Investigating the effect of changing in aggregation of stone materials containing high specific gravity with constant fineness modulus on penetration of chloride ion, compressive strength and density of heavy concrete

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Abstract: This study analyzed some physical and mechanical properties of concrete produced with magnetite (Fe2O3) aggregate supplied from Khaf county of Iran. Since in the concrete mix design of sand gradation is controlled and applied just by fineness modulus and being in the range of standard gradation. In this paper with fixing these two factors, the effect of changing sand grading by decreasing or increasing the amount percent of remained in sift on changes of chloride ion penetration, compressive strength and density of heavy-concrete is investigated. For this purpose, four types of sand grading with constant fineness modulus in standard grading zone and two kinds of gravel with different maximum nominal size design of concrete mixes are probed. In these concrete samples, chloride ion penetration as one of the parameters related to the concrete durability and in the other hand 7, 28 and 42 days compressive strength, slump and density of concrete are studied.

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1. Introduction

Widespread and increasing use of radioactive materials in medicine, research, and industries particularly nuclear energy industry that is considered as basic needs of human existence today, along with increased risk of human exposure from ionizing radiation is due to these materials. To avoid the harmful environmental effects, protection against nuclear radiations is one of the most important problems in the use of radioactive materials for radiation therapy or nuclear technology. With the development of nuclear energy and particularly for protection from fatal rays such as neutron and Y, which have the ability to penetrate objects, heavyweight concrete began to be used as a shield [1]. The first step in any treatment room planning of radiotherapy services is to establish the design criteria. These criteria comprise (i) the limitations imposed by the allowed dose equivalent rates in different areas of the facilities and (ii) the existing space for construction [2].Without losing the effect of shielding radiation, heavy concrete makes possible to reduce barrier thickness in limited spaces. It should be noted that in design of nuclear facilities with high production capacity reliable distance from residential areas and the population must be observed, in addition access to the vast resources of water particularly for use in various parts of these industries is very important. Therefore in most cases these facilities will be built adjacent seas and oceans. So the combination of strength and durability properties of this particular type of concrete due to continuous exposure in the aqueous environment is very important. In fact the purpose of this type of structure is design and implementation of concrete that provide the proper compressive strength hand has lower permeability especially in chloride penetration, as long as the cement mortar is of sufficient quality, it can provide good lubrication and contraction [3]. The compressive strength of heavy concrete also increases with iron ore content, while the tensile strength declines [4]. Thus, investigation of the effect of grading aggregate particularly sand on pore structure of concrete and permeability is more important.

2. The test processing

2-1- Consumable materials

2-1-1- Cement:

Type I: Portland cement of Ghaen cement factory, according to ASTM C150 with 370kg/cm² compressive strength used in design of concrete mixes. To prevent heat of quick and high hydration and later potential cracks, guidelines of using concrete have recommended not using the type III cement and acceleration in the preparation of this particular kind of concrete [4-5].

2-1-2- Aggregate:

Coarse and fine aggregates made of magnetite (Fe2O3) aggregate with 60% purity percent are gained from Khaf mine, one of the best mines of magnetite stone in the world, located at 10km of Torbat-e-Jam city. Completely broken down and washed sand and gravel are used. In order to create aggregates grading in the standard range and constant fineness modulus, one ton of sand and gravel is separated into individual grains according to ASTM C33 via standard sifts [6]. In this laboratory study coarse aggregate with two maximum nominal sizes of 25 and 12.5 mm and fine aggregate with fineness modulus of 2.83 are selected in four different kind of grading and based on standard grading range. The most important factors for fixing fineness module are mentioned below:

1- Fixing volume amount of coarse aggregate and fine aggregate and stability of coarse aggregate to fine aggregate ratio in any mix design.
2- Stability of quality and softness aggregate in design of mentioned mixes in order to study changes of fine aggregate in identical conditions for both aggregates with different maximum nominal sizes.

It is worth noting that these four different types of sand grading are created by changing remained amount on each sift and constant softness module of 2.83.Therefore, with considering the selection of two types of gravel gradation (the maximum sizes of grains are 25 and 12.5 mm) and 4 different types of sand gradation with constant fineness modulus of 2.8, totally eight different types of grading aggregates are used in concrete samples. Information relating to the tests carried out on gravel and sand with different nominal maximum sizes of 12.5 and 25 mm according to ASTM C637, are shown in Tables 1,2 and 3 their grading curves are presented in figures 1 and 2[7].

