Laboratory Study of the Effect of Recycled Fillers from Coking and Iron Concentrates Factories on the Roller Compacted Concrete Properties in Dams (RCC Dams)

Jaber Mahmoudi[1], Kourosh Qaderi[2], Mohammad Zounemat Kermani[3], Faeze Yazdi[4]

1- MSc of Water structures engineering

2- Member of faculty of water engineering, Shahid Bahonar University of Kerman

3- Member of faculty of water engineering, Shahid Bahonar University of Kerman

4- MSc of civil engineering, Supervisor of Civil and Chief Technical Officer of Barsoo Engineering Co.

Email: Mahmoudi.inbox@gmail.com

Abstract

This study presents mechanical and durability aspects of using different waste fillers including Iron powder, Iron concentrate, Coal Powder and Coke, which cannot be reused at industry process (samples from different parts of the Jalalabad Iron Ore Concentrate Plant and Zarand Coking Plant, Kerman, Iran) as well as mineral powder filler as a control sample to replace 3% and 6% of coarse and fine natural aggregate content in RCC. The concretes were investigated for absorption, compressive strength, workability and non-segregation of grains. The experimental results showed that RCCs of iron ore powder filler contents with 6% of the weight of coarse and fine natural aggregates had higher values of 28 days compressive strength and minimum 24-hour water absorption about 2.22%. In addition to that, using this type of waste in concrete may be more environmentally efficient, because this helps to remove some parts of wastes and protects the environment.

Keywords: Roller Compacted Concrete (RCC), Slump, Mix design, Compression strength, Water absorption.

1. INTRODUCTION

In order to achieve economic self-sufficiency, It is especially important to control the floods and surface water through the construction of dams witch considered essential and infrastructural. Since water supply has always been a fundamental human need for agriculture, industry and drinking water.

In the early 1980s, conventional concrete dam construction methods were replaced by the roller compacted concrete method. RCC dams use embankment dams construction's method, which is based on using heavy equipment machinery. Usage of heavy equipment machinery for constructing concrete dams, leads to development of RCC dams which despite the short construction time, they have the reliability of conventional concrete dams. Also, RCC dams are an economical competitive choice over embankment dams. Construction cost of RCC dams is less than conventional concrete dams as well as embankment dams. It is because of material saving, fast construction, less costly spillway, less risk of coffer dam overtopping and shorter and smaller size of diversion conduit [1].

In addition to economic benefits, the RCC is considered as a ‘‘green” concrete because the cement consumption in the RCC is lower as the RCC mixtures are normally designed with leaner binder content. Mineral admixtures are used extensively in RCC mixtures. The use of large amounts of mineral admixtures improves durability, reduce adiabatic temperature rise of concrete, construction costs, and gas emission accompanied with the manufacturing of cement clinker. Class F and Class C fly ashes, slag, and natural pozzolan have been used as mineral admixtures in the RCC [2].

Coarse aggregate size has a significant influence on the degree of RCC compaction in small layers and less effect in relatively thicker layers especially when large vibratory rollers are employed. The coarse aggregates with maximum-size diameter greater than 76 mm are seldom used in the RCC manufacturing because they cause problems in the layers spreading and compaction. However, the use of coarse aggregates with maximum-size diameter finer than 75 mm reduces the volume of voids and produces more cohesive mixture [3].

Waste coking and iron ore concentrates plants, which cannot be reused, is normally deposit causing obvious environmental problems. So use of these materials effectively in concrete, make them valorized. A mass of small particles is also produced due to the process of iron ore concentrate production, which usually does not have the ability to become concentrate, and is deposit. The waste Coke, consisting of non-consumable materials commonly used in particles smaller than 1 cm in diameter, are discharged as waste and disposed of in garbage dumps. This waste can be called coal in input materials, and called coke in exhaust materials. Applying the aggregates smaller than 75 microns (sieve NO. #200), if not plastic, can be a useful solution for reducing the free space among fine-aggregates. Typically, the use of about 2 to 8 percent of aggregates smaller than 75 microns in pavement roller concrete is common (ACI 325.9 R) [4].

