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# Impact of Recycled Polypropylene Fibers on the Density and Strength of Unreinforced Concrete

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## ABSTRACT

Polypropylene (PP) is widely used in the construction industry to produce a variety of materials. Accordingly, a huge amount of waste is produced during or after the construction activity. The PP fiber provides a good alternative solution to enhance concrete properties and more sustainable concrete produced in terms of isolation and weight reduction. In this study, 24 concrete cubic samples are cast by adding different PP fiber content to characterize this fiber effect on concrete density and unconfined compressive strength (UCS). The results demonstrate that using higher fiber content of 2%, 6%, and 10% leads to a mass reduction that equals to 59, 157, and 290 kg compared to normal concrete per one cubic meter. However, at higher PP fiber content, the unconfined compressive strength decreases compared to the controlled samples. The concrete mix with 2% PP fiber revealed a higher value of compressive strength with increment by (10-12)% at age (7-28) days compared to normal concrete. The outcomes imply that using PP fiber contributes to the protection of the environment by reducing the quantity of PP waste from construction materials.

**Keywords**: recycled fibers; polypropylene Fibers; mechanical properties of concrete; UCS.

## 1.0 INTRODUCTION

In the world of building and construction, continuous developments and innovations are evident in improving the performance of construction materials. The use of polypropylene fiber, particularly in concrete mixes, is a notable innovation [1-3]. This use has positive effects on the compressive properties of concrete by enhancing its strength and improving its load response [4].

The problem of waste resulting from construction work is one of the important environmental challenges of our time [5, 6]. As construction activities increase, the volume of excess material produced during these processes increases, contributing to the accumulation of construction waste. This includes residual concrete, bricks, timber, steel, and plastic waste, which lead to negative impacts on the environment and public health. In this context, it requires thinking about sustainable solutions to manage this waste and reduce its negative impact on the environment.

Plastic waste, especially polypropylene, is accelerating in the construction sector [7]. Polypropylene is widely used in the construction industry to produce a variety of materials, such as pipes, panels, doors, etc. This waste is considered as environmental challenge since it is accumulated on construction sites or disposed of in unsustainable ways. Plastic is the second most widely used material in construction [8], contributing about 4% of plastic waste worldwide [9]. Iraq is also in the fourth place in the Arab world in terms of the percentage of plastic waste destined globally at 0.8% [10]. Due to its negative impact on the environment and the high rate of degradation time, recycling is essential as stipulated in the SDGs goals 11 and 13 [11]. Ordinary unreinforced concrete is brittle and has low tensile stress strength, high cracks during concrete shrinkage, and relatively massive weights. This encourages researchers to add plastic fibers, especially polypropylene fibers, into concrete to enhance their mechanical properties in several ways. These fibers are commonly used as a kind of reinforcement in concrete to improve its strength, durability, and other properties.

Therefore, the PP fiber is widely used in fiber-reinforced concrete (FRC) following the optimization of concrete characteristics being inexpensive and durable material [12] to replace the steel fiber [13]. For example, Kakooei, et al. [1] studied the impact of using (0-2) kg/m$^3$ of PP fibers to improve the compressive strength of concrete compared to normal concrete. Compared to 0% of PP fiber concrete, Ramujee [14] observed an increase of more than 10 MPa in UCS value and about 1 MPa in tensile strength for concrete with 1.5 % PP fiber. On the other hand, the impact resistance improved by adding about 1 kg of PP fiber compared to normal concrete [15]. Using 1% Macro PP fiber, the compressive strength increases up to 10% compared to plain concrete by adding 0.1 of basalt fiber [16]. However, Pangestuti, et al. [17] observed that increasing the PP fiber content higher than 1% causes a drop in the compressive strength value.

Considering the density, [18] elaborated that adding 2.16% PP fiber decreases the density of concrete mix at about 5 kg per cubic meter compared to concrete with 0% PP fibers. On the same line, the fresh unit weight decreases about (1.5 – 2) kg by adding (1-1.5)% of PP fiber [19]. Meanwhile, Richardson [20] noticed a 200-gram

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reduction in cubic concrete sample weight by increasing the PP fiber content from 0.45 % to 1.8 %. Referring to the above studies, minimal lights are subjected to utilizing recycled PP fiber in concrete [21] such as in precast concrete [22] or in footpaths [23].

