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Effect of NGBFS and CBA as fine aggregate on the chloride permeability of concrete

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Abstract: - This paper presents the results of an investigation which was about influence of non-ground Coal Bottom Ash (CBA) and Non-Ground Granulated Blast-Furnace Slag (NGBFS) as fine aggregate on rapid chloride permeability of concrete. Series of Rapid Chloride Permeability Test (RCPT) were conducted with concrete specimens containing NGBFS and CBA in varying percentages from 10 to 50% with the step of 10% of fine aggregate by weight. Two basic series concrete specimens were prepared in laboratory. The first series (G) was contained NGBFS, the second series (B) was contained CBA as fine aggregate. Test results indicated that NGBFS or CBA improves the resistance to chloride ion penetration to some extent. 30% and 10% replacement ratios were selected as optimum replacement ratios for G and B series. It was concluded that GBFS was more impressive then CBA for blocking chloride ion movements.

Keywords:- *Aggregate, Chloride permeability, Coal bottom ash, Concrete, Granulated blast-furnace slag.*

I. INTRODUCTION

Chloride attack is accepted one of the principal cause for concrete degradation. Chloride ions were generally known as the most harmful agent for reinforced concrete. Mostly, low level of chloride ions can be tolerated in durable concrete. However, excessive chloride levels cannot be tolerated and it may occur over the service life by reason of external chloride sources. Mineral admixtures such as ground blast furnace slag or ground fly ash were currently used to improve durability of cement and concrete. At the same time, researches are in progress on the use of non-ground industrial by-products or industrial wastes such as non-ground granulated blast furnace slag (NGBFS) and coal bottom ash (CBA) in concrete as fine aggregate. Rapid Chloride Permeability Test (RCPT) approach was a relatively simple and quick test for measuring the permeability of concrete indirectly. This test shows quickly the general behavior of concrete permeability that is an important parameter for concrete durability. Production of durable concrete is a critical issue in order to gain economic, ecologic and technical advantages for the future of the concrete industry.

The objective of presented study was to make a comparative investigation of the influence of NGBFS and CBA on rapid chloride permeability of concrete. A series of RCPT is conducted on concrete specimens incorporated NGBFS and CBA in varying percentages by weight as fine aggregate.

II. PREVIOUS WORK

Usually it is not possible to prevent chloride entrance in concrete. Chloride penetration into concrete is a critical issue in the process of corrosion of reinforcing steel bars. The problem is particularly acute in a marine environment, in bridges and roadways subjected to deicing salts, and in parking garages into which salt is transported from salted roadways [1]. The chloride ingress depend on the sorptivity and chloride diffusivity of concrete, ability of concrete to bind chlorides, water/cement ratio, chloride diffusivity of aggregates, alkalinity of the binder, degree of exposure to chloride source, temperature, carbonation, hydrostatic head. Chloride ions can destroy the passive oxide film on reinforcement steel in concrete, even at high alkalinities [2]. The amount of chloride required to initiate rebar corrosion depends on the pH of the solution in contact with the reinforcement steel.

