ABRASION RESISTANCE AND TRANSPORT PROPERTIES OF ROAD CONCRETE

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ABSTRACT

Abrasion resistance and impermeability are vital in road concrete. In this experimental study the compressive strength, abrasion resistance and transport properties of the road concrete were investigated. In order to study transport properties, water sorptivity and depth of penetration of water under pressure were taken into consideration. For this purpose, four different concrete mixtures having 28-day compressive strength ranging from 32 to 64 MPa were prepared, using a CEM II B-M (L/W) 42.5 R type portland composite cement, crushed limestone aggregate having a maximum size of 22.4 mm and a superplasticizer admixture (if required). The slump value of the concrete mixtures was kept constant as 75±5 mm. Two series of concrete mixtures were prepared. One of the series was coated with two different types of surface hardener admixtures (SHA). Thus, the effect of w/c ratio and presence or absence of the SHA on the abrasion resistance and transport properties of the road concrete were determined. Test result demonstrated that, compressive strength of the mixture with high w/c ratio increased by using of the SHA. However, application of SHA had not a significant effect on the compressive strength of concrete with low w/c ratio. Expect for the mixture having w/c ratio of 0.63, the control mixture showed better transport property than the counterpart mixtures coated by the SHA. Furthermore, a close relationship was found between the compressive strength and abrasion resistance of the concrete. Besides, the abrasion resistance of the concrete mixtures was found to be improved considerably by applying SHA.

KEY WORDS

ROAD CONCRETE / WATER SORPTIVITY / DEPTH OF PENETRATION OF WATER UNDER PRESSURE / ABRASION RESISTANCE / SURFACE HARDENER ADMIXTURE.

1. INTRODUCTION

The concrete surface layer characteristics are directly associated with ability of the concrete to resist abrasion [1]. The term of abrasion generally refers to dry attrition. Floors, pavements, and hydraulic structures are subjected to abrasion; therefore, in these applications concrete must have a high abrasion resistance [2,3]. It is reported that the strong concrete has more resistance to abrasion than the weak concrete [3]. Thus, all factors that affect compressive strength also affect abrasion resistance of the concrete. The type of aggregate, mix proportion, workmanship, curing and surface finish or treatment used also have a strong influence on the abrasion resistance. Hard aggregate is more wear resistant than soft aggregate and a steel-troweled surface resists abrasion better than a surface that had not been troweled. Poor finishing practices may also lead to a weak surface layer and lower abrasion resistance [3,4]. Supplementary cementing materials generally do not affect this property beyond their influence on strength [3]. Concrete mixtures containing fly ash are just as abrasion resistant as portland cement concretes without fly ash. The abrasion resistance of fly ash concrete is related to its strength [5]. Abrasion resistant concrete with high air content is recommended for the freezing and thawing durability without influencing the wear resistance and strength [2].

The surface hardener admixtures are divided into two categories: non-metallic hardeners and metallic surface hardeners. Non-metallic hardeners usually contain graded quartz, corundum or silica aggregate, dry portland cement and chemical additives. However, metallic surface hardeners include clean iron fine chippings and anti-corrosion chemicals and sometimes involve a small amount of Portland cement. Generally, the SHA are sprinkled on the surface of finished fresh concrete without adding extra water. The surface hardener absorbs water from the concrete surface and forms a monolithic product which is highly abrasion resistant.

In the literature many studies are available about the abrasion resistance and transport properties of the concrete. However, there is no study related with the effect of surface hardeners on the abrasion resistance and transport properties of road concrete mixture.

The abrasion resistance of concrete pavement containing nano-particles was investigated by Hui li et al [6]. As the additives, TiO_2 and nano-SiO_2 were used. The polypropylene (PP) fibers-bearing concrete mixtures were also studied in this work for benchmarking. The results demonstrated that the abrasion resistance of concrete mixtures containing nano-particles and PP fibers was significantly greater than that of the control mixture. Additionally, in the concrete mixtures containing nano-particles, this improvement was more larger. Besides, it was reported that the abrasion resistance of concrete containing nano-TiO_2 was better than that of the mixture containing the same amount of nano-SiO_2.

