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Studying the influence of fiber reinforcement on the characteristics of roller compacted concrete used in airports with partial replacement of cement by cement kiln dust

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Abstract. Roller-compacted concrete is defined as that concrete of no-slump consistency in its' unhardened state that is transported, placed, and compacted by roller compaction. The purpose of this research is to study the effect of using steel fiber reinforcement on the properties of roller compacted concrete in which, 5%, and 10% of the cementitious materials were replaced by cement kiln dust. Different contents of steel fibers were used to reinforce concrete which were compacted using a manually controlled roller device. The results showed that the compressive strength of the roller compacted concrete with 5% replacement of cementitious materials increased by 19, 25, 32, and 42%, when the concrete was reinforced using steel fibers amounts of 30, 50, 70, and 90 Kg per m³ of concrete respectively. The corresponding increases in the flexural strength were (15, 34, 37, and 40%). Similar increases were recorded for specimens with 10% replacement. The research had confirmed the feasibility of using steel fiber reinforcement to enhance the properties of this kind of concrete to be used in airport pavements. Substitution of 5 to 10 % of the cementitious materials by cement kiln dust will save energy and contribute in decreasing the impact of pollutants on the environment.

1. Introduction

The American concrete institute [1] defines roller compacted concrete (RCC) as "no-slump concrete compacted by roller compaction that consisting of dense graded aggregate, that when being unhardened, will sustain a roller during compaction". The requirements of explosive growth in the infrastructure are the factors that contribute to the increase in the use of good quality concrete to serve for long term performance. But, the shortage of tensile strength is one of the unwanted characteristics in the concrete because of its brittle characteristics [2, 3]. Production of (RCC) is not considered to be a new construction method, as RCC have the same basic components of conventional concrete [4]. Choosing the ingredients of RCC is related to the design strength, the intended durability, and the expected usage of pavement (ACI 325.10R-99-2004) [5]. The compaction of pavement materials is important because of its direct impact on the characteristics of the RCC pavement. To attain a smooth top surface of RCC pavements with closed surface, non-plastic fines passing a 75µm sieve is recommended to be not less than 5, not more than 10%. Fines content due to ACI Committee 325 [5] is in the range of (2 to 8%).

The slump characteristic of RCC is zero slump. Moreover RCC possesses no bleeding water besides the low shrinkage due to the low water content in comparison to the conventional concrete. For this purpose, it needs compactor for placing [6]. As RCC is characterized with little bleeding, Gel water is removed immediately due to evaporation. This will induce shallow micro-cracks. Consequently curing of this type of concrete should be applied immediately after finishing the rolling compaction.



RCC has been utilized for sustaining heavy loads in areas with low speed traffic. However, it has been used recently in commercial areas and highways [7].

Cement production is an important industry in Iraq [8]. Because large amounts of (CKD) are resulted as a byproduct from cement factories; It is very important to minimize the risks and of these pollutants on the environment. This could be done by managing the waste in such a way to ensures safe disposal and a less transport cost [9]. Alikhan [10] proved that CKD may be used as substitution to cement in RCC in the construction of airports pavement to enhance the economy and environment, as lower amounts of cement could be used besides consumption of waste materials.

SF reinforcement can be used in concrete for the control of cracking where fibers are more effective than conventional reinforcing steel under earthquake and blast loadings [3]. The crack arresting role of SFs leads to change the mode of failure of concrete due to restraining of the cracks [3]. SFR-RCC is used for high –speed railway, covers plate and other important engineering component. It has high tensile strength, high bending, cracking, and impact resistance, good wear strength, and other properties [6]. To assess the effect of fibers on the flexural strength and the ductility of concrete, copper-plated micro-filament steel fiber bars were used obtaining good results [11]. The ductility of conventionally RC members is increased due to the addition of SFs, also the stability will be enhanced [12]. Despite the improved mechanical characteristics of (SFR-RCC), up to now, very few pavements of this type of concrete have been constructed; this may be interpreted due to the practical difficulties related to mixing SF with concrete ingredients in site to RCC [13].

