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Research Article

Performance of oil well sand concrete reinforced with polypropylene fibers and incorporating dune and alluvial sands

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Abstract:

In the context of recycling and valorizing industrial waste for use in sand concrete, this study contributes to finding a solution for sludge that is generally discharged into nature. Its use as an alternative material in sand concrete is being considered.The study aims to evaluate the effect of partially replacing oil well sand with dune sand and alluvial sand at substitution levels of 25 % and 30%, in combination with the addition of polypropylene fibers, on the mechanical properties of oil well sand concrete. The incorporation of dune sand and alluvial sand alongside oil well sand effectively reduces the proportion of oil well sand, resulting in notable improvements in compressive strength, tensile strength, and a decrease in shrinkage in the mixtures. Furthermore, the inclusion of polypropylene fibers produced a more pronounced enhancement in both strength (compressive and tensile) and shrinkage resistance.

1. Introduction

During drilling, production, and refining processes, large volumes of both solid and liquid industrial wastes are generated. The uncontrolled discharge of these pollutants into the environment poses serious risks of contaminating surrounding areas, potentially causing harmful effects on human health and ecosystems.Sand concrete is composed of various types of sand, cement, admixtures, supplementary materials, and water, with its distinguishing characteristic being the high proportion of sand compared to traditional concrete [1]. Environmental concerns associated with petroleum-based products are often linked to hydrocarbon pollutants [2].To address this issue, several researchers have explored the potential of using oil-contaminated sand in engineering applications as an alternative remediation approach. For instance,Cook et al. [3] carried out experimental studies on uniformly graded sands contaminated with crude oil to evaluate their compaction, compressive, and strength properties. Their results indicated that while oil contamination had little impact on compaction behavior, it reduced the internal friction angle and significantly increased the compressibility of the sand.Similarly, studies by Saberian and Khabiri [4], Akinwumi et al. [5], and Hassan et al. [6] demonstrated the positive effects of incorporating cement and other stabilizing materials into oil-contaminated sand. These findings have shifted the perception of oil-contaminated sand from a waste material to a potentially valuable resource with economic and engineering applications.This study aims to address a significant research gap by investigating the incorporation of dune and alluvial sands, along with the reinforcement of concrete using polypropylene fibers, to enhance its mechanical performance. Previous studies have investigated the impact of sand type on concrete properties [6, 7]. Numerous investigations have explored the use of dune sand as a fine aggregate in concrete production, particularly in desert regions, with the objectives of utilizing local resources for construction and reducing transportation costs [8,9]. Research by Bédérina et al. [10] demonstrated that dune sand can optimize the compaction of river sand, thereby improving the workability and mechanical properties of sand concrete.Polypropylene fibers are widely used across multiple industries, including chemical processing, energy, textile production, environmental protection, and construction [11–14]. Studies on fiber-reinforced concrete have shown that the inclusion of polypropylene fibers significantly enhances concrete performance by mitigating inherent limitations, such as low tensile strength, limited ductility, and poor energy absorption capacity [15,16]. Ashteyat et al. [17] reported that polypropylene fibers improve both the mechanical properties and durability of concrete. Research by Shehnila Fatima [18] further concluded that small volumes of polypropylene fibers reduce early-age shrinkage and moisture loss in concrete mixes, while also enhancing deformation capacity and ductility under compressive loads.The primary objective of this paper is to reduce the environmental impact of waste sands contaminated by hydrocarbon fluids from oil drilling operations. Specifically, this study investigates the effects of partially substituting oil well sand with dune and alluvial sands, in combination with polypropylene fiber reinforcement, on the mechanical properties of oil well sand concrete.

2. Materials

2.1 Cement

Portland cement CRS CEMI42.5 (sulfate-resistant cement), from Biskra Factory in Algeria, was used throughout this study.The cement had an absolute density of 3.25 g/cm³ and a specific surface area of 3215 cm²/g. Its chemical and clinker mineralogical compositions are presented in Table 1.

2.2 Sands

Three sands were used (Table 2) in this study.

Oil wells sand

Oil wells sand from the Hassi Messaoud oil wells drilling site was used; its fineness modulus and absolute density were 2.35 and 2.45 g/cm^3, respectively.

Alluvial sand

Alluvial sand, sourced from Baâge (El Meghaier, Algeria), was utilized in this research. The maximum particle size of the sand was 4 mm. It possessed a fineness modulus of 1.87 and an absolute density of 2.7 g/cm^3, respectively.

