

Variation of Water-Cement Ratio at Cellular Sprayed Concrete for Two-Lift Concrete Pavement

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ABSTRACT

The main purpose of this experiment is to confirm that unit water content in concrete do not increase after spraying on economical cellular sprayed concrete using silica fume and foam for the high strength and high quality of concrete for high performance. It can also use 2LCP process easily because of the use a batch plant. It is confirmed that increasing liquidity by generating foam makes the slump loss slower and it may help to solve the problem of construction delays. Finally, in this experiment the unit water content decreases due to the reduction of water during spray, adding water for producing foam doesn't have a great effect on durability such as dry shrinkage and freeze-thaw resistance etc. From the result it is concluded that the foam disappeared entirely after sprayed.

KEYWORDS: foam, cellular spray concrete, unit water content, water-cement ratio, silica fume

INTRODUCTION

High quality, durable aggregates used to construct pavements are becoming scarce and costly. In return, the construction industry has begun to focus on methods that promote sustainability and also preserving quality. Sustainable construction methods balance economic, environmental, and social benefits. One of such method is the two-layer concrete pavement system. This system consists of a thin high quality concrete surface placed on top of a thick econocrete layer of lower quality. [1]

Two-layer concrete paving is a wet-on-wet process. That is, the surface layer is placed over the lower layer when the concrete is wet. The placement of the surface layer is timed that the bottom layer is stiff enough to resist the mixing of the materials and sufficiently wet to promote a good bonding between both layers so that a monolithic concrete structure is formed. The time between placing layers is often not more than 30 minutes. Perhaps the challenge involved in the construction of two-layer concrete systems includes the additional costs and logistics required for two plants to produce different concrete mixtures. [2]

Cellular spray concrete is a process to produce a High-Performance Concrete (HPC) by adding binders and foam in ready-mixed concrete. By using this method we can solve the problem of two batch plants. After producing OPC in a batch plant and moving into the field, the produced OPC is used in the lower layer whereas the remixed HPC with OPC is poured on the top layer.

In this experiment, when HPC is remixed with OPC it change the water-binder ratio. Also, the unit water content is increased because of the water which is added to generate the foam and that by incorporating the powder is added to find the optimum amount of the foam to measure the W/C of OPC and W/B of HPC.

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EXPERIMENTAL PROCEDURES

Materials

Cementitious

Using cement which satisfies the standard Portland cement according to KS L 5201 in Korea standard (Powder 3,289 cm³ / g, density 3.15 g / cm³, loss on ignition 0.61%, stability 0.08%) [3].

The specific surface area of silica fume is about 200,000 cm²/g and is usually 50-60 times that of Portland cement. When 5% - 15% by weight of cement is substituted the internal structure of concrete gets denser and can exhibit a high strength and resistance to material segregation.

The expansive agent used was manufactured by S company and it is CSA expansive admixture type. The chemical properties are shown in Table 1.

Table 1. Chemical property of expansive agent

Constituent	SiO ₂	Al ₂ O ₃	CaO	MgO	R ₂ O	SO ₃	F-CaO	LOI
Proportion (%)	≥5.0	10-15	48-53	≥1.5	≥1.0	27-32	18-23	≥3.0

Aggregate and Foaming agent

The coarse aggregate (crushed stone) used in the research has a maximum size of 10mm and the fine aggregate which is crushed sand with a size of 5mm was used. The specific gravities of coarse aggregate and fine aggregates were 2.77 and 2.63, respectively. The absorption of coarse aggregate and fine aggregates were 0.56% and 1.00%, respectively.

Surface-active molecules of the foaming agent is composed of hydrophilic groups and hydrophobic groups in case of hydrophilic water, the hydrophobic groups are arranged at the interface which changed characteristic of the surface tension of an diluted aqueous solution the foaming agent and viscosity. In addition, by using ball-bearing effect of the fine entrained foam mixing of the concrete is made easier. In this paper, method of mixing concrete was used after generating foam of pre-foaming type using a domestic H's foaming agent [5].

Here the water is used to generate the foam, air content and unit quantity of water increases when there is over dose of foam into concrete. However, the increased air content before spray is due to excessively injected foam, most of it dissipates after spray and keeps ultimately a constant amount of air. Figure 2.1(a) is a graph showing the amount of air content which constantly converge after spray. Or figure 2.1(b) is a graph showing the compressive strength after spray.

