	49.1	45.8	44.2
Standard deviation		1.2	1.9	1.5	1.6

[1)] air entraining admixture (AEA) - surfactant

The reference concrete M40-1 was prepared with CEM I type of cement and w/c = 0.40. Others concrete mixtures were designed by changing the w/c ratio and aggregate sieve curve (Fig. 1). Increase of w/c ratio to 0.45 (M45-1 and M45-2) simulated a local changes of w/c ratio of concrete preparation due to segregation of mixture placed on building site.

Two different grain size distribution of coarse aggregate (Fig. 1) were used to reflect variable practice. The new experience provides evidence that a reduction in the 2-4 mm volume fraction of aggregates in concrete mixtures improves the resulting texture profile of surface layer.

2.2 EAC slabs

Concrete slabs of 350x350x50 mm, 150 mm and 100 mm cubes for durability tests, air voids analysis and compressive strength testing respectively were manufactured. After casting of slab specimens the surface of concrete was processed manually by a trowel and a retarding admixture was sprayed over the surface immediately after that. After sufficient hardening of cement paste the thin surface layer was removed by using of hand brush with stiff plastic bristles. Results of such surface treatment are

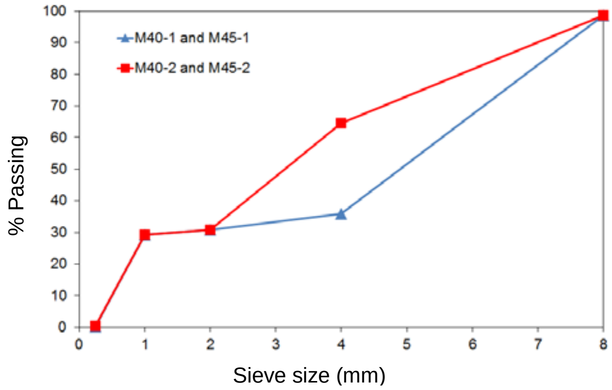
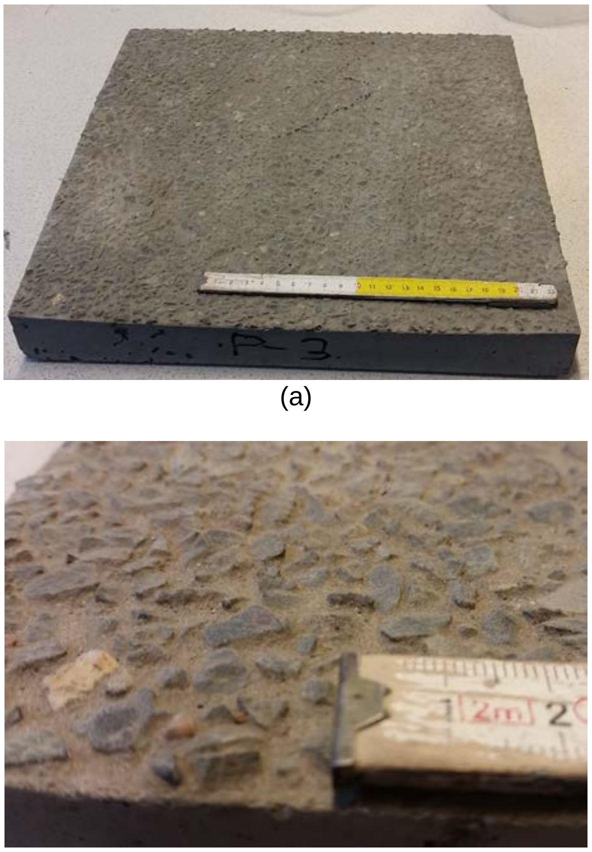


Fig. 1. Cumulative grading curves for concrete mixtures



(a)

(b)

Fig. 2. Slab specimens with exposed aggregate surface prepared at laboratory conditions: (a) overview (b) exposed aggregate surface

shown in Figure 2 – the aggregates are exposed to the depth of about 1 mm.

