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FIN SANDY CONCRETE REINFORCED WITH MACRO POLYPROPYLENE FIBER FOR RURAL AND DESERT HOUSING

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ABSTRACT

This research aimed to design a low cost fiber concrete as an alternative to earth-concrete reinforced with biomaterial fibers, where the latter is characterized by mechanical defects such as the low strength, the water degradation and the air erosion, as well as the continuous deformation related to the self-compression and unlimited subsidence of the bearing surface soil.

The designed concrete is composed of fine sand, cement in small quantities and polypropylene fibers available on the daily market. This material is easy to form due to the availability of fine sand in nature and the possibility of its production without much skill; in the same time, it is make at a low cost and short implementation time, unlike earth concrete where it needs time to dry and acquire the appropriate strength. Laboratory work has shown good results as the light density, the large ductility and an acceptable strength capacity of this material.

KEYWORDS: Earth concrete**;** Sandy concrete; Macro polypropylene fiber; Concrete strength; Ductility.

1. INTRODUCTION

From the beginning of human civilization man has found in natural caves his refuge to protect himself from climate change and animal threats (Jahren 2018). The second leg of civilization trip was the exploration of natural materials to build its habitat; Thus, man has used the natural materials available in his environment to meet his safety, and family and social obligations (Sparavigna 2011). Hence, from the mud he designed the earth-concrete to build his habitat and his house of worship where earth-concrete is used mainly to form load-bearing walls. However, the poor performance of this material forced the builder to adopt relatively large thicknesses to achieve the structural objectives. At an advanced time, and before the appearance of firebrick, man introduced the fiber of plants to treat the defects of this natural composite material (Sparavigna 2014). Admittedly, this material was characterized by an acceptable ductility, but it was not immune to the phenomenon of water and air erosion, the self-degeneration and the continuous deformation of the soil (Maini 2005, Bredenoord 2023).

Currently, to deal with these shortcomings, researchers are directing their work along two axes. The first group worked on soil characteristics to improve the properties of earth-concrete (Obonyo 2010, Guettala 2006, Arooz 20018, Ronsoux 2013); while the second attempts to get better material by investing the properties of fiber plants such as vegetable straw (Demir 2006) banana fibers Mostafa 2016), rice husk and ash (Damanhuri 2020)… etc.

In underdeveloped countries, especially in rural and deserted areas where mud does not exist, cost and ease of implementation become the two main construction criteria, To meet these two conditions, this work aims to provide an

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alternative to fiber earth concrete that is easy to manufacture and fulfills the respective properties for construction safety.

Meanwhile apart from the use of steel fibers, a third trend has appeared where the engineer chooses to use fibers produced industrially, such as glass fiber (Annamaneni 2023)., polyester fiber (Mohsin 2020), carbon fiber (Ghanem 2019), macro synthetic fibers (Bolat 2014), and polypropylene fibers Ravishankar (2021).

Adding that, all research works on polypropylene fiber show how can the fibers act within the concrete and the rate of improving its mechanical properties. Blazy and Blazy (2021) showed the possibility of using polypropylene fibers enhanced on concrete for architectural element of public spaces. Matar and Zéhil (2020 studied the ability to use the polypropylene fiber to improve the physical and mechanical properties of recycled aggregate concrete. Nasser et al. (2018) proved that the addition of propylene fibers for 1.5% of the cement volume improves significantly the strength of concrete in compression. Ahmad et al. (2021) worked on many volume ratio of polypropylene fiber to detect its performance on fresh concrete and hard concrete properties under compressive strength, split tensile strength flexure strength. Magnur et al. (2017) approved the same results. Memon et al. (2018) showed the inverse role of fiber length where they observed that with increase in size of fiber the compressive strength decreased significantly.

On the other hand, researches are carried out for the use of dune sand as main aggregate for concrete. Ahmad et al. (2022) presented a review on the effect of Dune sand on concrete properties. They indicated that dune sand can be used in concrete up to 40% without any negative effect on strength and durability; therefore, they indicated that the negative impact of this fine aggregate on strength and durability was due to poor grading and fineness, which restricts the complete (100%) substation of dune sand, but they noted its negative effect where a significant decrease in flowability was observed.

Based on this panoramic review, this study seeks to propose a conception and a suitable solutions for the use of dune sand as main aggregate, reinforced with macro polypropylene fiber, for housing construction in rural or desert areas in underdeveloped countries, where mud are not available.

2. INTEREST STATEMENT

The different effort to design concrete reinforced with fiber is in fact a return to an ancient technique where man invested the biomaterials of his environment to meet his construction needs. Historically, in the Middle East not so long ago, people added wheat straw to mud bricks to build their houses and hemp fibers to plaster.