This study is included of three consecutive parts. In the first part, materials and instruments were prepared and initial tests were performed to establish material properties. In the second part, material properties were checked with codes and proper mix design were defined by testing several initial mix designs. In the last part, main specimens were prepared and tests were conducted on 7, 14, 28, 42 and 90 days specimens.
In this research, we used 9 mix designs based on 140 kg/m^3 cement - II and Iron ore powder, Iron ore concentrate, Coal Powder and Coke as filler materials passing sieve no. #100 (0.15>) by replacing 3% and 6% of coarse and fine-aggregate content. Finally, the results were compared with mineral powder filler as control sample. In order to study the durability and mechanical properties of concrete, maximum density, VB time, compressive strength on 7, 14, 28, 42 and 90 days and 28-hour absorption of specimens were investigated.

2. EXPERIMENTAL PROGRAM

The material properties of the concrete mixture used in this experimental study are given in the following.

2.1. MATERIALS

2.1.1. AGGREGATE

Of 0–6, 6–12 and 12–25 mm grain size aggregate used in this study have been widely used in the most civil projects in Kerman for years, provided from Gloomak Region. The aggregate grade was designed as existing between the curves of 2-4-3-A and 2-4-3-B defined in journal No. 55 Iran Standards [5]. The properties of these aggregates are presented in Table 1 and Figure 1, 2. The gradation curves of mixing the aggregate consisted of coarse-aggregates (12-25 mm) (33%), fine-aggregates (6-12 mm) (22%) and fine-aggregates passing sieve No. 4 (4.75mm) (45%) and compared with the limits set by ACI 207-5R standard is presented in Figure 3 [6].

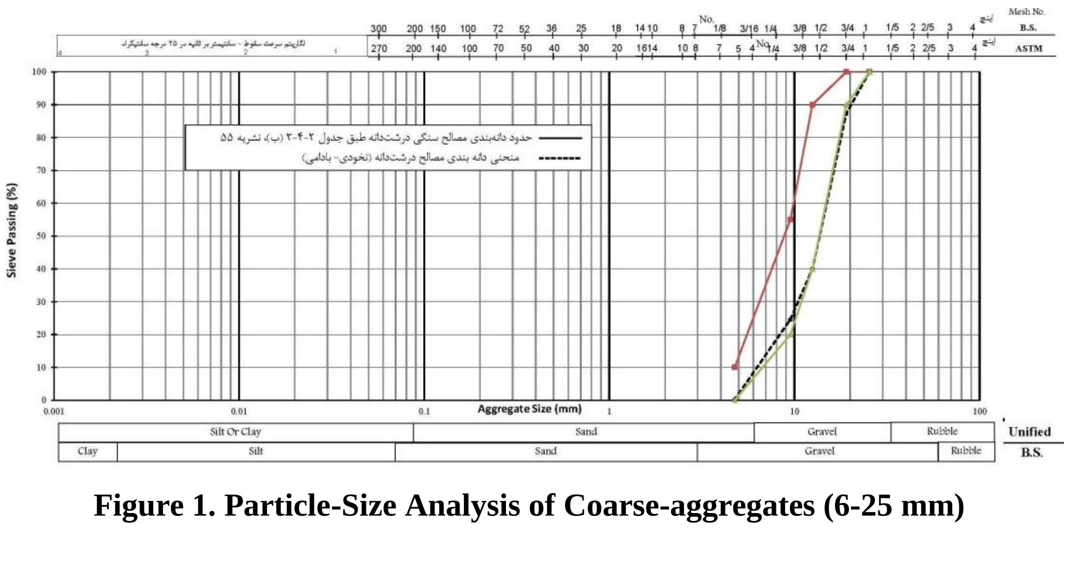

Figure 1. Particle-Size Analysis of Coarse-aggregates (6-25 mm)

