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Research Article

Using recycled plastic waste as fiber reinforcement on limestone residue mortar

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Abstract: The main purpose of the paper was to study the effect of the geometry of recycled plastic fiber on the performance of mortar based on natural limestone residue. The used fibers were collected from plastic waste of polypropylene, resulting from domestic sweeps fabrication. The main test variables were the type of recycled fibers and the fiber fraction. Two types of recycled fibers were used, straight and crimped fibers, having the same length (20 ± 2mm) and the same diameter (0.45 ± 0.07mm). Four dosages of fibers were considered, 0.5%, 1%, 1.5% and 2 wt. %. The obtained results show that the geometry of recycled plastic fibers has an important effect on the performances of limestone residue mortar. The addition of recycled fibers to mortar decreases its workability and the decrease is higher with crimped fibers. The results reveal that the limited dosage of recycled plastic fiber necessary to obtain a workable mortar is 1% and 0.5% for straight and crimped fibers, respectively. The benefit of recycled plastic fibers is well observed on the flexural and compressive behavior of limestone residue mortar, but the strength's values are higher in straight fibers mortar (SFM) than that in crimped fibers mortar (CFM). The microstructure analysis confirms the good performances of the fiber mortar.

Keywords: recycling, plastic fibers, mortars, strength, microstructure.

1. Introduction

In certain countries, the great need of natural aggregates for concrete production becomes a serious problem. Facing this materials crisis, builders should look for other sources, as residue, wastes and recycled materials. Several crushing stations are installed in Laghouat city, to the south of Algiers, for producing crushed limestone gravels. The enormous quantity of the residue resulting from this crushing operation is in abundance in the nature without any use in construction or in roadwork. The high proportion of fines contained in this residue is one of the main causes limiting its use in the fabrication of concrete; since it needs more mixing water and then can affect negatively concrete properties, as reported by Menadi et al. (2009). However, faced with the over-exploitation of river sand that leads to many ecological problems, the use of limestone residue as replacement sand becomes certainly an adequate solution for both economic and environmental issues (Benyamina et al., 2019) and a good attempt for conducting construction projects. It is important to note that some authors (Belhadj et al., 2014) think that the presence of fines in crushed sand has an economic advantage, since this sand does not need any filler, for its use in concrete. Other authors (Meziane et al., 2015) have also judged that fines present in crushed sand are responsible for its beneficial effect on the mechanical strength and the durability of mortar.

Plastic waste which is one of the most important solid wastes in the world (Bahij et al., 2020) increases every day with the increase of plastic consumption in different human and industrial activities, constituting a real threat for the public health and the environment. Due to its low biodegradability, plastic waste causes many environmental problems, but its recycling in construction is certainly a good way to resolve these problems and fight global warming (Belmokaddem et al., 2020; Rathore et al., 2021) and also to develop promising cementitious products for some particular utilizations. Many researchers have studied the feasibility of certain construction materials containing plastic waste as aggregates (Mercante et al., 2018; Hameed and Ahmed, 2019; Castillo et al., 2020; Liu et al., 2022; Al-Mansour et al., 2022) or as fibers (Serdar et al., 2015; Karanth et al., 2017; Bhogayata and Arora, 2018; Araya-Letelier et al., 2019; Echeverria et al., 2019; Alyousef et al., 2021; Awoyera et al., 2021; Mohammed and Mohammed, 2021; Thakare et al., 2021; Kumaresan et al., 2023).

In addition of their environmental benefits, plastic waste fibers can improve the mechanical performance of concrete and mortar and render them more ductile, by reducing cracking risk. Many examples in the literature confirmed all these benefits; such as the review of Kaliyavaradhan et al. (2022), where it is reported that the reinforcement of concrete by PVC fiber improves the compressive, the flexural and the split tensile strengths. Meza et al. (2021) have concluded that recycled PET fiber generates a similar improvement on the performance of concrete as that of virgin fibers. Also, Al-Tulaian et al. (2016) have previously demonstrated through their experimental tests that recycled plastic waste fibers significantly reduced the plastic shrinkage cracking, the total crack areas and the average crack widths of mortar slabs surface. In the work of Pešić et al. (2016), it was reported that the recycling of plastic fibers of high-density polyethylene have contributed to the reduction of plastic shrinkage cracking, drying shrinkage and water permeability. To effectively achieve a load transfer between the fiber and the matrix, Araya-Letelier et al. (2019) recommend the use of long fiber lengths and large fiber dosages.

In the light of the literature, there is usually a need to recycle the different wastes for the production of eco-friendly construction materials. It is in this context that, this study was conducted by replacing the alluvial sand that is over-exploited by limestone residue which is in abundance to prepare a mortar with low cost. For enhancing the mortar' quality, a recycled plastic waste obtained from the fabrication of domestic sweeps was used as fibrous reinforcement. The particularity of this work resides in evaluating the impact of the geometry of this waste on the properties of the mortar, at fresh and hardened state. Depending on its properties, the obtained mortar can have many applications in the structures. It is well known that the efficiency of fibers on the material quality seems depending on their nature, geometry, mechanical properties and dosage. Hence, the present investigation aims to evaluate how these parameters affect the material properties, such as the workability, the mechanical strength and the microstructure. In this work, two geometries, straight and crimped fibers were tested, in various dosages 0.5%, 1%, 1.5% and 2 wt. %.

2. Materials and tests

A limestone residue with granular class of 0/2mm, Portland cement CEM II/A of class of 42.5MPa and recycled plastic fibers were used for preparing the tested mortar. The residue which was used as sand is a natural residue resulting from the crushing of limestone rocks; it contains almost 27% of fines less than 0.16mm and 6% less than 0.063mm, has a specific density of 2.52g/cm^3, a fineness of 1.8, a visual sand equivalent of 68%, a compactness of 58% and an absorption of 4.5%. The value of 0.13ml/g of Methylene blue confirmed that the clay minerals present in this residue were not harmful for the material durability. The distribution of particle sizes of used residue is shown in Figure 1. The chemical composition of cement and limestone residue is given in Tables 1 and 2, respectively.

The fibers were collected from a plastic waste of polypropylene (PP) fibers, resulting from the fabrication of domestic sweeps. Fibers with two geometries were used, straight (Figure 2 (a)) and crimped (Figure 2 (b)) fibers, having the same length (20 ± 2mm) and the same diameter (0.45 ± 0.07mm). Figures 2(c, d) illustrate some microscopic details of recycled plastic fiber. The properties of the used fibers are regrouped in the Table 3. For each type of fibers, four dosages were considered in this investigation, 0.5%, 1%, 1.5% and 2wt. %. Mixture proportions of tested mortars are shown in Table 4.