In this study, recycled polypropylene (PP) fibers from packing tapes are used to reinforce a concrete mix (1:2:4) with an added fiber percentage of 2%, 6%, and 10% of the gravel weight to evaluate the reduction of concrete mix weight and improve the compressive strength of reinforced concrete with polypropylene fibers compared to normal concrete.

## 2.0 METHODS AND MATERIALS

Four groups of concrete mixes are used to module 24 cubic concrete samples (i.e., 6 samples for each group). The first group of samples consists of concrete mix design 1:2:4 and the other three groups have a fiber content of 2, 6, and 10 % for the percentage of the gravel weight as shown in Table 1. The cubic sample dimensions are 15 x 15 x 15 cm for length, width, and height, respectively.

### 2.1 Materials

The description of the materials that form each type of concrete and its physical properties is presented in the sections below.

#### 2.1.1 Cement

Al-jesar-packed cement is used in this research. The physical and chemical properties are checked according to the Iraqi specification NO.5 ( IQS 5: 1984) [24] as presented in Tables 2 and 3.

**Table 1.** Mix design of each group of samples.

| Group Type | Cement (kg) | Gravel (kg) | Sand (kg) | Fibers (%) Added | *w/c* |
|---|---|---|---|---|---|
| T0 | 3.81 | 15 | 7.62 | N/A | 0.5 |
| T2 | 3.81 | 15 | 7.62 | 2 | 0.5 |
| T6 | 3.81 | 15 | 7.62 | 6 | 0.5 |
| T10 | 3.81 | 15 | 7.62 | 10 | 0.5 |

**Table 2.** The chemical properties of Al-jesar Portland cement.

| Oxide | Test Result | Limits according to IQS | Conformed to IQS |
|---|---|---|---|
| Calcium oxide, CaO | 62.23 | ------------------ | |
| Silicon dioxide $SiO_2$ | 22.01 | ------------------ | |
| Aluminum oxide $Al_2O_3$ | 5.49 | ------------------ | |
| Ferric oxide $Fe_2O_3$ | 3.93 | ------------------ | |
| Magnesium oxide MgO | 2.54 | $\leq$ 5% | OK |
| Sulphur trioxide $SO_3$ | 2.23 | $\leq$2.3% | OK |
| Loss of ignition (L.O.I) | 0.83 | $\leq$4% | OK |
| Lime Saturation Factor (L.S.F) | 0.86 | 0.66 – 1.02 | OK |
| S.M. | 2.34 | ------------------ | |
| Tricalcium silicates $C_3S$ | 31.73 | ------------------ | |
| Dicalcium silicate $C_3A$ | 39.42 | ------------------ | |
| Tricalcium aluminate $C_3A$ | 3.44 | $\leq$3.5% | OK |
| Tetera calcium aluminum ferrite $C_4AF$ | 11.95 | ------------------ | |

**Table 3.** The physical properties of Al-jesar Portland cement.

| Physical properties | Test Result | Specification IQS:5-1984 |
|---|---|---|
| Specific gravity | 3.15 | |
| Fineness: specific surface, Blain. $cm^2/gm$ | 3452 | ≥ 2300 |
| Setting time, vicat's method | | |
| Initial hrs: min | 3:26 | ≥1 hr |
| Final hrs: min | 4:15 | ≤ 10 hrs |
| Soundness: autoclave % | 0.19 | 0.80 |
| Compressive strength, MP, fc 3d | 18.6 | > 15 |
| FC 7d | 26 | > 23 |
| Fc 28d | 39.5 | |