Mix Design

The main test parameter is the increased air content due to foam. At first in the standard mix, foam is not inserted and the variables are inserted to the foam in accordance to air content of 15, 20, 30, and 40%. It promotes pumping and workability through the incorporation of foam and helps in dispersion of the incorporated admixture subsequently. In addition, by dissipating the amount of air not more than 5% strength and durability were ensured after spray. The amount of unit cement was determined as 460 kg/cm³, long-term strength and durability was improved by substituting silica fume and expansive admixture for

cement weight ratio as 8.7% and 10% respectively. Because in variable VR 0 foam is not added, it was sprayed after mixing cement, silica fume and the expansive admixture sufficiently. In this process of variable VR 15, 20, 30, 40 spraying is carried out after adding foam and admixture in the ready mixed concrete. Table 2 is showing the mix proportion of cellular sprayed concrete.

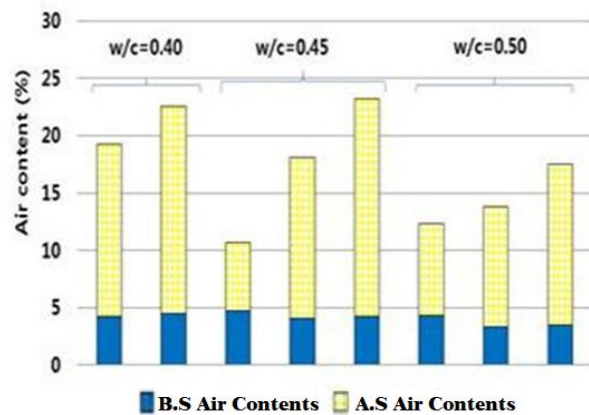


Figure 2.1(a) Air Content of Sprayed (Before Sprayed, After Sprayed)

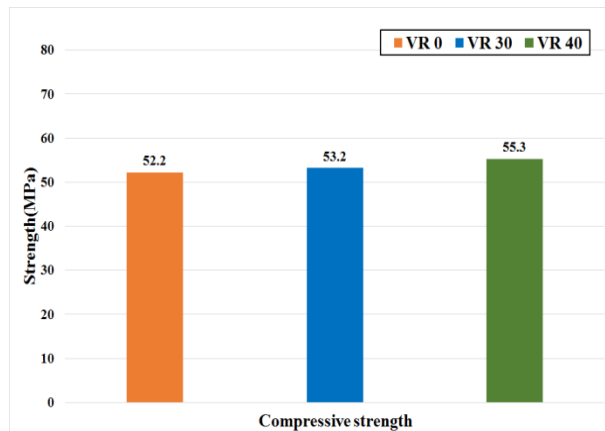


Figure 2.1(b) Compressive Strength after Spray

Table 2. Mix proportion of cellular sprayed concrete

Mix Type	Air Content (%)	W/C (%)	S/a (%)	Unit Weight (kg/m ³)						SP (%)
				Water	Cement	Silica Fume	Expansive Admixture	Sand	Gravel	
VR0		40	65	184	374	40	46	1068	609	1.3
VR15	15									
VR20	20									
VR30	30									
VR40	40									

Spraying Equipment

Shotcrete Mixer and Pump

The equipment used for mixing and pumping was the Allentown combination mixer-Pump type manufactured by Allentown shotcrete Technology. It consists of a mixer mounted at behind for blending cementitious material, aggregate and water, and a two piston pump mounted at the front to provide smooth flow of shotcrete into the pipe line. The pump is driven by 2 pistons, having a maximum material pressure of 122bar and mixer capacity of 280L. Figure 2(a) is showing the shotcrete machine.

Air Compressor

The machine, model PDS 390S, made by Hokuetsu Industries Co.Ltd, which supplies compressed air was used. This machine is situated nearby the shotcrete machine. The hose from the compressed air supplier machine which carries the compressed air was fastened at the nozzle or at the exit of shotcrete so as to shot the shotcrete with a high pressure onto the substrate surface. Figure 2(b) is showing the air compressor.

Foam Generator

Foam generator is the equipment which use high air pressure after making aqueous solution by mixing a foaming agent in water. The machine, model 100 Aerator, made by Stable Air Co.Ltd. Figure 2(c) shows the foam generator.

Unit Water Content Measurements

The unit water content measurement equipment is model Air-meter (DS-1000@), made by domestic D company which measures the unit water content, Air-meter which contains 10% or more air was used. Air-meter method is used to measure the unit water content per unit volume. It has measurement time of 5minutes and easy usability. Figure 2.3(d) shows the Air-meter equipment.

Also, Capacitance Measurement equipment model KETT Hi 330 was used made by domestic H company. It is equipment which measures water content of material by changing capacitance.



Figure 2.3(a) Shotcrete machine



Figure 2.3(b) Air Compressor



Figure 2.3(c) Foam generator



Figure 2.3(d) Unit water content measurement equipment

EXPERIMENTAL RESULTS AND DISCUSSION

Slump

Figure 3(a) is a graph which shows the change in slump height with the lapse of time. Measurement of variable VR 30, 40 were difficult because the slump is too large before adding the powder. On average the slump was reduced by 200mm after adding the powder, and in case of VR 30, 40 loss does not occur even when time elapsed by 2 hours. Therefore, in this type of experiment supply is possible in batch plant which takes two hours in the field. Also, in the 2LCP process when delayed to construction of the lower layer it may be helpful.