2. Objectives of research

The research objective was to study the effect of using SFR in construction of RCC pavements, in which part of the cement is substituted by CKD. The interrelated effects of the content of CKD and steel fibers on the characteristics of fresh and hardened RCC were discussed. The influence of SF reinforcement on the density, compressive and flexural strength of RCC was investigated. The appropriate content of SF that fulfill the desired targets of the research had been also studied.

3. Methodology

The methodology adopted to achieve the objectives included the following steps:

- 1- Preparation of the main equipment's, the locally manufactured manually operated compaction device (mini roller) and the required molds for the manually compaction process.
- 2- Selecting and testing raw materials (cement, coarse and fine aggregate, cement kiln dust (CKD), pozzolanic materials (fly ash class F), and water to be used in the work.
- 3- Fixing the weight of the crushed coarse aggregate, and the fine aggregate, according to ACI 327-14 [7].
- 4- Selecting the CMs percentage of the total air dry aggregate according to ACI 211.3R-02 (Reapproved 2009) [14], and ACI 325.10R-95 (Reapproved 2001) [15].
- 5- A constant percentage of 20% fly ash (Class F) was used by absolute volume of CMs. The CMs were partially replaced by either 5%, or 10% of its weight by CKD, according to previous research results [10].
- 6- SF content was chosen as a certain amount for each cubic meter of concrete. Different contents of SF, (30, 50, 70, and 90) Kg/m³, were used in the different mixes.
- 7- The highest density and the optimum water content was determined utilizing the modified proctor test according to ASTM D1557-12 (Method C). The same test was done for mixes with different contents of SF,
- 8- Mixing, placing, then, compacting the control samples and the samples with the chosen amounts of SF and CKD.

- 9- Curing all samples by immersion in water for different periods, then implementing the saw cutting process to get the required specimens for testing compressive, and flexural strength and for determining ultrasonic pulse velocity and bulk density.
- 10- Making a comparison between the results to show the effect and using different contents of Steel fibers besides CMs replacement by CKD, on the properties of RCC and selecting the suitable contents of CKD and SF that would achieve the desired engineering properties as well as meeting the goals of sustainable development.

4. Materials

4.1. Cement:

The cement used throughout the entire work is Portland cement (type V), from Kufa factory complying with the Iraqi specification (IQS 5:1984) [15].

4.2. Cement kiln dust (CKD)

The properties of CKD used in the present research are presented in table 1.

4.3. Fly ash properties

The properties of class F fly ash used in this work are shown in table 1.

Table 1. Properties of CKD, and Fly ash

Oxide composition%	CKD		Fly ash
	% by weight	% by weight	ASTM C618-05 Class F
SiO ₂	11.5	55	----
CaO	45.23	4.9	----
MgO	2.64	1.47	----
Fe ₂ O ₃	2.12	24.51	----
Al ₂ O ₃	4.58	5.35	----
SO ₃	7.28	0.30	Max 5 %
(SiO ₂) + (Al ₂ O ₃) + (Fe ₂ O ₃)	----	87.30	
Loss on ignition	23.00	5.62	Min 70 %
Specific gravity	----	2.2	Max 6 %
Specific Surface area, Blain m ² /Kg	----	375	----

4.4. Coarse aggregate

Crushed coarse aggregate brought from Al Nibae region complying to Iraqi specification IQS 45-84 (Reapproved 2016) [16] with nominal maximum size of 19 mm was used in this this work.

4.5. Fine Aggregate

Al Najaf desert sand complying to zone 2 of Iraqi specification IQS 45-84 (Reapproved 2016) [16] was used as a fine aggregate in this work.

The grain size distribution used in this work was selected according to the grading of type II (binder course) in accordance with SORB 2003 [17]. Table 2 shows the gradation of the aggregate used in the RCC mixtures.

4.6. Water

Tab water was used for mixing and curing of RCC specimens.

4.7. Steel Fiber

Smooth straight type steel fiber with more than 3000 MPa tensile strength and with length of 12-19 (mm) and 0.18 - 0.23 mm in diameter was used in this work, as shown in figure 1.