Thus, based on the environmental and economic interest, this research had the vision to investigate the feasibility of using dune sand reinforced with macro polypropylene fiber, for rural and desert construction, for low coast by a short implementation time and without much skill.

3. MATERIALS AND METHODS

3.1. Concrete composition

In this investigation, concrete was designed from fine sand (called desert or dune sand) and cement type CEM I/ 32.5 N/mm^2 enhanced by polypropylene fibers.

The sand was natural white sand for a maximum size of 1.18 mm (figure 1). The laboratory test gives the following values for the physical and mechanical properties: Specific gravity 2.61 g/cm^3, dry density 19 kN/m^3, specific surface area 114 cm^2/g, finesse modulus 1.4%, sand equivalent 83%, humidity 0.3%, and absorption 2.67%. While, the mineralogy composition was as follows:

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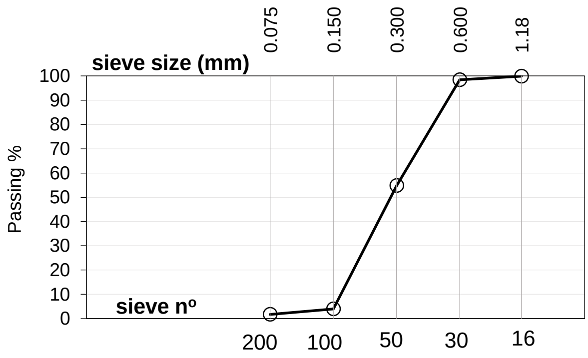

Fig.(1):-granular composition of Dune Sand

Table (1):- mineral composition of natural white fine sand

SiO_2	F_2O_3	Al_2O_2	CaO	K_2O	Na_2O	MgO	LOI	Total
72.2%	2.2%	11%	5.7%	2.6%	2.3%	1.7%	2%	99.7%

3.2. Macro Polypropylene fiber

The macro polypropylene fiber (PPF) is a synthetic textile fiber, which has a linear structure based on the monomer CnH_2n. The (PPF) is not degradable with soil and not decomposed by water. Table 1. gives the general physical, mechanical and chemical specification of the Polypropylene fiber (Kiron 2021, Mansfield 1999). Referring to the Engineering Toolbox Site (2009) and Kochem website, the physical and chemical properties of polypropylene used for the production of polypropylene rope are summarized in table 1**.**

Table (2):- Physical and chemical properties of Polypropylene fiber

Relative density	0.90-0.91	Thermal conductivity	6.0 (with air as 1.0)
Tensile strength (MPa)	>500	Abrasion resistance	Good
Elasticity (MPa)	3500	Chemical resistance	Excellent
Elongation at break (%)	10 to 45	Resistance to mildew, moth	Excellent
Moisture absorption (%)	0 to 0.05	Ability to protest friction	Excellent
Softening point (ºC)	140	Ability Against Acid affect	excellent
Melting point (ºC)	110-180	Ability Against Insect	Excellent

The fibers used in this work are extracted from rope of 0.6 cm in diameter, provided from the local market for domestic use (Figure 2). The rope was cut to a size of 4 and 8 cm; the measurement gave an average value of 0.3 mm of diameter for singular fiber. The laboratory tests gave the value of 0.905g/cm3 for density and 80 MPa for the tensile strength.

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Fig.(2):- polypropylene fiber

3.3. Concrete Mix batches Proportions

To calibrate the effect of the macro polypropylene fiber for a wide perception of this material on the behavior of concrete, the fine sandy concrete was prepared for an amount of 250 kg of cement per cubic meter.

In the second step, the fibers were added to the concrete during mixing in 2 sizes (4 and 8 cm) and 2 amounts of weight (2.5 and 5 kg/m3). The first control mix (M(0) without fiber was designed to define the resistance value of an eligible batch for a fiber of 8 cm. The addition of Polypropylene fiber showed an impossibility of providing a batch of W/C =0.7 for a suitable slump. Thus, the M(0) batch was modified to M(0/0) by increasing the amount of water to reach a value of W/C=1.55 which allowed the production of a concrete capable of accepting the fibers in the mixer and ensuring easy mixing and a valuable consistency. The main information on the concrete batches and the average output after compression test are detailed in Table 3.

