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Examining the Impact of Micro Silica Gel Additive on the Compressive Strength and Water Absorption of Roller Compacted Concrete Pavement

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Abstract

Roller compacted concrete pavement (RCCP) is one of the different types of concrete pavements which is considered as a new developing technology due to its rapid installation. However, RCCP is difficult to install in high thickness; therefore, it is essential to reduce the thickness of pavement while maintaining strength. Flexural strength and fatigue resistance are the most important parameters effective on design of thick pavements. These parameters are directly related to uniaxial compressive strength of concrete. Hence, this study determines and evaluates the compressive strength of 7-day and 28-day specimens. Given the durability of concrete pavements, particularly their penetrability against water, corrosive materials and minerals, the most important parameter is to reduce water absorption of RCCP. In order to increase strength and reduce water absorption of RCCP, different additives as well as a proper mix design can be significantly effective. This study examines the effect of various mix designs and different percentages of micro silica gel on RCCP. The suggested mix design is continuous aggregation and addition of 7% micro silica gel, which increases strength and durability of RCCP.

Keywords: roller concrete, pavement, compressive strength, water absorption, micro silica gel

1. Introduction

Roller compacted concrete pavement (RCCP) is a new method for development of materials such as stabilized soil or cement-modified basis, which was used for years as the basis of design and construction of pavements. Afterwards, RCCP has been used as a complete pavement without urgent need for coating layer. RCCP was first used in Vancouver, Canada in 1970 (Hodgkinson, 1991; Harrington et al., 2010). Fresh RCCP is different from conventional concrete which is more rigid and less efficient. Moreover, RCCP contains the same amount of cement used in concrete mixtures; its compressive strength is usually higher than 27 MPa. Size and aggregation of materials is controlled in a certain range for RCCP mix design (ACI 325.10R-95, 1995). RCCP and conventional pavement are mainly different in construction, joint distances and surface appearance.

RCCP is a mixture with maximum 19mm aggregate size for coating layer as well as cement materials and water. For mixing ratios of roller compacted concrete (RCC), concrete slump should be zero. RCC with >25cm in thickness is installed in several layers and beaten by vibratory rollers. Finally, rubber wheel rollers are used to compress the concrete (Garber et al., 2011). RCCP is usually designed to tolerate traffic loading directly; due to the slippery surface of concrete pavement for higher-speed highways and freeways, however, less thick asphalt coating may be used (Shabbir Hossain et al, 2015). Compared to other types of pavement, RCCP has noticeable advantages which encourage its employment in roads. These advantages may include fast easy installation, early opening to traffic, better mechanical strength and traffic loading tolerance, higher useful life than that of asphalt pavements (40-50 years compared to 15-20 years), better visibility at night, higher natural compatibility and less pollution compared to asphalt (Tahuni, 2008; Williams, 2013; LaHucik & Roesler, 2015). However, the difficulty in smoothing the surface and providing a proper texture to prevent vehicles from slipping limits the employment of RCCP (Alikhani & Moghadasnejad, 2015). RCCP can be used in roads specific for lower-speed heavy vehicles and tracked military vehicles, rural roads, high-traffic intersections, shoulders and U-turns, truck terminals and distribution centers, airports, cargo terminals, high-traffic roads in tropical areas, particularly on steep roads and ridges (Sharifi, 2001; ACI 325.10R-95, 1995).

For some reasons including abundant oil resources, lack of skilled people for design and installation of other pavements, unavailability of machinery required for concrete pavements and the lack of experience in this field, asphalt has been used traditionally for pavement in Iran. However, the reduced oil reservoirs, expensive resources as well as disadvantages of asphalt pavement have recently encouraged policymakers to use better alternatives instead or with asphalt pavement. In this regard, RCCP has been favorable for its advantages mentioned above. However, because of certain circumstances of Iran as well as the lack of required machinery, RCCP thickness needs to be reduced, as much as possible, for enough efficiency. To reduce RCCP thickness, hence, it is required to increase compressive strength; the best solution for this is to use additives in RCCP mix design followed by correcting rock aggregation.

Davarnia (2002) evaluated RCCP feasibility in Iran; he found that RCCP is well resistant to chemicals and less prone to changes in heat and humidity. Moreover, RCCP is followed by 30% economic savings in construction and maintenance compared to asphalt and other concrete pavements. Mohamadkhani, Azizkhani and Torki Harchegani (2012) used steel fibers in concrete pavements and found that steel fibers were more effective in increasing the compressive strength of RCCP than polypropylene fibers. Salemi and Behfarnia (2013) found that 5% cement replaced by silica nanoparticles increased compressive strength and freeze resistance of concrete by 30% and 83%, respectively. Moreover, the cement replaced by 3% alumina nanoparticles could improve the compressive strength and durability of concrete against cold by 8% and 81%, respectively. Considering the positive effect of polypropylene fibers on strength, they found that the combination of nanoparticles and these fibers increases compressive strength and freeze resistance of concrete pavements due to the reduced porosity and permeability as well as tensile strength due to the polypropylene fibers.