Nazari nad Riahi investigated the abrasion resistance of concrete containing SiO_2 and Al_2O_3 nano-particles cured at different conditions [7]. In this study, in addition to a control mixture without nano-particles, two different series of mixtures were prepared by partial replacement (0.5, 1.0, 1.5 and 2 wt%) of either SiO_2 or Al_2O_3 nano-particles with cement. It is reported that the abrasion resistance of concrete increased with increasing nano-particles content.

The effect of fine aggregate replacement with Class F fly ash on the abrasion resistance of concrete was investigated by Siddique [8]. For this purpose, the Class F fly ash was substituted for fine aggregate as 10%, 20%, 30% and 40% by weight. Test results showed that abrasion resistance and compressive strength of concrete mixtures increased with increasing the fly ash replacement level. Abrasion resistance of the concrete mixture having 40% fly ash replacement level was approximately 40% higher than that of the control mixture without fly ash.

The effect of fine aggregate replacement with metakaolin (MK) on the strength and abrasion resistance of concrete was investigated by Rashad [9]. The sand was partially replaced with MK at levels of 10%, 20%, 30%, 40% and 50%, by weight. Test results indicated that up to 40% MK substitution level the compressive strength, splitting tensile strength and abrasion resistance of the concrete increased. Beyond 40% MK the above mentioned properties were decreased.

The Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete (SSC) containing coal bottom ash was investigated by Siddique [10]. For this purpose, fine aggregates were replaced with 0%, 10%, 20% and 30% bottom ash. Test results indicated that abrasion resistance of the SSC mixtures decreased whereas its transport properties improved with the increasing bottom ash content.

In this study, the effect of different types of surface hardener admixture on the compressive strength, abrasion resistance, water sorptivity and depth of water penetration under pressure of road concrete were investigated.

2. EXPERIMENTAL DETAILS

2.1 Materials

In this study a CEM II B-M (L/W) 42.5 R type portland cement and a Class C fly ash were used as cementitious materials in the concrete mixtures. The chemical composition, fineness and mechanical properties of cement and fly ash provided from their manufacturers are shown in Table 1.

Table 1 – Chemical composition and mechanical properties of cement and fly ash

Item (%)	**Cement**	**Fly ash**
SiO_2	22.79	50.29
Al_2O_3	7.59	18.12
Fe_2O_3	3.31	9.68
CaO	54.72	7.03
MgO	1.70	6.72
K_2O	0.94	1.62
Na_2O	0.33	1.44
SO_3	3.15	2.19
Cl^-	0.009	-
Free CaO	2.02	-
Loss on ignition	3.00	1.17
Total	99.60	98.26

Physical properties		**Cement**	**Fly ash**
Specific gravity		2.98	2.2
Blaine specific surface (cm^2/g)		3860	3540
Residual of 0.090 mm sieve (%)		0.6	5.3
Residual of 0.032 mm sieve (%)		15.2	18.3
Mechanical properties		**Cement**	**Fly ash**
Compressive strength (MPa)	2-day	28.6	-
	7-day	43.2	-
	28-day	55.2	-
Strength activity index (%)	28-day	-	83.4
	90-day	-	92.5

The specific gravity and water absorption capacity of the aggregates used in the experiments were determined in accordance with EN 1097-6 standard. The SSD bulk specific gravity, loose bulk density and gradation of the combined aggregate, obtained by mixing 60% 0-5 mm, 20% 5-15 mm and 20% 15-25 mm aggregate size fractions by mass, and the standard gradation limits are shown in Table 2 and Figure 1, respectively. In this study, two different types of surface hardener admixtures (SHA) and one type polycarboxylate ether-based super plasticizer (SP) admixture were used. Some properties of the SP admixture and SHA, obtained from their manufacturers are given in Table 3.

Table 2 – Physical properties of aggregates

Aggregate Type	Aggregate Size (mm)	SSD bulk specific gravity	Absorption capacity (%)	Loose bulk density (kg/m^3)	Fineness modulus
Limestone	0–5	2.68	1.1	1740	3.49
	5–15	2.65	0.4	1505	-
	15-25	2.70	0.4	1503	-

Table 3 – Some properties of surface hardener and plasticizer admixtures

Properties of surface hardener admixture					
Type	**Content**	**Size fraction (mm)**	**Aggregate hardness (MOHS)**	**Bulk density (kg/m^3)**	**28-day compressive strength (MPa)**
A	Hydraulic binder, corundum aggregate	0.3-1.5	8-9	1550	75-80
B	Hydraulic binder, aluminum oxide corundum aggregate	0.3-2.5	6-8	1540	70-80