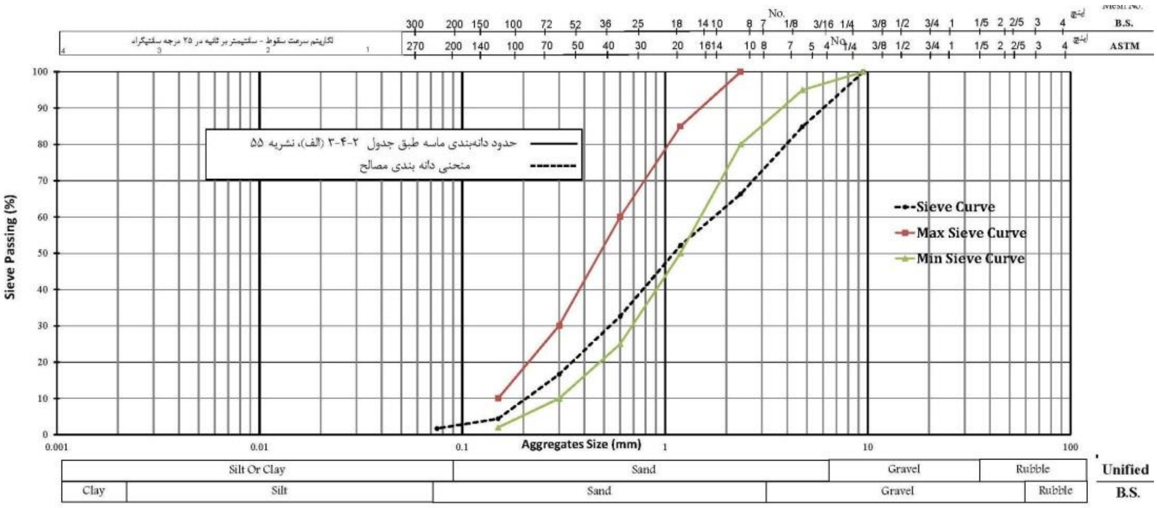

Figure 2. Particle-Size Analysis of Fine-aggregates (0-6 mm)

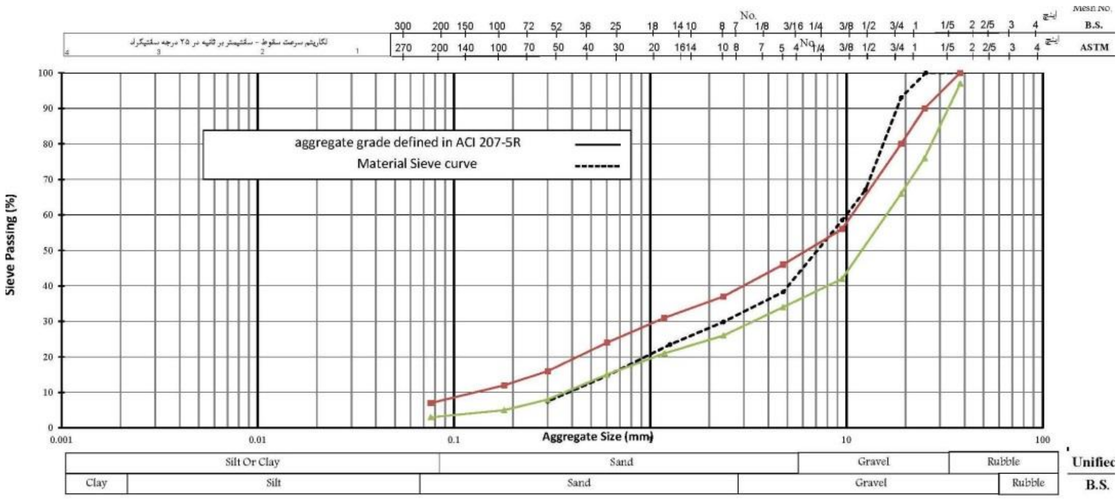

Figure 3. Particle-Size Analysis of aggregates in Mix Design (0-25 mm)