According to Villena, Triches, Prudencio (2011), one of the pozzolans used in RCCP is rice husk ash to modify some RCCP properties including flexural strength and modulus of elasticity, the optimal amount of which is 5% by weight of cement in the concrete mix design. Modares and Hoseini (2014) reported that the cement replaced by 3-5% rice husk ash increased RCC flexibility, though fatigue life of RCC mixture containing 3% rice husk ash was comparable to conventional RCC. They also reported an inverse relationship between RCC fatigue life and its porosity. Dinnasr, Soroushian and Qabrab (2013) used a high volume of fly ash in concrete pavements; they found that pozzolan reaction of fly ash by cement hydrate increased the strength and durability of concrete leading to more useful life and economic savings. Mardani and Ramyar (2013) used high volume of fly ash in RCC and found that the cement replaced by 40-60% fly ash increased optimal moisture and reduced compressive, tensile and flexural strength at all ages. Nili and Zaheri (2011) showed that the concrete pavements are less resistat to salt and the surface flakes; therefore, microsilica used in RCCP mixture is followed by higher increase in compressive strength and salt resistance compared to natural pozzolan and fly ash.

Azadi (2001) examined RCCP permeability using pozzolan and noted that silica fume is one of the pozzolans used in concrete pavements, particularly RCCP. Due to its finer aggregates compared to cement, silica fume improves mechanical properties and reduces permeability of the pavement. Addition of 25% cement replaced by silica fume in RCCP increased compressive strength by 58% and decreased permeability by 33%. Vahedifard, Nili and Mihan (2010) showed that 10% micro silica significantly increased RCCP compressive strength and freeze resistance whereby durability of the pavement against difficult climatic conditions. KrishnaRao, ChandrasekharRao and Sravana (2013) examined different mix designs containing zero, 25, 50, 75 and 100% sand and gravel and found that the highest RCC compressive, tensile and flexural strength occurred in days 3, 7 and 28 by the mixture containing 50% sand and 50% gravel.

In general, literature review suggests that cement can be partially replaced by an optimal percentage of microsilica in RCCP due to its properties and availability. However, microsilica aggregates are finer than that of cement; hence, they require lubricant used as grout for proper mixture. On the other hand, the mixing process is followed by pulmonary complications and health hazards for operators; moreover, human errors will reduce the optimal percentage. Considering the previous experiences, this study used microsilica gel, which is produced industrially by a certain ratio, as an additive to examine its effect on physical and mechanical properties of RCCP such as compressive strength and water absorption on which other parameters depend directly or indirectly.

2. Materials and Methods

The most important parameters effective on RCCP thickness include flexural strength, fatigue resistance and modulus of elasticity which are directly related to uniaxial compressive strength of concrete (Volume 354, 2009; Harington et al., 2010). However, flexural strength and modulus of elasticity can be calculated by compressive strength. In literature, compressive strength is used as a basis for comparison; therefore, this study evaluated the compressive strength of specimens at days 7 days and 28.

There is no standard and test to measure RCCP durability. ASTM C666 which discusses the durability of conventional concrete presents no accurate results for RCCP (ACI 325.10R-95, 1995; Harington et al., 2010); hence, ASTM C666 is not helpful. Considering literature, one way to enhance RCCP durability against freezing conditions is to reduce blank spots of RCC mixture thereby its permeability to prevent freezing. By a proper continuous aggregation, microsilica can increase RCCP compressive strength under different climates as well as freezing and thawing conditions. Therefore, this study examined 30-min water absorption and final water absorption of specimens based on the relevant standard. Once the rock materials including flaky and pea materials as well as manufactured and natural gravel were selected, their physical properties were determined to calculate water content of mixture using material moisture content. By determining material, cement and water content of the mixture, 0.025 m^3 raw concrete was produced by a 3-blade mixer. Once the VB test was approved, specimens of reference concrete were taken and tested after 7 and 28 days of treatment. The purpose of this study is to determine the effect of microsilica gel on some physical and mechanical properties of RCCP; by determining the mix design of reference concrete, new designs were produced by adding different percentages of microsilica gel (4-8% by weight of cement) and the process was repeated. For a more accurate result, three sets of concrete were produced per mix design to eliminate human error. To produce 10×10×10 cm specimens for 30 min water absorption and final water absorption tests and to re-average specimens, six specimens were taken from each set. For 7-day and 28-day compressive strength test, six 15×15×15 cm specimens were taken from each set. In total, 126 10×10×10 cm and 108 15×15×15 cm specimens were taken from accepted designs. Finally, compressive strength and water absorption of specimens containing microsilica gel and reference specimens were compared to determine the effect of gel on compressive strength and water absorption of RCCP.

3. Specifications of the Used Materials

3.1 Aggregates

RCCP is approximately composed of 75-85% aggregates; therefore, aggregates are effective on physical and mechanical properties of concrete, such as efficiency, potential segregation and compressibility. However, proper rock materials reduce economic costs and extend the life of pavement; moreover, they are effective on modulus of elasticity, thermal properties and durability of the pavement (Garber et al., 2011). Therefore, this study selected materials of which durability and quality comply with ASTM C33.

RCC containing natural sand generally requires less water content than RCC containing manufactured sand to reach a certain amount of fluidity, while RCC containing manufactured sand requires extra energy for compression. Hence, less segregation takes place resulting in higher flexural strength. For a relatively smooth surface, the largest aggregate should not exceed 19 mm in size. Thus, the materials used in this study comply with the aggregation suggested by the Portland Cement Association of America.

3.2 Cement

This study used Portland cement Type II. This type of cement is specially used as modified Portland cement in concretes which require medium heat hydration and are moderately attacked by sulfates. To determine cement content for removability, finishing, abrasive resistance and ideal durability of plain works, ACI 302.1R-04 suggests the cement content for the largest aggregate used, as listed in Table 1.

Table1. Minimum cement content for the largest aggregate used (ACI 302.1R, 2004).

Largest aggregate (mm)	Cement (kg/m^3)
38.00	279
25.00	308
19.00	320
13.00	350
10.00	362

3.3 Water

The water used in this study was drinking water with different contents for different designs.