Seven series of concrete slabs were made (Table 2). Reference concrete slab (P1) was manufactured using M40-1 concrete mixture and 0,1 kg/m^2 of retarding admixture with known degree of penetration of concrete surface RD-1. Others concrete slabs were made using mix proportioning given in Table 1, increasing the amount of retarding admixture RD-1 (P2), using another retarding admixture RD-2 with a larger degree of penetration (P3). Additionally another concrete slab was made exactly like the reference slab, but over the surface

Table 2. Preparation of concrete slabs

Slabs designation	Concrete mixture	Retarding admixture	Amount of retarding admixture (kg/m^2)	Additional operation
P1	M40-1*)	RD-1	0.1	-
P2	M40-1*)	RD-1	0.5	-
P3	M40-1*)	RD-2	0.1	-
P4	M40-1*)	RD-1	0.1	Dilution of paste by additional water
P5	M45-1*)	RD-1	0.1	-
P6	M45-2*)	RD-1	0.1	-
P7	M40-2*)	RD-1	0.1	-

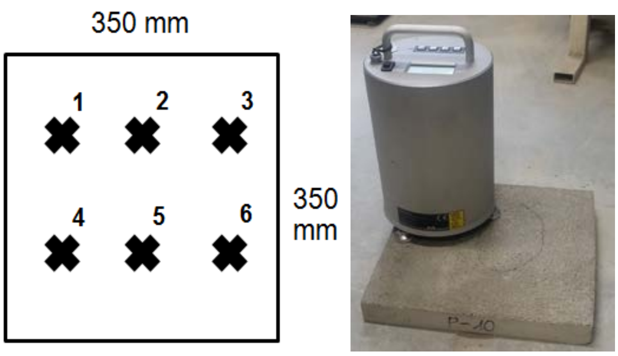
*) according to Table 1

tap water was sprayed after casting and after that the surface was processed by a trowel (P4). Slab P4 was intended to reflect the presence of extra water on the surface of pavement, sometimes observed on building sites after processing.

2.3 Methods

The compressive strength was measured according to PN-EN 12390-3 using Controls Automax 5/50-C5652 testing machine. The strength tests were performed on three 100 mm cube specimens for each concrete mix.

The air void characteristic in hardened concrete was determined using a computer-driven system of automatic image analysis (GLINICKI and ZIELIŃSKI, 2008). Tests were performed using polished concrete specimens 100x100x25 mm cut from 150mm cube specimens. The measurement procedure complied with standard requirements imposed by PN-EN 480-11.



(a) (b)

Fig. 3. Scheme of profile measurement (a) and view of measurement of EAC pavement. Points 1-6 represent a center of measurement machine.

Macrotexture profile of pavement slab was measured according to EN ISO 13473-1 using ELAtextur rotating laser technique. The EAC profile is determined by measuring a mean profile depth (MPD) on the laser sensor path 400 mm. The data is used to the estimated texture depth (ETD) which is equivalent of sand-patch method. The measurement procedure was done for each concrete slab at 6 places presented at Figure 3.

The rate of water absorption was tested in accordance with ASTM C1585. Concrete disc with a diameter 94 mm were drilled through the thickness of slabs. Hence the high of cores was approximately 50 mm (Fig. 4). After drilling cored specimens and placed in an environmental chamber at temperature of 50°C and RH of 80% for 3 days. Then, each specimen was stored in an individually sealed container for 15 days to attain an equilibrium of internal humidity. The specimens were placed in a pan containing water filled up to 3±1 mm above the top of the supporting device. The mass of the specimens was measured at regular intervals. The initial sorptivity (S_i) was calculated based on mass intake during the first 6 h. Rate of water absorption was obtained as average of three measurements for each concrete slabs.

Fig. 4. Drilled concrete core from EAC slab

Rapid chloride migration test was applied to determine the non-steady state migration coefficient according to Nordtest Method NT Build 492. The non-steady-state migration coefficient (D_{nssm}), is calculated from the generalized Fick's law where was added migration part and convert to Nernst-Planck equation. The test was conducted on three specimens for each concrete mix. Specimens drilled from concrete slabs (Ø=94 mm, h=50 mm) were placed into measuring rig with exposed aggregate face towards chloride ion solution.