Table 1. Physical Test results of aggregates

Density & Water absorption			fractions of aggregate	Ductility of aggregate	Prolongation Of aggregate	Lose weight of aggregates by Los Angeles Test			fineness Modulus	Materials
Water absorption %	Real Density (Kg/m^3)	Bulk Density (Kg/m^3)	%	%	%	abrasion%	RPM	Type		
0.8	2654	2703	51	10	18	23	500	B	-	Coarse Aggregates (10-25 mm)
1.1	2641	2712	66	18	12				-	Coarse Aggregates (5-10 mm)
2.0	2580	2720	-	-	-	-	-	-	3.43	Fine Aggregates (0-6 mm)

2.1.2. CEMENT

CEM − II type of cement in appropriate to Iran Standards was used to prepare the concrete mixtures, whose physical and chemical characteristics are given in Table 2 [7, 8].

Table 2. Chemical characteristic of cement

Physical characteristics	Value
Water Concentrate %	25
Autoclave %	0.01>
Specific gravity (gr/Cm^3)	3.16
Specific area (m^2/Kg)	316
Setting period (Minutes)	Initial setting: 170
	Final setting: 215
Compressive strength (Lb./in^2)	1 days: 1370
	3 days: 2210
	7 days: 2900
	28 days: 3530

Table 3. Physical characteristic of cement

Chemical characteristics	Value (%)
CaO	62.71
SO_3	3.06
Cl^-	-
C_3S	51
C_2S	21
C_3A	5
Ignition Loss	1.92
Remaining Desolved	0.42

2.1.3. WATER

The water used for mixing the concrete mixtures of the experimental studies was potable and appropriate to the Iran Standards [9]. Analysis results of the water used in test mixtures are given in Table 4.

Table 4. Analysis results of the water used in test mixtures

Num	Examined Factors		Results		Concrete Standard*
1	PH	Acidity	7.9	-	7
2	EC	Electro Conductivity	1.28 (ds/m)	-	-
3	S.A.R.	Sodium Absorption Ratio	2.32	-	-
			Concentration as ppm	Concentration as meq/L	Concentration as ppm
4	Na^+	Sodium	108.1	4.7	-
5	Ca_2^+	Calcium	96	4.8	-
6	Mg_2^+	Magnesium	40.8	3.4	200
7	K^+	Potassium	0	0	-
8	Cl^-	Chloride	287.5	8.1	1000
9	HCO_3^-	Bi-carbonate	292.8	4.8	-
10	CO_3^{2-}	Carbonate	0	0	-
11	SO_4^{2-}	Soleplate	0	0	1000
12	TDS	Total dissolved solids	819.2	-	1000
13	TSS	Total Suspended solids	0	-	-
14	THD	Total Hardness	-	410	-
15	Na_2O+0.658 K_2O	Alkalinity	145.7	-	600

Description: Section 9 "national building laws" by considering the medium environmental conditions

2.1.4. FILLER

Typically, the number of aggregates passing through the sieve #100 called the filler. The filler used in this research is the waste of coke factories and iron ore concentrates with various percentages whose chemical characteristics are given in Table 5.

