Influence of polypropylene fibers reinforcement on the mechanical properties of roller compacted concrete used in airports with partial replacement of cement by cement kiln dust

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Abstract. This study presents the influence of polypropylene fiber (PPF) reinforcement on the mechanical properties of roller compacted concrete (RCC) in which the cementitious materials (CMs) were partially replaced with cement kiln dust (CKD). Characteristics of RCC with partial replacement of CMs with CKD, reinforced with different PPF contents (0.04, 0.1, 0.5, 1, and 2.5%) were studied. The results clarified that the inclusion of PPF could affect the mechanical properties and cracking behaviour of RCC. It was shown that reinforcing RCC with 0.04%, and 0.1% PPF enhanced the flexural and compressive strength of RCC beside that the mode of tensile failure of RCC had been changed from brittle to ductile failure with successive cracking pattern. The research results indicated that a substantial increase (more than 57%) in flexural strength of RCC was attained by using 0.1% PPF to reinforce RCC with 5% or 10% of CMs replaced with CKD. These findings is of great important in utilizing RCC reinforced with PPF (PPFRCC) in airports pavements. However, it was noticed that using more than 0.1% content of PPF affected adversely the mechanical properties of RCC. The present research proved that using specified content of PPF could improve the mechanical properties of PPFRCC to fulfil the requirement airport aprons concrete pavements beside the beneficial impact on reducing the contamination of the environment.

1. Introduction
Roller compacted concrete is a type of concrete that is compacted with rollers. This type of concrete can support the compacting roller weight before completing hydration reactions of cement compounds [1]. RCC is usually laid in layers with a compacted thickness of no more than 250 mm. In this regard, roller compaction is done with conventional earthwork machinery or heavy road construction equipment often a vibrating roller, in layers called lifts [2][3]. RCC pavements are typically built to carry traffic immediately after completion [4].

RCC is a high-strength material that has been successfully invested in many applications, such as: low-maintenance highways, parking lots, industrial roads, intersections, city streets, heavy-duty pavements, highway weighing stations, airport pavements, pavement bases, and pavement shoulders airport aprons, container ports, and heavy industrial facilities. These uses of RCC had resulted in significant cost savings over asphalt cement and Portland cement concrete pavements, besides its low
RCC contains the same ingredients as conventional concrete but with different grading requirements and different types of admixtures. Also, RCC is characterized with different consistency requirements as it possesses zero slump when mixed and placed [7], it must be dry enough to be compacted by vibratory rollers, but wet enough to allow for distribution [8][9][10]. A small amount of paste has a big impact on RCC's mechanical behavior compared to conventional concrete. RCC's tensile strength to compressive strength ratio varies between 7% and 13%.[10][11], while other researchers [12] stated that the ratio between flexural and compressive strength of RCC is approximately 0.15, whereas it ranges between 0.10 to 0.12 in the case of conventional concrete. However, A minimum 28-day compressive strength (fc) of 30 MPa, flexural strength of (4.1-4.8) MPa are generally specified when RCC is used as a surface course for airport pavements [6][13][14].

Many attempts were furnished to use certain lowcost materials to substitute cement in RCC. Debbarma et al. (2020) [15] mentioned that the use of industrial wastes (15% of fly ash (FA)) could be employed to produce sustainable RCC pavement mixes. CKD was intended to activate fly ash to act as a supplementary binder material with cement due to its high percentage of alkalis as stated by Czapik et al. (2020) [16]. In fact, it is so important to reduce the risks of pollution that these contaminants pose to the environment, as large quantities of (CKD) are generated as a byproduct of cement plants. The CKD consists of unreacted raw feed and partially calcined ash and clinker dust. The constituents of ckd are halides, alkali sulfates, and other volatiles as stated by Adaska (2008) [17], and ASTM D 5370-14 [18]. In this respect, Altameemi and Alikhan [19] demonstrated that CKD can be used as a cement substitute in RCC in the construction of airport pavements to save cost and assist the environment by using less cement beside consuming waste materials. They stated that the RCC specimens in which 5% of the CMs was replaced by CKD possessed the best properties in comparison with other specimens with 10, and 20% replacement percentages. The study showed that the RCC with 5%, partial replacement of CMs by CKD could fulfill the requirements of the surface layer of airport apron pavements. Ramakrishnan (1986) [20] suggested that blended cements do not affect most of the characteristics of hardened concrete adversely. Also, Maslehuddin et al. (2009) [21] showed that no indicative differences were found for f_c of (0 and 5) percent CKD cement concrete.