Table (3):- Coding samples and input and output information

Batch	Fresh concrete density	Number of fiber	W/C	Fiber length	Fiber ratio	Slump*	Average load (P)	Strength*	ΔH	ε
	Kg/m^3	Per cube		(cm)	kg/m^3	(cm)	(kN)	(MPa)	(mm)	%
M(0)	1840	0	0.70	-	-	8.0	108.00	4.800	0.4	0.27
M(0/0)	1702	0	1.55	-	-	18	20.50	0.911	0.2	0.13
M(4/2.5)	1717	3297.4	1.55	4	2.5	6.7	62.17	2.763	9	6.00
M(8/2.5)	1717	1648.7	1.55	8	2.5	6.1	68.70	3.053	10	6.67
M(4/5.0)	1737	6594.8	1.55	4	5.0	5.9	82.20	3.653	12	8.00
M(8/5.0)	1737	3297.4	1.55	8	5.0	5.1	79.30	3.524	13	8.67

* The values of Slump and Compression Strength are for the average value of 5 samples for each batch

3.4. Sampling

To investigate the role of fiber on the concrete behavior 5 cubic samples of 15 cm were taken for each batch. The total number of trial tests were 25 samples coded as in table 3. According to ASTM-192 recommendation [15] samples were cured for 24 hours, and conserved in water with a temperature of 22±2C^o.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Effect of fibers on the sandy concrete

4.1.1. The consistency

Analysis of the effect of fiber length and weight on the slump of fibred concrete, in both cases either for 2.5 and 5 kg of fibers either for 4 and 8 cm, shows that the fibers decrease the consistency and significantly reduce the slump of the fibered concrete (Figure 3).

The conception of concrete mix for W/C=1.55 gives the concrete high fluidity; however, the addition of fiber reduce significantly the workability (figure 4, 5). This phenomena could be explained by the special structure of fibers which act as a interstitial textile which behaves according to the intensity of the interlocking of fibers and their amount of number in the concrete batch (Table 1).

Fig.(3): -Slump test

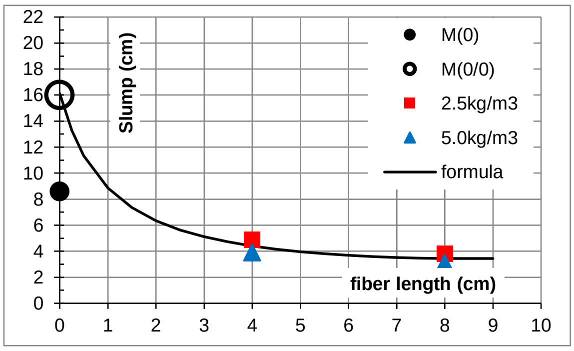

Fig.(4):- role of fiber length

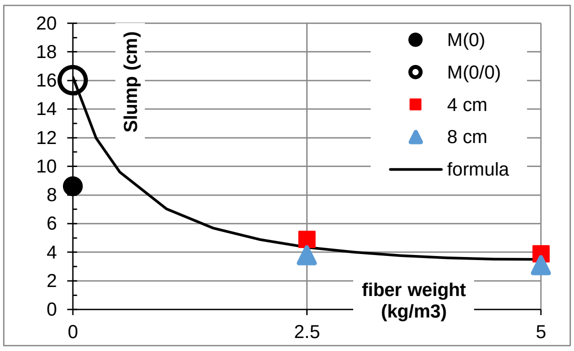

Fig.(5):- role of fiber weight

To control the quantity and the length of fibers, general relationship, between slump and either length or weight, are proposed in the form as follows:

For length

$$S = \frac{1}{[6.2\ \mathrm{x}10^{-2} + (5.42\ \mathrm{x}10^{-2})L - (3.21\mathrm{x}10^{-3})L^2]} \qquad (1)$$

For weight

$$S = \frac{1}{[6.16\mathrm{x}10^{-2} + (8.98\mathrm{x}\ 10^{-3})\ W - (8.99\mathrm{x}10^{-5})\ W^2]} \qquad (2)$$

Where: S slump (cm), L fiber length (cm), W fiber weight kg/m^3

The previous mathematical simulation allows choose the adequate length and quantity, where it seems that the values should be respectively less than 2.5 kg of weight and 4 cm of length.

4.1.2. The Compression Strength

Concrete were subjected to the mono-axial compression test, per set of 5 samples, at age of 28 days. The control samples (M(0) collapsed for an average load of 108 kN (4.8MPa) and the collapse shape has taken a regular pyramid form (Figure 6). Furthermore, the samples M(0/0) are collapsed under an average load of 20.9 kN (1.2 MPa), here, the drop of strength is due to the huge quantity of water where it reaches 375 l/m_3.

Whereas, the concrete reinforced with polypropylene fiber maintained their cubic shape (figure 7) and recovered some strength according to the length and the fiber ratio (figure 8). Moreover, the specimens are collapsed after a large deformation due to the enormous ductility that the concrete gained by the addition of the fibers, where the deformation (ε) reached a value of 8% for M(8/50).