Table 5. Chemical characteristic of fillers %

	Iron ore Concentrate	Iron ore powder	Coke	Coal
C_{Fixed}	-	-	68.78	47.93
Volatile substances	-	-	9.26	32.65
Moisture	-	-	1.90	0.39
Ash	-	-	20.06	19.04
L.O.I	0.0	4.24	80.39	80.19
K_2O	01	0.47	0.85	0.91
SiO_2	5.69	36.10	7.69	10.21
Fe_2O_3	90.27	35.5	4.80	1.68
Cl	-	0.27	0.30	0.20
Al_2O_3	0.69	5.02	3.77	4.78
TiO_2	0.13	0.38	0.1	0.17
SO_3	0.02	0.67	0.51	0.36
MgO	1.46	11.3	0.29	0.30
La&Lu	1>	1>	1>	1>
CaO	1.10	4.9	0.79	0.92
P_2O_5	0.008	0.17	0.02	0.02
Na_2O	0.36	0.82	0.49	0.26

Waste Coal is one of the products of Zarand Coal Factory that is obtained during the process of coal processing for the production of coke and consumption in iron melting furnaces.

3. Identification and Formulation of the RCC Mixtures

3.1. Determine the optimum water-cement ratio

A modified Vebe apparatus which is described in CRD-C 53 [10] was used for determining the consistency of RCC. Since RCC mixture with Vebe time between 15 and 20 s has a sufficient workability [11]. The results are shown in table 6.

Table 6. Water-cement ratio Results

Specific gravity of fresh concrete	Slump	Concrete Temp.	Lab. Temp.	VB time	$\frac{W}{C}$
gr/Cm^3	mm	° C	° C	S	
2.097	None	15.1	19.6	120<	0.35
2.154	None	18.0	19.8	120<	0.45
2.171	None	18.4	19.8	120<	0.55
2.395	·	17.7	19.5	15	0.80
2.237	·	18.0	20.4	34	0.7
2.349	·	18.4	20.8	18	0.75
2.365	·	23.2	21.9	18	0.80
2.375	·	20.5	19.6	22	0.75

3.2. Specimens

In total, nine different concrete mixtures given in Table 7 were prepared. Cylindrical samples were used with height of 30 cm (12 in.) and diameter of 15.2 cm (6 in.). Samples were casted in three layers by vibrating method with Vebe table following the USBR 4906 [12]. Totally 72 specimens were made with 140 kg cement materials per cubic meter. Amount of 3% and 6% of total coarse and fine-aggregate materials were replaced by fillers in different mix design to investigate the effects of different amount of fillers. The results are shown in table 7.

Table 7. Mixing ratio (kg/m^3)

$\frac{W}{C}$	Weight of water	Weight of fine-aggr.	Weight of coarse-aggr.	Weight of coarse-aggr.	Type of filler	Weight of filler	Weight of Cement	Specimens No.
0.8	112+34	945	460	690	6% mineral powder	130	140	RCC-1
0.8	112+34	945	460	690	6% iron concentrate	130	140	RCC-2
0.8	112+34	945	460	690	6% coke	130	140	RCC-3
0.8	112+34	945	460	690	3% mineral powder+3% iron concentrate	65 + 65	140	RCC-4
0.8	112+34	945	460	690	3% mineral powder+3% iron powder	65 + 65	140	RCC-5
0.8	112+34	945	460	690	6% iron powder	130	140	RCC-6
0.8	112+34	945	460	690	6% coal powder	130	140	RCC-7
0.8	112+34	945	460	690	3% mineral powder+3% coal	65 + 65	140	RCC-8
0.8	112+34	945	460	690	3% mineral powder+3% coke	65 + 65	140	RCC-9

Compressive strength test, workability test by VB time, water absorption test and compacted concrete density tests were conducted at the ages of 7, 14, 28, 42 and 90 days.

4. EXPERIMENTAL

4.1. VB TIME

A modified Vebe apparatus was used to determine the workability of mix designs. The results are shown in table 8.

Table 8. Workability Results

Specific gravity of fresh concrete (gr/Cm^3)	VB Time (sec)	Specimens No.
2.298	18	RCC-1
2.336	18	RCC-2
2.191	105	RCC-3
2.395	15	RCC-4
2.326	16	RCC-5
2.361	38	RCC-6
2.205	40	RCC-7
2.251	36	RCC-8
2.229	36	RCC-9

4.2. 24-HOUR WATER ABSORPTION

24-hour Water absorption test on concrete specimens was performed according to ASTM C642 standard. The results are shown in figure 4.