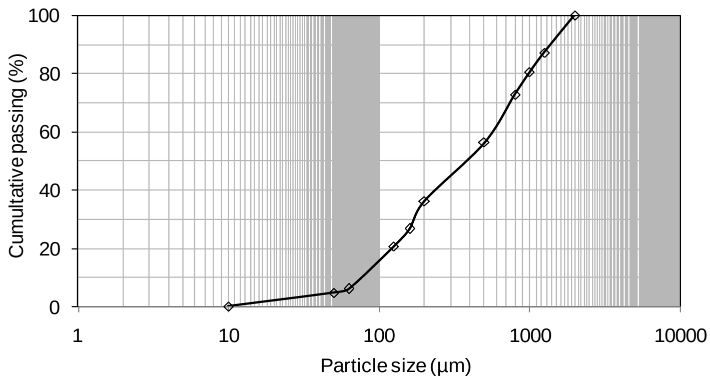


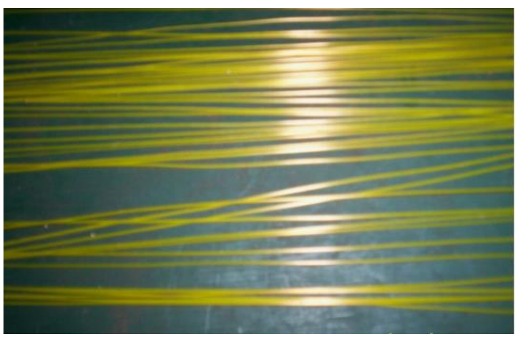
Figure 1. Particle size distribution of limestone residue.

Table 1. Chemical composition of the cement (%).

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SiO_3	K_2O	Na_2O
65.90	21.94	4.82	3.94	1.65	0.98	0.60	0.10

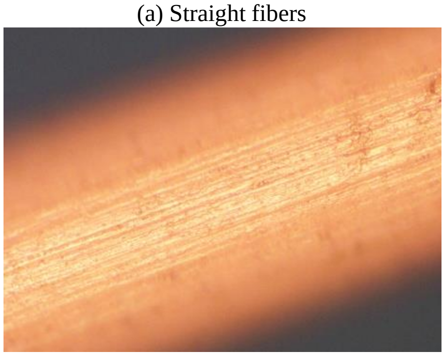
Table 2. Chemical composition of the limestone residue (%).

$CaCO_3$	SO_3^{-2}	Insolubles materials
90	0.51	6.8

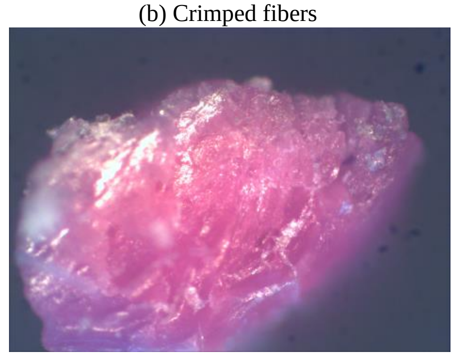


(a) Straight fibers

(b) Crimped fibers



(c) Microscopic appearance of the fiber surface 100X



(d) Microscopic appearance of the fiber cross-section 100X

Figure 2. Shape and geometry of recycled plastic fibers.

Table 3. Properties of recycled plastic fibers.

Specific density	Tensile strength	Modulus of elasticity	Water absorption
0.99 g/cm^3	210-250 N/mm^2	4-5 GPa	Nil

To estimate the mortar workability, the flow time was measured for each mix, by using workabilimeter B, according to French Standards NF P18-452. Prismatic samples 40x40x160mm were cast and conserved under a plastic film, in controlled chamber (HR = 80 ± 5%, T = 14 ± 2°C), until the testing day. Mechanical strengths were measured at 3, 7-, 14-, 28- and 91-days aging, using "CONTROLS" testing machine (Figure 3 (a)). According to the European Standards EN 196-1, the flexural strength was measured on prismatic samples 40x40x160mm (Figure 3 (b)) and the compressive strength on the half-prisms, resulting from the first test 40x40x80mm (Figure 3 (c)). Each strength value was the average of three results, with a standard deviation of about 6%. To investigate the quality of the matrix, the distribution of fibers and their anchorage, a microstructural observation by scanning electron microscopy (SEM) technique was carried out on the material.

Table 4. Mixture amounts of mortars.

Mix	Cement C (g)	Sand S (g)	Water W (g)	Superplasticizer Sp (g)	Straight fiber (g)	Crimped fiber (g)
CM	400	1200	220	11.5		
SFM5	400	1200	220	11.5	9.2 (0.5%)	
SFM10	400	1200	220	11.5	18.3 (1%)	
SFM15	400	1200	220	11.5	27.5 (1.5%)	
SFM20	400	1200	220	11.5	36.6 (2%)	
CFM5	400	1200	220	11.5		9.2 (0.5%)
CFM10	400	1200	220	11.5		18.3 (1%)
CFM15	400	1200	220	11.5		27.5 (1.5%)
CFM20	400	1200	220	11.5		36.6 (2%)
C/S = 1/3; W/C = 0,55; Sp = 2.88%						

CM: control mortar; SFM10: mortar with 1% of straight fibers; CFM10: mortar with 1% of crimped fibers.

(a) Machine used for mechanical tests (b) Flexural test (c) Compressive test

Figure 3. Mechanical tests.

3. Experimental results and discussions

3.1. *Fresh mortar properties*

The effect of the introduction of recycled plastic fibers on the workability of mortar is shown in Figure 4. An increase of the flow time of mortar is observed with the increase of fiber amount. Figure 5, where the percentage increase of flow time of different mortars is given, with regard to control mortar, clearly shows the great effect of fiber dosage on the workability. This negative effect of used fibers on the workability is probably due to their physical behavior into the mortar's mass, where they react as inclusions having high specific surface. The vast majority of literature researches (Sahmaran et al., 2005; Söylev and Özturan, 2014; Bertelsen et al., 2019; Jain et al., 2019; Adnan and Dawood, 2020; Seshaiah et al., 2021) are in concordance with this conclusion. It is very clear that crimped fibers produce less plastic mortar (Figure 6), by comparison to straight fibers, due to their irregular shape which generates strong interactions between fiber and matrix and also traps more water. The flow time in the case of crimped fibers is almost 40% higher than that required by straight fibers, for the fiber dosages 0.5%, 1% and 1.5%; but with the dosage of 2% of fibers, this percentage goes down to 10%. Since the workability is the most important property of cementitious materials during their fresh state and also affecting their hardened properties, it is necessary to find the optimal composition that leads to both workable and resistant material. According to the experimental results and visual observations, the dosage by weight of fibers should be limited at 1% and 0.5% for straight and crimped fibers, respectively, to maintain mortar's workability.