Chloride binding capacity of the concrete should be high to Show high resistance to environmental harmful agents. There are many researches [3-7], about chloride binding capacity of concrete and effects of ground supplementary materials on it. Aggregates can also affect the transport properties of concrete [8]. However, very limited data exist on the role of aggregate in chloride ion ingress. Page et al [9] concluded that chlorides can be transported through the aggregate as well as through the surrounding cement paste in the concrete. Emiko et al [10] found that volume of the lightweight aggregate have reasonable effects on penetrability properties of lightweight aggregate concrete. The concrete diffusivity was influenced by many parameters such as the interfacial zone property between aggregate particles and bulk cement paste as well as the microstructure of the cement paste itself (porosity and pore structure)[11]. Rock type of coarse and fine aggregate was one of the most important factors which determine the diffusivity of concrete. The geometry of the pathways for the penetration of aggressive species was necessarily more complicated in concrete[12]. Two complementary approaches have been introduced for evaluating the influence of interfacial transition zone (ITZ) on transport properties of concrete. Results obtained by Garboczi et al. [13] and Bourdette et al. [14] have clearly emphasized the fact that the concrete transport properties were influenced by the connectivity of ITZ and the excess in tortuosity introduced by increasing the aggregate content in the mixture. Bourdette et al. [14] indicated that the effective diffusion coefficient of chloride ions was 6 to 12 times greater in the ITZ than in the bulk cement paste. Poon et al.[15] showed that fly ash having very similar properties with bottom ash has dual effect in concrete. The first one of these effects was being a micro-aggregate and the second was being a pozzolana. They demonstrated that fly ash had improved the interfacial bond between the paste and the aggregates in the concrete. Such concrete has lower chloride diffusivity than the equivalent plain cement concrete or concrete prepared with lower fly ash contents. According to Polden and Peelen [16] concretes made with blast furnace slag cements and fly ash cements show lower chloride penetration so these concrete types have higher electrical resistance. Oh et al. [17] defines high performance concrete as the concrete having high resistance to chloride penetration as well as high strength. They have approved the positive effects of silica fume, fly ash (FA) or slag cement concretes on the property of chloride resistance. It was reported that water-binder ratio, maximum size aggregates, aggregate particle distribution and aggregate-paste volume ratio also affect the chloride ingress. Hooton and Titherington [18], Aldea et al. [19] were also found out that usage of supplementary cementing materials like slag to produce high performance concrete for both accelerated and ambient curing conditions provide high chloride resistance to chloride penetration. There are few researches about the usage of GBFS or CBA in concrete. Yüksel et. al. [20] used non-ground GBFS as fine aggregate replacement alone and they observed that GBFS improves the chloride resistance of concrete. Ghafoori and Bucholc [21], Basheer and Bai [22] were also used bottom ash as fine aggregate replacement. They reported that bottom ash increases the chloride permeability due to its high water absorption rate but decreases the chloride transport coefficient because of high binding capacity of chlorides. They also showed that it was possible to produce concrete types with bottom ash which have low permeability and high chloride resistance if a low dosage of super plasticizer or chemical admixtures reducing water requirement.

The chloride diffusion coefficient is an important parameter in order to predict the service life of concrete structures. However, the transport of chloride ions through concrete is a complex subject and there are many groups of methods to calculate the diffusion coefficient. Natural diffusion methods, migration methods, and resistivity methods could be shown as examples of these groups of methods. Migration methods which are used in this study imply the application of an electrical field through the concrete. The RCPT method is in group of migration methods. It is a standardized accelerated method. Castellote and Andrade [23] arranged methods to calculate the diffusion coefficient according to three different importance factors. Their ranking is as follows: R1/M > M6 > R1 > D3 > M4 > M1 >D2 > M3 = M5, where M1 is describes the test procedure described in ASTM C1202-97.

III. EXPERIMENTAL STUDY

III. I. Materials

A commercially available CEM I 42.5 N type cement conforming requirements of EN 197-1 was used. Two fractions (0-4 mm and 4-7 mm) of river aggregate was used as fine and coarse aggregate. NGBFS was provided from Ereğli Iron & Steel Works Company in Kdz. Ereğli, Turkey. Particle size distribution for both of NGBFS and CBA were shown on Table 1. Physical properties of the aggregate, NGBFS, and CBA were shown in Table 2. Chemical composition of NGBFS was shown in Table 3 that results were provided from R&D laboratories of the Ereğli Iron & Steel Works Company. Fly ash (FA) was used as mineral admixture which was classified as V-type according to Turkish Standard EN 197-1 and it was also classified as F-type according to ASTM C 618. Chemical composition of CBA was shown in Table 3. Other important properties of CBA used in this study were tested in R&D laboratories of Turkish Cement Manufacturers' Association. They were shown in Table 4. It should be noted that activity index was high and free CaO content was zero. A hyper-plasticizer which is 0.7 % of cement by weight was used to give a proper workability for the concrete mixtures

Table 1. Particle size distribution of NGBFS and CBA

Sieve size (mm)	Passing (%) NGBFS	CBA
8.00	-	-
6.70	-	-
4.75	-	-
4.00	99.38	94.03
3.35	98.20	91.90
2.36	92.16	86.23
1.70	77.10	76.97
1.18	62.26	61.70
0.60	17.72	36.63
0.30	4.94	-
0.212	2.84	-
0.10	0.80	6.57
0.075	0.44	3.80
0.045	0.12	1.07

Table 2. Physical properties of aggregate, NGBFS, CBA and FA

Property	Aggregate (0-7 mm)	NGBFS	CBA	FA
Loose unit weight (kg/m3)	1930	1052	620	870
Compact unit weight (kg/m3)	1950	1236	660	1110
Specific gravity	2.68	2.08	1.39	1.87
Clay lumps and friable particles (%)	5.00	-	2.40	-
Very fine particles (%)	4.00	3.00	7.00	-
Organic impurities (with NaOH sol.)	Light yellow	Light yellow	-	-

Table 3. Chemical composition of NGBFS and CBA (%)