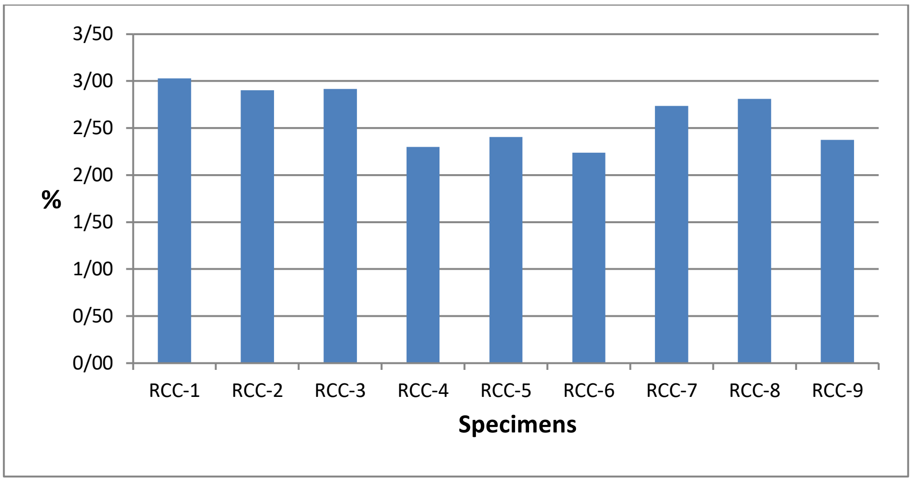

Figure 4. 24-houre water absorption

4.3. WEIGHT OF MASS

The specific density of concrete depends on the specific weight of the sand and the porosity of the roller concrete mass. There are a few air vents in roller concrete, varying between 0.5 and 5%, which reduces the action of compacting. The results are shown in figure 5.

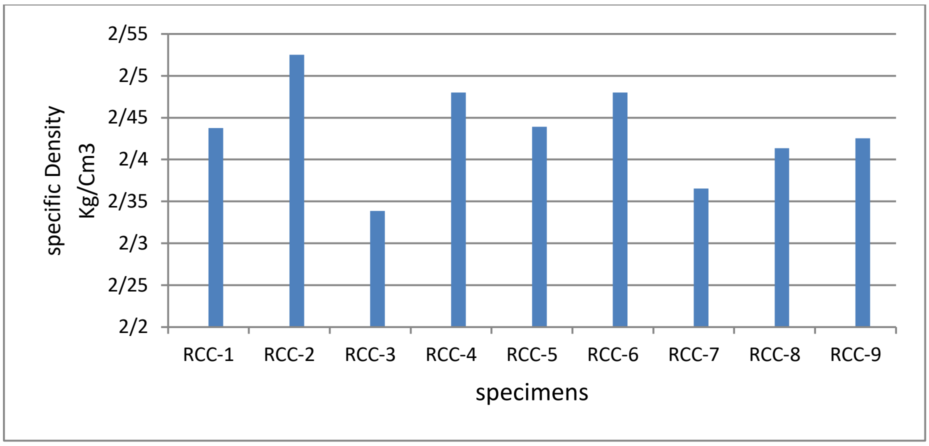

Figure 5. Specific density of specimens

4.4. Concrete compressive strength

Compressive strengths results of the various mixes are presented in Fig. 6 to fig. 8 for ages of 7, 14, 28, 42 and 90 days. Comparatively to the reference concrete, at twenty days old, the increase in compressive strength was in the mix design for RCC6 with 6% iron ore powder filler. In a study, Friedin (2005) proved that the high levels of CaO and SO_3 in the ash of wind makes the wind ash have a good cement property and therefore gradually increases the compressive strength [13].