#### 2.1.2 Fine aggregate and coarse aggregate

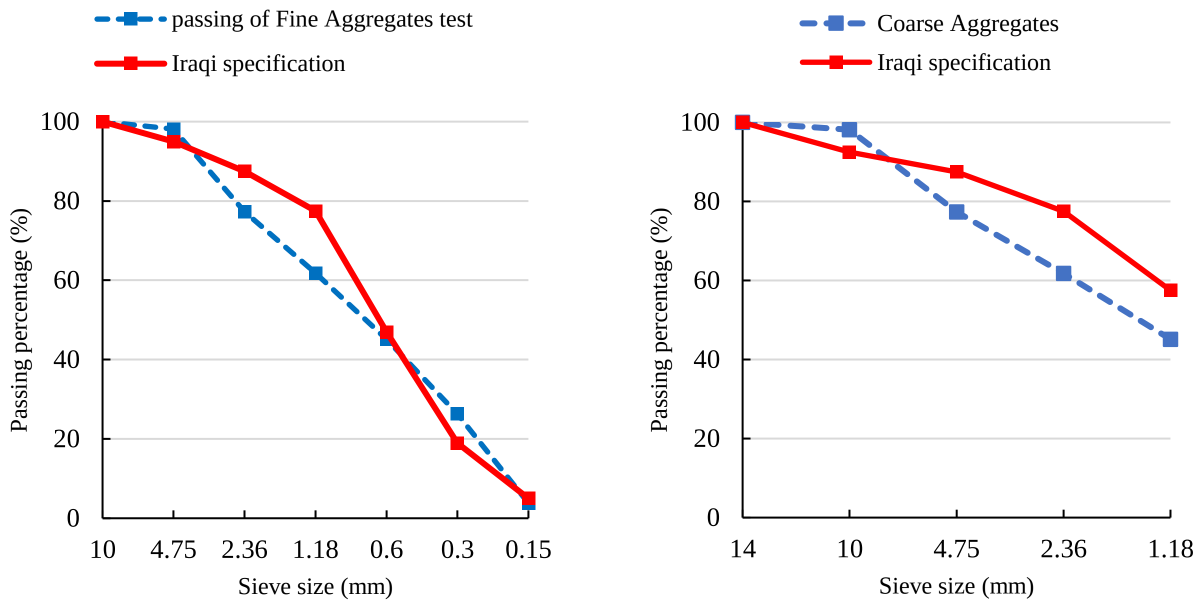
The aggregate used in all the mix designs is collected from local suppliers by considering the maximum size and the grading of the aggregate. The coarse aggregate is well washed to remove the impurities and clays adhesive to the aggregate particles. Tables 4 and 5 present the granular gradation of both fine and coarse aggregate concerning the Iraqi specification, respectively [25]. Meanwhile, Figure 1 (A and B) presents the matching of the fine and coarse aggregate diagram with the ideal graduation by [25].

**Table 4.** Fine aggregate graduation concerning the Iraqi specification.

| No | Sieve size | Passing% | |
|---|---|---|---|
| | | Fine Aggregates test | Iraqi specification |
| 1 | 10 (mm) | 100 | 100 |
| 2 | 4.75 (mm) | 98.15 | 90 -100 |
| 3 | 2.36(mm) | 77.32 | 75 -100 |
| 4 | 1.18(mm) | 61.80 | 55 - 90 |
| 5 | 600 (μm) | 45.14 | 35 - 59 |
| 6 | 300(μm) | 26.34 | 8 - 30 |
| 7 | 150 (μm) | 3.8 | 0 - 10 |

**Table 5.** Coarse aggregate graduation concerning the Iraqi specification.

| Sieve size | Passing% | |
|---|---|---|
| | Coarse Aggregates | Iraqi specification |
| 14 (mm) | 100 | 100 |
| 10 (mm) | 98.15 | 85 -100 |
| 4.75 (mm) | 77.32 | 75 -100 |
| 2.36 (mm) | 61.80 | 55 - 90 |
| 1.18 (mm) | 45.14 | 35 - 59 |




(A) Fine Aggregate (B) Coarse Aggregate

**Figure 1.** Chart shows the conformity of aggregate samples used in this research with the Iraqi specifications for granular graduation.

### 2.1.3 Polypropylene (PP) fibre

Below is the process of collecting, treating, and manufacturing polypropylene fibers from the construction waste to be used in the mixed concrete design.

1. Collecting: Packing polypropylene tapes used to pack bricks and ceramics stocks are collected from construction waste by carefully choosing the undamaged tapes and strips for recycling, as in Figure 2.
2. After assembling the polypropylene tapes or strips, the tapes are washed and cleaned of dust and dirt, then cut using a manual scissor into pieces with the length of about 13 mm.
3. Then these cut pieces are converted into fibers using a rotary grinder as in Figure 3.