3.4 Additives

Microsilica gel is a combination of microsilica and super-lubricant with various additives to produce concretes with certain properties and efficiencies. Microsilica gel is the most suitable additive to increase durability of concrete under different climates. Microsilica gel seals the concrete, increases compressive, flexural and tensile strengths, reduces permeability of concrete, increases resistance to chemicals and harmful ions, reduces concrete shrinkage, reduces water consumption, reduces segregation of materials and cement paste, and increases the useful life of concrete (Instructions of Micro silica gel factory, 2012).

4. Material Tests

Before producing concrete specimens, knowledge is required on some physical properties of materials used in the mix design; this considerably helps the provision of optimal mix design. In this study, coarse materials included pea and flaky aggregates (the largest nominal size = 19 mm). Fine materials included manufactured and natural sands, which are very effective in determining filler content of the mix design. Evaporable moisture content, density and water absorption of coarse and fine materials were tested for mix designs; Table 2 lists the results of physical tests on materials.

Table2. Results of physical tests on materials

Type	Saturation density (gr/cm^3)	Water absorption (%)	Moisture content (%)
Coarse sand (flaky)	2.68	1.37	0.89
Fine sand (pea)	2.69	1.31	0.50
Natural sand	2.63	1.17	2.20
Manufactured sand	2.61	1.40	0.87

5. RCCP Mix Design

RCC requires more fine aggregates to fill blank spots of the concrete and function under compression by vibratory roller (Shekarchi et al., 2013; Garber et al., 2011). To achieve adequate compressive strength, water/ cementitious (W/C) ratio as well as efficiency of the mixture need to be emphasized. Hence, components of the mixture were determined for efficient compression. RCCP efficiency was determined using fluidity test by determining the time required for compression of the vibrating specimen under overload by VB design. Aggregation is one of the most important factors in RCCP strength and durability; therefore, RCCP aggregates need to be solid and continuous to maintain reliability of the mixture during and after installation. Moreover, it is required to minimize the blank spots and avoid the mixtures with open and wide aggregation. In this study, aggregation was determined by PCA curve. Aggregation of the reference mixture included 47% coarse and 53% fine materials. According to PCA curve, filler content was 4%, which is within the suggested range (2%-8%). Table 3 shows aggregation of the reference mixture.

Table3. Aggregation of reference mixture

Particle Size (mm)	Allowed aggregation in Iowa Uni (PCA)		Ideal aggregation inIowa Uni. PCA
	Minimum passing	Maximum passing	
25	100	100	100
19	90	100	95
12.5	70	90	82
9.5	60	85	71
4.75	40	65	53
2.38	30	50	39
1.18	20	40	30
0.6	15	30	23
0.3	10	25	17
0.15	6	18	11
0.075	2	8	4

Cementitious content is the least value which provides flexural strength. Dry materials contain 10-17% cementitious content, which is directly calculated by the ratio of cement weight to total dry materials (ACI 325.10R-95, 1995). Considering at least 300 kg/m^3 7-day compressive strength and at most 19 mm aggregate, 330 kg/m^3 cementitious content (14% of dry materials) was determined here, which also complies with ACI 302.1R-04 (Table 1).

By determining the size of aggregates and cementitious content, the amount of materials was determined in accordance with the National Method for Concrete Mix Design for a certain volume of RCC (0.025 m^3). By keeping those amounts constant, the optimal W/C ratio was determined by VB test based on ASTM C1170.

6. VB Test

The modified VB test is performed by VB device to determine the optimal W/C ratio of RCCP. The VB device consists of a vibrating table with constant frequency and amplitude, as well as a 0.0094 m^3 metal mold on the table. The mold contains 13.5kg fresh concrete and tolerates 22.7 kg overload on the surface. The interval from the moment when the load starts to exert on the concrete and the device starts to vibrate until the moment when the concrete encircles the overload and starts to extract (VB time) is calculated and recorded by a chronometer. Laboratory studies indicate that the best VB time is 30-45 s for RCCP with at most 19 mm nominal aggregate (Volume 354, 2008). This study produced and installed various mix designs in vitro; the best ratio of coarse to fine materials (47%:53%) was obtained for the available aggregates. Once the optimal percentage of coarse and fine aggregates was determined, the main mix designs were run to determine filler content. The first design contained 2% filler and 0.40 W/C ratio to determine the optimal W/C ratio by trial and error. This design was produced in 44 s VB time; however, it was excluded after sampling for its highly porous appearance. Then, the filler content increased to 3% and the test was repeated by 0.40 W/C ratio. As shown in Table 4, three different designs were tested by 3% filler content and variable W/C ratios. The best design contained 3% filler and 0.42 W/C ratio in 37 s VB time.

Table4. Filler content and optimal W/C ratio

Design	Filler (%)	W/C	VB time (s)
1	2	0.40	44
2	3	0.40	49
3	3	0.41	45
4	3	0.42	37

Two designs containing 3% filler were excluded for their VB time (>45 s), while the design 4 was considered as the reference design and sampled for physical and mechanical tests at days 7 and 28.

7. Water Absorption Test

Once the aggregation as well as cement content and optimal W/C ratio were determined, two 30 min water absorption and final water absorption tests were performed on the specimens treated for 7 days to ensure the correct aggregation and optimality of the design. Then, the specimens with reasonable water absorption were tested for 7-day and 28-day compressive strengths; for the rest of the specimens, the primary mix design was modified and the process was repeated. By keeping the entire parameters constant and adding different percentages of microsilica gel (4-8% by weight of cement), a new RCCP mixture was produced as described above; specimens were taken and tested for 30 min water absorption and final water absorption to compare to the reference design. It is noteworthy that these experiments were performed by 10×10×10 cm cubic specimens, based on the old BS 1881.