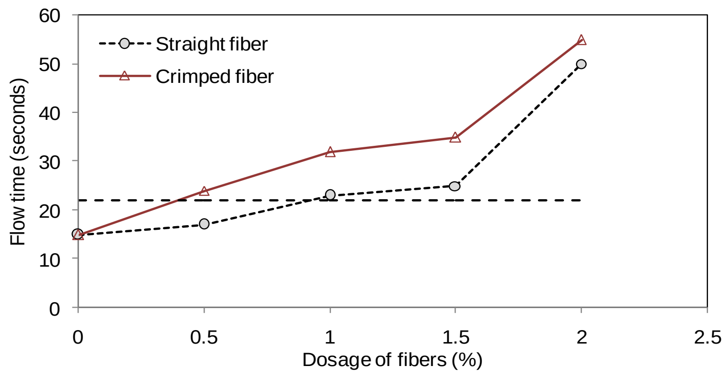


Figure 4. Variation of flow time of recycled plastic fiber mortar.

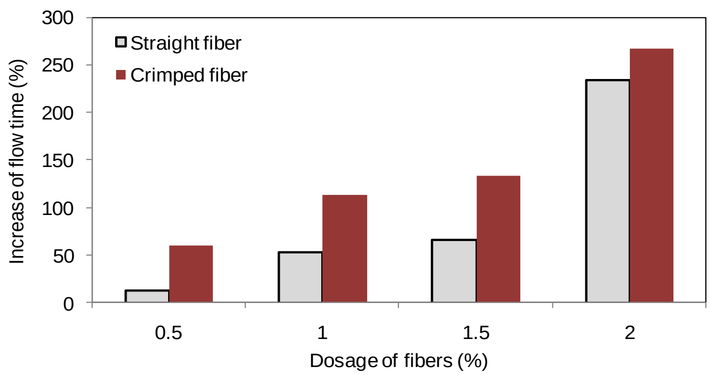


Figure 5. Percentage increase of flow time in recycled plastic fiber mortar.

Figure 6. Fresh mortar mixture with crimped fiber.

3.2. *Hardened mortar properties*

3.2.1. Flexural strength

The Figures 7 and 8 show the evolution of the flexural strength in straight fibers mortar and in crimped fibers mortar, respectively. A continuous increase of the strength with age is observed in all tested mortars, whatever the geometry of fiber.

This strength's increase is certainly due to the favorable humidity (HR = 80 ± 5%), where samples were conserved, which constitutes the best curing conditions for the continuity of hydration reaction. This conservation also improves the quality of the transition zone (matrix-fiber) that positively reflects on the mechanical strength of fiber mortar. Singh et al. (2004) have showed that the interface fiber-matrix reaches its maximum strength after only two days curing, but the matrix strength needs a long time. An increase of the strength is also detected with fiber dosage for the two types of mortars.

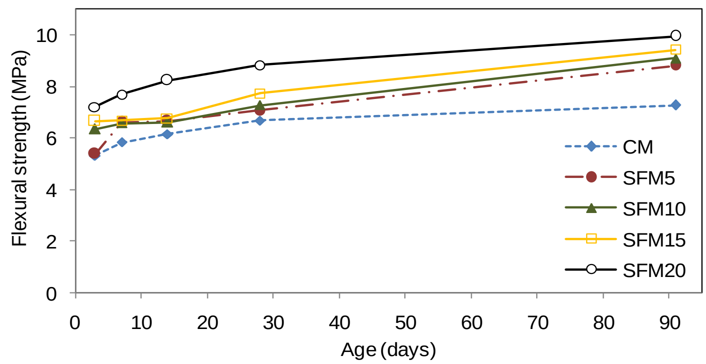


Figure 7. Flexural strength in straight fibers mortar.

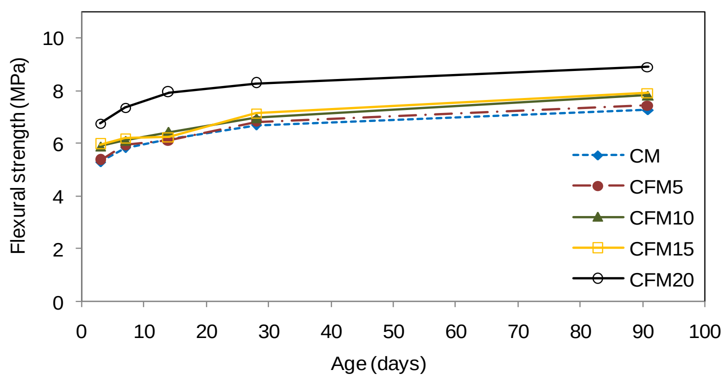


Figure 8. Flexural strength in crimped fibers mortar.

According to the Figure 9, the flexural strength values are higher in straight fibers mortar (SFM) for all ages. This result may be related to the low workability of crimped fibers mortar, compared to straight fibers mortar. The low workability leads to some difficulties during implementation and molding operation, which prevents obtaining a more compact material with better mechanical strengths. The Table 5 gives the percentage of the flexural augmentation of recycled plastic fiber mortars, compared to control mortar. For example, at the age of 28 days, the increase of the flexural strength is about 32% in mortar SFM20 and 24% in mortar CFM20, and after 90 days, it reaches 37% and 23% in SFM20 and CFM20, respectively. These results confirmed the mechanical benefits of the use of 2% of recycled plastic fibers, as reinforcement of limestone residue mortar. The positive effect of synthetic fibers on the flexural behavior which is already confirmed by numerous researches (Sun and Xu, 2009; Alamshahi et al., 2012; Al -Hadithi and Hilal, 2016; Özbay et al., 2021) is certainly due to their high energy absorption capacity, as reported by Latifi et al. (2022).