**Figure 2.** Collecting polypropylene tapes or strips from construction waste.

(A) (B)

**Figure 3.** (A) Cutting the tapes to 13 mm length to simulate the length of the fiber. (B) Grinding the 13 mm pieces to create fibers.

### 2.2 Material mixing, casting, and curing

In this stage, the materials are mixed and classified into four mix designs as presented in Table 1 by considering the fiber content for each mix as in Figure 4 (A). The mixture is cast in a cubic mold with a dimension of 150 x 150 x 150 mm as in Figure 4 (B). Finally, the samples are moved to water for curing purposes (Figure 4 (C)) to be tested at curing times of 7 and 28 days.

(A) (B) (C)

**Figure 4**. (A) Mixing, (B) Puring, and (C) Curing of mixed concrete with different fiber content.

### 2.3 Material mixing, casting, and curing

#### 2.3.1 Dry density

For each group of concrete with fiber content, the cubic samples are removed from water dried using absorbing fabric and then left inside the oven for 2 hrs at 100$^o$ C to eliminate the effect of water on the determined mass of samples. The samples are then left to reach room temperature for 1 hour outside the oven. It is followed by mass measurement of samples using balance with a total capacity of 10 kg and perception of 0.01 g. The dry density is then determined using the below equation:

$$\text{Dry density} = \frac{\text{M}}{\text{V}} \qquad (kg/m^3) \qquad (1)$$

Where, the mass is the measured value by balance and the volume is measured by measuring tape of the sample length, width, and height.

#### 2.3.2 Unconfined compressive Strength (UCS)

The cubic samples of concrete with fiber content (0, 2, 6, and 10) % are tested under compression in the laboratory of Samarra University, College of Engineering at curing of 7 and 28 days. Three samples are tested for each fiber content for each curing duration mentioned above. The peak failure compressive stress is measured for each sample using the below equation:

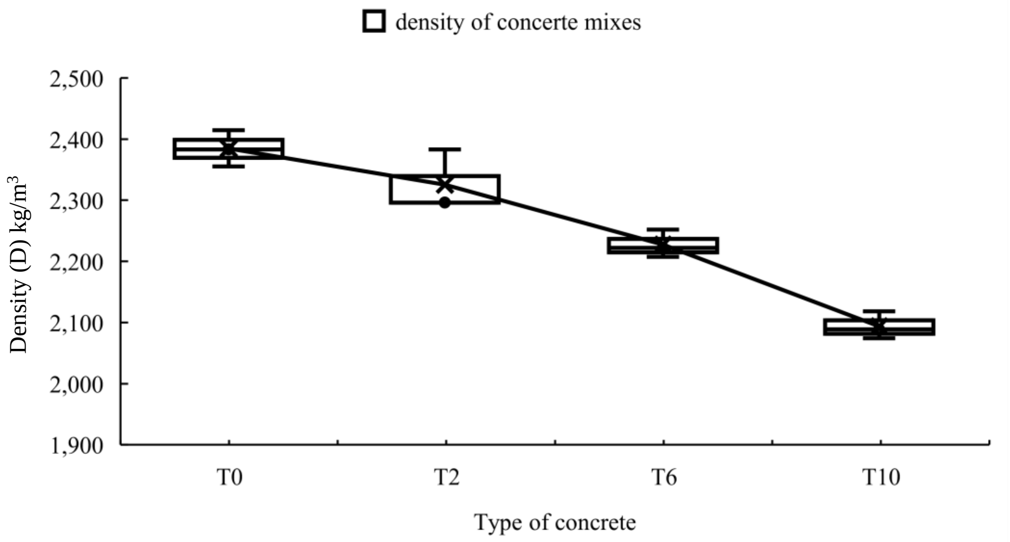
$$\text{UCS (MPa)} = \frac{\text{L}}{\text{A}} \qquad (N/mm^2) \qquad (2)$$

where L is the compressive load applied on the cross-section area (A) of the cubic concrete sample.