Fig.(6):-Collapse form of M(0)

Fig. (7):-Collapse form of M(4/25)

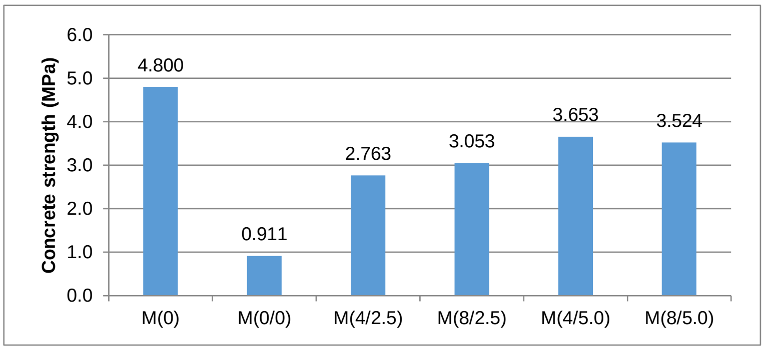

Fig.(8):- relation between compression strength and both length and weight

Figures 9, and 10 show that the increasing rate of compressive strength is more sensitive to the weight of the fiber than to its length. On the other hand, the rise of the length from 4 to 8 cm is insignificant contrary to the weight which can add a significant value to the resistance of the concrete. This result is confirmed by the number of fiber for M(4/50) and M(8/25) where the strength of the first is better than the second one. Thus, for better feasibility its is interesting to find the balance between weight and length to make the granular medium more homogeneous and give it a better consistency.

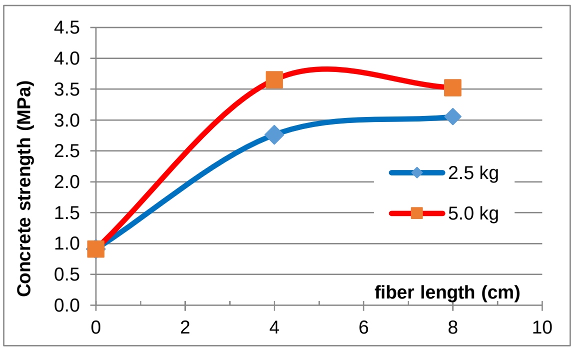

Fig.(9): -Role of length of fiber

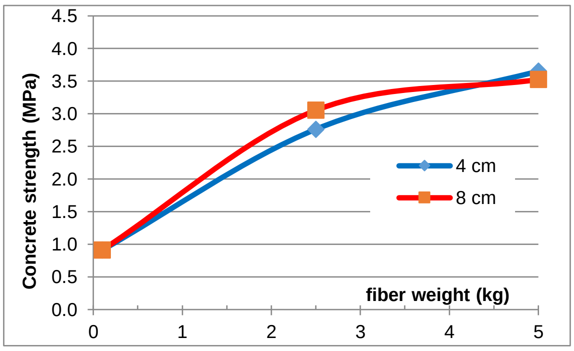

Fig.(10): -Role of weight of fiber

4.1.3. The Ductility

The value of the deformation were noted before the sample lose totally the capacity of resisting to the applied loads (Table 3). These values prove that the most important contribution of fibers to the concrete properties is the large ductility before rupture.

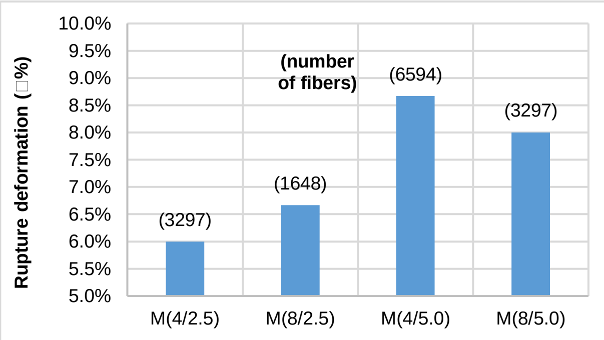

Fig.(11):- Relation between number of fibers and the collapse deformation

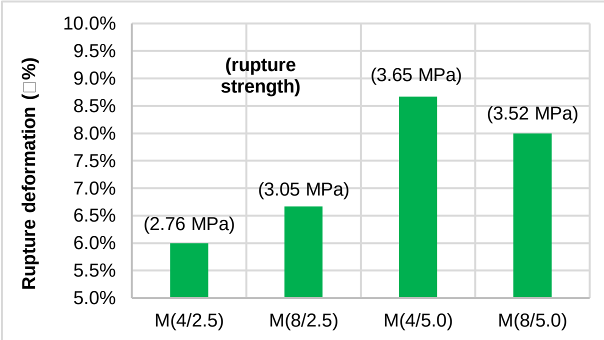

Fig.(12):- Relation between stress and the collapse deformation

The value of the collapse deformation, as shows in figure (11), depends on the length, the weight of fibers, consequently the number of fibers; where all these factors contributes to the strength of the fiber concrete (figure 12). These results allow to conclude that the concrete batch M(4/50) is the best mixing where it assure a wide ductility and significant strength.