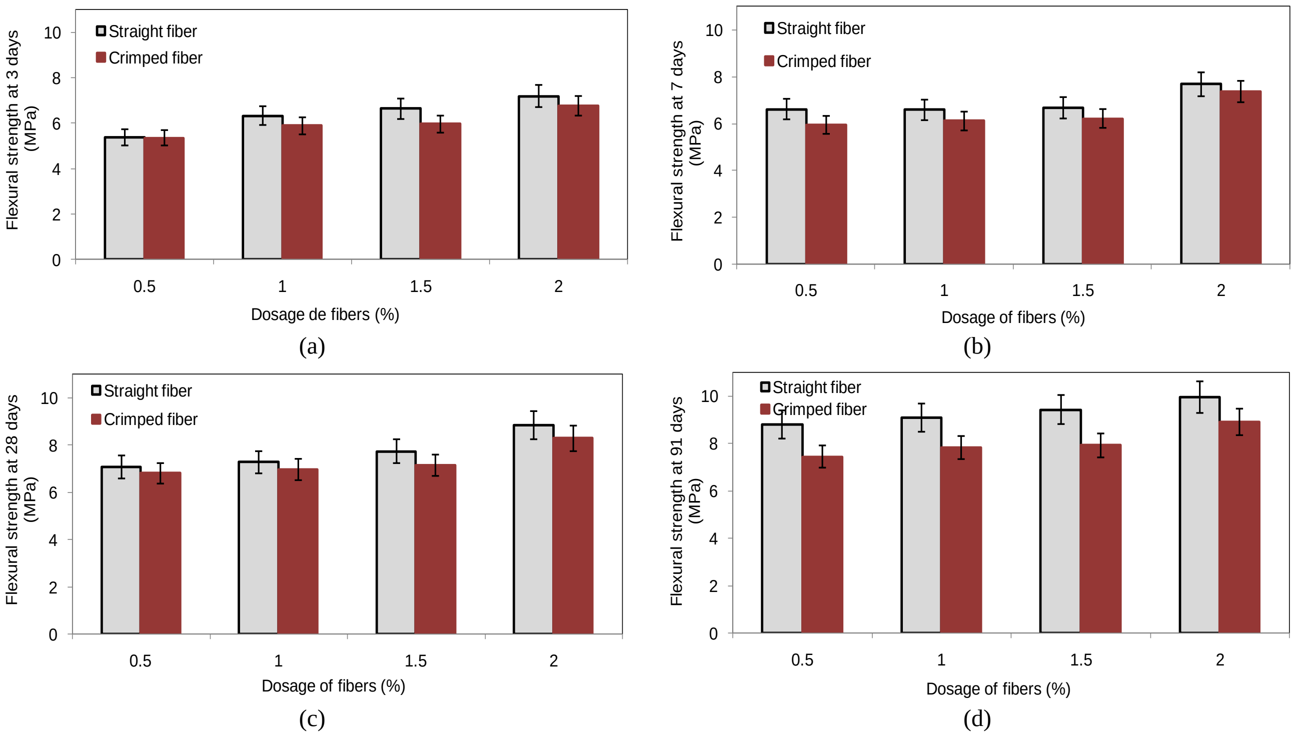


Figure 9. Effect of the geometry of fiber on the flexural strength of mortars: (a) at 3 days, (b) at 7 days, (c) at 28 days, and (d) at 91 days.

Table 5. Augmentation percentage of flexural strength of mortars (%).

Age (days)	03	07	14	28	91
SFM5	1	13	8	6	22
SFM10	19	13	8	9	25
SFM15	25	14	10	16	30
SFM20	36	32	34	32	37
CFM5	1	2	0	2	2
CFM10	11	5	5	4	8
CFM15	12	7	2	7	9
CFM20	27	26	29	24	23

3.2.2. Compressive strength

The variation of the compressive strength is presented in Figures 10 and 11 for straight fibers mortar and crimped fibers mortar, respectively. The controlled conservation of mortars under plastic film at a temperature of 14 ± 2°C and a humidity of 80 ± 5%, has encouraged the continuation of the hydration reaction, which has resulted in a better maturation and then an increase of their compressive strength in the time. The beneficial effect of recycled plastic fibers on the compressive behavior of mortar is usually assured with the two types of fibers; nevertheless, it is slightly more important with straight fibers (Figure 12). These findings are in accordance with some literature studies (Cifuentes et al., 2013; Oghabi and Khoshvatan, 2020). In many published works, however, it was stated that fibers have no effect on the compressive strength of the material; they can rather reduce it (Bouziani et al., 2014; Manica et al., 2019; Marthong, 2019; Yao et al., 2019; Kilic and Gokce Gok, 2021). Nonetheless, since the objective of the incorporation of fibers in concrete is the improvement of its tension behavior and the reduction of cracking, their non-significant effect on the compressive strength is of no importance. In the same sense, it seems that the effect of fibers on the compressive behavior depends on their nature, their dosage, their geometric parameters and their orientation. By comparison to other type of fibers, the high flexibility of recycled plastic fibers used in this work helps them to be easily arranged into the mortar's mass, without impacting its compactness and then participates successfully to improve the compressive behavior.

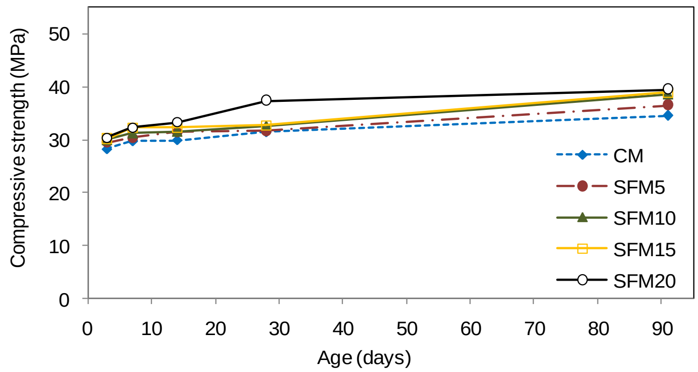


Figure 10. Compressive strength in straight fibers mortars.