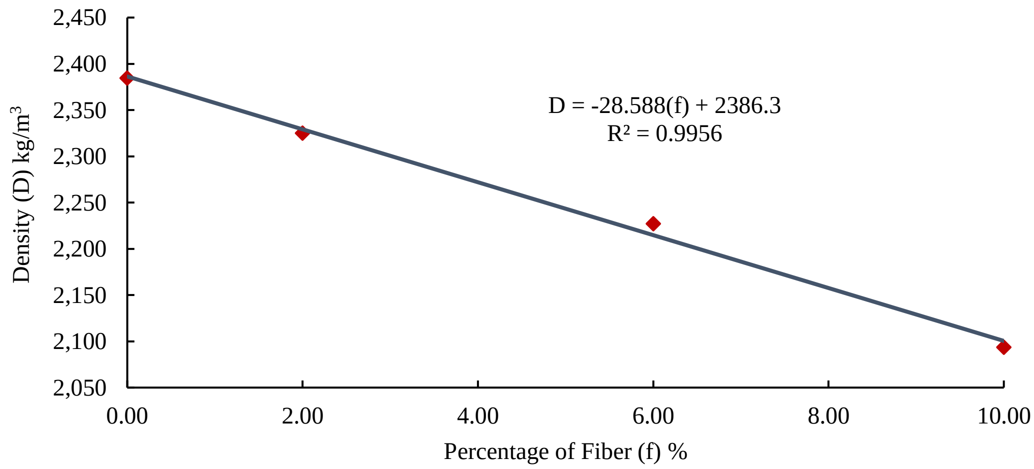
## 3.0 RESULTS AND DISCUSSION

### 3.1 The impact of fiber content on the density

The content of polypropylene (PP) fiber has a significant effect on the density of concrete mix as presented in Figure 5 (A). The density range is decreased by increasing the fiber content. Particularly, the density of concrete without PP fiber is higher than the density of concrete with PP fiber content of 2, 6, and 10 % by 2.54, 7.06, and 13.88 %, respectively. In other words, the usage of PP fiber content of 2, 6, and 10 % in concrete leads to a mass reduction of equal to 59, 157, and 290 kg compared to normal concrete (T0) per one cubic meter. PP fibers are lightweight materials (0.90–0.91 g / cm$^3$) [26] when added to concrete mixture; thus, they disperse throughout the mixture and occupy the space between the aggregate particles. Since these fibers are lighter than traditional concrete materials such as sand, gravel, and cement, adding it reduces the overall mass of the mixture per unit volume, leading to a decrease in density. Besides, this behaviour of mass decreasing, concerning the increase of the added fiber content, can be justified by increasing of void ratio inter-matrix of the concrete mix as observed by previous studies [18, 27, 28]. This reduction is very effective in terms of the total dead load of concrete. Meanwhile, a good fitting is presented in Figure 5 (B) between the average density value and each fiber content with a regression score value ($R^2$) of 0.99.




(A)

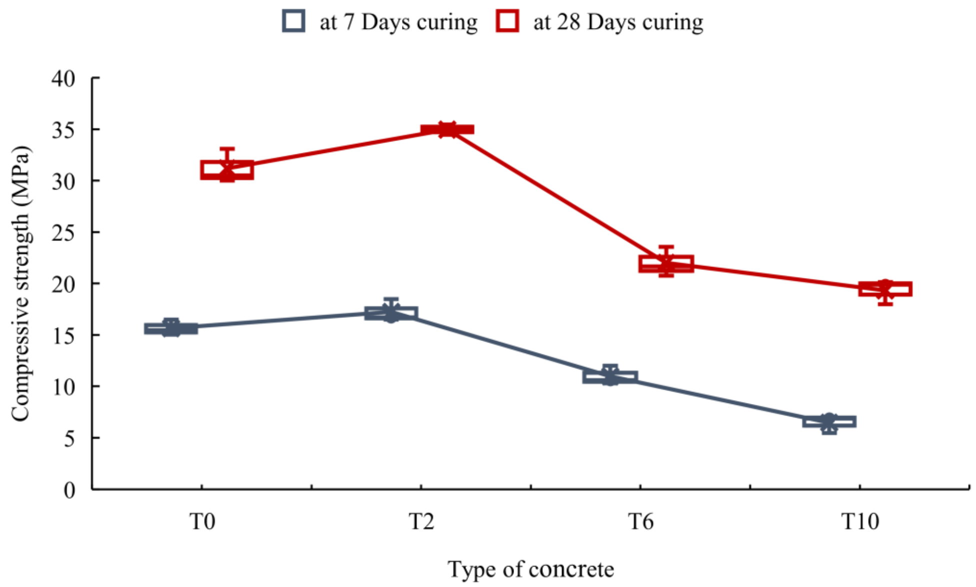



(B)