The test on 7-day specimens of the design 4 showed that the water absorption was 3.1%, which is higher than the values recommended by the standard 354. Therefore, the design 4 was excluded and the new mix design (the design 5) was produced by the same properties of the design 3 and 4% filler content. Before adding Microsilica gel, it is required to perform the water absorption test on the reference specimens to ensure the effect of gel on these designs. The 30 min water absorption and final water absorption were equal to 1.6 and 2.5%, respectively, for the mix design 5. Thus, the design 5 was considered as the reference design for its water absorption (30 min and final) and VB time (43 s) (BS 1881, 2011).

8. Compressive Strength Test

Compressive strength was tested on 7-day and 28-day 15×15×15 cm specimens based on ASTM C39 by applying a certain rate of axial compression on molded specimens. Compressive strength is calculated by dividing maximum force applied on the cross-section during experiment. Note that, values of compressive strength depend on the size and shape of specimens; gauging, mixing, sampling and molding processes; age of specimens; temperature and moisture during treatment. Therefore, cautions are required to eliminate error.

9. Results

Among additives, cement can be partially replaced by an optimal percentage of microsilica due to its properties and availability. Considering the previous experiences, this study used microsilica gel, which is produced industrially by a certain ratio, as an additive to RCCP. Melting and freezing effects are directly related to RCC water absorption and inversely related to durability of the pavement (Tahuni, 2008). Hence, it is required to reduce RCC water absorption to increase durability of the pavement. For this purpose, maximum 2.5% water absorption is required for RCCP specimens containing 14% cement (Volume 354, 2009). In this study, the tests performed on hardened concrete included 30 min water absorption test, final water absorption test as well as 7-day and 28-day compressive strength tests on specimens of the reference design without microsilica gel and designs with different percentages of microsilica gel. Once the reference RCCP design was determined, 4-8% microsilica gel was added to the reference design by keeping the entire parameters constant. Since microsilica gel added to concrete reduces W/C ratio, the concrete mixture was re-tested to ensure the VB time. VB time of the specimen with 4% microsilica gel added was reasonable (33 s), while higher additions significantly reduced VB time. Hence, the test was repeated several times for values >4% to maintain the VB time within the reasonable ranges considering the optimal W/C ratio. Table 5 lists the results of VB test with different percentages of microsilica gel and W/C ratios. Obviously, the designs 0-11 and 0-14 were excluded for their lower VB times.

Table5. Results of VB test for RCC mix designs with different percentages of Microsilica gel

Design	Microsilica Gel (%)	W/C ratio	Modified VB time (s)
5 (reference)	-	0.42	43
6	-	0.42	43
7	-	0.42	42
8	4	0.42	33
9	4	0.42	32
10	4	0.42	34
11-0	5	0.41	26
11	5	0.40	34
12	5	0.40	33
13	5	0.40	34
14-0	6	0.39	28
14	6	0.38	35
15	6	0.38	35
16	6	0.38	34
17	7	0.36	38
18	7	0.36	36
19	7	0.36	39
20	8	0.34	34
21	8	0.34	33
22	8	0.34	34

Analyzing the results of physical and mechanical tests at days 7 and 28 days shows that:

- The increase in microsilica gel content reduces W/C ratio (Figure 1); W/C ratio is 0.42 in the reference design without microsilica gel, while it is 0.34 in the design 12 containing 8% microsilica gel.
- The increase in microsilica gel content reduces density of specimens; density insignificantly decreased by 7% gel, while it significantly decreased by higher percentages of the gel (Figure 2).

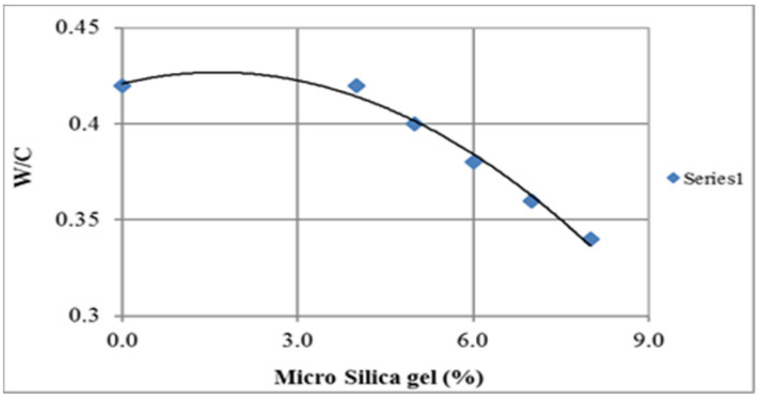

Figure1. Relationship between W/C ratio and percentage of micro silica gel

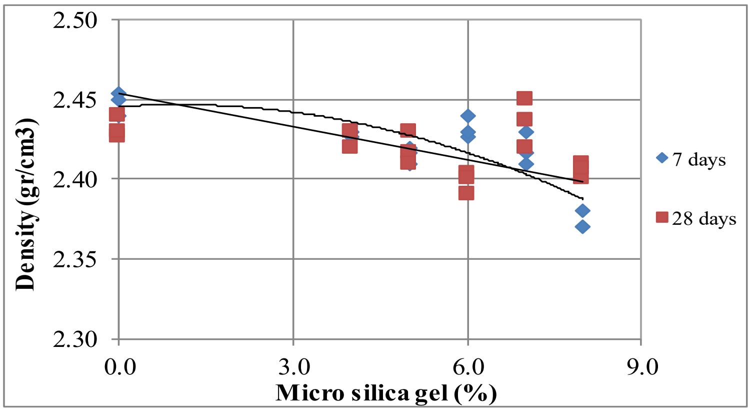

Figure2. Relationship between density of specimens and percentage of micro silica gel