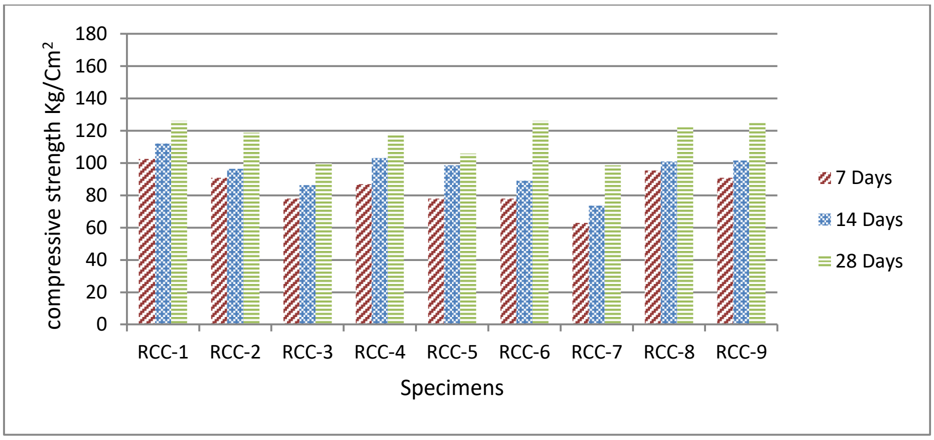

Figure 6. 7, 14, 28-days compressive strength results

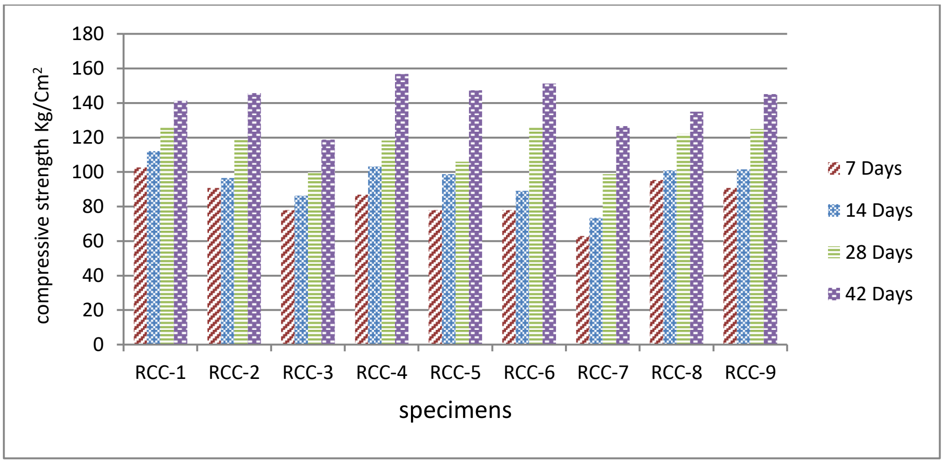

Figure 7. 7, 14, 28, 42-days compressive strength

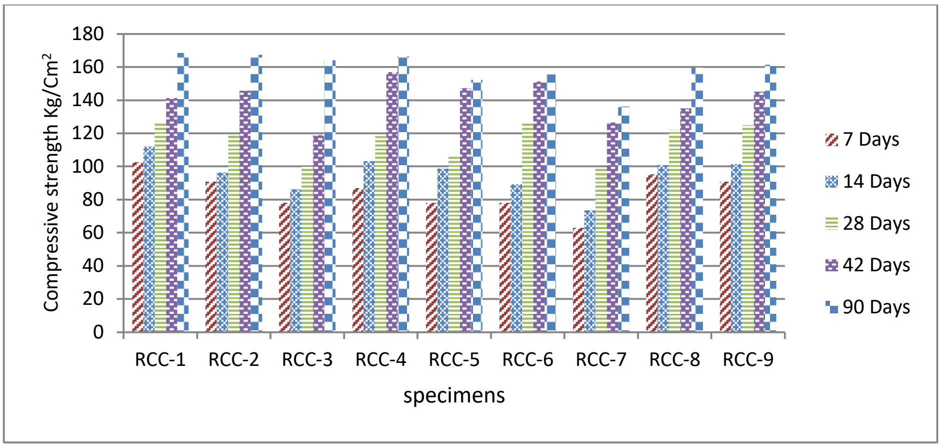

Figure 8. 7, 14, 28, 42, 90-days compressive strength

5. CONCLUSIONS

In this research, different fillers from coking and iron concentrate plants (passing sieve No. #100) made up 6% of the coarse and fine-aggregates weight, and also 3% of the filler along with 3% of the mineral powder filler has been used and investigated. The purpose of this study was to analyze the effect of various fillers on the roller concrete properties, mechanical properties of concrete and it's permeability. The tests results indicated a significant change in the mechanical properties and durability of the roller compacted concrete.

1. Using a high water percentage caused the segregation, which prevented by use of fillers to some extent. According to the design and time of VB, the optimal water-cement ratio was obtained amount of 0.8
2. The highest 7-days compressive strength of concrete is related to the RCC1 mixing design with the mineral powder filler, indicating increased compressive strength at the early ages.
3. The highest 28-days concrete compressive strength is related to the RCC6 mixing design with Iron Ore Powder Filler, indicating an increase in the final strength of the concrete at an advanced age by the filler.
4. The lowest compressive strength growth over time (90 days) is observed in RCC1 and RCC3 mixing designs made with 6% mineral powder filler and 6% coke filler, which to some extent indicates that these fillers are not very effective in the cement hydration.
5. The best performance of compressive strength up to 28 days is related to the RCC6 mixing design containing 6% Iron Ore Powder Filler, which at the ages has more compressive strength and performance similar to that expected from Pozzolans.