Table 2. The gradation of aggregate

Sieve size (mm)	Passing %	Grading (SORB2003) [17] limits
1 (25)	100	100
3/4 (19)	95	95-100
1/2 (12.5)	80	70-90
3/8 (9.5)	68	56-80
4 (4.75)	50	35-65
8 (2.36)	38	23-49
No.50 (0.3)	12	5 -19
No.200 (0.075)	6	3 – 9



Figure 1. Steel fiber

5. Specimens preparation and testing

5.1. Mix proportioning modified Procter test

For this work two fractions of the aggregates were chosen and mixed according to (ACI 327R-14) [7], 54% coarse aggregate (4.75 mm-19 mm) and 46% fine aggregate (75 μ m-4.75 mm). The yield was well graded combined aggregate grading within the limits of asphaltic concrete binder course as per SORB 2003[17]. Eleven (6 kg) batches of the combined air dry aggregate were mixed for the preparation of density test specimens. A CMs content of 14% by dry mass of aggregates which is within the ranges preferred by ACI 211.3R-02 (Reapproved 2009) [14], and ACI 325.10R-95 (Reapproved 2001) [18]. A fly ash content of 20% by absolute volume of CMs was used in all mixes. Dry density tests were done according to ASTM D1557-1 METHOD C [19], at specified moisture contents which were chosen according to ACI 327R-14. The same procedure was repeated for the other two percentages of CKD and for mixes with SFR. In all calculations the bulk specific gravity (dry basis) of the materials were employed depending on the lab tests results. Tables 3 includes the amount of each ingredient of plain RCC mixtures with 5%, and 10% replacement of CMs with CKD, as well as the amounts of the ingredients of the mixtures reinforced with 90 Kg/m³ SF. These amounts were calculated for one mold needed 0.016 m³ of concrete.

5.2. The molds

Steel molds with (380*380*100) mm inside dimensions were used in this work for casting the RCC specimens. Each mold was connected to a (650*650*10) mm steel base plate.

Table 3. Amounts of materials for one mold (0.016 m^3) of RCC for plain and reinforced concrete with different CKD replacement of CMs.

Materials	CKD amount for:				
	Plain concrete			Reinforced concrete (90 kg/m^3 SF)	
	0% of CMs	5 % of CMs	10 % of CMs	5 % of CMs	10 % of CMs
Coarse Agg.(kg)	17.157	17.22	17.27	17.04	17.07
Fine Agg.(kg)	14.62	14.67	14.71	14.52	14.54
Cement (kg)	3.79	3.56	3.33	3.53	3.30
CKD (kg)	0	0.24	0.48	0.24	0.48
Fly ash (kg)	0.66	0.66	0.66	0.66	0.66
Water (litter)	1.62	1.59	1.57	2.02	1.99
W/CMs %	0.36	0.36	0.35	0.46	0.45
Steel fibers (kg)	-	-	-	1.16	1.16

5.3. Mixing Process

Firstly, dry mixing of materials had been done for 2 to 3 minutes. Then the water was added to the dry constituents, which were calculated according to the design moisture content for each mix. The wet mixing processed for about three minutes, then steel fibers were gradually added to the mix, while mixing continued for 2 to 3 minutes. The SF were added carefully to control the tendency of the fibers to form balls. Next, the mixture was placed in the mold. The molds were cleaned before placing of RCC mixes and oil coated to facilitate extraction the specimens form molds. Figure 2 shows the steel fibers in the concrete mixture.

5.4. Compaction of specimens

The first part of compaction was done using a vibrating table after the mix was cast in the molds at three layers. Each layer was vibrated for (20 to 30 sec). After the vibration process had been finished, the molds were covered with a nylon sheet to keep moisture content from loss. Then the concrete was compacted by the roller device shown in figure 3, proposed by a previous researcher (Abed 2014) [20]. The rolling action was taken in the (x-x) direction with 15 passes back and forth.

**Figure 2.** The steel fibers in the mixture.**Figure 3.** The roller device.

Then the same sequence was repeated in the y-y direction so that the compaction of all parts of the mixture would be ensured in each direction of rolling. The compaction by the roller device is shown in fig. 3. The roller compaction device is fixed at the back on an axle with two wheels.