New researches had been accomplished to use fibers to develop the characteristics of RCC with partially replacement of CMs with CKD. Altameemi and Alkelabi [22] studied the influence of steel fiber reinforcement on the characteristics of RCC with partial replacement of cement by cement kiln dust. Their results confirmed the feasibility of using steel fiber reinforcement to enhance the properties of SFRRCC used in airport pavements. Polymeric fibers had been used to reinforce concrete mixtures in many places, because of their advantages over metallic fibers regarding to chemical stability, light weight, and economic benefits. Polymeric fibers, especially PPF, had been considered to be beneficial in reducing shrinkage cracking beside enhancing some mechanical properties of concrete [23]. Aulia (2002) [24] presented that the use of polypropylene fiber could affect the fracture properties of high-strength concrete dramatically, but had almost no effects on the compressive strength and modulus of elasticity of hardened concrete. It was shown that using PPF in concrete could help to decrease concrete permeability and its tendency to bleed.[25]. Haider Araby Ibrahim [26] indicated that the addition of PPF had resulted in increasing the flexural strength of recycled self-compacting concrete. He found that best results values were documented when the content of PPF was 0.1 %. According to the results obtained in this study, Figure (1) gives a comparison between the for concrete reinforced with PPF with the flexural strength of plain concrete.
1. Research problem
The important work that had been furnished for using RCC in the construction of airport aprons might continue to get benefit of the gained structural and economic achievements. Moreover, it is of great importance to modify the cracking behavior of RCC, to enhance its low cracking resistance. Previous works employed the technique of using fiber reinforcement to improve the tensile strength, ductility, and toughness of RCC. However, using steel fiber reinforcement in RCC used in airport aprons pavements faced many short-coming related to serviceability and communication problems [22]. The authors expect that incorporation of PPF reinforcement may solve part of those shortcomings. Moreover, substitution of part of the CMs by CKD is a suitable way to enhance the economy of construction, besides solve some environmental problems. This research hypothesis is that the use of PPF to reinforce RCC will enhance concrete properties especially those related to cracking behavior, besides its economic and environmental impact.

1.2. Aim and objective of the research
The primary goal of this research is to investigate the impact of using PPF reinforcement on the properties of RCC pavement in which CMs is partially replaced by (CKD). The effects of CKD and PPF on the mechanical properties, and cracking behavior of fresh and hardened RCC are investigated utilizing RCC specimens reinforced with different contents of PPF. Those specimens were casted, compacted in the laboratory, then tested in conditions similar to site conditions. The proper amounts of PPF to achieve the desired results were investigated to verify the suitability of PPFRRCC pavements to be used in civil airports.

2. Methodology

2.1. Materials
In this research, materials include aggregate, cementitious materials (containing cement and CKD and fly ash), water and polypropylene fibers were used.

2.1.1. Coarse and fine aggregate
Coarse aggregate used in this work was crushed gravel with a nominal maximum size of 19 mm obtained from Al Nibaee quarry. Annajaf desert sand was used as fine aggregate. Both types of aggregate were complying with the limits of IQS No.45-84; (revised 2016) [27].