Figure 3(b) is the change of slump per spray process. In this process pumping was not done because the slump of variable VR 15, 20 after mixing powder was 55, 50mm respectively. So, spraying could not be proceeded. The slump of variable VR 30, 40 that is increased by the foam is decreased after sprayed.

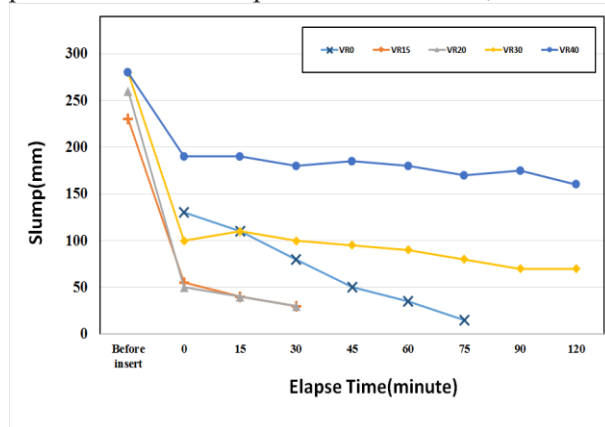


Figure 3(a). Slump with the lapse of time

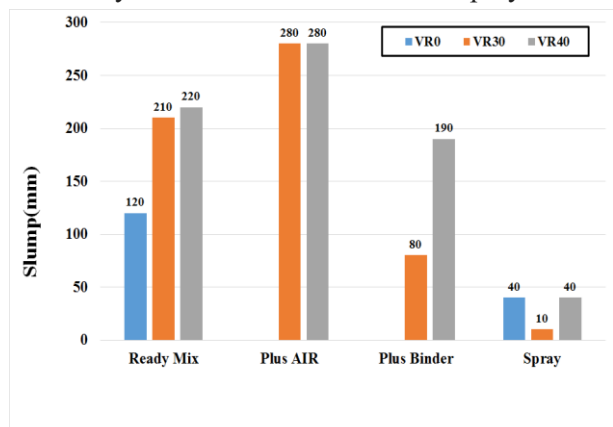


Figure 3(b). The change of slump per spray process

Unit quantity of water

Figures 3(c), (d) are graph which show unit water content with the elapse of time with two different variables. Figure 3(c) is the VR variable with added silica fume and expansive additive whereas figure 3(d) is a graph of OPC variable adding only the foam in the Ordinary Portland Cement of unit cement amount of 460 kg/ m³. The experiment of OPC variable was conducted only for comparison where the spray was not done. Measurement of unit quantity of water content is a result measured by the Air-meter method. Here, unit quantity of VR variable is determined higher because the density of the binder used in the variable VR is smaller than that of OPC variable. From this it was also confirmed that as more the amount of foam increases the more amount of unit water content increase.