Properties of super plasticizer admixture						
Type	**Alkali content (%) (Na_2O)**	**Density (g/cm^3)**	**Solids content (%)**	**Chloride content (%)**	**pH , 25 °C**	**Operating** ** **range (%)**
SP**	< 5	1.098	35.73	0.012	5.97	0.6—2.0

* SP: Polycarboxylate ether-based super plasticizer admixture
** By weight of cement

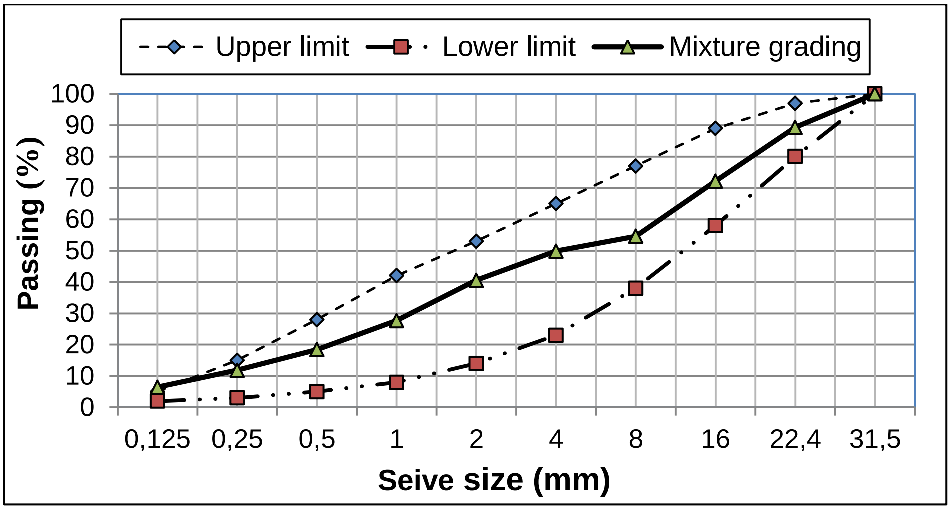

Figure 1- Gradation curve of combined aggregate and TS 802 standard limits

2.2 Mixture Proportions

Using four different water/binder (w/b) ratios i.e. 0.36, 0.42, 0.54 and 0.63, four concrete mixtures were prepared. In addition to the control mixture containing no surface hardener (SHA), two series of the mixtures were coated with two different types of SHA for each w/b ratio. The corrected mix proportions of the concrete mixtures are summarized in Table 4. It can be seen from table that in all of the concrete mixtures the amount of fly ash, water content and slump were kept constant as 80 kg/m^3, 195 kg/m^3 and 75±5 mm, respectively. In order to keep the slump constant, the superplasticizer content of the mixtures was adjusted in the range of 0.36 to 1.61 kg/m^3. The mixtures are designated by w/b ratio and type of the SHA, e.g. the control mixture having a w/b ratios of 0.36 is designated as C-36 whereas, the mixture having the same w/b ratio and coated with A type of SHA is designated as C-36-A.

Nine 100 mm and three 150 mm cube specimens were prepared from each mixture. The concrete mixtures were placed into molds, vibrated and the top surface of them was finished by troweling. In SHA-bearing mixtures with high w/b ratios, bleeding water was taken from surface by a towel as prescribed by the manufacture. After one hour, the SHA was sprinkled to the surface of concrete and the upper surface of concrete was finished by troweling. The specimens were demolded a day after casting and were cured in standard condition (20±2°C and 95% relative humidity) up to testing day.