Table 1. The results of experiments conducted on aggregates with a maximum nominal size of 12.5 mm and 25mm

Nominal maximum size of coarse	12.5mm	25mm	Standard No.
Specific gravity of coarse aggregate	4092kg/m^3	4288kg/m^3	ASTM C127
Specific gravity of fine aggregate	4362kg/m^3	4362kg/m^3	ASTM C128
Water absorption of coarse aggregate%	1.55	1.59	ASTM C127
Water absorption of fine aggregate%	0.7	0.7	ASTM C128

Table 2. The results of the coarse aggregate gradation

Sieve size	coarse aggregate	4.75mm	9.5mm	12.5mm	19mm	25mm	37.5mm
Percent passing	D max= 25mm	0	39.697	48.092	73.302	96.238	100
Percent passing	D max=12.5mm	0	60.363	91.563	100	100	100

Table 3. The results of the fine aggregate gradation

Sieve size	Sand type	No.4	No.8	No.16	No.30	No.50	No.100
Percent passing	A	100	94	66.9	40.2	13.5	2.3
Percent passing	B	100	90.2	61.5	41	22.5	2.3
Percent passing	C	100	83.4	63.5	43.6	24.1	2.3
Percent passing	D	100	81.2	56.9	47.1	30	2.3

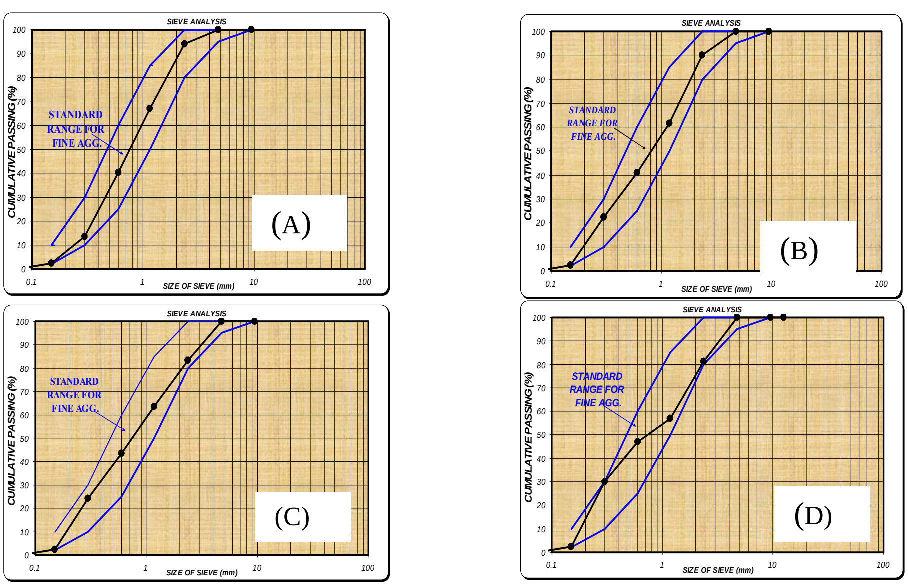


Fig 1. Fine aggregate gradation curves with different values of the rejection of standard sieve and constant Fineness modulus (2.83).

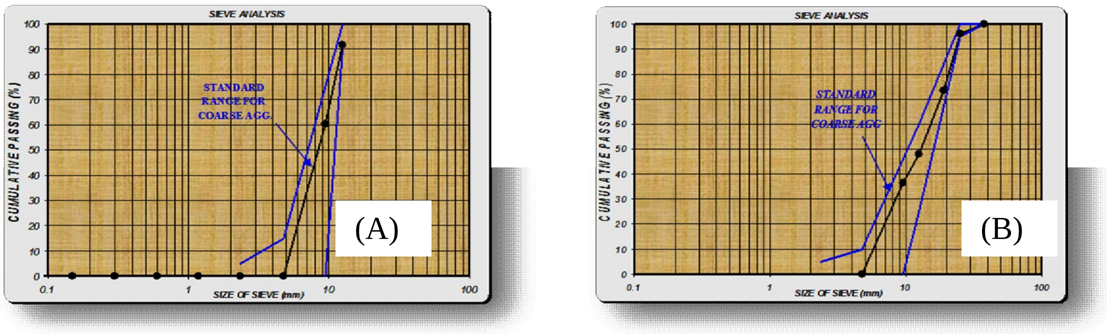


Fig2. Coarse aggregate gradation curves with a maximum nominal size of (A) 12.5 and (B) 25 mm

2-2 The design of mix

Heavy concrete mix design widely applied in radiation protection is much like the method used in the normal-weight concrete and The ACI 211.1 standard is described in Appendix 4, [8].According to the choice of two maximum sizes of 12.5 and 25 mm, we have used two mix designs. Since aggregates have special high weighs and least water greatly helps reduce water of concrete and separation of aggregates, water to cement ratio of 0.4is used in the design of mix. For each mix, four different types of sand gradation with constant fineness modulus of 2.83 presented in gradation tables and curves are used. The designs of Concrete mix are presented in Table 4. Finally, eight different types of concrete samples with different gradations were studied and their details are shown in Table 4.