Figure 1. A comparison between flexural strength of plain and PPF reinforced recycled self-compacting concrete.
2.1.2. Cementitious materials

2.1.2.1. Cement
Al-Kufa sulphate resistant Portland cement (type V) was used throughout the entire work. The physical and chemical properties of this cement were within the requirements of Iraqi specification IQS NO.5-2019 [28].

2.1.2.2. Cement kiln dust (CKD)
The (CKD) used in this work was brought from Kufa cement factory. Table (1) shows the chemical composition of (CKD) used in this work.

2.1.2.3. Fly ash properties
Class F fly ash, bought from an authorized agent, was used. Table (2) presents its properties.

Table 1. lists the properties of CKD and fly ash used in this study.

| Oxide composition\%       | CKD % by weight | Fly ash % by weight | ASTM C 618-05 Class F fly ash |
|---------------------------|-----------------|---------------------|-------------------------------|
| SiO₂                      | 12.02           | 56                  |                               |
| CaO                       | 45.22           | 4.8                 |                               |
| MgO                       | 2.3             | 1.48                |                               |
| Fe₂O₃                     | 2.4             | 24.81               |                               |
| Al₂O₃                     | 4.3             | 5.3                 |                               |
| SO₃                       | 7.02            | 0.36                | 5%, Max.                      |
| K₂O                       | 1.007           | ----                |                               |
| Na₂O                      | 0.628           | ----                |                               |
| (SiO₂) + (Al₂O₃) + (Fe₂O₃) | ----            | 86.11               | 70%, Min.                     |
| Loss on Ignition          | 24.95           | 5.78                | 6%, Max.                      |
| Insoluble Residue         | 9.09            | ----                |                               |
| Specific gravity          | ----            | 2.45                |                               |
| Fineness (% retained on 45μm) Specific surface area, Blain method, m²/kg | 28.99 | 375 |

2.1.2.4. Water
The tap water, was used for mixing and curing of RCC specimens.

2.1.2.5. Polypropylene fibers
Table (2) shows the properties of the PPF used in this work, while Figure (3.1) shows the polypropylene before addition to control mix.

Table 2. Properties of polypropylene fibers.

| Property                  | Value         |
|---------------------------|---------------|
| Specific gravity          | 0.91          |
| Color                     | White         |
| Length                    | 10mm          |
| Modulus of elasticity     | 3500 Mpa      |
| Absorption                | None          |
2.2. Specimens’ preparation and testing
CMs, coarse and fine aggregate, and CKD were the materials used in this work for production of RCC. According to the assumption ranges proposed by ACI 211.3R-02 (Reapproved 2009) [29], and ACI 325.10R-95 (Reapproved 2001) [30], the content of CMs was designed to be (14 %) of the weight of total aggregate, so as to apply the midrange value between those ranges. CMs had been replaced by various CKD proportions (0 %, 5 %, 10 %) by weight CMs. Fixed aggregate ratios of 46% fine aggregate and 54% coarse crushed aggregate were employed according to ACI 327R-14[5]. Class F fly ash was used as an additive at proportion of 20% of absolute volume of CMs. PPF were added to the concrete mixture in five different proportions, which were (0.04%, 0.1%, 0.5%, 1%, 2.5%) of the total concrete weight.

The optimum moisture content (OMC), and maximum dry density for each content of CKD, and PPF were determined using the (2700 KN-m/m3) modified proctor compaction test (ASTM D1557-12) [31]. For the PPFRCC compaction test, procedure C with a mold with 152.4mm diameter was used. The test was performed for thirteen samples. The first sample was containing the calculated amount of coarse and fine aggregate, cement and fly ash. In the second and third samples, (5%, and 10%) of the CMs weight was replaced with CKD. In the remaining samples, PPF was added to it in proportions of (0.04%, 0.1%, 0.5%, 1%, 2.5%) by weight of concrete for mixes with (5, or 10) % CKD replacement of CMs. Different water content (4 %, 5 %, 6 %, 8 %) was used. Then, the results of dry density were plotted against moisture content. The modified proctor molds were prepared for each mix proportion (with different CKD and PPF content). The total number of molds for determination of the OMC reached fifty-two for all mixes. The results were represented by a curve with a defined maximum dry density and optimum content of water.