- The gradual increase in gel percentage reduces both density and water absorption. Density and water absorption of the reference design are equal to 2.44 gr/cm^3 and 2.5%, respectively, while the density and water absorption of the design 12 containing 8% gel are equal to 2.39 gr/cm^3 and 2.3%, respectively (Figures 3 and 4). In fact, microsilica gel reduces water absorption by reducing the effective porosity of the concrete.

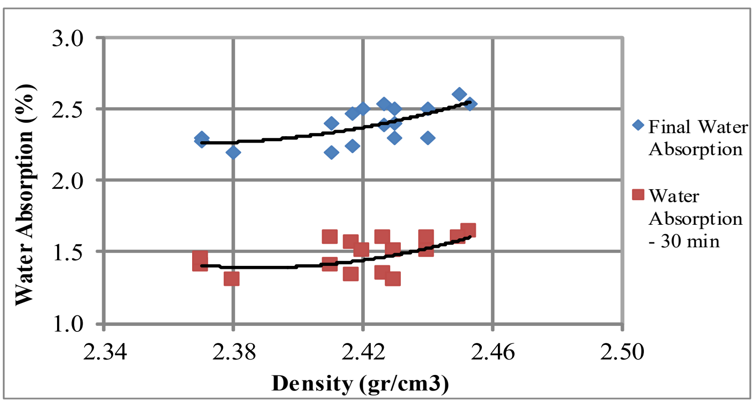

Figure3. Relationship between water absorption and density of specimens

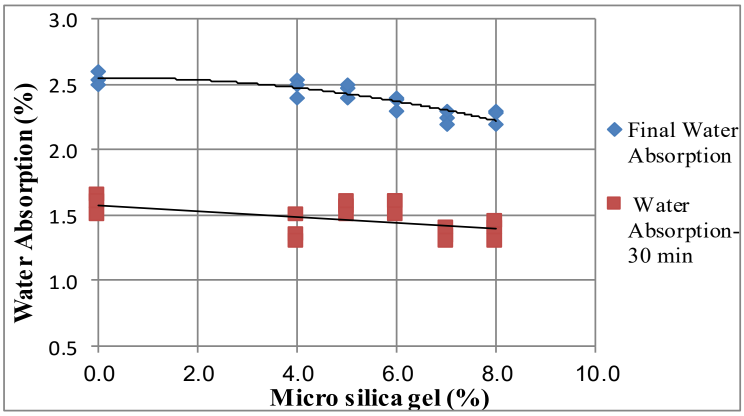

Figure4. Relationship between water absorption and percentage of microsilica gel

- There is a direct relationship between water absorption and W/C ratio. Studies show that the reduction in W/C ratio reduces water absorption of RCCP (Figure 5).
- W/C ratio reduced to 0.36% due to the increase in micro silica gel increases the uniaxial compressive strength, while the lower values reduce compressive strength. This is due to the reduced efficiency, reduced compression and increased porosity of the concrete (Figure 6).

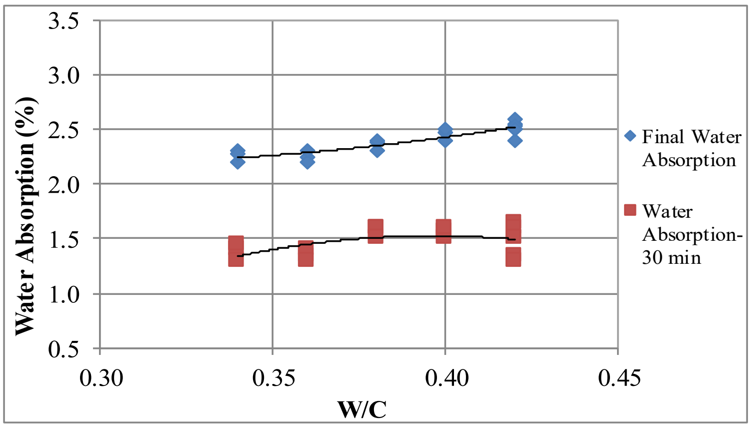

Figure5. Relationship between water absorption and W/C ratio

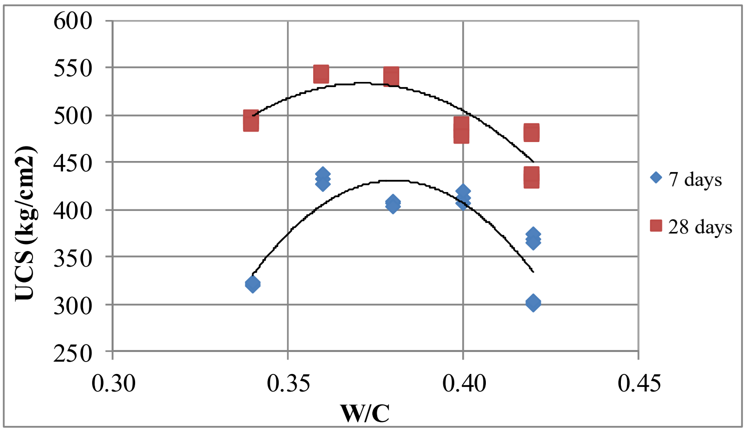

Figure6. Relationship between compressive strength and W/C ratio

- Although the increase in W/C ratio increases density of specimens (Figure 7), no direct relationship exists between compressive strength and W/C ratio (Fig. 6) as well as compressive strength and density of specimens (Figure 8). Maximum compressive strength of specimens occurs in 0.35-0.40 W/C ratio and decreases in values >0.40.