Table4.Resultsofconcretemix design

Concrete mix design for maximum nominal size25mm					
Mix ID	Sand type	water(kg)	cement(kg)	Sand (kg)	Crushed stone(kg)
SP 25-A	A	202	505	1072.109	1616.141
SP 25-B	B	202	505	1072.109	1616.141
SP 25-C	C	202	505	1072.109	1616.141
SP 25-D	D	202	505	1072.109	1616.141
Concrete mix design for maximum nominal size12.5mm					
Mix ID	Sand type	water(kg)	cement(kg)	Sand (kg)	Crushed stone (kg)
SP 12.5-A	A	230	575	995.72	1367.5
SP 12.5-B	B	230	575	995.72	1367.5
SP 12.5-C	C	230	575	995.72	1367.5
SP 12.6-D	D	230	575	995.72	1367.5

Note: For example the code SP 12.5-A means coarse aggregate gradation curves with a maximum nominal size of 12.5 mm and A sand type.

2-3- making mixes and preparation of samples:

Aggregates such as crushed, washed and separated-grain gravel and sand (the remained amounts of each standard sieve are split apart to achieve a desired gradation) have been used in the design of concrete mixes. All concrete mixes are performed using a horizontal mixer and low speed.15cm × 15cm × 15cm cube mold sampling was conducted in three layers. Prepared samples are removed from molds after 24 h at laboratory temperature and maintained in a pool of processing water with a constant temperature of 23°C. In order to performance of Chloride ion penetration test, The specimens were then cured in water at 23ºCfor 28 days; five sides of one sample of each mix design are covered by Epoxy varnish to become completely impermeable. Samples prepared according to ASTM C1152 were in a solution of water and salt 90 days (165 gr of salt per liter of water). So that the samples were completely under water and salt solution and the side without Epoxy varnish was free from the surrounding.

2-4 Tests performed on samples

2-4-1 Experiment related to investigating the properties of fresh concrete

2-4-2 Experiment for determination of Slump

To study the properties of fresh concrete, relative efficiency determining test is done according to ASTM C143 standard immediately after the preparation of concrete mix [9]. Results are presented in Table 5.

2-4-1-2 Experiment for determination the Unit volume weight of concrete

The average special weight of fresh concrete is obtained from molded samples immediately after molding and compressing concrete samples. The results are shown in Table 5.

2-4-2 Experiment for investigation of hardened concrete properties

2-4-2-1 Experiment for determination of compressive strength of concrete

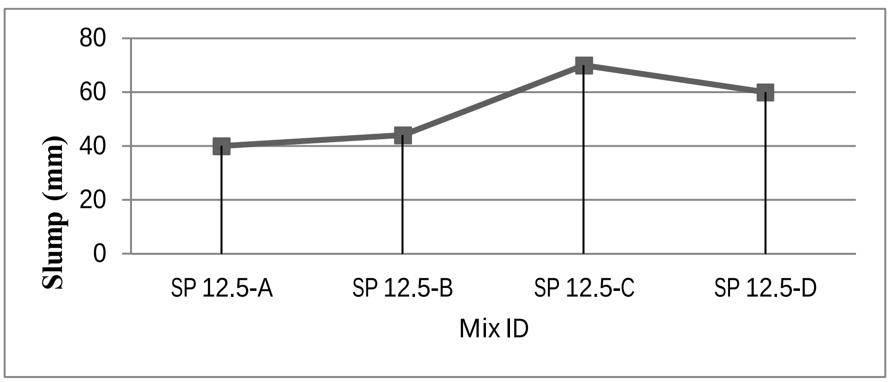
In order to determine the average compressive strength of concrete over time**,** Cubic samples with dimensions of 15cm × 15cm × 15cm are tested after 7, 28 and 42 days. Concrete breaker Jack is used to break down concrete samples. Force rate is kept about 680 to 700kgf/s. The results of this experiment are presented in Table 5.