2.2.1. Proportion of specimen reinforced with polypropylene fibers
Weight of water for mix proportion of PPFRCC mixtures was determined depending on the optimum moisture content results. Other ingredient contents were calculated according to the employed assumptions stated before. A sample of calculation results of ingredients weights in 1 m3 of one concrete mix is shown in Table (3).

Table 3. Ingredients in 1m3 PPRRCC mix with 5% of CMs replaced by CKD, PPF = 0.04%

| material         | Coarse aggregate | Fine aggregate | cement | Fly ash | CKD | PPF | Water | W/CMs | Over all |
|------------------|------------------|----------------|--------|---------|-----|-----|-------|-------|---------|
| weight (kg)      | 1069             | 911            | 217    | 45      | 14  | 0.791| 103   | 0.39  | 2360    |
2.3. The molds
For casting RCC specimens, the steel mold used in this work had inner dimensions of (380*380*100) mm. It was attached to a steel base plate of (650*600*10) mm with four (100*100*10) mm steel angles fixed on it.

2.4. Mixing process
The mold was cleaned, especially from the inside where the concrete was poured, before placing the RCC mix in the mold, nylon sheets were used to prevent the leaking out of water and fine mix materials from the sides of the mold during compacting concrete, in addition to minimizing the adhesion of the mixture to the mold after hardening. The materials were mixed proportioning the RCC mixture for two minutes. Half of the coarse, and fine aggregate with half of water content were added firstly, followed by cementitious materials (cement, CKD and PPF), The remaining content of aggregate were then added, and then the remaining water.[31]. The wet mixing process continued for (4-6) minutes. PPFs were added to the wet mixture, blended uniformly through the mixing period.

2.5. Compaction of specimens
As had been suggested by previous researchers Sarsam [32], (Abed 2014) [33], Altameemi and Alikhan [19], and Altameemi and Alkelabi [22], after the mix was cast in three layers in the molds, the first part of compaction was performed using a vibrating table. Each layer was vibrated for 30 sec. To simulate initial compaction at the site during the transport and paving of the mixture. The molds were covered with a nylon sheet after the vibration process was completed to prevent moisture loss. The concrete was then compacted using the roller system shown in Figure (3) to simulate site compaction conditions. Three parts of rolling process was performed, in each part, 15 rolling passes back and forth in the x-x, and y-y direction were utilized to ensure that all parts of the mixture were efficiently compacted. The rolling was done in the first part with a static load of 38 kg, which reflected the rolling device's self-weight. In the second and third parts, the same roller compaction technique was used, but with an additional static weight of 38 kg and 69 kg in the second and third parts, respectively.

![Figure 3. The roller device.](image)

2.6. Curing process
Curing was applied immediately after the rolling compaction had been completed. The molds were thus covered as quickly as possible to prevent moisture loss. A layer of nylon cover was used for the initial curing of molds for 24 hours before taking of the specimens from the molds. Then the RCC specimens were cured using the curing method proposed by Altameemi [34] which utilized dripping system for continuous controlled moist curing using a network of drip sprinkles fixed on plastic tubes connected to a source of tap water. This curing method was intended to simulate site curing of RCC pavements.
2.7. Sawing and testing of Specimens
Saw cut had been done in accordance with ASTM C42/C42 M-04[35] using a steel-diamond saw disk. The specimens were sawed into cubes with a size of 100*100*100 mm and prisms with a size of 380*100*100 mm. The sawed cubic specimens were tested at 28 days after casting according to BS EN 12390-3-19 [36] using 1900 KN capacity compression machine. The average of readings of three cubes was considered, while prisms were tested for flexural strength in accordance with ASTM C78-02 [37]. The flexural strength of RCC was determined by averaging the results of two prisms.