Porosity accessible to water was measured according to French standard NF P18-459. Measurement was obtained as average of three specimens drilled from concrete slabs (Ø=94 mm, h=50 mm).

The frost-salt surface scaling resistance test was carried out with an automatic chamber for freezing and thawing of samples, using Slab test, according to European technical specification CEN/TS 12390-9. Four slab specimens 150×150×50 mm for each concrete slabs were subjected to 56 freeze-thaw cycles while the exposed aggregate surface was exposed to 3% NaCl solution. To assess scaling resistance of concrete the criteria of the Swedish standard SS 137244 were used.

3.0 RESULTS AND DISCUSION

Concrete specimens designated with the same w/c ratio and different coarse aggregates proportion obtained similar values of compressive strength, differences are statistically negligible. The change a w/c ratio from 0.4 to 0.45 caused a decrease compressive strength of concrete specimens by 13% and 10% for both proportion of coarse aggregates respectively. Air voids characterization revealed the air void characteristics adequate for frost resistant concrete (Table 3). The spacing factor was within the range from 0.15 mm to 0.20 mm, A_{300} in the range from 1.51 % to 1.86%. Consistency measured as slump of concrete mixtures revealed increase of fluidity with increase of 2-4 mm fraction of coarse aggregates. Most likely it is a reason of decrease of air content which was measured by pressure method and obtained in hardened concrete. Receive results allow to make an assumption about similar air voids microstructure of concrete test specimens.

Table 3. Properties of fresh concrete mix and the air void characteristics of concrete

Concrete series	Slump (mm)	Air content*) (%)	Air void characteristics**)			
			A (%)	A (mm^{-1})	L (mm)	A_{300} (%)
M40-1	20	5.5	4.32	39.75	0.15	1.86
M40-2	40	5.1	4.15	32.59	0.19	1.51
M45-1	50	5.7	4.76	31.87	0.18	1.79
M45-2	80	5.0	4.08	29.56	0.20	1.55

*) Pressure method
**) Hardened concrete

Before cutting and drilling the profile of slab surface was measured. Obtained results revealed a slight increase of ETD for slab P3 with retarding admixture with greater penetration approximately about 0.15 mm (Fig. 5). A change of proportion of aggregate in concrete mixture do not have any consequences on measured values for both w/c ratio. Considering concrete slab with different w/c ratio and the same coarse aggregate proportion the ETD values were 35-40 % higher with increase of water in concrete. The measurements clearly revealed influence of w/c ratio on the depth of penetration and action of retarding admixture.

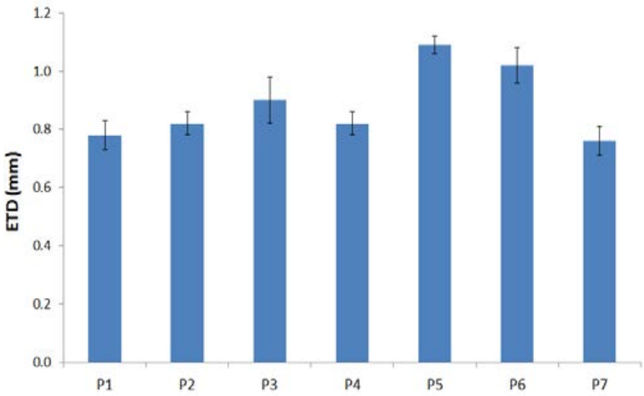


Fig. 5. Equivalent Texture Depth (ETD) of concrete slabs

According to measurement of porosity accessible to water we specified class of durability using (Baroghel-Bouny, 2006) criteria (Fig. 6). Reference concrete slab was classified as concrete with “low” durability. Significant increase of porosity accessible to water was observed only for concrete with high w/c ratio 0.45. After that change obtained “very low” durability class. Measurements revealed not enough sensitive that method to observe other materials changes. However visible is slightly increase of porosity accessible to water of all concrete slab compared to reference concrete.