Table 4 – Mixture proportions (kg/m^3) and fresh properties of concrete mixtures

Mix		C-63	C-54	C-42	C-36
Cement		222	272	372	448
Fly ash		80	80	80	80
Water		190	190	190	190
Aggregate	**0-5 mm**	822	803	762	732
	5-15 mm	458	448	425	408
	15-25 mm	554	541	514	493
Super plasticizer		0	0.36	1.42	1.61
w/c ratio (by weight)		0.63	0.54	0.42	0.36
Unit weight (kg/m^3)					
Theoretical		2326	2334	2345	2353
Measured-Fresh		2368	2375	2437	2452
Measured-Hardened (SSD)		2416	2434	2437	2495
ΣPaste		492	542	642	718
ΣMortar		1314	1345	1404	1450
Fresh concrete properties					
Air content (%)		2.7	1.9	1.6	1.2
Vebe-time (s)		3.3	4.4	7.5	4.0
Slump values (mm)		80	70	70	70

2.4 Test Methods

The consistency of fresh concrete mixtures was measured by Vebe consistometer as well as slump method according to ASTM C1170 and EN 12350-2 standards, respectively. The 7 and 28-day compressive strength and unit weight of hardened concrete mixtures were determined on 100 mm cube specimen in accordance with EN 12390-3 and EN 12390-7 standards, respectively. The 28-day permeability of 150 mm cube specimens was obtained in accordance with EN 12390-8 standard. The 28-day water sorptivity test was performed on 100 mm cube specimens in accordance with ASTM C1585.

The 28-day abrasion resistance test was performed on 71 mm cube specimens. At first, specimens were dried in an oven at 50 °C until a constant weight. Afterwards, to obtain their original weights, the specimens were weighted. The abrasion system consist of a 750 mm diameter steel disc, rotating at a speed of 30 ± 1 rpm, a counter and a lever, which could apply 300 N on the specimens. At the beginning of the test, 20 ± 0.5 g of wear dust (corundum crystalline Al_2O_3) was spread on the disc, the specimens were placed, the load was applied to the specimen and the disc was rotated for 90 revolutions. Then, the surfaces of the disc and the sample were cleaned by a brush, and the specimen was weighed. The same procedure was repeated for 3 periods, where the specimen was rotated 90^o at the beginning of each period. Thus, at the end of fourth period the specimens were abraded 360 times.

3. TEST RESULTS AND DISCUSSION

3.1. Fresh properties

The fresh properties of concrete mixtures are shown in Table 4. The mixtures having lower w/b ratio showed lower air content due to their better compactibility. As it was expected, the unit weight of the mixtures increased by decreasing w/b ratio. Besides, for the given slump value, the super plasticizer requirement of the mixtures increased from 0.36 to 1.61 kg/m^3 when the w/b ratio decreased from 0.63 to 0.36. The Vebe consistometer test results demonstrated that the Vebe time of C-63, C-54 and C-36 concrete mixtures were in the range of 3-5 seconds which was within the limit specified for V-4 concrete in accordance with EN 206-1 standard. However, Vebe time of the C-42 concrete mixtures was 7.5 seconds which is within the 6-10 seconds limit specified for V-3 concrete in accordance with the standard.

3.2. Compressive strength

The 7 and 28-day compressive strength test results as well as 28-day relative compressive strength of the concrete mixtures, based on the strength of corresponding control mixture, are shown in Table 5 and Figure 2. Each value presented is the average of three measurements. As it can be seen from the table; the maximum values of strength belong to C-36 series mixtures having the lowest w/b ratio (0.36). As expected, increasing w/b ratio caused a decrease in the strength of the mixture. It is known that this fact is due to the greater capillary porosity of the concrete. Therefore, the 7 and 28-day compressive strength of concrete mixture increased from 21.6 to 52.6 MPa and from 32.74 to 64.12 MPa, respectively with decreasing the w/b ratio from 0.63 to 0.36. For the series coated by A type of SHA, i.e. C-36-A, C-42-A, C-54-A and C-63-A, the 28-day compressive strength increased by 3%, 5%, 8% and 14%, respectively, compared to the strength of the corresponding control concrete. The similar values were obtained as 1%, 3%, 7% and 12% for C-36-B, C-42-B, C-54-B and C-63-B mixtures, respectively, compared to the control mixture. It seems that the increase in the strength of specimens having high w/b ratio (0.63 and 0.54) and coated with SHA is due to removing of bleed water from their top surfaces before the application of the SHA. However, in the series with lower w/b ratio (0.42 and 0.36) using of SHA has not a significant effect on the compressive strength of concrete mixture. In these series mixture the bleeding water was not observed. Thus, no bleed water was collected from the specimens.