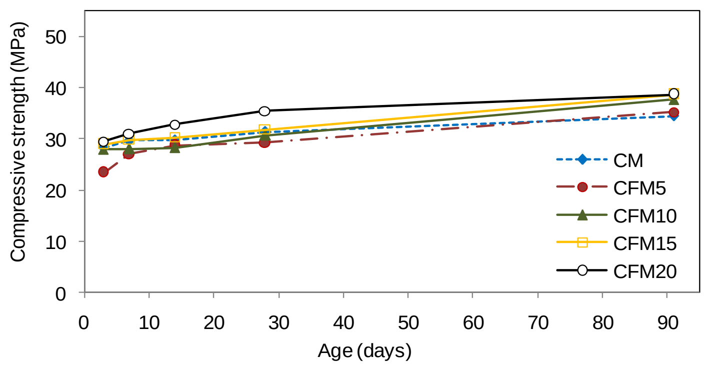
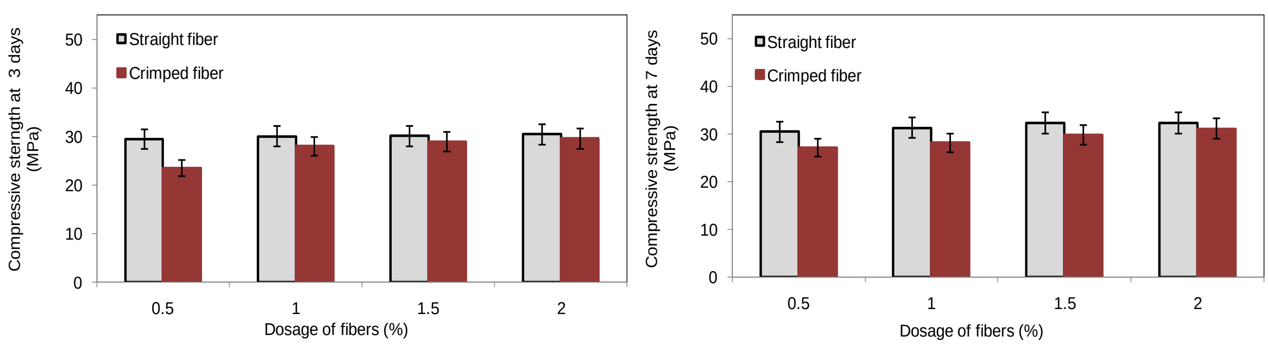
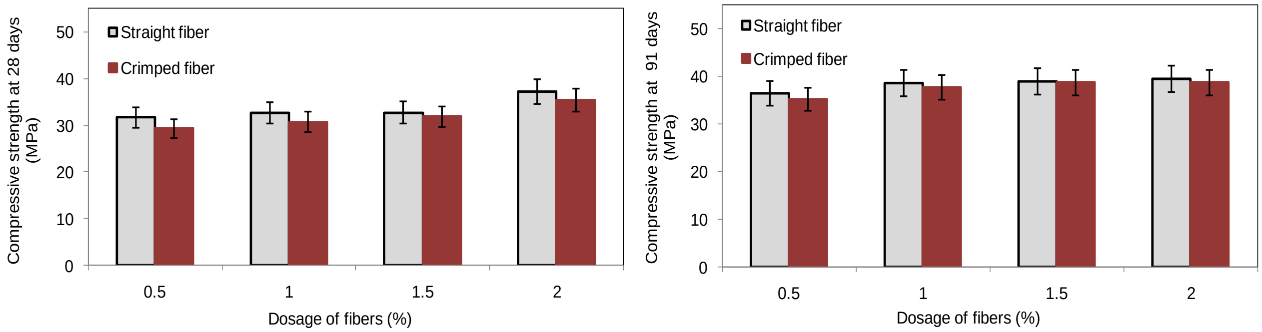


Figure 11. Compressive strength in crimped fibers mortars.

The increase of the compressive strength is given in percentage (%) in Table 6, by comparison to control mortar. From the mechanical point of view, a dosage of 2% of recycled plastic fibers is a beneficial dosage (Table 6), since it has induced a compressive strength gain of about 19% in straight fibers mortar and 13% in crimped fibers mortar, at 28 days, compared to control mortar and 14% and 12% respectively, at 90 days.



(a) (b)



(c) (d)

Figure 12. Effect of the geometry of fiber on the compressive strength of mortars:
(a) at 3 days, (b) at 7 days, (c) at 28 days, and (d) at 91 days.

Table 6. Augmentation percentage of compressive strength of mortars (%).

Age (days)	03	07	14	28	91
SFM5	4	2	5	1	6
SFM10	6	5	6	4	12
SFM15	6	9	8	4	18
SFM20	8	9	11	19	14
CFM5	-17	-9	-4	-7	2
CFM10	-1	-6	-6	-2	9
CFM15	2	0	2	2	12
CFM20	4	5	10	13	12

3.3. *Microstructure analysis of mortars*

The microstructure analysis is a very efficiency way to explain the mechanical behavior of fiber materials, such as the flexural strength, the toughness and the fracture energy. Using this type of analysis, it is easy to examine the distribution of fibers in the matrix, the quality of the transition zone between the matrix and the fiber and also the quality of fiber surface. The SEM analysis is conducted on mortar samples after mechanical testing. The plastic fibers of polypropylene (straight and crimped fibers) used in this work have a smooth surface which explains the small quantity of paste attached to the surface of the fiber (Figure 13 (a)) and also the creation of certain porosity between the fiber and the matrix of about 5µm (Figure 13 (b)). This porosity participates to the pull-out of fibers from the matrix, when their anchorage is insufficient in the fracture zone (Figure 13 (c)). Smarzewski1 and Barnat-Hunek (2018) have already reported in their work, that the presence of pores in the transition zone of polypropylene fiber-mortar increases the material absorptivity.

During the microstructure inspection, a limited number of fibers are pulled-out from the matrix, probably due to the efficiency of used fiber length and also to the randomly orientation of fiber into the mortar, which increases the probability to have more fibers oriented in the sense of failure load. All these observations are already confirmed by the good mechanical behavior of fiber mortars in the previous sections. As shown in Figure 13 (d), no damage is observed on the contact surface fiber-matrix after its pull-out. Thanks to their morphology, the recycled plastic fibers of polypropylene possess a high energy absorption capacity; they start to fail themselves before the transfer of the load to the matrix, which confirmed once again their efficiency to improve the flexural behavior of the material, at peak and post loading (Figure 13 (d)). It can be seen in Figures 13 (e, f) that the tested mortars have a dense microstructure, probably due to the evolution of the hydration reaction and also to the limestone residue used as sand that contains 27% of fines less than 0.16mm. These fines are responsible to fill-in the pores and then increase the compactness of the mortar. This observation explains the high strength values, exceeding 6.7MPa for flexure and 31MPa for compression, in all mortars at 28 days aging.