This process included three stages. In the first stage, the rolling was performed with a static load of 38 kg which represented the self-weight of the rolling device. The same procedure of roller compaction was repeated in the second and third stages, but after adding an additional static weight of 38 kg and 69 kg in second and third stages respectively (Abed 2014) [20].

5.5. Curing Process

The molds had been covered as soon as possible to prevent moisture loss from the samples. After one day of casting, the specimens were water cured for 10 days utilizing dripping system introduced by Al-Tameemi [21]. Curing regime was intended to simulate the condition of RCC pavements in service.

5.6. Sawing and testing of Specimens

Sawing all RCC slabs using a cutting machine to make cube and prism specimens. The saw cut had was done in accordance with ASTM C42/C42M-04 [22]. The specimens were sawed in the form of (10*10*10) cm dimensions' cubes and (38*10*10) cm dimensions' prisms. Cubes were used for bulk density and also were tested for compressive strength in accordance with B.S. 1881 part 116: 1983 [23]. While prisms were tested for flexural strength according to ASTM C 78-02 [24]. Sawing was done after curing slabs for 28 days. It is worth mentioning that cutting of slabs was not suitable for early time (less than 28 days), because of failure in the cutting processes at early age according to previous study [10]. The average readings of three cubes was taken for each sample to detect the compressive strength, while the average of the results of two prisms were used for the flexural strength of RCC. Bulk density of RCC specimens was found according to ASTM C 914-95 (Reapproved 2004) [25]. This method including using wax, was used because of the rough nature of specimens' surfaces.

5.7. UPV Tests

The pulse velocity tests to evaluate the quality of RCC specimens were carried out using (Pundit lab) model device according to ASTM C597-97 [26].

6. Results and Discussion

6.1. Steel fibers effect on density and workability of SFR-RCC

The of bulk density results for all specimens are shown in figure 4. It can be seen that the bulk density of the control RCC mix with (0%) of CKD and (0 Kg/m³ SFR) was 2.361 ton/m³. Also, the bulk density of all mixes increased with increasing the amount of steel fiber. The density of concrete mixes with CKD replacement of 5% and SF of (90 kg/m³) was the greatest density in comparison with other mixes.

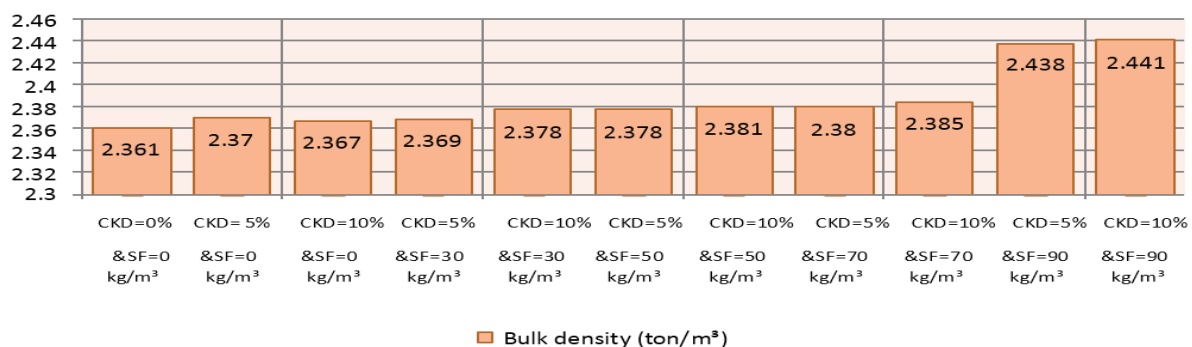


Figure 4. The bulk density results for all specimens.

6.2. Steel fibers effect of on compressive strength of SFR-RCC

Figure 6 shows the relationship between compressive and flexural strength at 28 days of plain RCC and CKD percentage, while figure 7 shows the relationship between CKD, SF and compressive strength of plain and reinforced RCC specimens. From figure (6), the control mix with (5%) of CKD and (0 kg/m³ SFR) possessed a compressive strength of 30.99 MPa at 28 days. Also, the test results of

plain samples (with no SFR) at 28-days showed that the partial replacement of (5%) of CMs by CKD was better than (10%) of CKD replacement concerning compressive strength. The results showed that in case of the specimens with 5% replacement of CMs by CKD and reinforced with (30 kg/m^3 SFR), the compressive strength was increased by (18.66 %) compared to plain concrete specimens with (0% SF) with the same CKD replacement. For (10%) replacement of CMs with CKD and using (30 kg/m^3 SFR), the compressive strength increased by (14.79%).