4.2. Contribution of fiber on the compression strength

Several studies have been interested in knowing the way in which the fibers act within the concrete

Cox (1952) introduced his original theory of the stress transfer from the paper matrix to the fiber, which could be used in the same way for fiber concrete. Li and Stang (2001), Laranjera (2010) proposed a probabilistic parameter (*f*) to take into account the random distribution of fibers in concrete batch. They proposed a probabilistic parameter (η_{ϕ}), its value is defined by integration of the density function of 2 parameters p(z), p(Φ), where (z) the center of gravity of fibers and (Φ) its orientation in the space. For volume material this parameter take the form ($\eta_{\phi 3D}$) and has the value $\eta_{\phi 3D}$ =1/2.

Taking into account this parameter, the total compression load F_t is transferred within the concrete body in proportion between plain concrete and fibers:

$$F_t = F_f + F_c \qquad (3)$$

Where F_t, F_f, F_c are respectively the applied force on the total section, the portion force on the fibers, the portion force on the plain concrete. Meanwhile, due to the high flexibility of the fibers, they form in the mixture a kind of space mesh tissue. This lead to look at the contribution as an integral body in the matrix of the concrete. From this point of view, the contribution of the fibers is calculated by the difference in strength between the two cases plain concrete and fiber concrete, (Figure 13).

As shown the fiber of 4 cm length and 5 kg volume ratio has the best performance between the four composition of fiber concrete; that confirm the results given bellow regarding the ductility and the strength of the fiber dune sand. On the other hand, the number of fibers remains the dominate factor to assure a better homogeneity of concrete mix for fresh and hard concrete. figure (14) shows that the effect of the number of fibers is not limited for 4cm length as well as for 5 kg weight able to increase strength; contrary to 8 cm length here its effect stagnate.

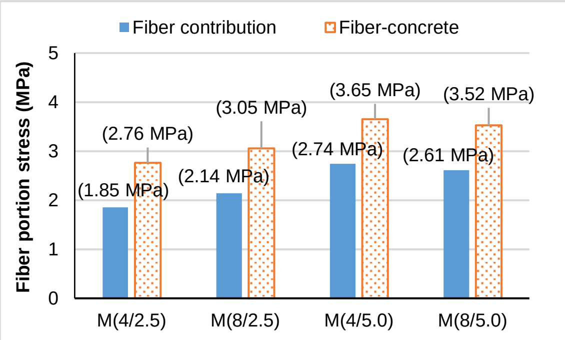

Fig.(13):- The fiber contribution to the strength of fiber concrete

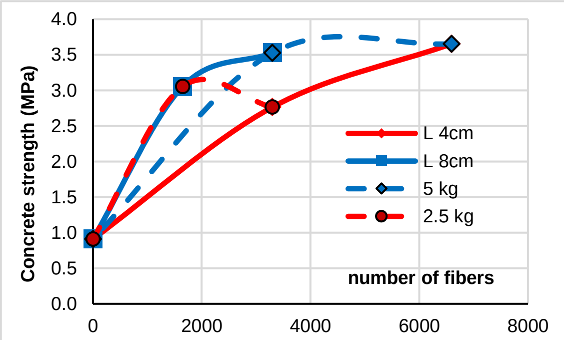

Fig.(14):-Effect of number of fibers

Hence, the adding of fiber to the concrete batch needs the good choice of the physical properties of the fiber as well as the volume ratio to have the better number which compose the space fiber tissue in the matrix of the dune sand concrete.

5. CONCLUSION

The study prove the feasibility of using polypropylene fiber to improve the mechanical properties of dune sand concrete under compression loads; Generally, the polypropylene fiber has the ability and the performance to improve moderately the strength of the sand dune concrete and to increase significantly its ductility and its toughness.

However, the length and the weight, consequently the number of fiber, condition the performance of the hardened concrete, where for the same weight ratio of fiber, the experimental results show that for the fiber for 4 cm of length and 5 kg of weight perform the concrete better than fiber for 8 cm of length and 2.5 kg of weight.

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