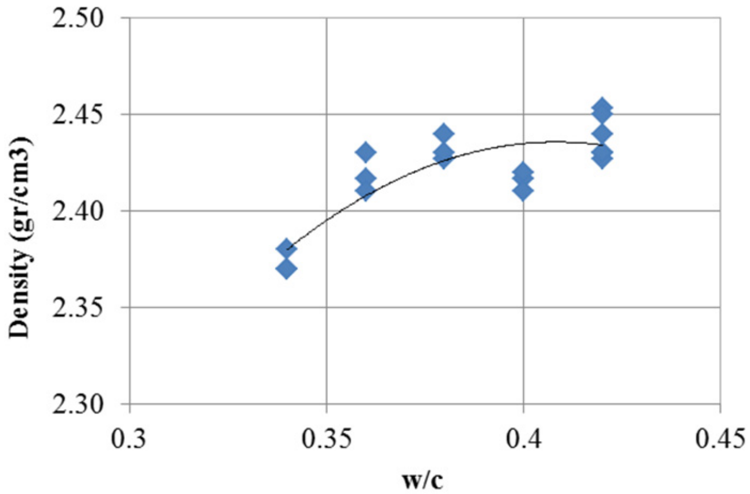

Figure7. Relationship between density and W/C ratio

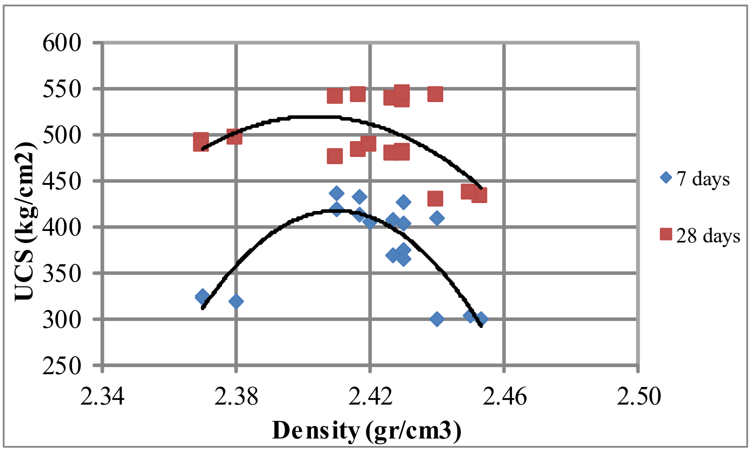

Figure8. Relationship between compressive strength and density

- Maximum compressive strength occurs in 38s VB time (Figure 9), by adding 7% micro silica gel (Figure 10)

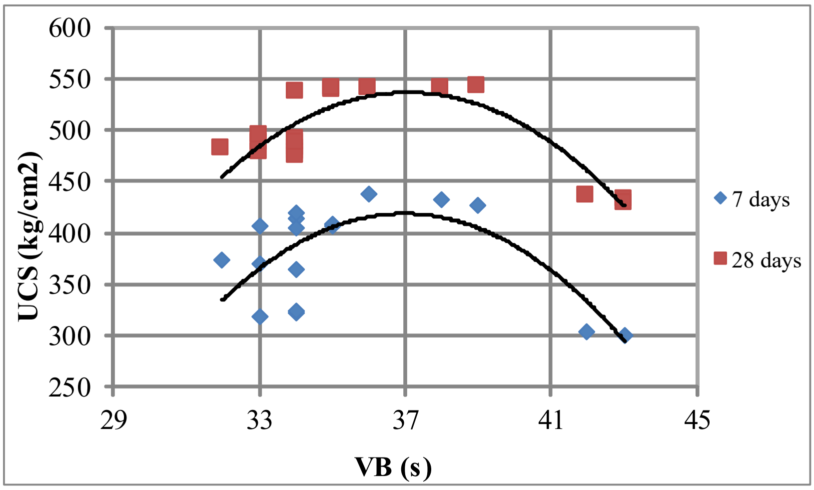

Figure9. Relationship between compressive strength and VB time

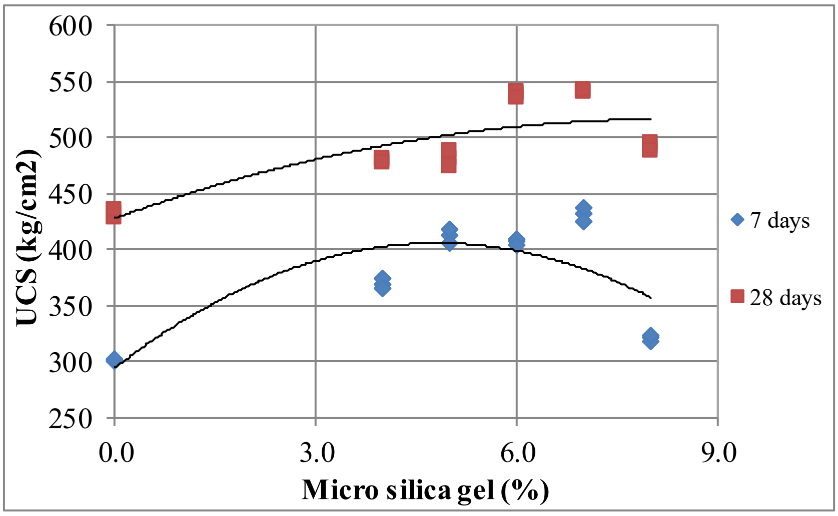

Figure10. Relationship between compressive strength and percentage of micro silica gel

- In general, 7% microsilica gel maximizes compressive strength and minimizes water absorption which is the most important parameter of RCCP durability (Figures 11 and 12).