2-4-2-2 Experiment for determination percent of Chloride ion penetration in concrete

After preparing powder from different samples in various depths 0-1, 1-2, 2-3 and 3-4cm (ASTM C1152) the amount of chloride of investigated samples is measured by using electro potentiometric (ASTM C114) and satisfactory results are achieved. Results of this experiment are presented in Table 5.

Table 5. Overall results of tests conducted on concrete samples

Mix ID	Specific gravity of concrete (kg/cm³)	slump (mm)	compressive strength (kg/cm²)			depth of Chloride ion penetration(cm)			
			7 day	28 day	42day	0-1	1-2	2-3	3-4
						percent of Chloride ion%			
SP 25-A	3334.07	30	349.33	463.18	480.23	0.75	0.45	0.35	0.25
SP 25-B	3349.62	40	360.35	486.15	489.56	0.8	0.65	0.45	0.35
SP 25-C	3351.55	45	369	489	505.6	0.65	0.45	0.3	0.2
SP 25-D	3356.77	30	384.10	503.21	515.33	0.55	0.35	0.25	0.15
SP 12.5-A	3205.29	40	367.42	467.50	484.32	0.55	0.40	0.30	0.20
SP 12.5-B	3233.33	44	372.07	477.35	489.26	0.75	0.55	0.35	0.30
SP 12.5-C	3257.77	70	361.73	483	498.53	0.55	0.35	0.25	0.15
SP 12.6-D	3291.85	60	392.2	493.3	510.87	0.45	0.30	0.20	0.10



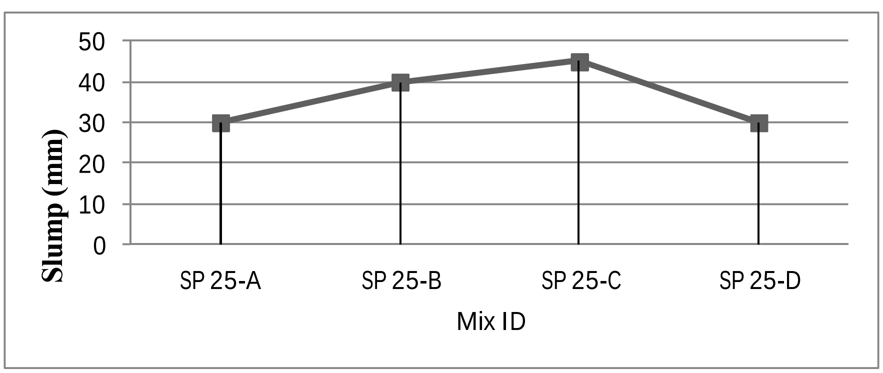


Figure 3. Graph showing change of slump in concrete, Based on the different aggregation.

3. Result and discussion

3-1- Slump and flow of concrete

One of the most important characteristic of aggregates affecting on properties of concrete is shape of particles. Shape of Particles is the main factor in changes of mix performance. Due to the high special weight of materials, to water run Policy some measures such as increasing smallness of grading tissue.(decreasing fineness modulus of aggregate mix), Increasing cement or adhesive materials, Using crushed aggregate, decreasing water-cement ratio and increasing powder materials can be useful to reduce bleeding. By considering the amount of allocated water of two mentioned designs of mix, slump higher than obtained values is expected (Expected slump = 100 mm).It should be noted that stone materials such as gravel and sand used are crushed and this factor is a clear reason for flowing concrete. The results presented in Table (7) indicate that the slump of concrete of SP 25-Asamples increases from SP 25-A to SP 25-C by changing grading of sand respectively and the slump of SP 25-D sample is lower than SP 25-C sample. Changes of slump between SP 12.5 samples are the same as SP 25 samples. It is noteworthy that in general the slump of the concrete of SP 12.5 samples is more than SP 25 samples. Figure 3 shows changes of the slump of SP 25 concrete samples with the change of sand gradation and figure 4 shows changes of the slump of SP 12.5 concrete samples with the change of sand gradation.