6. The results of 24-hour water absorption of specimens showed that the minimum water absorption was related to the RCC6 mixing design with iron ore powder filler, with amount of 2.24%, which is acceptable and ideal for dam construction projects.
7. The lowest VB time measured in the study was related to the RCC4 mixing design with 3% mineral powder filler and 3% iron ore concentrate with amount of 15 seconds.
8. By studying the results of the fillers chemical tests, iron ore powder was known to be close to the pozzolan group type F.

6. ACKNOWLEDGMENT

Funding for this study was provided by MANA construction company.

7. REFERENCES

1. USBR 4913. Procedure for water permeability of concrete.
2. J.F. Lamond, Significance of Tests and Properties of Concrete and Concrete-Making Materials, 2006, ISBN 0-8031-3367-7, pp. 595–601.
3. P.K. Mehta, P.J.M. Monteiro (Concrete: Microstructure, Properties, and Materials), fourth ed., 2014, ISBN 9780071797870.
4. American concrete Institute Committee 325.9R. Guide for construction of concrete pavements. ACI Materials Jornal 2015.
5. M. Dehqani pour, 1389, Instructions for implementation of general technical projects on construction works based on the publication No. 55
6. American concrete Institute Committee207. Roller Compacted Concrete. 207.5R.ACI Materials Jornal 1998.
7. ASTM C114 - 15 Standard Test Methods for Chemical Analysis of Hydraulic Cement
8. Iran national standard, 392, standard methods for physical Analysis of Hydraulic Cement
9. Development and Promotion of National Building Regulations Office, ninth topic, 1392
10. CRD-C 53. Test method for consistency of no-slump concrete using the modified Vebe apparatus
11. USBR. Roller compacted concrete, design and construction consideration for hydraulic structures. Technical Service Center; 2005.
12. USBR 4906. Casting no-slump concrete in cylinder molds using vibratory table
13. FreidinC. Influence of variability of oil shale fly ash on compressive strength of cementless building compounds. Constr Build Mater 2005;19:127–33.