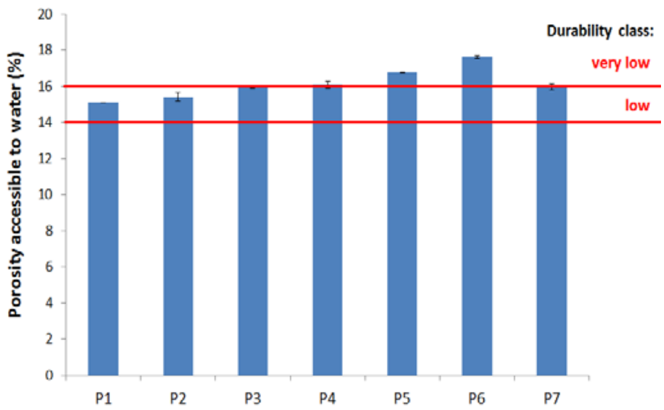


Fig. 6. Porosity accessible to water of concrete slabs (Durability class – Baroghel-Bouny, 2006)

Much more sensitive method to assess the porosity of concrete slab is the initial rate of water absorption, designated by measurement of water absorption EAC surface of concrete slab. Increase surface area of EAC surface of concrete pavement compared to cut specimens caused a significant deviation between measurement Fig. 7). Hence interpretation of results of water absorption it not clear, because quite large standard deviation of three measurements were recorded. The smallest initial rate of water absorption $35 \cdot 10^{-4}$ mm/s$^{1/2}$ was obtained for reference concrete slab P1. The proposed manner of processing of concrete slabs and material changes increase the initial rate of water absorption. The highest rate of water absorption was observed for slabs with 0.45 w/c ratio without any significant influence of aggregate gradation. Additionally the effect of extra water on the surface before processing by trowel was revealed, it caused an increase of the initial rate of water absorption by 22 % (slab P4).

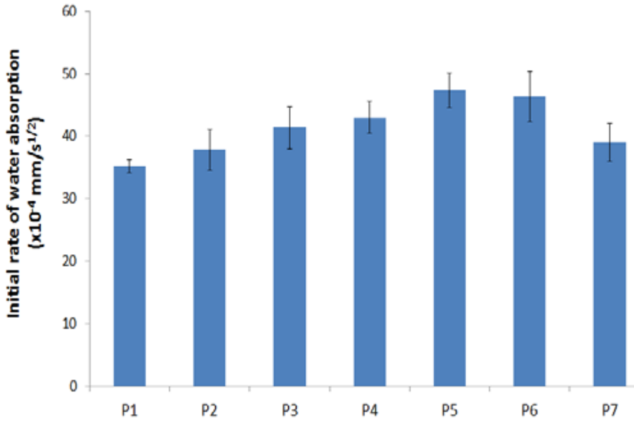


Fig. 7. Initial rate of water absorption of EAC slabs

The chloride migration test was much more significant to observe the changes of aggregate gradation than the measurement of rate of water absorption (Fig. 8). The reference concrete slab P1 achieved quite high chloride migration coefficient and it was $11.7 \cdot 10^{-12}$ m^2/s. According to description proposed by (Tang, 1996) reference EAC layer has been classified as a having acceptable resistance resistance to chloride migration. An increase of 2-4 mm fraction of aggregate revealed 40% and 15% higher values of chloride migration coefficient for slabs with 0.40 and 0.45 w/c ratio respectively. It should be noted, that the deviation of results was up to 15% of chloride migration coefficient values. Hence that influence of coarse aggregate fraction on the D_{nssm} for highest w/c ratio is on the verge of statistical significance.

