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Research Article

Sustainable Rehabilitation of Oil-Contaminated Sand: Enhancing Mechanical Properties through Alluvial Sand Substitution and Polypropylene Fiber Reinforcement

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Abstract:

The waste generated by drilling activities in the hydrocarbon industry poses a significant environmental threat, making its management essential. One effective approach is to repurpose this waste for sand concrete production, providing a sustainable alternative to conventional sand concrete. This study experimentally investigates the feasibility of incorporating oil well sand into sand concrete reinforced with polypropylene fibers. The oil content in the well sand was reduced from 20% to 5% by partially replacing it with alluvial sand in varying proportions (20% and 30%). Fiber reinforcement was introduced at dosages of 1 and 1.5 kg/m³. Reducing the oil content by incorporating alluvial sand improved both the fresh and hardened properties of the sand concrete. The optimal mechanical performance, in terms of compressive and tensile strength, was achieved with a mixture containing 30% alluvial sand and 70% oil well sand. A fiber dosage of 1.5 kg/m³ had a more pronounced effect on the compressive and tensile strength, as well as the shrinkage behavior, of the mixtures containing 30% alluvial sand and 70% oil well sand.

1. Introduction

The Hassi Messaoud region is considered Algeria's most important hub for the oil industry. Drilling, production, and refining operations generate large amounts of solid and liquid industrial waste. These waste materials, known as cuttings, are disposed of in a designated area called a quagmire. The release of these pollutants into the environment poses a significant risk of contamination, potentially causing harmful effects on both the human health and the ecosystem.Environmental concerns related to petroleum-based substances often involve the release of hydrocarbon pollutants [1]. Repurposing contaminated soil for construction has emerged as a viable remediation strategy [2].Several studies have investigated the use of oil-contaminated sand in engineering applications as an alternative remediation method. Research findings indicate that oil-contaminated sand can be effectively utilized in road base materials or as a surface layer for parking areas [3,4].Hassan et al. [5] examined the benefits of stabilizing oil-contaminated sand by incorporating cement and other materials. Their research has transformed the perception of contaminated sand from waste into a valuable resource with economic potential.This study explores the incorporation of alluvial sands and reinforced concrete with polypropylene fibers to enhance strength. Previous research [5,6] has investigated how different sand types influence concrete properties. Additionally, polypropylene fibers have been recognized as a cost-effective solution for improving various concrete characteristics.Studies have highlighted several advantages of polypropylene fibers, including enhanced bonding strength [7], improved long-term tensile strength [8], increased impact resistance [9], and reduced plastic shrinkage [10]. These fibers help mitigate plastic and early drying shrinkage by enhancing the tensile properties of concrete and preventing crack formation during the drying process.The main objective of this study is to minimize the environmental impact of hydrocarbon-contaminated reject sands from oil well drilling sites. Specifically, it aims to assess how replacing oil-contaminated sands with alluvial sands and incorporating polypropylene fibers influences the mechanical properties of the resulting concrete.

2. Materials

2.1 Cement

The cement used in this study was Portland cement CRS CEMI 42.5, specifically chosen for its sulfate resistance. It was procured from the Biskra Factory in Algeria. The cement exhibited an absolute density of 3.25 g/cm^3 and a specific surface area of 3215 cm^2/g. A detailed analysis of its chemical composition and clinker mineralogical composition can be found in Table 1.

2.2 Sands

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

Oil wells sand

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

2.3 Adjuvant

The sand concrete mixtures incorporated an Algerian superplasticizer known as Medaplast SP 40. The manufacturer's recommended dosage ranged from 0.5% to 2.5% by weight of cement, depending on the desired performance.

2.4 Polypropylene fibers

To reinforce the sand concrete derived from oil wells, polypropylene (PP) fibers of the monofilament type were employed. These fibers were obtained from the TEKNACHEM Company in Setif, Algeria. Table 3 provides a comprehensive overview of the characteristics of these fibers.The raw materials used in this work and previously described, have been photographed and presented in Fig. 1.

3. Experimental study

To produce plain sand concrete, the cement-to-sand ratio was maintained according to EN 196 standards, with one part cement mixed with three parts sand in all compositions, both with and without fibers. The required water content was determined using a flow table.

For polypropylene fiber-reinforced sand concrete, two fiber dosages were used: 1 kg/m^3 and 1.5 kg/m^3. The addition of fibers significantly reduced workability [11], making it necessary to incorporate a superplasticizer.

Two distinct plain sand concrete mixtures were prepared and designated as follows: 100% OWS, consisting entirely of oil well sand concrete, and 30% AS – 70% OWS, containing 30% alluvial sand and 70% oil well sand. The mixture proportions are presented in Table 4.The mixing process began with blending the different types of sand, followed by the addition of cement. Polypropylene fibers were then manually dispersed to ensure uniform distribution throughout the concrete. Water was gradually incorporated into the mixture. The prepared mixtures were poured into molds in two layers and compacted using a vibrating table. After approximately 24 hours, the specimens were demolded and stored under laboratory conditions at a temperature of 25–35°C and a humidity level of 40% ± 10%.