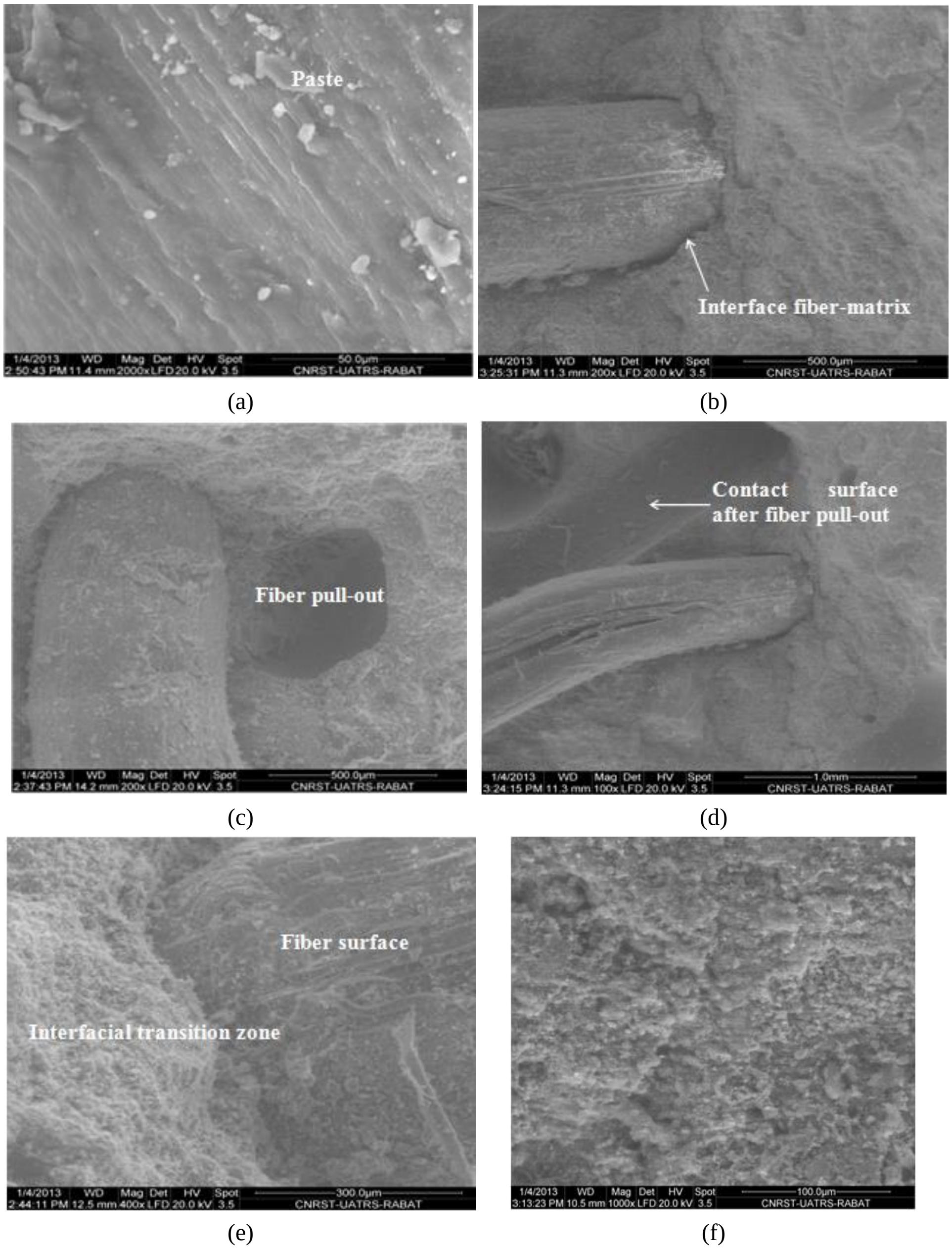


Figure 13. SEM photographs of recycled plastic fiber mortar microstructure.

4. Conclusions

In this study, mortars are prepared with limestone residue as fine aggregate and recycled plastic waste as fiber. The workability and the mechanical characteristics, which are the important characteristics of cementitious materials, are investigated for different weight dosages and geometries of fibers. From the present study, the following conclusions are drawn:

1. The valorization of limestone residue as sand in mortar is a good solution for both economical and environmental problems and a good attempt for conducting construction projects.
2. The geometry and the dosage of recycled plastic fibers have an important effect on the performances of limestone residue mortar.

3. The addition of recycled fibers to mortar decreases the workability and the decrease is higher with crimped fibers, because their irregular shape generates strong interactions between fiber and matrix and traps more water.
4. The workability decreases with the increase of the dosage of recycled fiber, due to their physical effect in the matrix, where fibers act as inclusions having high specific surface.
5. For producing a workable mortar, the dosage by weight of recycled plastic fiber should be limited at 1% for straight fibers and 0.5% for crimped fibers.
6. The flexural behavior of limestone residue mortar is better with the presence of recycled plastic fibers, particularly straight fibers, due to their high energy absorption capacity. At the same dosage, the mortar is more workable and is easier to set up with straight fibers which positively affected the mechanical strengths.
7. The addition of recycled plastic fibers to limestone residue mortar slightly improves the compressive strength; the improvement percentage is higher with straight fibers.
8. The mechanical strength of limestone residue mortar increases with the dosage of recycled plastic fibers.
9. The microstructure analysis conducted on all mortars confirms the good performances of the fiber mortar, by showing a dense material with an effective fiber length and also a good orientation of fiber into the mortar.
10. The results of the current investigation clearly show that the polypropylene recycled plastic waste, resulting from domestic sweeps fabrication, can be used successfully as fibers to produce a workable mortar with interesting mechanical characteristics.

References

Adnan, H. M., & Dawood, A. O. (2020). Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers. Case Studies in Construction Materials, 13, e00367. https://doi.org/10.1016/j.cscm.2020.e00367.

Alamshahi, V., Taeb, A., Ghaffarzadeh, R., & Rezaee, M. A. (2012). Effect of composition and length of PP and polyseter fibres on mechanical properties of cement based composites. Construction and Building Materials, 36, 534-537. http://dx.doi.org/10.1016/j.conbuildmat.2012.06.005.

Al -Hadithi. A. I., & Hilal, N. N. (2016). The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fibers. Journal of Building Engineering, 8, 20-28. https://doi.org/10.1016/j.jobe.2016.06.011.

Al-Mansour, A., Chen. S., Xu, C. , Peng, Y., Wang, J., Ruan, S., & Zeng, Q. (2022). Sustainable cement mortar with recycled plastics enabled by the matrix-aggregate compatibility improvement. Construction and Building Materials, 318, 125994. https://doi.org/10.1016/j.conbuildmat.2021.125994.