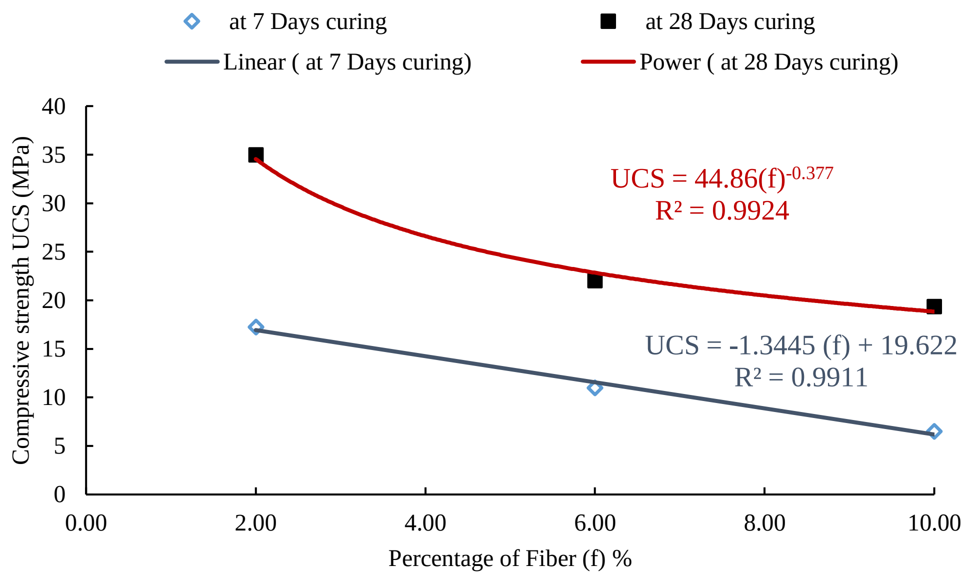
**Figure 5.** The effect of fiber content on the density of concrete. (A) distribution and ranges of densities concerning the mix design type. (B) the correlation between the average density and the fiber content.

### 3.2 The impact of fiber content on the UCS of Concrete

The average UCS values and their range are presented in Figure 6 (A) and Table 6 for each concrete mix design. The UCS values show a great development concerning curing time. The average UCS of concrete type T0, T2, T6, and T10 increases by 99, 102, 100, and 198 % at 28 days compared to 7 days curing duration, respectively. The general trend of UCS range of values implies that the highest UCS obtained is for T2 (i.e., 2% of PP fiber content) at both 7 and 28 days of curing. The magnitude of increment is 10, 57, and 69 % at 7 days of curing and by 12, 59, and 81 % at 28 days for T0, T6, and T10, respectively.




(A)




(B)

**Figure 6.** The effect of fiber content on the UCS value of concrete at 7- and 28-days curing. (A) distribution and range of UCS values concerning the mix design type. (B) the correlation between the average value and the fiber content.

These results suggest that adding 2 % of PP fiber may develop compressive characteristics of normal concrete. On the other hand, increasing the fiber content to 6 and 10 % causes a reduction in compressive strength that reaches up to 29% and 38% of the normal concrete. These outcomes are in line with previous studies which stated that the presence of PP fibers in higher content reduces UCS value [29]. There are several justifications behind this behaviour such as increasing air voids due to the hindering compaction by high fiber content interface [18]. Besides, accumulation and lack of proper distribution of fiber within the concrete matrix cause weak zones inside the concrete [30] and creating coarse pores in the concrete macro-structure [31]. Figure 6 (B) presents a relation between the PP fiber content (f) and the UCS average values at 7 and 28 days.