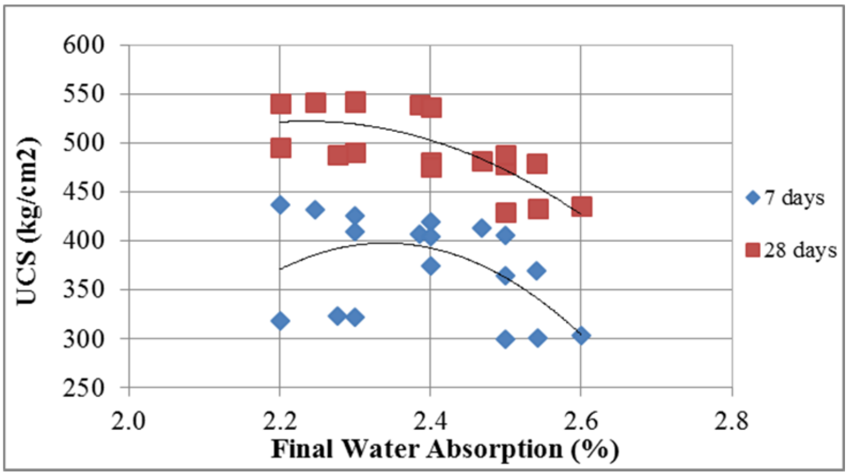

Figure11. Relationship between compressive strength and final water absorption

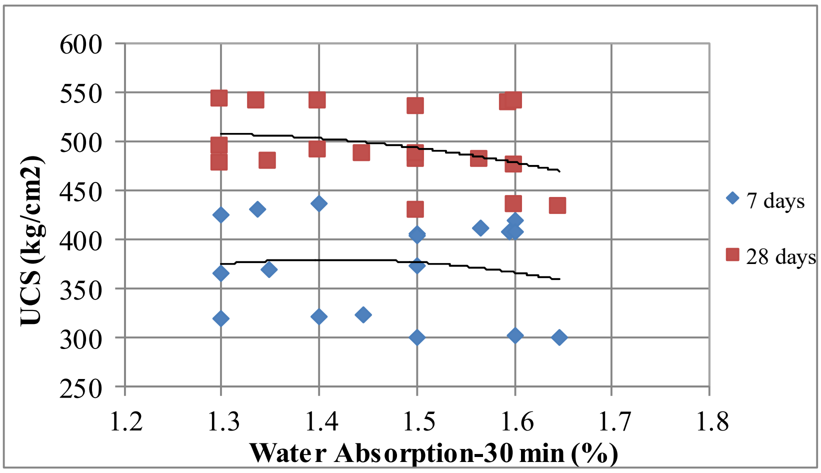

Figure12. Relationship between compressive strength and 30 min water absorption

10. Conclusion

Highly durable concrete is required for RCCP as the final traffic surface. As noted earlier, flexural strength and fatigue resistance of RCCP are directly related to uniaxial compressive strength of concrete. In addition, water absorption is another important property which controls the durability of the concrete particularly against corrosives or saturation. Since it is difficult to provide prerequisites of a durable concrete while installing the pavement, it is required to design higher quality concrete. Hence, this study examined the effect of microsilica gel on quality of RCCP by its compressive strength and water absorption.

The results revealed that 7% microsilica gel added on the RCC specimen maximized compressive strength; 7-day compressive strength of reference specimens was equal to 301 kg/cm^2, while the strength of specimens containing 7% microsilica gel was equal to 432 kg/cm^2. Moreover, 28-day compressive strength of reference specimens was equal to 433 kg/cm^2, while the strength of specimens containing 7% microsilica gel was equal to 541 kg/cm^2. Generally, the microsilica gel added to the specimens increased strength by 120 kg/cm^2 (one third of the primary strength), on average. Considering the costs of producing microsilica gel, the increased RCC strength by reducing thickness of the pavement, reduced installation time, better compression and lower additional costs can be followed by considerably economic savings. Microslical gel minimized water absorption which is one of the most important parameters effective on RCC durability; this increases the useful life of the pavement and additional cost-effectiveness. There were slight differences in the design containing 7% gel and the design containing 6% gel; therefore, 6% gel can be considered for designs to minimize the primary costs.

Considering the results obtained by the present study as well as the reviewed literature, it is recommended to consider the followings for future works:

1. To examine the effect of microsilica gel on RCCP penetrability
2. To design RCCP by optimal percentages of microsilica gel and full economic analysis of a pavement project and to compare the same project under similar conditions without microsilica gel
3. To examine the effect of microsilica gel on RCCP exposed to water erosion in order to achieve erosive strength
4. To determine the exact effect of microsilica gel on flexural strength and fatigue resistance of RCCP
5. To examine the effect of microsilica gel on RCCP failures, concrete corrosive resistance as well as salt and sulfate resistance

References

ACI 302.1R (2004). *Guide for Concrete Floor and Slab Construction*. American Concrete Institute.

ACI 325.10R (1995) (Reapproved 2001). *Report on Roller-Compacted Concrete Pavements*. American Concrete Institute.