Table 5 – The compressive strength of concrete mixture

	Compressive strength (MPa)					
	7-days			28-days		
w/c ratio	**C**	**C-A**	**C-B**	**C**	**C-A**	**C-B**
0.63	21.6	24.8	24.2	32.7	37.5	36.7
0.54	30.0	33.1	32.3	44.6	48.3	47.8
0.42	42.5	44.2	43.4	53.0	55.5	54.6
0.36	50.9	52.6	52.3	62.5	64.1	63.2

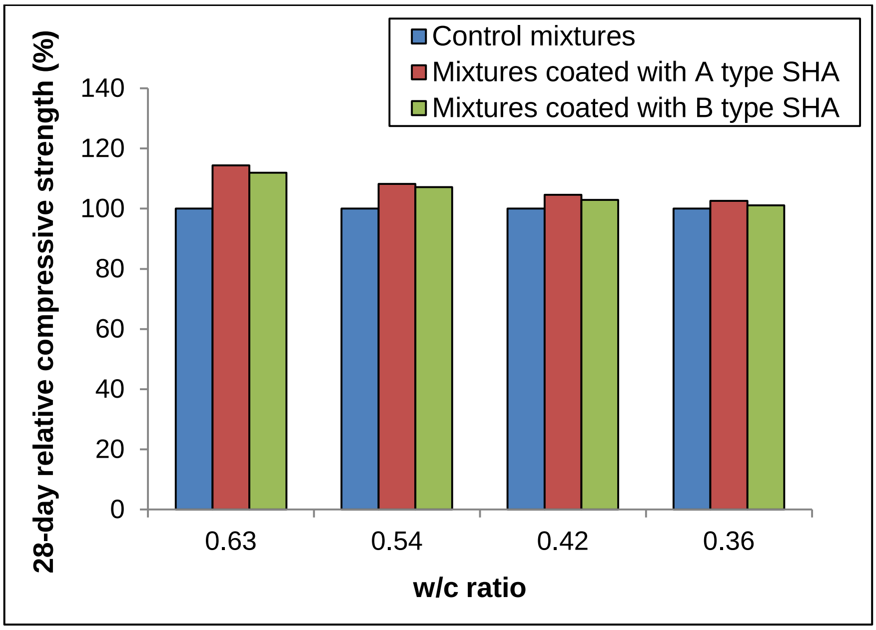

Figure 2 - The 28-day relative compressive strength (%)

3.3. Transport properties

The 28-day initial and secondary rate of water absorption, the relationship between water sorptivity and w/c ratio as well as depths of penetration of water under pressure – w/c ratio relationship are shown in Table 6, Figure 3 and 4, respectively. Each value presented is the average of three measurements. In order to investigate the effect of the SHA on transport properties of road concrete mixture, these properties were measured at the top surface of the specimens which were coated by the SHA. For the sake of comparison the same procedure was applied to the control specimens. It is believed that the water absorption of concrete depends on the permeable capillary porosity of the concrete mixture. As expected, in all concrete series the transport properties were improved with decreasing w/c ratio of the concrete mixture.

In all of the concrete mixtures, initial rate of sorptivity value was higher than that of secondary rate of sorptivity. For each w/b ratio, excluding 0.63, the rate of absorption of the control mixture was lower than those of the concrete mixtures coated with SHA, indicating that, SHA had higher water absorption capacity than the plain concrete. In all w/b ratios, the absorption rate of the series coated with A type SHA was lower than that of the series coated with B type SHA. This may be attributed, in part, to the higher fineness of A type SHA compared to that of B type and in part, to the differences between the composition of these admixtures.

It is interesting to note that, in w/b ratio of 0.36, the sorptivity values of the series coated with A and B types SHA were two and three times higher than that of the control mixtures, respectively. Beside, at similar w/b ratio, the depth of water penetration under pressure values of the control series were 19% and 21% lower than that of the series coated with either A or B types SHA, respectively. The difference in water sorptivity and depth of water penetration under pressure values between the control series and the series coated with different types of SHA decreased by increasing w/b ratio of the mixtures. So that, in the mixtures having maximum w/b ratio (0.63) the differences between these values was negligible.

As recommended by the admixture manufacturer, in concrete mixtures coated with SHA, before applying of the SHA, bleeding water was removed from the concrete surface by a towel. However, this process was not applied in the control series where there was no need to coat them. Thus, the lower performance of the control series, compared to that of the coated series, at least in part, may be due to the removal of bleeding water from the top surface of the latter mixtures.