**Table 6.** The average UCS value for different concrete mix designs at 7 and 28 curing times.

| Concrete Type | UCS at 7 days (MPa) | UCS at 28 days (Mpa) |
|---|---|---|
| T0 | 15.66 | 31.20 |
| T2 | 17.23 | 34.96 |
| T6 | 10.97 | 21.99 |
| T10 | 6.47 | 19.33 |

### 3.3 The relation between the density and UCS

Figure 7 exhibits a correlation of UCS values corresponding to the density of concrete samples. The relation implies an inverse interaction between the concrete density and its compressive strength. By increasing the fiber content, the density of concrete decreases by highlighting the positivity of decreasing the dead load of concrete. Meanwhile, this behaviour is associated with a reduction in UCS values that must be considered in mix design.

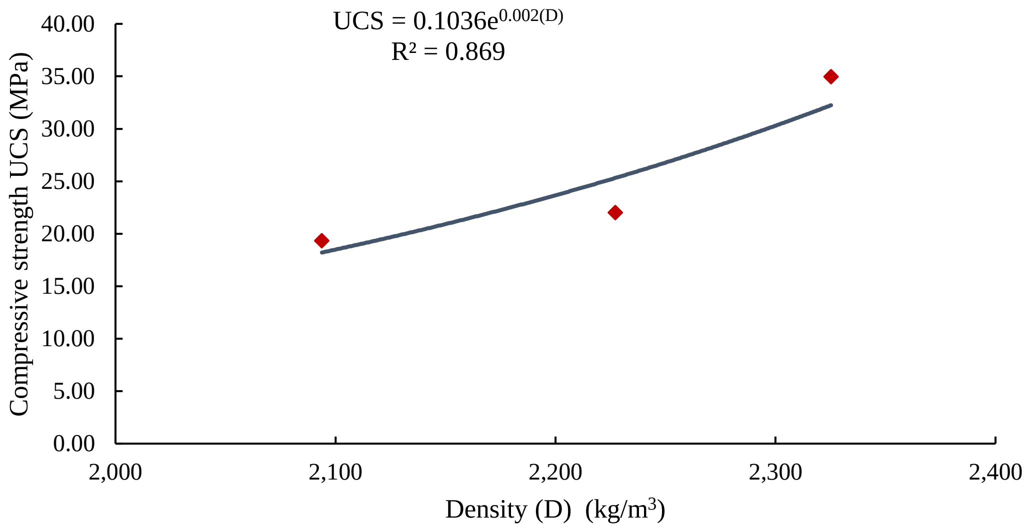



**Figure 7.** The correlation between the average UCS value at 28 days and the density of concrete reinforced by PP fiber.

### 3.4 The environmental impact of recycling PP Fibers

As this study aims to recycle the PP fibers resulting from construction activities, it is crucial to discuss the impact of the current study's proposed solution on the environment. PP fibers are used widely in packing construction materials because of their durability, strength, and low cost. Therefore, reducing the amount of PP waste material could significantly help in reducing the magnitude of these undegraded materials. Table 7 presents the analysis of the approximate amount of recycled PP tape concerning fiber content per cubic meter of concrete. This amount of recycled PP waste in concrete is considered significant compared to the total amount of PP waste as reported by [32].

**Table 7.** The mass of recycled PP waste recycled at each cubic meter of concrete concerning the fiber content.

| Concrete Type | PP Fiber content (%) | Total amount of PP material recycled (Kg/m$^3$) |
|---|---|---|
| T2 | 2 | 29.6 |
| T6 | 6 | 88.8 |
| T10 | 10 | 148.1 |

## 4.0 CONCLUSION

An experimental study has been conducted to characterize the effect of using recycled PP fibers in a constant concrete mix with different fiber content. The results elaborated that using PP fibers in a certain percentage contributes to the development of the physical and mechanical characteristics of concrete. The below points summarize the main conclusions:

- The study outcomes proved that using recycled PP fiber positively contributes to enhancing the concrete compressive strength at lower percentage of added fiber and reducing the density following the increase in fiber content.
- The optimal PP fiber content is about 2% where the unconfined compressive strength reaches a higher value.
- Increasing the fiber content above optimal value causes a significant reduction in UCS values, although, the density of the concrete mix decreases.

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