3. Results and discussion
3.1. Compressive strength
Figure (4) explain the results of compressive strength for plain RCC with different percentage of CMs replacement with CKD.

![Figure 4](image)

**Figure 4.** Compressive strength with CKD % substitution of CMs of control samples.

The results showed that with replacement of 5% CMs with CKD, compressive strength increased by approximately (3.3 %) in comparison with control mix. However, when CMs replacement with CKD increased to 10 compressive strength of RCC decreased by about (4.8%) compared to control mix results. It can be concluded that the 5% substitution of CMs could improve the RCC's mechanical properties. This could be attributed to the contribution of fine CKD in reducing the volume of voids in the paste of CMs, resulting in greater density and better mechanical properties. On the other hand high amounts of CKD as characterized with low release of calcium silicate compounds (C3S and C2S) besides high insoluble residue and high loos on ignition. Thus, the use of high CKD content to replace CMs will result in reduction compressive strength. These findings are in line with the results obtained by Mohammad and Hilal (2004) [38] who found that replacement of (10,30,50) percent of cement with CKD resulted in a decrease in compressive strength which mainly affects the rate of strength gain. Additionally, in CKD, there is a greater amount of chloride, Crystallization causes the assortment of hydration products to be crystallized, which causes the pore system of hardened samples to open, leading to a decrease in strength.

3.2. Effect of PPF on compressive strength
The results of compressive strength of the RCC specimens reinforced with different content of P.P.F. are shown in figure (5)
Figure 5. shows the relationship between compressive strength and percentages of CKD, and PPF.

After addition PPF by different percentage (0.04, 0.1, 0.5, 1, 2.5) % to RCC mixes with (5%, 10%) of CMs replaced with CKD, the results of tests showed that reinforcing the RCC with (0.04%) PPF, resulted in a bout (4.4%) decrease in comparison to the mixes with replacement of 5% of CMs with CKD. However, in case of mixes with 10% of CMs replace by CKD the compressive strength was increased by about (6%) compared to plain mixture the same CKD. Also, the results showed that where using 0.1% PPF. in mixes with replacement of 5% and 10% of CMs by CKD the compressive strength was increased by about (10.7%). Moreover, it can be noticed that increasing the content of PPF more than (0.1%) could reduce the compressive strength of PPFRRCC. For mixes with the replacement of 5% of CMs by CKD, using 0.5% P.P.F. decrease the compressive strength by about (22.5%), while in mixes with 10% of CMs by CKD, the compressive strength was decreased by about (18.5%). A large decrease in compressive strength was encountered when using (2.5%) PPF. The reduction was (56.5%) and (61.3%) for mixes with CMs replace (5%, 10%), respectively. This reduction in compressive strength is interpreted to “the low polypropylene fiber elasticity modulus. The compressive strength decreases and this causes, before failure appears, a drastic transformation attributable to the strain. In addition, the bond between fibers and the matrix is reduced in proportion to single-fiber structures and reinforcements due to the structural properties of polypropylene”.[39]

3.3. Flexural strength

For RCC specimens with different contents of CKD and polypropylene fibers, Figure (6) shows the results for flexural strength at 28 days. It appears that the flexural strength results were reduced compared to the control mix with all CKD replacement percentages. It can also be noted that the highest flexural strength value for the control mix (0 % CKD) was 6,233 MPa, then decreased to 5,544 MPa for the mix (5 % CKD).

When increasing CKD replacement to (10 % CKD) of CMs, the result also shows a significant decrease in flexural strength as it reaches 5.306 MPa.
Figure 6. Flexural strength with CKD % substitution of CMs of control samples.

The decrease in flexural strength with increased percentages of CKD replacement is related to the same reasons mentioned when discussing the results of compressive strength. High chloride content of CKD, which causes hydration products to crystallize, leading to a weakening of the pore system and a reduction in strength as a consequence.