	SiO_2	CaO	MgO	Al_2O_3	SO_3	MnO	P_2O_3	Fe_2O_3	K_2O
NGBFS	35.09	37.79	5.50	17.54	0.66	0.83	0.37	-	-
CBA	57.90	2.00	3.20	22.60	-	-	-	6.50	0.604

Table 4. Properties of CBA (%)

Property	Value	Property	Value
Loss on ignition	1.67	45µ sieve residue (by weight. %)	25.8
SO_3^-	0.08	7 day strength activity index	76.9
Cl^-	0.0064	28 day strength activity index	85.7
Free CaO	0.00	90 day strength activity index	100

III. II. Method

Two series (G, B) of concrete specimens were produced in the laboratory. Mix proportions of these series were presented in Table 5. NGBFS was replaced 0-4 mm fine aggregate in G series, and CBA was replaced 0-4 mm fine aggregate in B series. The replacement ratio was changed from zero to 50% with the steps of 10%. Also, a reference specimen (R) group was produced for comparison of results. Each subgroup was constituted with three specimens and the arithmetic average of individual results was considered. The shape of specimens was cylindrical having 200 mm length and 100 mm dimension. All specimens were de-molded after 24 hour and kept in water for the next 27 days. Then they were cut into three slices having 50 mm length. These slices were stored in laboratory where the temperature was 18±3 oC and relative humidity was changed in between 50 to 60 %. RCPT was conducted at the 90th day by following the test procedure described in ASTM C1202-97. RCPT method covers the determination of the electrical conductance of concrete. It consists of monitoring the amount of electrical current passed through cylinders during a 6-h period. A potential difference of 60 V DC was maintained across the ends of the cylinder, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed has been found to be related to the resistance of the specimen to chloride ion penetration. At the end of experiment, electrical current (in amperes) versus time (in seconds) graphs were drawn. The area underneath the curve was integrated in order to obtain total charge passed during the test period. The total charge passed was taken as a measure of the electrical conductance of the concrete.

Table 5. Mix proportions of series (kg/m^3)

Code	Replacement ratio (%)	Cem.	Water	FA	Chem. Admix.	C.A. (4-7)	F.A. (0-4)	NGBFS	CBA
R	0	350	167	35	2.45	1120	720	0	0
G10	10	350	167	35	2.45	1120	648	72	0
G20	20	350	167	35	2.45	1120	576	144	0
G30	30	350	167	35	2.45	1120	504	216	0
G40	40	350	167	35	2.45	1120	432	288	0
G50	50	350	167	35	2.45	1120	360	360	0
B10	10	350	167	35	2.45	1120	648	0	72
B20	20	350	167	35	2.45	1120	576	0	144
B30	30	350	167	35	2.45	1120	504	0	216
B40	40	350	167	35	2.45	1120	432	0	288
B50	50	350	167	35	2.45	1120	360	0	360

FA: Fly ash; C.A.: Coarse aggregate; F.A.: Fine aggregate

IV. RESULTS AND DISCUSSION

Test results with error bars for G series were shown in Fig. 1. Charge passed from specimens was continuously decreased in between 0 to 30 % replacement ratios. The maximum decrease was observed as 27.7 % at the 30% replacement ratio. This shows that GBFS replacement decreases rapid chloride permeability. However, charge passed from specimens was increased in between 30 to 50 % replacement ratios. The total charge passed from the specimen was increased to the same level of reference specimen (no replacement) at 50 % replacement ratio. As a result, even 50 % replacement doesn't change rapid chloride permeability of concrete with respect to reference concrete. 30 % replacement ratio can be selected the optimum replacement ratio for G series concrete.