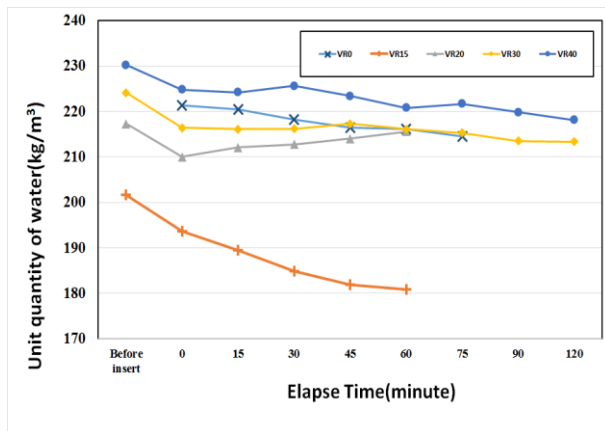


Figure 3(c). Unit water content with the lapse of time in VR variable

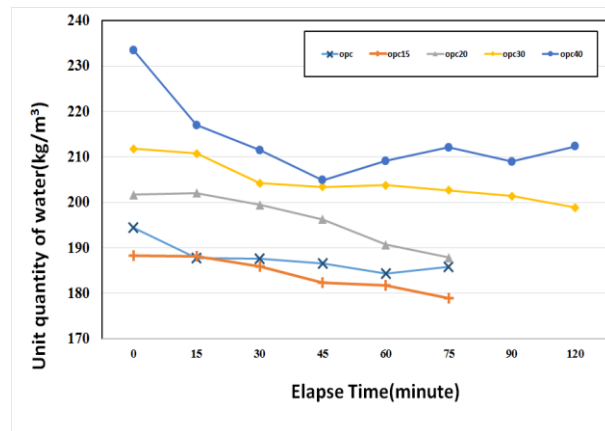


Figure 3(d). Unit water content with the lapse of time in OPC variable

Figure 3(c) is a graph that converts unit quantity of water to water-binder ratio by measuring the unit quantity of water per spray process. It was measured by the Air-meter method. Because the slump of variable VR 15, 20 after mixing powder was 55, 50mm respectively pumping was not done. So spraying could not be proceeded. Both variable VR 40 and VR 0 does not contain foam as it is confirmed that the water-binder ratio after spraying came out similar. In the mixture, water added by foam and additional admixtures were combined. In variable VR40, spray progressed with 130L mix, where 56L foam was added. To adjust 40% air content in one truck ready-mixed concrete, the foam should be added 9 minutes continuously. This can be calculated through the discharge rate of the foam generator. Variable VR 30 was able to confirm that the water-binder ratio came out smaller, which may be an indicator that can show a better durability.

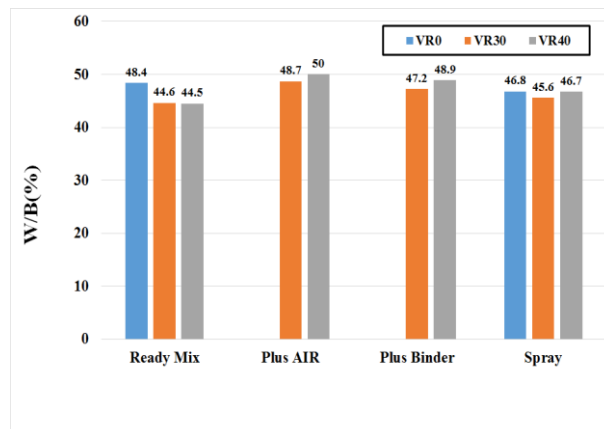


Figure 3(c). Convert unit water content to water-binder ratio

Table 3,4 and 5 shows the change in water-binder ratio per spray process. Here, water-binder ratio compares Theoretical Unit Water Content (TUWC) with measurement value of Air-meter (AM), Capacitance measurement (CM) method. After adding cellular capacitance measurement is impossible because air content is over 10%. Table 3 is shows the change of water-binder ratio of VR 0 per spray process. When compared with the TUWC, CM was similar and AM was higher than that. It is thought that errors due to mechanical. Table 4 shows the change of water-binder ratio of VR 30 per spray process. In ready-mixed

concrete, water-binder ratio was higher than that of VR0 because there is no added powder. W/B ratio was increased by the added foam and decrease by the added powder. Spray effect is not considered in TUWC because a small amount of quantity is reduced after spraying. Overall, when compared with the TUWC the amount of change was not large. Therefore, increased unit water content by the cellular was decreased during sprayed, and it is expected to have no effect on durability. Table 5 is showing the change of water-binder ratio of VR 40 per spray process.

Table 3. The change of water-binder ratio of VR 0 per spray process (%)

	Ready Mixed Concrete	Added Cellular	Added Powder	Sprayed
Theoretical Unit Water Content	40	X	X	40
Capacitance Measurement Method	39.8	X	X	38.3
Air-meter Method	48.4	X	X	46.8

Table 4. The change of water-binder ratio of VR 30 per spray process (%)

	Ready Mixed Concrete	Added Cellular	Added Powder	Sprayed
Theoretical Unit Water Content	49.2	55.3	45	45
Capacitance Measurement Method	49.6	X	X	47
Air-meter Method	44.6	48.7	47.2	45.6

Table 5. The change of water-binder ratio of VR 40 per spray process (%)

	Ready Mixed Concrete	Added Cellular	Added Powder	Sprayed
Theoretical Unit Water Content	49.2	60.2	48.9	48.9
Capacitance Measurement Method	49.8	X	X	48.3
Air-meter Method	44.5	50	48.9	46.7

CONCLUSIONS

As the part of study the purpose of this paper is to produce more economical concrete using foam which gives high performance through high-strength and high quality of concrete. It is easy to use 2LCP process because of the use a batch plant. On the other side, it observes about changing water-binder ratio of cellular sprayed concrete using the foam. It is also confirmed that mixing foam do not increase the unit water content and it has no effect on durability. Overall conclusions of this experiment were as follows.

[1] It is concluded that increasing liquidity by generating foam makes the slump loss slower. It is expected to help for a sudden construction delay or for a construction site which is located far from the batch plant.

[2] Test results show that measured unit water content per spray process increased due to foam and water-binder ratio decrease due to the water which disappeared during spray. Added water for producing foam has disappeared and unit water content was decreased slightly. It is found that adding water for producing foam doesn't have a great effect on durability such as dry shrinkage and freeze-thaw resistance etc.

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