Dune sand

Dune sand from El Oued, Algeria, characterized by a maximum particle size of 1 mm, was employed in this study. The sand had a fineness modulus of 1.2 and an absolute density of 2.64 g/cm^3, respectively.

2.3 Adjuvant

The super plasticizer used in the mortar mixtures is Medaplast SP 40, an Algerian product based on Ether Polycarboxylate. According to the manufacturer, the recommended dosage ranges from 0.5% to 2.5% by weight of cement, depending on the desired performance.

2.4 Polypropylene fibers

The fibers used in this study to reinforce the sand concrete from oil wells are polypropylene (PP) monofilament fibers, sourced from TEKNACHEM Company in Setif, Algeria. The various characteristics of these fibers are detailed in Table 3.

3. Experimental study

To produce plain sand concrete, the cement-to-sand ratio followed the EN 196 standards, where one part cement was mixed with three parts sand in all mixtures, with and without fibers. The required water content was determined using a flow table test.For polypropylene fiber-reinforced sand concrete, fibers were incorporated at a dosage of 1 kg/m³ [19]. However, as reported in reference [15], the addition of fibers reduced the workability of the mixtures. Therefore, a super plasticizer was introduced to enhance workability.Three types of plain sand concrete mixtures were prepared and designated as follows: 100% OWS (oil well sand concrete), 25% DS + 75% OWS (25% dune sand and 75% oil well sand), and 30% AS + 70% OWS (30% alluvial sand and 70% oil well sand). The detailed mix proportions are presented in Table 4.The proportions of the mixtures are given in Table 4.The mixing procedure began with the blending of the different sands, followed by the addition of cement to the mixture. Polypropylene fibers were then carefully dispersed by hand to ensure uniform distribution throughout the concrete. Water was gradually incorporated into the mix. The fresh mixtures were cast into molds in two layers and compacted using a vibration table. After approximately 24 hours, all specimens were demolded and placed under laboratory conditions at a temperature of 25–35 °C and a relative humidity of 40% ± 10%.To assess the mechanical properties, prismatic specimens measuring 40 mm × 40 mm × 160 mm were prepared in accordance with European Standard EN 196-1. These samples were cured in water for 28 days. Tensile strength was determined through three-point bending tests on three prisms of the same dimensions. Subsequently, half of the fractured specimens were subjected to compressive strength testing on the 40 mm × 40 mm sections, in accordance with EN 196-1 specifications. Both compressive and tensile strengths were measured at different curing ages.Shrinkage tests were performed in compliance with NF P 15-433. The procedure involved monitoring changes in specimen length over time, starting from demolding until stabilization. Shrinkage was evaluated at different ages to quantify the extent of deformation.

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4. Results and discussion

Effect of substitution on mechanical strength: Compressive strength

These results indicate an increase in the compressive strength of concrete when using a blend of 25% dune sand (DS) with 75% oil well sand (OWS), and 30% alluvial sand (AS) with 70% OWS, compared to conventional concrete made entirely with OWS. This improvement is attributed to the reduced proportion of OWS in the mix. Furthermore, concrete incorporating a combination of OWS and AS demonstrated higher compressive strength than that containing OWS and DS. Several studies [20,21] have reported strength enhancements up to a certain replacement ratio of dune sand. According to Bouziani et al. [22], increased aggregate compactness can contribute to a further improvement in strength.

Effect of substitution on mechanical strength: Tensile strength

Similar to the case of compressive strength, the tensile strength of concrete containing 25% dune sand (DS) with 75% oil well sand (OWS), and 30% alluvial sand (AS) with 70% OWS, was higher than that of plain concrete made entirely with OWS. Moreover, concrete incorporating alluvial sand exhibited greater tensile strength than concrete containing dune sand (25% DS + 75% OWS). This difference can be attributed to the higher specific surface area of dune sand, which leads to an increased volume of voids. In contrast, the larger particle size of alluvial sand contributes to the enhanced resistance of concrete made with AS compared to that made with DS [23]. Additionally, research has shown that replacing 40% to 50% of natural dune sand with waste ceramic aggregate results in the most significant improvements in both compressive and flexural strength compared to the reference mortar [24].