Alikhani, M., & Moghadas, N. F. (2015). Properties and Performance of Roller Compacted Concrete Pavement and Its Economic Evaluation. *Indian Journal of Fundamental and Applied Life Sciences, 5*(S2), 1788-1794.

ASTM C1170 (2008). Standard Test Methods for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table. American Society for Testing and Materials.

ASTM C1176 (2013). Standard Practice for Making Roller Compacted Concrete in Cylinder Molds Using a Vibrating Table. American Society for Testing and Materials.

ASTM C33 (2013). Standard specification for concrete Aggregates. American Society for Testing and Materials.

ASTM C39 (2004). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. American Society for Testing and Materials.

Azadi, A. (2001). *Roller compacted concrete pavement permeability using pozzolana*. M.S. Final Project. Civil engineering and environment department. Tarbiat Modarres University. Tehran.

BS 1881-122 (2011). Method for determination of water absorption. British Standard Testing concrete.

Davarnia, Sh. (2001). Roller compacted concrete pavement feasibility for roads in Iran. M.S. Final Project. Civil engineering. Khajeh Nasir Universty. Tehran.

Din Nassar, R., Soroushian, P., & Ghebrab, T. (2013). Field Investigation of High-Volume Fly Ash Pavement Concrete. Resources. *Conservation and Recycling, 73*, 78-85. http://dx.doi.org/10.1680/coma.11.00059

Garber, S., Rasmussen, R. O., & Harrington, D. (2011). *Guide to Cement–Based integrated Pavement solutions*. Ames: Institue for Transportation. Iowa State University.

Harrington, D., Abdo, F., Adaska, W., & Hazaree, C. (2010). *Guide for Roller-Compacted Concrete Pavements.* Ames: National Concrete Pavement Technology Center. Institute for Transportation. Iowa State University.

Hodgkinson, J. R. (1991). *Design and Construction of Roller Compacted concrete (RCC) Pavement.* Cement and Concrete Association of Australia.

Journal No.354 (2009). *Guide for design and placement of roller concrete for pavement of roads in Iran.* Deputy to strategic monitoring. Execution system office. Tehran.

KrishnaRao, S., ChandrasekharRao, T., & Sravana, P. (2013). Effect of Manufacture Sand on Strength Characteristics of Roller Compacted Concrete. *International Journal of Engineering Research and Technology, 2*(2).

LaHucik, J., & Roesler, J. (2015). Low Fines Content Roller-Compacted Concrete. Airfield and Highway Pavements 2015: 441-452. doi: 10.1061/9780784479216.040.

Madhkhani, M., Azizkhani, R., Torki Harchegani, ME. (2012). Effects of Pozzolans Together With Steel and Polypropylene Fibers on Mechanical Properties of RCC Pavements. *Construction and Building Materials*. 26(1): 102-112. http://dx.doi.org/10.1016/j.conbuildmat.2011.05.009

Mardani, A. A., & Ramyar, K. (2013). Mechanical Properties of High-Volume Fly Ash Roller Compacted Concrete Designed by Maximum Density Method. *Construction and Building Materials, 38*, 356-364.

Modarres, A., & Hosseini, Z. (2014). Mechanical Properties of Roller Compacted Concrete Containing Rice Husk Ash With Original and Recycled Asphalt Pavement Material. *Materials and Design, 64*, 227-236.

Namikaran web site, Manufacturer Guidebook for micro silica gel (2012). www.namikaran.com.

Nili, M., & Zaheri, M. (2011). Dicer Salt-Scaling Resistance of Non-air-Entrained Roller Compacted Concrete Pavements. *Construction and Building Materials, 25*(4), 1671-1676. http://dx.doi.org/10.1016/j.matdes.2014.07.072

Salemi, N., & Behfarnia, K. (2013). Effect of Nano-Particles on Durability of Fiber-Reinforced Concrete Pavement. *Construction and Building Materials, 48*, 934-941. http://dx.doi.org/10.1016/j.conbuildmat.2013.07.088

Shabbir, H. M., & Celik, O. H. (2015). Roller Compacted Concrete Pavement in Virginia. *Airfield and Highway Pavements, 2015*, 429-440. http://dx.doi.org/10.1061/9780784479216.039

Sharifi, M. (2001). *Silica soot impact on enhancing the properties of roller compacted concrete pavement*. M.S. final Project. Department of technology Tehran University. Tehran.

Shekarchizadeh, M., Chini, M., Ne'matichari, M., & Eftekhar, M. H. (2014). Roller concerte pavement. Elm va adab Pub. Tehran.

Tahouni, Sh., & Mirmohammadali, J. (2008). *Pavement design for industrial slab and heavy unloading sites* (asphalt pavement, concrete pavement, roller concrete and block concrete). Elm va adab Pub. Tehran.

Vahedifard, F., Nili, M., & Meehan, L. (2010). Assessing the effects of Supplementary Cementitious Materials on The Performance of Low-Cement Roller Compacted Concrete Pavement. *Construction and Building Materials, 24*(12), 2528-2535. http://dx.doi.org/10.1016/j.conbuildmat.2010.06.003.

Villena, J., Triches, G., & Prudencio, L. R. (2011). Replacing the Aggregate by Rice Husk Ash in Roller Compacted Concrete for Composite Pavements. ASCE. *Pavement and Materials,* 19-27.

Williams, S. (2013). Comparison of the Superpave Gyratory and Proctor Compaction Methods for the Design of Roller-Compacted Concrete Pavements. Transportation Research Record, 2342, 106-112.

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