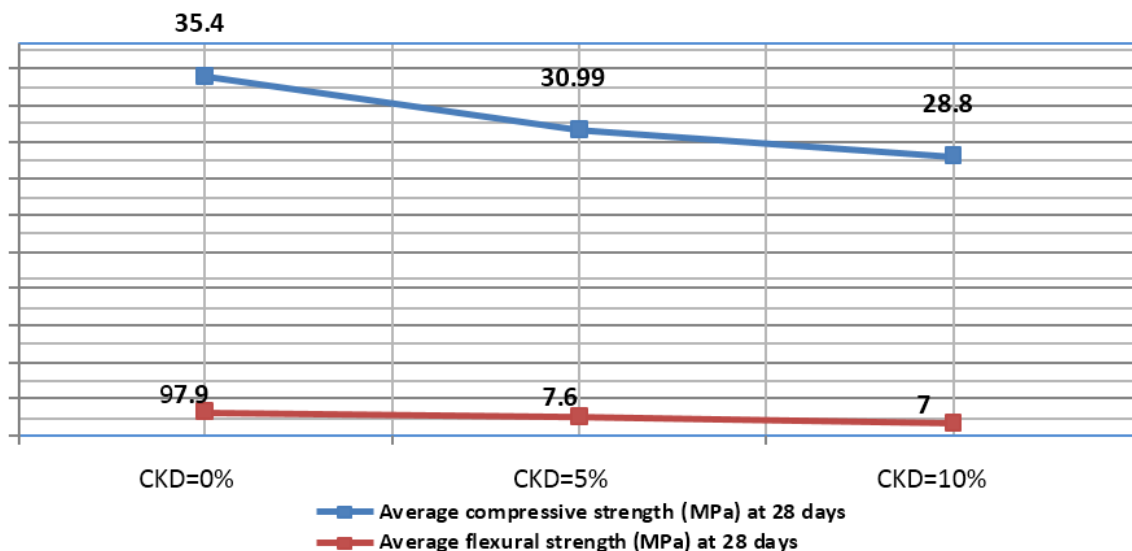


Figure 5. Relationship between Compressive, Flexural strength and CKD percentage.

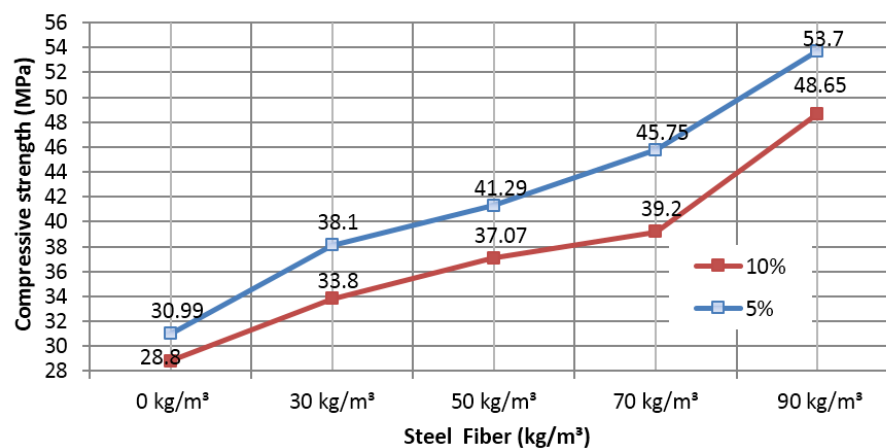


Figure 6. Relationship between compressive strength and (CKD & SF) for SFR-RCC specimens.

Other results showed that the reinforced specimens with 5% replacement of CMs by CKD possessed an increase in the compressive strength by approximately (24.94, 32.24, and 42.29%) when the concrete was reinforced with (50, 70, and 90 kg/m^3 SFR), respectively compared with the results of plain concrete with the same CKD replacement. These results were complying with the requirements of roller compacted concrete mixes used for airport pavement applications.