Effect of substitution on mechanical strength: Shrinkage

The shrinkage of concrete mixtures containing 25% dune sand (DS) with 75% oil well sand (OWS) and 30% alluvial sand (AS) with 70% OWS was lower than that of plain concrete made entirely with OWS. This reduction in shrinkage can be attributed to differences in the particle size distribution and surface texture of the sands used in these mixtures. Such physical properties of the aggregates influence the adhesion and bonding between the cement paste and the aggregates. Moreover, an increase in aggregate size enhances the restraint effect, further reducing drying shrinkage [25,26]. Previous studies have reported that concrete mixtures combining river sand with 15% dune sand exhibited the highest shrinkage, whereas mixtures made solely with river sand showed lower shrinkage [22].

Effect of polypropylene fibers on mechanical strength

Compressive strength

Figure 4 illustrates the improvement in the compressive strength of sand concrete when alluvial sand is incorporated into the mixture with oil well sand (30% AS + 70% OWS) compared to a mixture with dune sand (25% DS + 75% OWS). This enhancement in compressive strength can be further achieved by increasing the content of polypropylene fibers in the matrix, as their presence promotes a preferential orientation that contributes to overall strength gains. This effect is attributed to the fibers' ability to limit crack initiation and propagation, as demonstrated by Topçu and Canbaz [27]. Ramujee [28] also reported that the inclusion of polypropylene fibers enhances both the tensile and compressive strength of concrete. Similarly, S. Ahmed et al. [29] found that low amounts of polypropylene fibers improve compressive strength, whereas higher concentrations can reduce it by 3% to 5% compared to conventional concrete.

Tensile strength

Figure 5 illustrates the increase in tensile strength for the mixtures (25% DS + 75% OWS) and (30% AS + 70% OWS) with a fiber dosage of 1 kg/m³, compared to the same mixtures without fibers. The influence of fiber content was found to be particularly significant. This improvement is attributed to the alignment of fibers along the specimen's length. During loading, when the specimens are subjected to stress, the applied force acts perpendicular to the fibers, reducing crack propagation and thereby enhancing tensile strength.Hsie et al. [30] reported that polypropylene hybrid fiber-reinforced concrete exhibits a notable enhancement in mechanical strength. This improvement is mainly due to the high elastic modulus and stiffness of monofilament fibers, which possess a rough surface texture. Similarly, Kakooei et al. [31] observed that the improvement in mechanical performance of polypropylene fiber-reinforced concrete is largely a result of fibers being wider than the cracks, enabling them to form bridging connections that increase the material's resistance to deformation.

Shrinkage

Figure 6 illustrates the reduction in shrinkage for the mixtures (25% DS + 75% OWS) and (30% AS + 70% OWS) with a fiber dosage of 1 kg/m³, compared to the same mixtures without fibers. The incorporation of fibers decreases the drying shrinkage of reinforced sand concrete, and this effect becomes more pronounced as the fiber content increases. The observed reduction in shrinkage can be attributed to the formation of fiber networks, which provide a reinforcing mechanism that limits deformation and lowers the shrinkage rate of the concrete. Similar results have been reported in previous studies [32–34], where the inclusion of fibers effectively reduced shrinkage. Sun et al. [35] also demonstrated that shrinkage strains in concrete diminish with increasing fiber dosage.Atiş and Karahan [36] explained the reduction in drying shrinkage caused by fiber addition, noting that the fibers are randomly distributed within the concrete mixture, with only a portion aligning parallel to the shrinkage strain.

Table 1 *Chemical and mineralogical compositions of cement (%).*

I. CHEMICAL COMPOSITION (WT %)							
Al_2O_3	SiO_2	Fe_2O_3	SO_3	CaO	K_2O	Na_2O	LOI
4.68	21.14	5.45	2.44	65.23	0.35	0.17	0.78
Mineralogical composition (%)							
C_3S		C_2S		C_3A		C_4AF	
69.42		8.36		3.02		17.26	

Table 2 *Physical properties of used sands.*

SAND	Apparent density (Kg/m³)	Specificdensity (Kg/m³)	Sand equivalent (SE) (%)	Finenes smodulus (FM) (%)
Oil well sand (OWS)	1370	2450	74	2.35
Dune sand (DS)	1560	2640	85	1.2
Alluvial sand (AS)	1640	2700	80	1.87

Table 3 *Physical and mechanical properties of polypropylene fibers [19].*

Length (mm)	Diameter (microns)	Tensile strength (MPa)	Elasticmodulus (MPa)
12	28	320-400	3500-3900

