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The effects of nano Al_2O_3 particles replacement on carbonation resistance properties of ultra high performance concrete (UHPC)

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Abstract – **The carbonation of concrete is one of the main reasons for corrosion of reinforcement in concrete. The atmospheric CO_2 reacts with the concretes hydration product calcium hydroxide and produced the calcium carbonate in cement matrix of concrete due to the modern urbanization play the main role on CO_2 emission. This issue will be rectifying by modern construction material nano Al_2O_3 particles in concrete. In order In the present investigation, carbonation resistance of ultra high performance concrete (UHPC) containing nano Al_2O_3 particles have been investigated at an age of 91th, 182th, 273th, 365th, 547th and 730th day. The cement was partially replaced by 0.5%, 1%, 1.5%, 2% and 3% nano Al_2O_3 particles. The results were revealed that increasing the nano Al_2O_3 was reduced the carbonation penetration depth and resistance against the carbonation. This may be due to better packing of nano Al_2O_3 was arrest the permeable voids and reduced the porosity samples that was lead to resistance against ingress of CO_2 in cement matrix of nano Al_2O_3 blended UHPC.**

Keywords* — *nano Al_2O_3, ultra high performance concrete, carbonation resistance.

I. Introduction

One of the goals construction sector utilizes modern construction materials with improved characteristics and their function in the structure to improving durability and sustainability [1], [2]. The rapid increase of population leads to urbanization and industrialization as well as modern technologies have led to higher emission corban, which significantly boosted the concentration of CO_2 in the atmosphere [3]–[5]. The durability of concrete is a major concern while exposed to carbon dioxide (CO_2) causing carbonation and it once the steel rebar starts to corrode, the corrosion products induce internal expansion, resulting in cracks and spalling, which leads to the failure of concrete structures. Stefanidou et al [6] studied the effects of nano Al_2O_3 replacement on compressive strength, porosity and carbonation studies in lime- pozzolan and lime- metakaolin based cement paste. The cementitious material was replaced by a weight of 0% and 1.5 % of nano α-Al_2O_3 particles having a size of 500nm. The results revealed that nano Al_2O_3 addition improves the compressive strength and enhanced the durability performance against the carbonation. Still now, only few studies available on effect of nano Al_2O_3 particles in ultra high performance concrete. There remains a lack of understanding of the effects of nano Al_2O_3 particles in the carbonation resistance of UHPC. The main objective of this research work is to study the effects of Al_2O_3 particles replacement on the carbonation penetration depth.

II. Materials and Methods

The Ordinary Portland Cement -53 grade[7], silica fume [8], Quartz powder, nano Al_2O_3 (size 20-30nm and surface area of 180 m^2/g), River sand, Polypropylene fibers [9], Polycarboxylic ether super-plasticizer [10] were used for fabrication of UHPC. The elemental composition of Cement, Silica Fume, Quartz Powder and nano Al_2O_3 particles were shown in Table 1. Figure 1 illustrates the scanning electron microscope images of Cement, Silica Fume, Quartz Powder and nano Al_2O_3 particles. The six different mixture proportions, was developed based ASTM C1856/C1856M-17 guideline [11]. The CON mixture was without nano Al_2O_3 particles and other five mixture proportions were containing 0.5%, 1%, 1.5%, 2% and 3% nano Al_2O_3 replaced by weight of cement. Tables 1**,** show the mixture proportions details of six series mix.

Table 1 the elemental composition

Elements	Cement	Silica Fume	Quartz Powder	Nano Al_2O_3
O	54.9	65.95	69.85	66.62
Si	12.48	30.8	30.15	-
Al	5.79	1.57	-	33.38
Ca	18.17	-	-	-
Na	-	1.68	-	-
C	4.82	-	-	-
Fe	2.44	-	-	-
K	0.92	-	-	-
S	0.48	-	-	-

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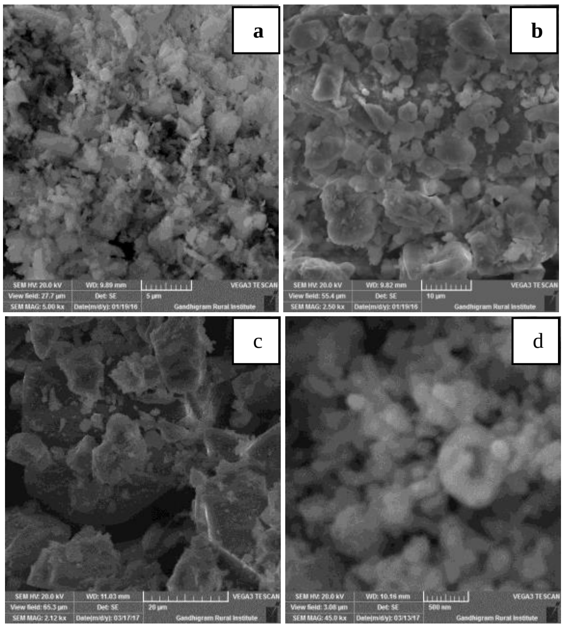

Figure 1 scanning electron microscope images of (a) Cement, (b) Silica Fume, (c) Quartz Powder and (d) nano Al_2O_3 particles.