Measurement of surface scaling resistance of concrete slabs revealed very good durability of EAC surface after 56 freezing-thawing cycles for pavement made with mixture with 0.40 w/c ratio (Fig. 9). Exception was concrete slab made with addition on surface extra water before processing by trowel (P4), which was on border good and very good durability class according to Swedish standard SS 137244. It must be noted, that results of surface scaling test was very small, and only EAC slabs with higer w/c ratio increase mase of scaled material to 0.28 kg/m^2 and 0.34 kg/m^2 respectively for small amount and higer amount of 2-4 mm fraction of

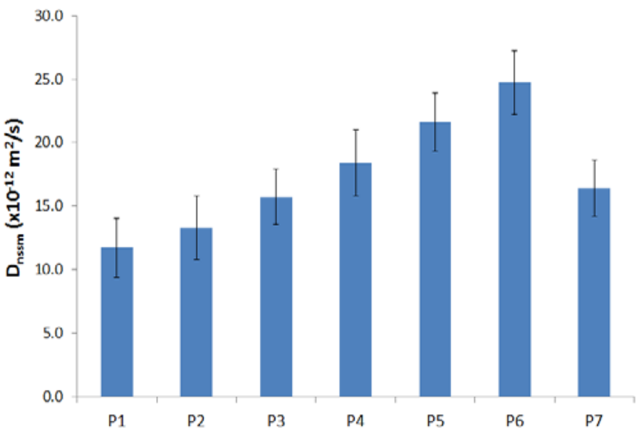


Fig. 8. Average chloride migration coefficient - D_{nssm} of concrete slabs (Durability class – Tang, 1996)

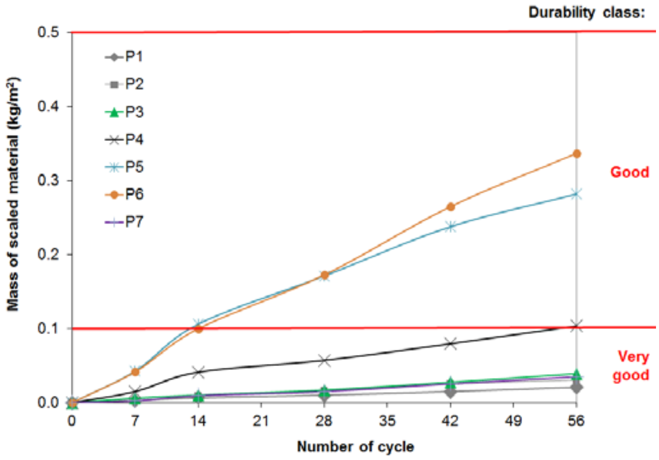


Fig. 9. Surface scaling resistance of EAC slabs (Durability class – SS 137244, 2005)

coarse aggregates. It is still good category o surface scaling resistance.

To summarize test results we should notice, that properly air entrained EAC slabs with w/c ratio up to 0.45 provide good quality of pavement. The proportion of coarse aggregate in concrete pavement do not have significant influence on surface scaling resistance. Only appearance water on top surface slightly increase the surface scaling resistance.

Measurement of porosity accessible to water is not sensitive enough to distinguish a subtle materials and preparation changes, except increase w/c ratio. Much more appropriate methods to determine indirectly the durability of EAC pavement was measurement of chloride migration coefficient and water absorption, especially initial rate of water absorption. Both used methods shown similar tendency between compared materials but the changeable surface area of exposed aggregate layer caused the largest, than cut specimens, deviation of results. Interpretation a results in that case is difficult and can't clearly interpret changes.

4.0 CONCLUSIONS

On the basis of test results the following conclusions can be drawn:

- Increase of retarding admixture much more than recommended 0.1 kg/m^2 does not have significant impact on texture profile and durability of final EAC pavement.
- Using a deeper penetration retarded admixture influence on macrotexture EAC pavements and increase ETD about 0.15 mm but do not have significant impact on water absorption, chloride migration and surface scaling resistance.
- An increase in w/c ratio from 0.40 to 0.45 increased the depth of penetration of retarding admixture and consequently ETD was 35-40% higher.
- Local bleeding on the surface of the EAC pavement layer before processing and spraying retarded admixture caused significant deterioration of durability class measured as chloride migration coefficient and porosity accessible to water.

Acknowledgement

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