3.3.1. Effect of P.P.F. on flexural strength

The results of flexural strength of the RCC specimens reinforced with different content of PPF are shown in figure (7). After addition PPF by different percentage (0.04, 0.1, 0.5, 1, 2.5) % to RCC mixes with (5%, 10%) of CMs replaced with CKD, the results of tests showed that reinforcing the RCC with (0.04%) PPF resulted in a bout (7%) increase in comparison with the mixes with replacement of 5% of CMs with. However, in case of mixes with 10% of CMs replace by CKD the flexural strength was increased by about (4%) compared to plain mixture the same CKD. Also, the results showed that using 0.1% P.P.F. in mixes with replacement of 5% or 10% of CMs by CKD, the flexural strength was increased by more than 57% respectively. Moreover, it can be noticed that increasing the content of P.P.F. more than (0.1%) could reduce the flexural strength of PPFRRCC. For mixes with the replacement of 5% of CMs by CKD, using 0.5% PPF decrease the flexural strength by about (12%), while in mixes with 10% of CMs by CKD, the flexural strength was decreased by about (42%),

Figure 7. Shows the relationship between (CKD, PPF) and flexural strength.
A large decrease in flexural strength was encountered when using (2.5%) PPF. The reduction was (77.8%) and (60.9%) for mixes with CMs replace (5%, 10%) respectively. Low volume fractions of PPF had a greater influence on flexural strength, but increased PPF levels led to a decrease in flexural strength. The addition of PPF to RCC blends has improved its mechanical characteristics. But to a certain ratio, which is 0.1%, after which the effect becomes the opposite. The increase in flexural strength due to inclusion of PPF could be justified by the high stretched film's strength of the fibers that may vary from 300 MPa to 500 MPa [39].

3.4. Cracking behavior of PPFRCC

The test results proved that using PPF to reinforce RCC specimens enhanced significantly the cracking behavior to PPFRCC. The brittle crack pattern associated with control specimens (without PPF) had been changed to ductile failure with successive cracking. This finding is clarified in Figure (8).

![Figure 8. The ductile failure of a PPFRCC specimen.](image)

This behavior could be interpreted according to the fact that PPFs are high-performance have a hydrophobic surface as a reinforcement material, so the fiber does not flocculate when it is soaked with a cement binder in the matrix material. Therefore, micro-propylene fibers are used to avoid the appearance of small cracks that may occur due to changes in the early thermal volume of the hardened cement materials, plastic shrinkage and premature drying [39]

4. Conclusions

According to the conditions of the research, including the types of materials, experimental circumstances, the following remarks can be concluded:

- The research results confirm the research hypothesis that the addition of certain contents of PPF to reinforce RCC with partial replacement of CMs with CKD, did enhance the mechanical properties of this type of concrete.

- Using of PPF to reinforce RCC enhanced cracking behavior of concrete. Tensile failure had been changed from brittle to ductile failure with successive cracking behavior.

- Reinforcement of RCC with PPF content of (0.1%) by weight of CMs was the best choice to enhance the flexural, as well as compressive strength of RCC.
Using more than 0.1% content of PPF to reinforce RCC with partial replacement of CMs with CKD, affected adversely, the mechanical properties, besides lowering the density of RCC

A substantial increase in flexural strength of RCC was attained by using 0.1% PPF to reinforce RCC with 5% or 10% of CMs replaced with CKD. These findings is great important in utilizing P.P.F.R.- RCC in parameter of airports.

RCC with 5% or 10% CMs replacement with CKD reinforced with 0.04% or 0.1% PPF can fulfill the requirement of the aerodrome design manual and related advisory circulars for mechanical properties of RCC pavements at airports aprons.

RCC with 5% CMs replaced by CKD when reinforced with 0.5% P.P.F. can be suitable for subsurface pavement layers in airports.

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