Table 2 mixture proportions by weight of cement

Ingredient	CON	0.5 AL	1.0 AL	1.5 AL	2.0 AL	3.0 AL
Cement	1	0.995	0.99	0.985	0.98	0.97
Silica Fume	0.30	0.30	0.30	0.30	0.30	0.30
Nano Al_2O_3	0	0.005	0.01	0.015	0.020	0.030
Quartz Powder	0.430	0.430	0.430	0.430	0.430	0.430
Sand	2.183	2.183	2.183	2.183	2.183	2.183
Water	0.24	0.24	0.24	0.24	0.24	0.24
Superplasticizer	0.04	0.04	0.04	0.04	0.04	0.04
f_{ck} 28th day (MPa)	122.65	130.18	136.80	147.02	155.59	145.40

III. Mixing, Casting and Curing:

The six series of mixes mixed with the help of a mortar mixture machine [12]. Then, fresh concrete was placed in 50 mm cubic moulds and kept in room temperature. After 24 hours, the 50 mm cubic moulds were demoulded and the specimens placed in normal water curing for 28 days[13] . After the 28 days of curing period specimens were placed for carbonation exposure for 730 days in natural exposure in rooftop location.

IV. Experimental Techniques

The carbonation penetration depth of 50mm cube specimens was investigated at an age of 91th, 182th, 273th, 365th, 547th and 730thday of natural exposure in rooftop location exposed to the atmospheric CO_2 according to DD CEN/TS 12390-10 (2007) codel provision [14]. After that the carbonation depth was measured by spraying of phenolphthalein indicator on the surface of half broken cubes. The unreacted area appears pink color as shown in Figure 2 and then the digital vernier caliper used to measure the uncolored depth of concrete specimens from the outer surface of concrete cubes.

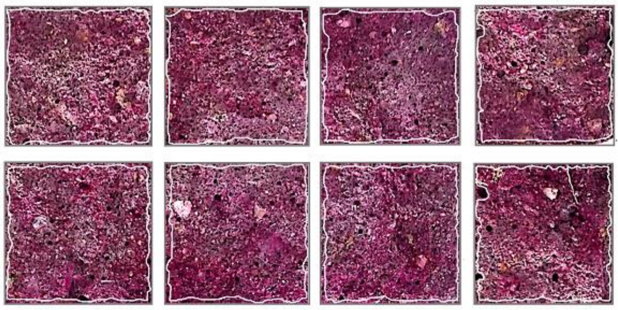

Figure 2 the color change of concrete specimens

V. Results and Discussions

Figure 3 to Figure 8 indicates the effects of nano Al_2O_3 particles replacement on, the carbonation penetration depth of ultra high performance concrete at age of 91th, 182th, 273th, 365th, 547th and 730th days of natural exposure in rooftop location exposed to the atmospheric CO_2.

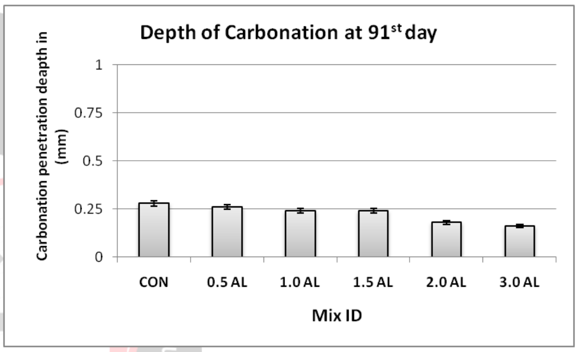

Figure 3 carbonation depth at age of 91st day

After the 91 days CO_2 exposure period, the carbonation depth was reduced 7.14%, 14.28%, 14.28%, 35.71% and 42.86% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

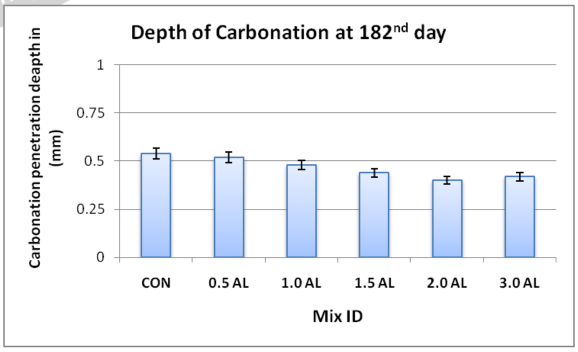

Figure 4 carbonation depth at age of 182ndday

After the 182 days CO_2 exposure period, the carbonation depth was reduced 3.70%, 11.11%, 18.52%, 25.93% and 22.22% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