Table 6 – Initial and secondary rate of water absorption of concrete mixture

	Initial rate of absorption ($mm/s^{1/2}$)			Secondary rate of absorption ($mm/s^{1/2}$)		
w/c	C	A	B	C	A	B
0.36	0.0010	0.0016	0.0018	0.00020	0.00050	0.00060
0.42	0.0014	0.0021	0.0025	0.00022	0.00073	0.00074
0.54	0.0020	0.0029	0.0031	0.00030	0.00033	0.00040
0.63	0.0044	0.0032	0.0037	0.00080	0.00050	0.00080

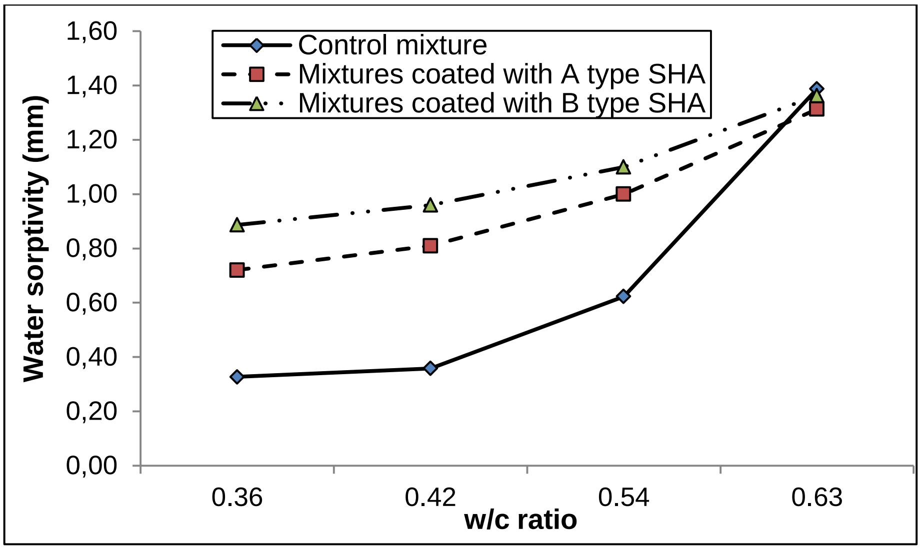

Figure 3 - Relationship between water sorptivity and w/c ratio of concrete mixture

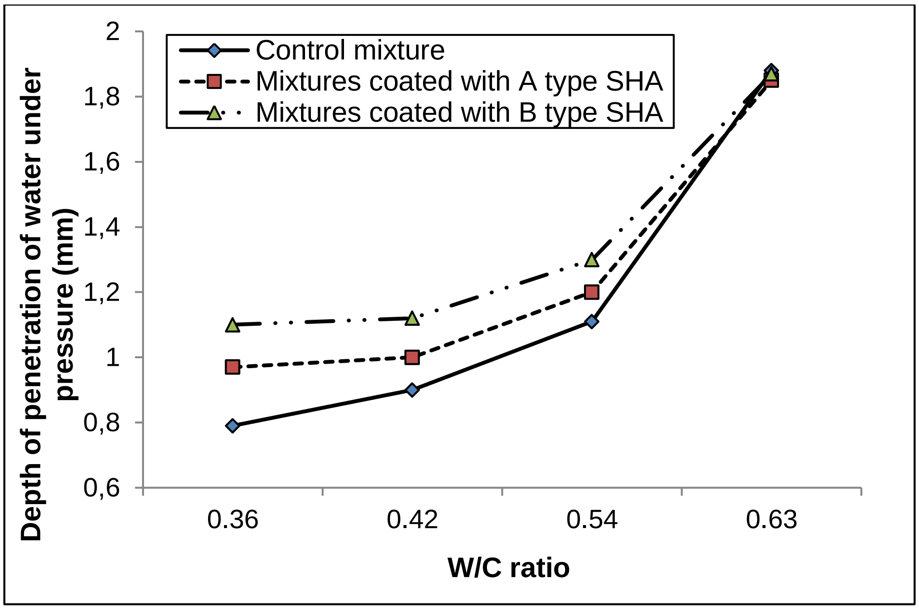

Figure 4 - Relationship between water permeability and w/c ratio of concrete mixtures