3-2- compressive strength of concrete

According to the results presented in table (5), 7, 28 and 42 days compressive strengths are increased between SP25 samples by changing of grading from SP 25-A to SP 25-D. The increased amount of 7, 28 and 42 days compressive strengths of SP 25-D concrete samples are 9.95%, 8.64% and 7.3% respectively as compared with SP 25-A samples.in the other hand 7, 28 and 42 days compressive strengths are increased by changing of sand grading from SP 12.5-A to SP 12.5-D. The increased amount of 7, 28 and 42 days compressive strengths of SP 12.5-D concrete samples are 6.74%, 5.51% and 5.30% respectively as compared with SP 12.5-A samples. Considering various curves of sand grading and comparison with the compressive strength of concrete show that strength of concrete samples is increased by increasing the remained percent on No.100 sieve (from 13.5% to 30%) and fixing the fineness modulus of sand (FM=2.83). So the solid concrete is created. Moreover, as mentioned in the previous section, this increase of strength is also associated with the increase of slump. Figure 4 shows changes of 7, 28, 42 days compressive strengths of SP 25 and SP12.5 concrete samples with the change of sand gradation.

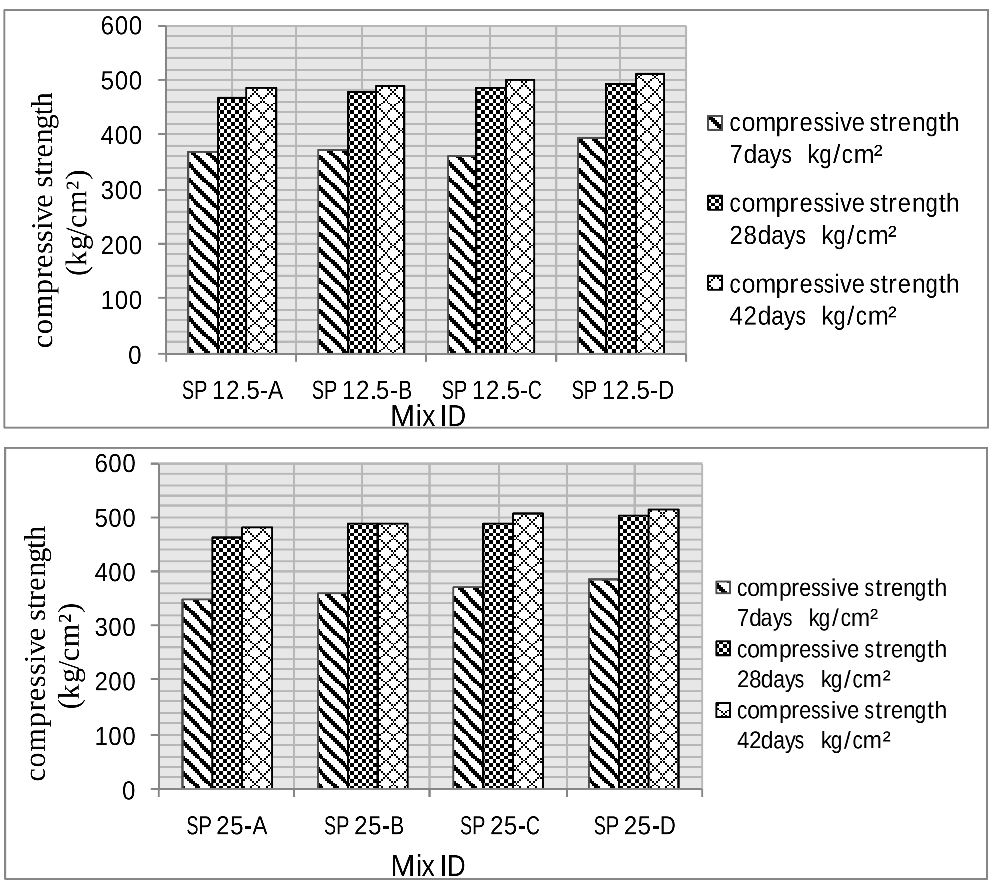


Figure 4. Graph showing change of compressive strength in concretes Based on the different aggregation.