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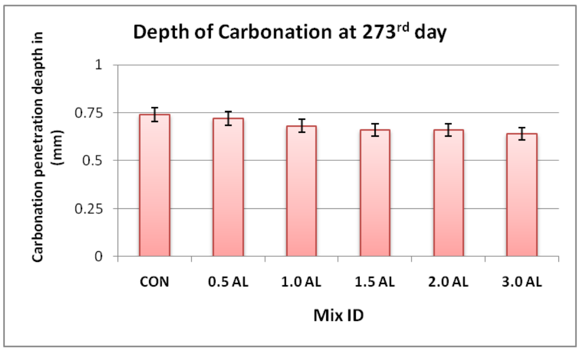

Figure 5 carbonation depth at age of 273rd day

After the 273 days CO_2 exposure period, the carbonation depth was reduced 2.70%, 8.11%, 10.81%, 10.81% and 13.51% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

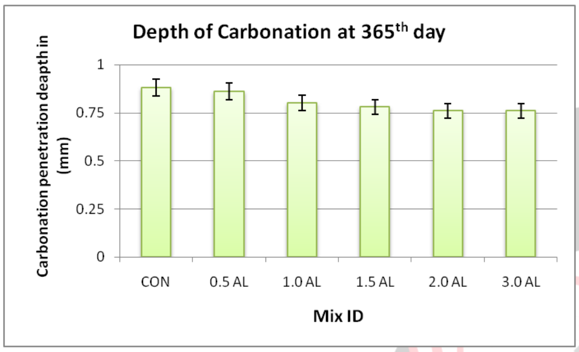

Figure 6 carbonation depth at age of 365th day

After the 365 days CO_2 exposure period, the carbonation depth was reduced 2.27%, 9.09%, 11.36%, 13.63% and 13.63% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

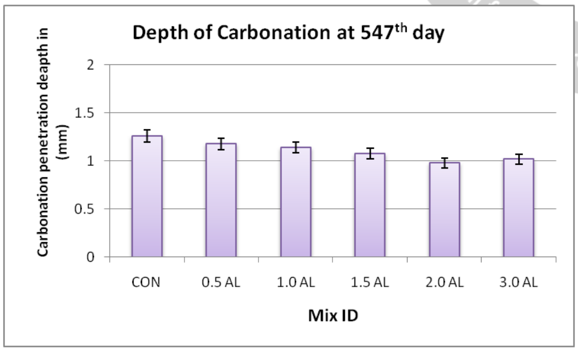

Figure 7 carbonation depth at age of 547th day

After the 547 days CO_2 exposure period, the carbonation depth was reduced 6.35%, 9.52%, 14.28%, 22.22% and 19.04% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

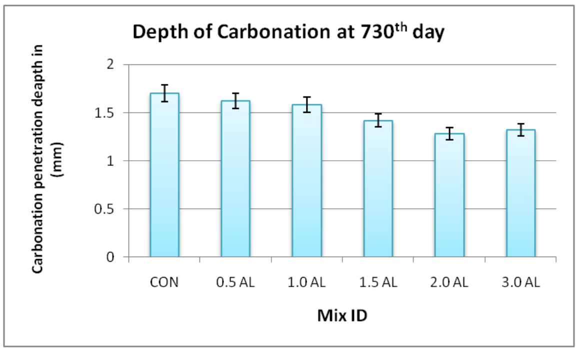

Figure 8 carbonation depth at age of 730th day

After the 730 days CO_2 exposure period, the carbonation depth was reduced 4.71%, 7.06%, 16.47%, 24.70% and 22.35% for mixes 0.5 AL, 1.0 AL, 1.5 AL, 2.0 AL and 3.0 AL, respectively in comparison to control mixture without nano Al_2O_3 particles.

The replacement of nano Al_2O_3 particles was reduced the carbonation penetration depth mix compared to CON mix at all ages of testing (91th, 182th, 273th, 365th, 547th and 730th days). The carbonation penetration depth was directly proportional to the exposure period.

The 2.0 AL mix experienced the lowest carbonation penetration depth of 1.28 mm after 730 days of the exposure period and the CON mix was higher carbonation penetration depth of 1.70 mm after 730 days of exposure period compared to all other mix proportions at all ages of curing.

VI. CONCLUSIONS

The test results reveals that the inclusions of nano Al_2O_3 particles in ultra high performance concrete was lead to reduced the carbonation depth of concrete specimens and improves the durability behavior of nano Al_2O_3 blended ultra high performance concrete. The inclusions of nano Al_2O_3 particles were reduced carbonation penetration depth of concrete. This may be due to nano Al_2O_3 particles act as the micropores filling material, higher compactness and densification of ultra high performance concrete cement matrix was lead to resistance against ingress of CO_2 into the nano Al_2O_3 blended ultra high performance concrete.

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