6.3. Steel fibers effect on flexural strength of SFR-RCC

The results of flexural strength tests for control samples and samples that contain different contents of SF with replacement (5%, 10%) by CMs were shown as in figure 7, the control mix with (0%) of CKD

and (0 kg/m³ SFR) possessed a flexural strength of 7.9 MPa at 28 days. Also, the flexural strength results of plain samples at 28-days showed that the partial replacement of (5%) of CMs by CKD was better than (10%) of CKD replacement.

The results showed that in the case of the specimens with 5% replacement of CMs by CKD and reinforced with (30 kg/m³ SFR), the flexural strength increased approximately by (14.60 %) compared to plain concrete specimens with (0 kg/m³ SFR) with the same CKD replacement. For (10%) replacement of CMs with CKD and using (30 kg/m³ SFR), the flexural strength was increased approximately by (4.10%) compared with the results of (10%) replacement of CKD plain concrete. These results are accepted with respect to the requirements of roller compacted concrete mixes used for airport pavement applications.

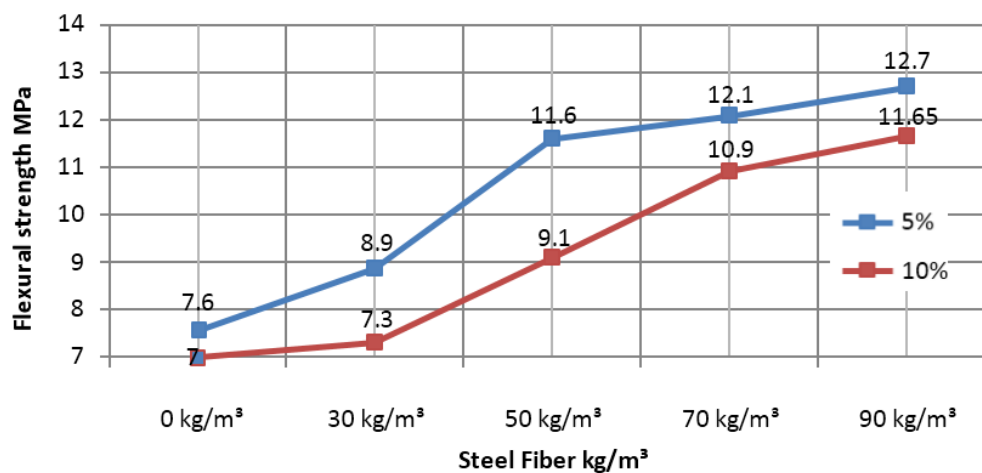


Figure 7. Relationship between flexural strength and (CKD& SF) for SFR-RCC specimens.

Other results showed that the reinforced specimens with 5% replacement of CMs by CKD possessed an increase in the flexural strength by approximately (34.48, 37.2, and 40.15 %) when the concrete was reinforced with (50, 70, and 90 kg/m³ SFR) respectively, compared with the results of plain concrete with the same CKD replacement. Furthermore the reinforced specimens with 10 % replacement of CMs by CKD possessed an increase in the flexural strength by approximately (23.1, 35.75, and 39.9 %) when the concrete was reinforced with (50, 70, and 90 kg/m³ SFR) respectively compared with the results of plain concrete with the same CKD replacement. The compressive, and flexural strength increased after using steel fibers in all mixes. This could be attributed to the role of steel fibers in arresting cracks resulting from the test loads. This would work to increase the carrying capacity of RCC members.