Table 4 *Mixtures proportions (1 m^3).*

MIXTURES	Sand (Kg)	Cement (Kg)	Water (L)	Fibers (Kg)	Super plasticizer (Kg)	W/C
100% Oil well sand	1394.85	464.95	278.97	/	9.30	0.6
25% Dune sand + 75% Oil well sand	1418.07	472.69	283.61	/	4.72	0.6
	1410.72	470.24	282.14	1	4.70	0.6
30% Alluvial sand + 70% Oil well sand	1447.83	482.61	289.57	/	4.82	0.6
	1441.74	480.58	288.34	1	4.80	0.6

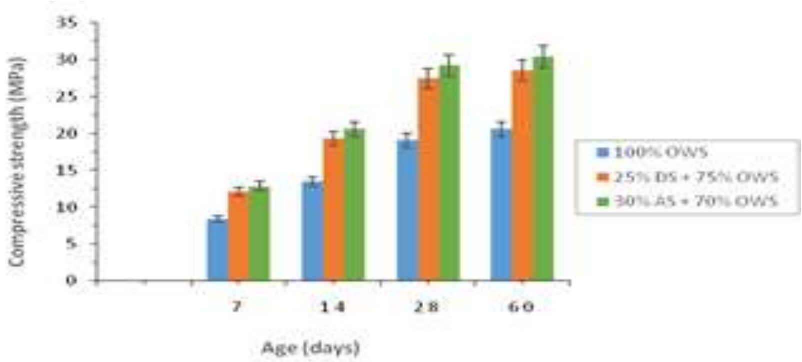

Figure 1. *Compressive strength as a function of age*

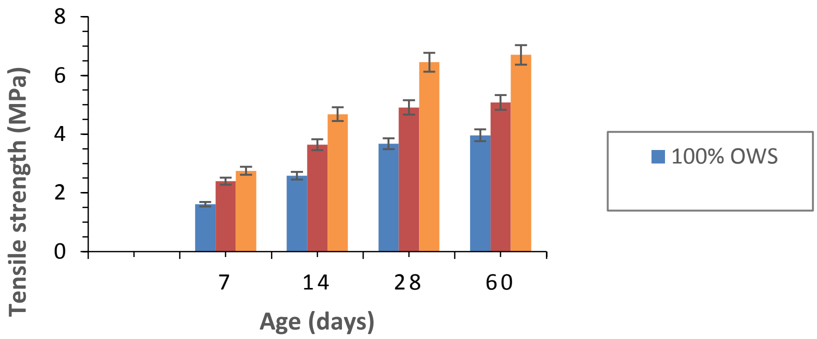

Figure 2.*Tensile strength as a function of age*

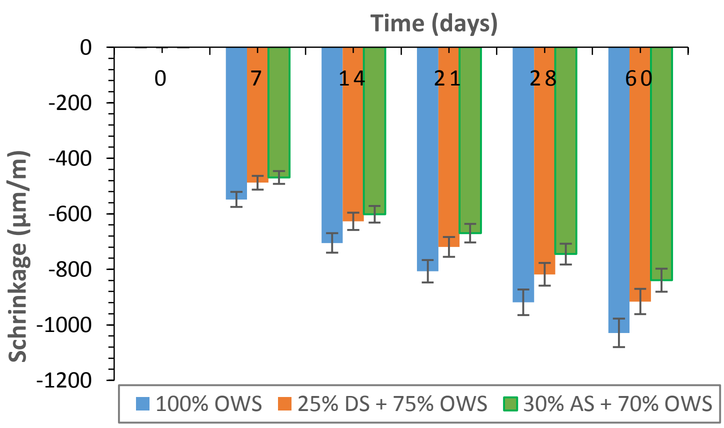

Figure 3. *Shrinkage as a function of age*

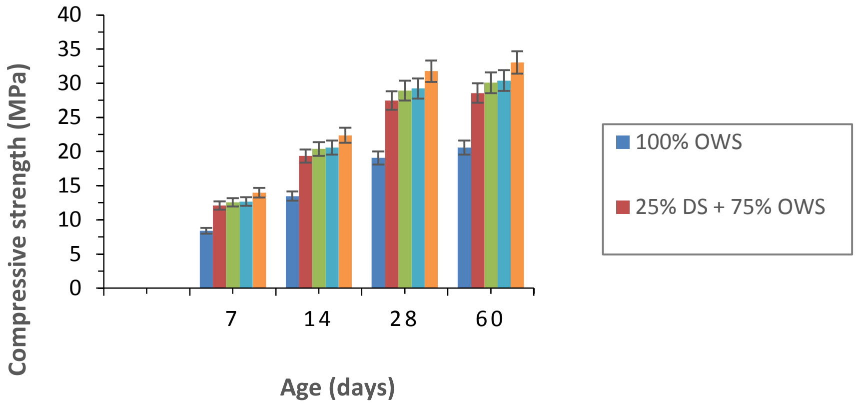

Figure 4. *Effect of polypropylene fibers on compressive strength*

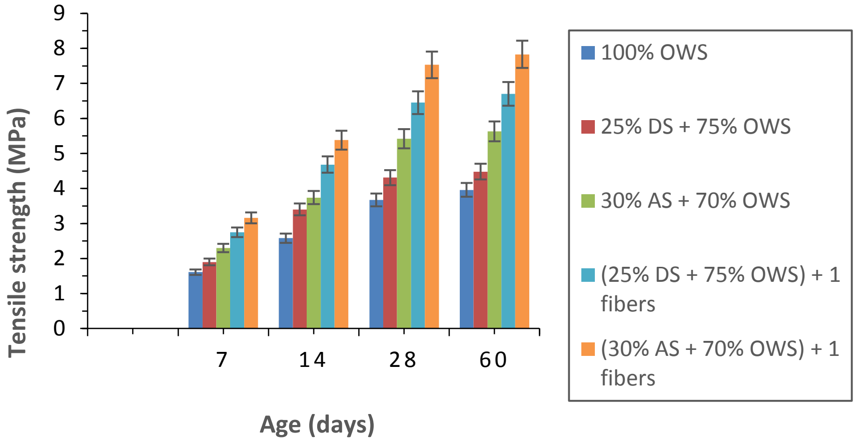

Figure 5*. Effect of polypropylene fibers on tensile strength*

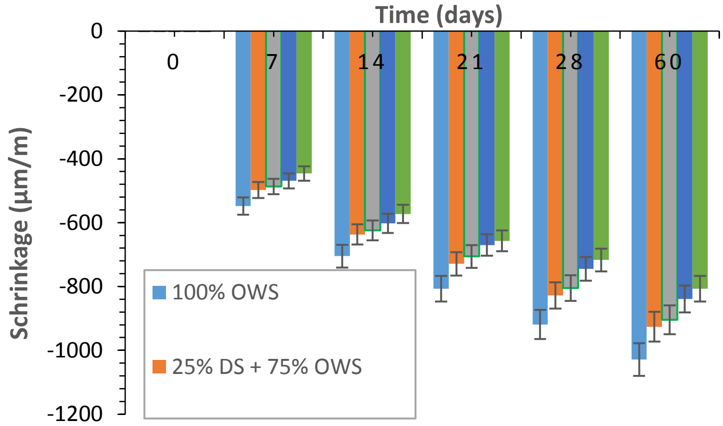

Figure 6. *Effect of polypropylene fiber on shrink age*

5. Conclusions

In this study, the performance of oil well sand concrete reinforced with polypropylene fibers and incorporating dune and alluvial sands was investigated. Based on the experimental results, the following conclusions were drawn:

- The incorporation of 25% dune sand and 30% alluvial sand led to an improvement in compressive strength, demonstrating a notable enhancement compared to the control concrete composed solely of oil well sand (witness concrete). Furthermore, the compressive strength of the mixture containing 30% alluvial sand (AS) exceeded that of the mixture with 25% dune sand (DS).
- The tensile strength improved with the addition of 25% dune sand and 30% alluvial sand, showing a significant enhancement compared to

the control concrete made with only oil well sand (witness concrete). Moreover, the tensile strength of concrete with 30% alluvial sand (AS) was higher than that of concrete with 25% dune sand (DS).

- Shrinkage performance improved with the addition of 25% dune sand and 30% alluvial sand, compared to the control concrete made solely with oil well sand (witness concrete). This reduction in shrinkage can be attributed to variations in particle size distribution and the surface texture of the sands used in these mixtures.
- The addition of polypropylene fibers further enhanced the compressive and tensile strengths of sand concrete. Moreover, it significantly improved shrinkage resistance, highlighting the crucial role of fibers in enhancing the durability and resilience of sand concrete.

These findings confirm the effectiveness of using dune sand and alluvial sand as partial replacements for oil well sand in improving the mechanical properties of sand concrete, while also emphasizing the beneficial contribution of polypropylene fibers in further strengthening these properties.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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