Al-Tulaian, B. S., Al-Shannag, M. J., & Al-Hozaimy, A. R. (2016). Recycled plastic waste fibers for reinforcing Portland cement mortar. Construction and Building Materials, 127, 102-110. https://doi.org/10.1016/j.conbuildmat.2016.09.131.

Alyousef, R., Mohammadhosseini, H., Tahir, M. M., & Alabduljabbar, H. (2021). Green concrete composites production comprising metalized plastic waste fibers and palm oil fuel ash. Materialstoday: PROCEEDINGS, 39(2), 911-916. https://doi.org/10.1016/j.matpr.2020.04.023.

Araya-Letelier, G., Maturana, P., Carrasco, M., Antico, F. C., & Gómez, M. S. (2019). Mechanical-damage behavior of mortars reinforced with recycled polypropylene fibers. Sustainability, 11, 2200. https://doi.org/10.3390/su11082200.

Awoyera, P. O., Olalusi, O. B., Ibia, S., & Prakash A, K. (2021). Water absorption, strength and microscale properties of interlocking concrete blocks made with plastic fibre and ceramic aggregates. Case Studies in Construction Materials, 15, e00677. https://doi.org/10.1016/j.cscm.2021.e00677.

Bahij, S., Omary, S., Feugeas, F., & Faqiri, A. (2020). Fresh and hardened properties of concrete containing different forms of plastic waste-A review. Waste Management, 113, 157-175. https://doi.org/10.1016/j.wasman.2020.05.048

Belhadj, B., Bederina, M., Benguettache, K., & Queneudec, M. (2014). Effect of the type of sand on the fracture and mechanical properties of sand concrete. Advances in Concrete Construction, 2(1), 13-27. https://doi.org/10.12989/ACC2014.2.1.013.

Belmokaddem, M., Mahi, A., Senhadji, Y., & Pekmezci, B. Y. (2020). Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate. Construction and Building Materials, 257, 119559. https://doi.org/10.1016/j.conbuildmat.2020.119559.

Benyamina, S., Menadi, B., Bernard, S. K., & Kenai, S. (2019). Performance of self-compacting concrete with manufactured crushed sand. Advances in Concrete Construction, 7(2), 87-96. https://doi.org/10.12989/acc.2019.7.2.087.

Bertelsen, I.M.G., Ottosen, L.M., & Fischer, G. (2019). Quantitative analysis of the influence of synthetic fibres on plastic shrinkage cracking using digital image correlation. Construction and Building Materials, 199, 124-137. https://doi.org/10.1016/j.conbuildmat.2018.11.268.

Bhogayata, A. C., & Arora, N. K. (2018). Impact strength, permeability and chemical resistance of concrete reinforced with metalized plastic waste fibers. Construction and Building Materials, 161, 254-266. https://doi.org/10.1016/j.conbuildmat.2017.11.135.

Bouziani, T., Benmounah, A., Makhloufi, Z., Bederina, M., & T'kint, M. Q. (2014). Properties of flowable sand concretes reinforced by polypropylene fibers. Journal of Adhesion Science and Technology, 28(18), 1823-1834. https://doi.org/10.1080/01694243.2014.924176.

Caggiano, A., Gambarelli, S., Martinelli, E., Nisticò, N., & Pepe, M. (2016). Experimental characterization of the post-cracking response in hybrid steel/polypropylene fiber-reinforced concrete. Construction and Building Materials, 125, 1035-1043. https://doi.org/10.1016/j.conbuildmat.2016.08.068.

Castillo, E.D.R., Almesfer, N., Saggi, O., & Ingham, J. (2020). Light-weight concrete with artificial aggregate manufactured from plastic waste. Construction and Building Materials, 265, 120199. https://doi.org/10.1016/j.conbuildmat.2020.120199.

Cifuentes, H., García, F., Maeso, O., & Medina, F. (2013). Influence of the properties of polypropylene fibres on the fracture behaviour of low, normal and high-strength FRC. Construction and Building Materials, 45, 130-137. https://doi.org/10.1016/j.conbuildmat.2013.03.098.

Echeverria, C. A., Pahlevani, F., Handoko, W., Jiang, C., Doolan, C., & Sahajwalla, V. (2019). Engineered hybrid fibre reinforced composites for sound absorption building applications. Resources, Conservation and Recycling, 143, 1-14. https://doi-org.sndl1.arn.dz/10.1016/j.resconrec.2018.12.014.

Hameed, A. M., & Ahmed, B. A. (2019). Employment the plastic waste to produce the light weight concrete. Energy Procedia, 157, 30-38. https://doi.org/10.1016/j.egypro.2018.11.160.

Jain, A., Siddique, S., Gupta, T., Jain, S., Sharma, R.K., & Chaudhary, S. (2019). Fresh, strength, durability and microstructural properties of shredded waste plastic concrete. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 43, 455-465. https://doi.org/10.1007/s40996-018-0178-0.

Kaliyavaradhan. S. K., Prem. P. R., Ambily. P. S., & Mo. K. H. (2022). Effective utilization of e-waste plastics and glasses in construction products - a review and future research directions. Resources Conservation and Recycling, 176, 105936. https://doi-org.sndl1.arn.dz/10.1016/j.resconrec.2021.105936.

Karanth, S. S., Ghorpade, V. G., & Rao, H. S. (2017). Shear and impact strength of waste plastic fibre reinforced concrete. Advances in Concrete Construction, 5(2), 173-182. https://doi.org/10.12989/acc.2017.5.2.173.

Kilic, I., & Gokce Gok, S. (2021). Strength and durability of roller compacted concrete with different types and addition rates of polypropylene fibers. Revista De La Construcción. Journal of Construction, 20(2), 205–214. https://doi.org/10.7764/RDLC.20.2.205.

Kumaresan, M., Sindhu, S., & Anandh, S. (2023). Feasibility study of using waste badminton string fibers in concrete by morphological, microstructural and tensile characteris-tics. Revista de la construcción. Journal of construction, 22(3), 694-708. https://doi.org/10.7764/RDLC.22.3.694.

Latifi, M. R., Biricik, O., & Aghabaglou, A. M. (2022). Effect of the addition of polypropylene fiber on concrete properties. Journal of Adhesion Science and Technology, 36(4), 345-369. https://doi.org/10.1080/01694243.2021.1922221.