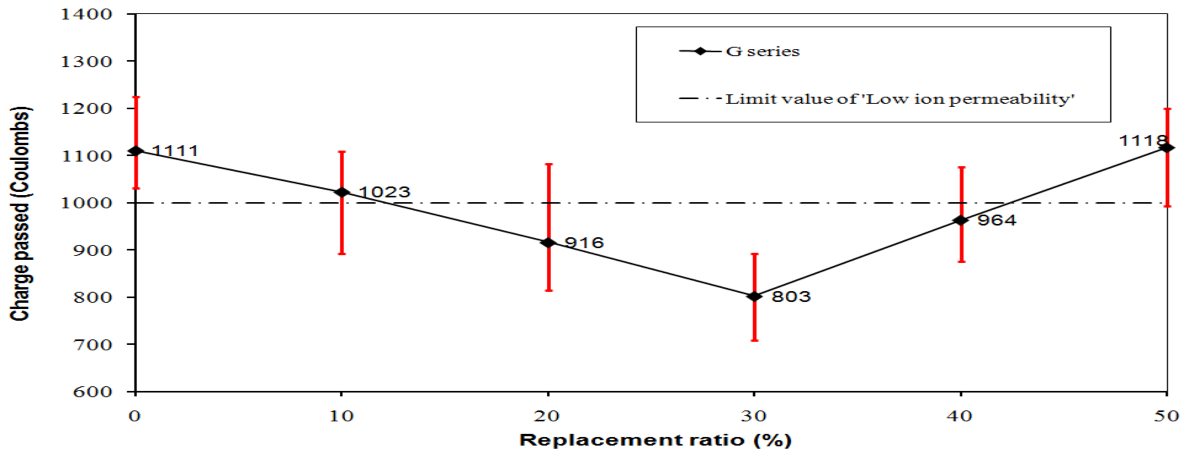

Figure 1: RCPT test results of G series

B series has a different behavior as compared to G series (Fig. 2). A slight (13.1 %) decrease in total charge passed through specimens was observed at the 10 % replacement ratio. Then a gradual increase was observed in between 10 to 40 % replacement ratios. Lastly, a sharp (28.9 %) increase was observed after the 40 % replacement ratio. This trend shows that 10 % was the best ratio for B series concrete. However, as compared to the chloride permeability of reference concrete (0 % replacement), 40 % was also an acceptable replacement ratio since the charge passed on this level (1064 Coulomb) was less than that of reference concrete.

The reason of decreases observed in chloride permeability can be explained with the chloride binding capacity of the replaced materials and the structure of the concrete. Both of these materials have high chloride binding capacity when they were used in concrete. Since reactivity of blast furnace slag is depends on particle diameter and we used it as in non-ground form we do not expect extra hydration products. The differences in terms of surface characteristics, particle shape, particle strength, porosity and permeability of NGBFS and CBA from natural fine aggregate are getting important at this stage. Normal concrete shows a dense structure composed of irregular grains and the hydrated products attach to the aggregate surface strongly. For the low replacement ratios such as 10 or 20%, the concrete has compact and dense structure similar to the normal concrete. However, in the case of increased replacement ratios the microstructure of concrete changes its network structure. Yüksel and Genç [24] investigated compressive, flexural and split tensile strength, water absorption, and microstructure of concrete containing NGBFS or CBA as fine aggregate in different replacement ratios. They concluded that NGBFS and/or CBA decreases tensile and compressive strength of concrete and the rate of decrease depend on the type of replacement material. The transition zone between aggregate and cement paste was getting relatively weak than as in the control concrete. CBA decreases the strength more than NGBFS since CBA contains lumped particles which are not present in NGBFS. Also the SEM analyses and water absorption tests showed that the replaced concrete was more porous than the reference normal concrete. When aggregate is replaced by either NGBFS or CBA, water absorption ratios of concretes are increases.