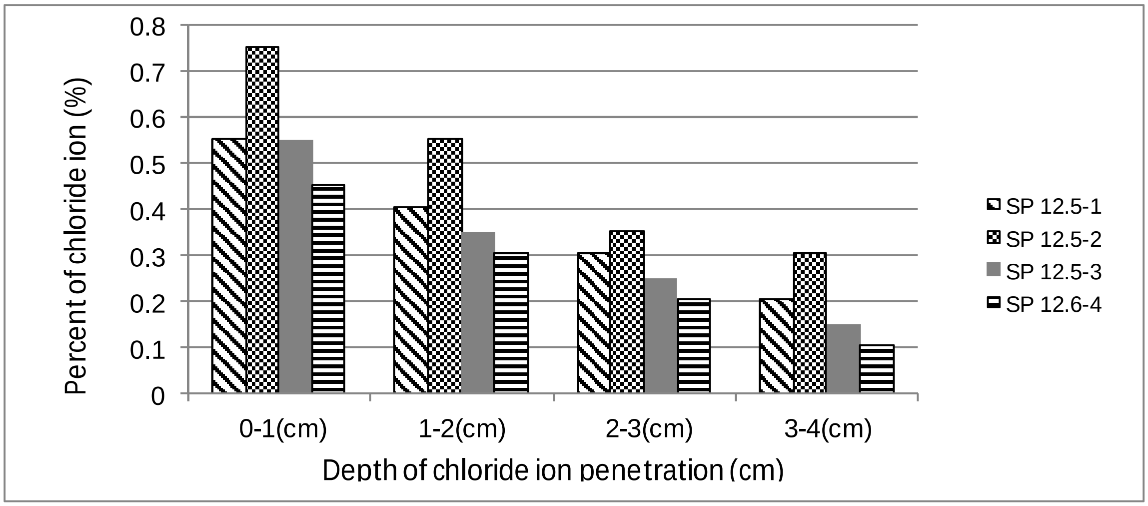


Figure 5. Graph showing change of chloride ion penetration in various depths of concrete samples, base on changes in aggregate.

4. Conclusion

Chloride ion penetration: According to the results presented in table 5, the percent of chloride ion penetration of SP 25 samples is increased by increasing the remained percent on No.100 sieve from SP 25-A to SP 25-B and it is remarkably decreased in SP 25-C and SP 25-D samples as compared with SP 25-A and SP 25-B samples. Even as the permeability coefficient of SP 25-D is less than permeability coefficient of SP-25-A sample. Changes of concrete permeability coefficient among SP 12.5 are the same as SP 25 samples. This result is also true for different depths in discussed samples. In four types of sand grading mentioned in this paper, grading changes alters the grain distribution and leads to create concrete samples with different pore structures. This eventually causes a change of percent penetration of chloride ion in different samples of concrete. Figure 5 shows Changes of the percent penetration of chloride ion in SP-25 and SP 12.5 concrete samples with changes of sand grading.

According to the results presented in table (5), with the rise of remained percent on NO.100 sieve from 13.5% to 30%, Unit volume weight is increasing. Considering that the concretes with a unit volume weight greater than 2600 kg/m3 are called heavyweight, all of the concrete samples in this study can be called heavyweight concrete. It is noteworthy that in general the unit volume weights of the concrete of SP 25 samples are more than SP 12.5 samples.

the rise of remained percent on NO.100 sieve (increase passed percent of NO.50 sieve) from 13.5% to 24.1%, sand acts as ball and the performance of concrete is increased. With increasing remained percent on the No.100 to 30% sieve, special surface of sand increases and leads to increase percent absorption of water by sand compared with ball performance and then the slump of concrete decreases.

With constant fineness modulus of sand in the range of standard grading curve, the change of sand grading with increasing and decreasing of remained amount on sieves significantly alters strength properties and permeability of the concrete.

Considering various curves of sand grading and comparison with the compressive strength of concrete show that strength of concrete samples is increased by increasing the remained percent on No.100 sieve (from 11.2% to 27.7%) and fixing the fineness modulus of sand (FM=2.83). So the solid concrete is created.

samples of concrete made of(D) type sand that have maximum remained percent on the NO.100 sieve(27.7%)includes the highest compressive strength and by comparing the changes of compressive strength in the ages of 7,28 and 42 days, we find that Difference of development of compressive strength decreases by increasing age of investigated samples from SP-A to SP-D. The percent development of strength in different ages are mentioned briefly: The percent development of compressive strength of SP-25-A compare with SP-

25-D: (9.95%, 7 days), (8.64%, 28 days) and (7.3%, 42 days) and the percent development of compressive strength of SP-12.5-A compare with SP-12.5-D: (6.74%, 7 days), (5.51%, 28 days) and (5.30, 42 days).

Samples of concrete made of (D) type sand that have maximum remained percent on the NO.100 sieve (27.7%) are selected as the most efficient kinds of Sand gradation. They have the best and lowest percentage of chloride ion penetration.

With comparing the changes of compressive strength and the percent of chloride ion penetration of SP-25 and SP-12.5 samples with each other, we find that the increase in compressive strength of SP 25-A to SP-25-D samples and SP 12.5-A to SP 12.5-D samples doesn't lead to same changes of the penetration of chloride ion. In fact porosity alone has no effect on the rate of chloride penetration of concrete but pore structure of concrete (size and connection of pores) affects on penetration parameters.

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