3.4. Abrasion resistance

The weight loss of the concrete mixtures exposed to the abrasion test is shown in Table 7. Each value presented is the average of three measurements. The abrasion resistance of the concrete mixtures was determined on the surfaces coated by the SHA. For the sake of comparison the top surface of control mixture troweled by hand was subjected to the abrasion test. The abrasion resistance was measured in terms of weight loss of the concrete after exposing to the abrasion test. The weight loss of the concrete decreased with increasing compressive strength of the concrete, indicating that there was a close relationship between the compressive strength and the abrasion resistance of the mixture. The same results were obtained by the other researchers [11,12]. In the concrete mixture containing no SHA, reducing the w/b ratio from 0.63 to 0.36 caused an 87% increase in the 28-day compressive strength. However, the reduction in loss of weight of the concrete upon abrasion was only 8% when w/b ratio of it was reduced from 0.63 to 0.36. Hence, the change of w/b ratio is more effective on the compressive strength than the abrasion resistance of the concrete. Besides the abrasion resistance of the all concrete series was improved by applying the SHA. The effect was more pronounced when A type SHA was used.

Table 7 – Weight loss of concrete mixtures after exposed to abrasion (%)

RN*	**C-36**	**C-36-A**	**C-36-B**	**C-42**	**C-42-A**	**C-42-B**	**C-54**	**C-54-A**	**C-54-B**	**C-63**	**C-63-A**	**C-63-B**
0	0	0	0	0	0	0	0	0	0	0	0	0
90	0.39	0.19	0.26	0.48	0.32	0.28	0.56	0.30	0.27	0.54	0.44	0.29
180	0.83	0.46	0.59	0.89	0.53	0.68	1.01	0.63	0,60	0.91	0.82	0.70
270	1.35	0.76	0.77	1.39	0.82	0.95	1.54	1.01	0.98	1.62	1.16	1.07
360	2.02	1.10	1.15	2.10	1.13	1.24	2.13	1.37	1.29	2.17	1.45	1.48
Relative weight loss of concrete compared to control mixture (%)												
0	0	0	0	0	0	0	0	0	0	0	0	0
90	100	49	65	100	66	60	100	54	48	100	82	53
180	100	55	72	100	60	77	100	62	60	100	90	77
270	100	56	57	100	59	68	100	66	64	100	72	66
360	100	55	57	100	54	59	100	64	60	100	67	68

* Revolution number

4. CONCLUSIONS

In this study, the effect of different types of surface hardener admixture on the compressive strength, abrasion resistance, water sorptivity and depth of water penetration under pressure of road concrete were studied and the following conclusions were drawn:

- ✓ Compared to the control mixtures containing no surface hardener, the compressive strength of concrete having high w/b ratio (0.63 and 0.54) and coated with surface hardener increased due to the removing of the bleed water from their top surfaces before the application of the surface hardener. However, regardless of the age of concrete in the series with lower w/b ratio (0.42 and 0.36), using of surface hardener had not a significant effect on the compressive strength of concrete. In these series, since no bleeding was occurred, collection of the bleed water was not the case.

- ✓ For each w/b ratio, excluding 0.63, the transport properties of the control mixture was better than that of the concrete mixtures coated with surface hardener. The effect was attributed to the higher water absorption capacity of the surface hardener than that of plain concrete. However, in the mixtures having 0.63 w/b ratio, the concrete coated with surface hardener and the corresponding control mixture showed similar characteristics in terms of transport properties.

- ✓ In all of the concrete series, abrasion resistance of the concrete mixtures was improved by applying the surface hardener admixtures.

- ✓ As expected, the compressive strength and abrasion resistance of concrete increased with decreasing w/b ratio of the mixture. However, the change of w/b ratio was more effective on the compressive strength than on the abrasion resistance.

- ✓ In terms of compressive strength, transport properties and abrasion resistance, the concrete mixture coated with A type surface hardener was more successful than those mixtures coated with B type.

Acknowledgement

The authors would like to thank Izmir Çim-Beton Ready Mixed Concrete Plant and Draco Construction Chemicals Company authorities for their kind assistance in providing the cement and superplasticizer admixture as well as determining the chemical composition of these products.

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