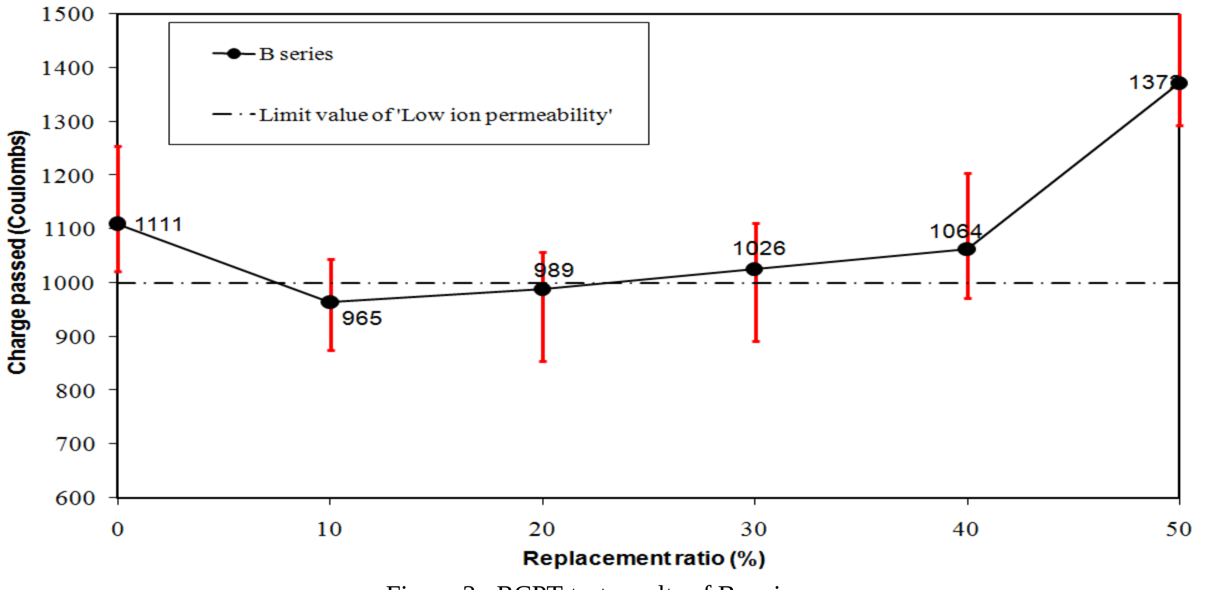

Figure 2: RCPT test results of B series

Non-reacted particles of NGBFS or CBA were efficient to fill up the large capillary pores at low levels of replacement. The new pore system enhanced impermeability of concrete. Generally, the permeability of concrete is influenced by the volume, size, and continuity of the pores. However, for the high level of replacement ratios, since the structure of concrete was changed from compact to porous, the strength is decreased and permeability is increased. Delagrave et al [12] indicated that aggregates modify the microstructure and the transport properties of mortars. This modification can be attributed to the presence of numerous interfacial transition zones. Aggregates in cement pastes act as solid inclusions increasing the tortuosity of the matrix while the presence of numerous interfacial transition zones tends to facilitate the movement of chloride ions.

The concrete produced with NGBFS and CBA as fine aggregate has high permeability than the normal concrete at a high replacement ratio. The increase found in chloride permeability at high replacement ratio such as 50 % can be explained with the diffusivity. The rate of chloride ion ingress into concrete was influenced by both the diffusivity of the cement paste fraction and by the diffusivity of the aggregate. Hobbs [25] states that highly permeable aggregate could increase the chloride ion diffusivity of concrete by a factor of ten.

Measured slump values of fresh concrete are changing 6 cm to 12 cm in G series, and as replacement ratio increases the slump value is increases too. Contrary, measured slump values were decreased in B series due to high absorption capacity of CBA. Andrade et al [26] stated that w/c ratio of the concrete cannot be taken as exact because of the high porosity of the bottom ash. The water absorbed internally by the bottom ash is released to the concrete over time, being part of the production process with the concrete still in the fresh state. Therefore, mixing process was not so easy as compared to reference specimen and large capillary pores were existed for high replacement ratio such as 40 or 50 % replacement. This case affected chloride permeability of concrete. Sharp increase observed in chloride permeability at 50 % replacement in B series can be explained with this event. High slump values measured in G series for replacement ratio higher than 30 % can also results in more capillary pores and high permeability.

Chloride ion penetrability based on charge passed was classified according to the qualitative terms in the ASTM C 1202 – 97. Chloride ion penetration obtained in this study was shown in Table 6. It was found that NGBFS or CBA improves the resistance against chloride ingress. While chloride ion penetrability of normal concrete (R) was “low”, the same parameter of G20, G30, G40, B10, B20 subgroups were “very low”. NGBFS or CBA contributes to concrete chloride ion penetration.

Table 6. Classification of chloride ion permeability of all series with respect to ASTM C1202-97

Code	Charge passed (Coulombs)	Chloride ion penetrability
R	1111	Low
G10	1023	Low
G20	916	Very Low
G30	803	Very Low
G40	964	Very Low
G50	1118	Low
B10	965	Very Low
B20	989	Very Low
B30	1026	Low
B40	1064	Low
B50	1372	Low

V. CONCLUSION

Based upon evaluation of the results following conclusions can be drawn.

(1) Chloride permeability was decreased at low replacement ratios then increased again at high replacement ratios. The decreases observed at low replacement levels depend on chloride binding capacity of GBFS and CBA.

(2) The increased chloride permeability at high replacement levels could be explained with the transport properties of concrete. Since the concrete was more porous and permeable on high replacement ratios movement of chloride ions facilitated. Then chloride binding capacities of GBFS or CBA were not adequate to obstruct chloride ion movements.

(3) NGBFS was more effective then CBA to block chloride ions movement. 30 % and 10 % replacement ratios could be selected as optimum replacement ratios for NGBFS and CBA respectively.

(4) Use of industrial by-products as fine aggregate in concrete exposing chloride ions will help to produce durable and environmental friendly concretes.

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