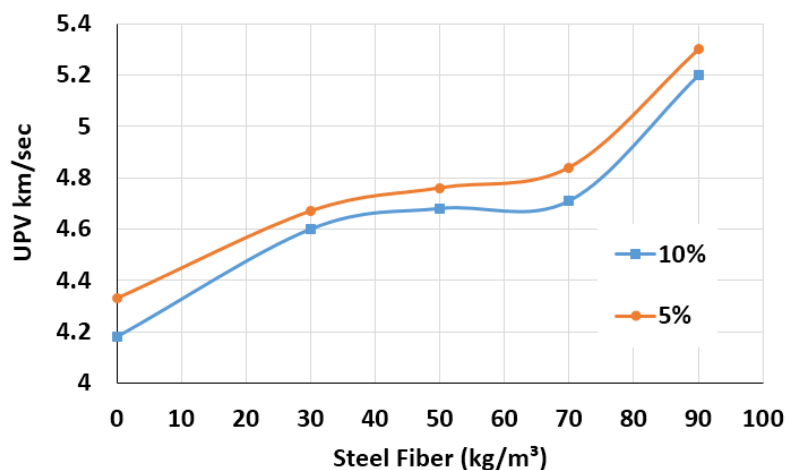
6.4. Effect of steel fibers on ultrasonic pulse velocity (UPV) through SFR-RCC

The UPV results for samples containing different amounts of SF with (0%, 5%, and 10%) CMs replacement by CMs at different ages are reported in table 4. It can be noticed that the UPV results showed an increase in velocity with the increase in RCC age, reaching 4.47 km/sec at 28-days for the control mix with (0%) of CKD and (0 Kg/ m³ SFR).

Table (4) Results of UPV at ages of (3, 7, 14, 21 &28) days.

CKD		0%	5%					10%				
	SF (kg/m ³)	0	0	30	50	70	90	0	30	50	70	90
Velocity (km/sec) at age of	3-days	2.96	2.93	3.20	3.12	3.21	3.53	2.79	3.04	3.34	3.15	3.45
	7-days	3.69	3.58	3.97	3.98	4.10	4.18	3.50	3.92	3.90	3.97	3.91
	14-days	3.94	3.66	4.13	4.24	4.59	4.56	3.58	4.02	4.16	4.46	4.46
	21-days	4.23	4.15	4.60	4.63	4.72	4.83	3.81	4.51	4.59	4.63	4.80
	28-days	4.47	4.33	4.67	4.76	4.81	5.30	4.18	4.60	4.68	4.71	5.20

The UPV results for all specimens at 28 day age are illustrated in figure 8. The results showed an increase in the pulse velocity with increasing the content of SF, where the sample with 5% CKD and 90 kg/m³ SFR was 5.30 km/sec. However, the velocity was noticed to decrease with the increasing CKD ratio, indicating the well-known relationship between UPV and modulus of elasticity.

**Figure 8.** The UPV results for all specimens at 28 day age.

The increase in pulse velocity with increasing the content of SFs could be attributed to the propagation of ultrasonic waves via SF at a higher rate. Thus, the content of SF should be taken into consideration when analyzing the results of speed in RCC reinforced with the high amount of reinforcement. This also indicates that the relationship between strength and velocity in SFR-RCC is not similar to the relationship adopted for the plain concrete. Additionally, the results of UPV indicated that the RCC mixes had a good concrete quality, especially for the fiber reinforced specimens. These results are within the requirements of the surface layer of pavements used in airport apron. The results had shown the feasibility of using SF to reinforce RCC in which CKD was used as a substitution for 5 to 10 % of CMs, which contributes to enhance the properties of RCC and deleting the negative impacts of CKD on the environment. However, the surface treatment must be taken into consideration, to avoid the risk of steel fiber damage, and the expected effect of SF on air crafts communication in airports. Using an asphaltic overlay may give a solution for such problems.

7. Conclusions

- 1- The results proved that density, compressive, and flexural strength of RCC, besides UPV results were enhanced by reinforcing the concrete with SF.
- 2- These improvements of the RCC characteristics, increased with increasing the content of SF in the RCC mixes.
- 3- Adding (30, 50, 70, and 90 kg/m³) of SF enabled the SFR-RCC to be used as a surface coarse in airport pavement.

- 4- Regarding the consistency of the concrete, there was a decrease in the workability of RCC (more water requirement) with increasing fiber content. Moreover, water requirement was decreased when using CKD replacement up to 10%.
- 5- Using SF with the proposed replacement proportion of CKD in pavement design, is well sustainable to be used in airport aprons construction.
- 6- An asphaltic overlay must be utilized to avoid the risk of breaking of SF in SFR-RCC pavements used in airport aprons, as the pavement surface is expected to be exposed to high fictional stresses.

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