Liu, T., Nafees, A., Khan, S., Javed, M. F, Aslam, F., Alabduljabbar, H., Xiong, J. J., Khan, M. I., & Malik, M. Y. (2022). Comparative study of mechanical properties between irradiated and regular plastic waste as a replacement of cement and fine aggregate for manufacturing of green concrete. Ain Shams Engineering Journal, 13(2), 101563. https://doi.org/10.1016/j.asej.2021.08.006.

Manica, G., Bolina, F., Tutikian, B., & Valadares, M. (2019). Analysis of the resistance to fire of solid concrete boards with polypropylene microfibers and long curing time. Revista de la Construcción. Journal of Construction, 18(3), 595-602. https://doi.org/10.7764/RDLC.18.3.595.

Marthong, C. (2019). Effect of waste cement bag fibers on the mechanical strength of concrete. Advances in Materials Research, 8(2), 103-115. http://dx.doi.org/10.12989/amr.2019.8.2.103.

Menadi, B, Kenai, S., Khatib, J., & Ait-Mokhtar, A. (2009). Strength and durability of concrete incorporating crushed limestone sand. Construction and Building Materials, 23, 625-633. https://doi.org/10.1016/j.conbuildmat.2008.02.005.

Mercante, I., Alejandrino, C., Ojeda, J.P., Chini, J., Maroto, C., & Fajardo, N. (2018). Mortar and concrete composites with recycled plastic: A review. Science and Technology of Materials, 30(S1), 69-79. https://doi-org.sndl1.arn.dz/10.1016/j.stmat.2018.11.003.

Meza, A., Pujadas, P., Meza, L. M., Pardo-Bosch, F., & López-Carreño, R. D. (2021). Mechanical optimization of concrete with recycled PET fibres based on a statistical-experimental study. Materials, 14 (2), 240. https://doi.org/10.3390/ma14020240.

Meziane, E-H., Ezziane, K., Kenai, S., & Kadri, A. (2015). Mechanical, hydration, and durability modifications provided to mortar made with crushed sand and blended cements. Journal of Adhesion Science and Technology, 29(18), 1987-2005. https://doi.org/10.1080/01694243.2015.1048931.

Mohammed, A. A., & Mohammed, I. I. (2021). Effect of fiber parameters on the strength properties of concrete reinforced with PET waste fibers Iranian Journal of Science and Technology, Transactions of Civil Engineering, 45, 1493-1509. https://doi.org/10.1007/s40996-021-00663-2.

Oghabi, M., & Khoshvatan, M. (2020). The laboratory experiment of the effect of quantity and length of plastic fiber on compressive strength and tensile resistance of self-compacting concrete. KSCE Journal of Civil Engineering, 24(8), 2477-2484. https://doi.org/10.1007/s12205-020-1578-9.

Özbay, A. E. Özsoy, Erkek, O., & Çeribaşı, S. (2021). The effect of polypropylene, steel, and macro synthetic fibers on mechanical behavior of cementitious composites. Revista De La Construcción. Journal of Construction, 20(3), 591–601. https://doi.org/10.7764/RDLC.20.3.591.

Pešić, N., Živanović, S., Garcia, R., & Papastergiou, P. (2016). Mechanical properties of concrete reinforced with recycled HDPE plastic fibres. Construction and Building Materials, 115, 362-370. https://doi.org/10.1016/j.conbuildmat.2016.04.050.

Rathore, R. S., Chouhan, H.S., & Prakash, D. (2021). Influence of plastic waste on the performance of mortar and concrete: A review. Materialstoday: PROCEEDINGS, 47(14), 4708-4711. https://doi-org.sndl1.arn.dz/10.1016/j.matpr.2021.05.603.

Sahmaran, M. Yurtseven, A., & Yaman, I.O. (2005). Workability of hybrid fiber reinforced self-compacting concrete. Building and Environment, 40(12), 1672-1677. https://doi-org.sndl1.arn.dz/10.1016/j.buildenv.2004.12.014.

Serdar. M., Baričević. A. Rukavina. M.J., Pezer. M., Bjegović. D., & Štirmer. N. (2015). Shrinkage behaviour of fibre reinforced concrete with recycled tyre polymer fibres. International Journal of Polymer Science, 2015. Article ID 145918, 9p. https://doi.org/10.1155/2015/145918.

Seshaiah, B., Srinivasa Rao P., & Subba Rao P. (2021). Effect of mineral admixtures on the properties of steel fibre reinforced SCC proportioned using plastic viscosity and development of regression & ANN model. Computers and Concrete, 27(6), 523-535. http://dx.doi.org/10.12989/cac.2021.27.6.523.

Singh, S., Shukla, A., & Brown, R. (2004). Pullout behavior of polypropylene fibers from cementitious matrix. Cement and Concrete Research, 34(10), 1919-1925. https://doi-org.sndl1.arn.dz/10.1016/j.cemconres.2004.02.014.

Smarzewski1, P., & Barnat-Hunek, D. (2018). Property assessment of hybrid fiber-reinforced ultra-high-performance concrete. International Journal of Civil Engineering, 16, 593-606. https://doi.org/10.1007/s40999-017-0145-3.

Söylev, T. A., & Özturan, T. (2014). Durability, physical and mechanical properties of fiber-reinforced concretes at low-volume fraction Construction and Building Materials, 73, 67-75. https://doi.org/10.1016/j.conbuildmat.2014.09.058.

Standards EN 196-1, (2005), Methods of testing cement-part 1: Determination of strength: BSI London, UK.

Standards NF P18-452, (1988), Concretes - Measuring the flow time of concretes and mortars using a workabilitymeter, Paris, France.

Sun, Z., & Xu, Q. (2009). Microscopic, physical and mechanical analysis of polypropylene fiber reinforced concrete, Materials Science and Engineering: A, 527(1-2), 198-204. https://doi.org/10.1016/j.msea.2009.07.056.

Thakare, A. A., Singh, A., Gupta, V., Siddique, S., & Chaudhary, S. (2021). Sustainable development of self-compacting cementitious mixes using waste originated fibers: A review. Resources, Conservation and Recycling, 168, 105250. https://doi-org.sndl1.arn.dz/10.1016/j.resconrec.2020.105250.

Yao, Z., Li, X., Fu, C., & Xue, W. (2019). Mechanical properties of polypropylene macrofiber-reinforced concrete. Advances in Materials Science and Engineering, 2019, Article ID 7590214, 8p. https://doi.org/10.1155/2019/7590214.