To evaluate the mechanical properties, prismatic test samples measuring 40 mm × 40 mm × 160 mm were prepared in accordance with European Standard EN 196-1. These samples were immersed in water for 28 days. Tensile strength tests were conducted on three prismatic samples of the same dimensions using the three-point bending method. Subsequently, half of the samples tested for tensile strength underwent compression tests on a 40 mm ×

40 mm section, following EN 196-1 standards. Both compressive and tensile strengths were assessed at various ages.
Shrinkage tests, performed in accordance with standard NF P 15-433, involved monitoring the dimensional changes of the specimens over time, from demolding until length stabilization.

4. Results and discussion

4.1 Effect of substitution on mechanical strength: Compressive strength

The results indicate that incorporating 30% alluvial sand (AS) with 70% oil well sand (OWS) significantly enhances the compressive strength compared to concrete produced solely with 100% OWS. This improvement, measured at 41.87%, is primarily attributed to the reduced reliance on OWS. Error bars (mean ± standard deviation, n = 3) are presented in Fig. 2 to illustrate the variability of the measurements. The relatively narrow ranges demonstrate that the data are both reproducible and reliable. Statistical analysis (ANOVA, $p < 0.05$) further confirmed that the strength gain observed in the 30% AS + 70% OWS mixture is statistically significant compared with the control (100% OWS). The variation in strength is closely linked to differences in the granular distribution and surface texture of the sands. A lower smoothness coefficient reflects smoother sand particles, which tend to produce weaker concrete, as reported in earlier studies [12, 13].

4.2 Effect of substitution on mechanical strength: tensile strength

The tensile strength increased by approximately 53.39% compared to the lowest value recorded in concrete made entirely with 100% oil well sand (OWS). Error bars (mean ± standard deviation, n = 3) are shown in Fig. 3 to illustrate the variability of the data. The relatively narrow error ranges confirm the reproducibility of the results. Statistical analysis (ANOVA, $p < 0.05$) indicated that the improvement in tensile strength for mixtures containing alluvial sand (AS) is statistically significant when compared with the control (100% OWS). This enhancement is primarily attributed to the higher specific surface area of OWS, which increases void content and water demand, thereby weakening the cementitious matrix. In contrast, the larger particle size of AS facilitates better packing and interlocking, reducing voids and enhancing the overall mechanical performance. These combined effects explain the superior strength observed in concrete incorporating AS compared to that produced exclusively with OWS [3, 4].

4.3 Effect of substitution on mechanical strength: Shrinkage

The shrinkage of concrete mixtures containing 30% alluvial sand (AS) and 70% oil well sand (OWS) was lower than that of plain concrete produced entirely with 100% OWS. After 90 days, the shrinkage reduction was measured at 18.67%. Error bars (mean ± standard deviation, n = 3) are presented in Fig. 4 to illustrate measurement variability. The narrow error ranges indicate consistent shrinkage behavior across replicates. Statistical analysis (ANOVA, $p < 0.05$) confirmed that the reduction in shrinkage for the 30% AS + 70% OWS mixture is significant compared with the control (100% OWS). This reduction is attributed to differences in granular gradation and the surface smoothness of the sands used in the mixtures. Previous studies have reported that concrete made with river sand combined with 15% dune sand exhibited the highest shrinkage, whereas mixtures composed solely of river sand showed lower shrinkage [14]. These findings are consistent with the present study, confirming that increasing the proportion of alluvial sand reduces shrinkage.

5. Effect of polypropylene fibers on mechanical strength

5.1 Compressive strength

Figure 5 shows the improvement in the compressive strength of sand concrete when alluvial sand (AS) is blended with oil well sand (OWS) in a 30% AS and 70% OWS mixture, compared with concrete made entirely of 100% OWS. After 90 days, compressive strength increased by 9.48% and 13.69% for fiber dosages of 1 and 1.5 kg/m³, respectively. Error bars (mean ± standard deviation, n = 3) are presented in Fig. 5 to illustrate the variability of the results. The narrow error ranges indicate good reproducibility across replicates. Statistical analysis (ANOVA, $p < 0.05$) confirmed that the strength enhancement resulting from polypropylene fiber incorporation is statistically significant compared with the control mixture without fibers. This improvement is attributed to the fibers' ability to restrict crack initiation and propagation, thereby strengthening the cementitious matrix. This mechanism is consistent with previous findings reported by Topçu and Canbaz [15].

5.2 Tensile strength

Figure 6 illustrates a marked improvement in the tensile strength of sand concrete made with a 30% alluvial sand (AS) and 70% oil well sand (OWS) blend, compared with concrete produced solely with OWS. After 90 days, tensile strength increased by 11.06% and 14.77% for fiber dosages of 1 and 1.5 kg/m³, respectively. Error bars (mean ± standard deviation, n = 3) are included in Fig. 6 to reflect the variability of the data. The relatively narrow error ranges confirm the reproducibility of the results. Statistical analysis (ANOVA, $p < 0.05$) verified that these strength gains are statistically significant compared with the control mixture without fibers. Moreover, the mixture containing 1.5 kg/m³ of fibers achieved higher tensile strength than that with 1 kg/m³, indicating a dosage-dependent improvement. This enhancement is attributed to the fibers' ability to align within the specimens, causing cracks to propagate perpendicular to their orientation during loading, thereby reducing crack formation and enhancing tensile resistance. This mechanism is consistent with the findings of Kakooei, Akil, Jamshidi, and Rouhi [16], who reported that polypropylene fibers act as crack-bridging elements, improving mechanical performance by limiting crack widening.

5.3 Shrinkage

Figure 7 illustrates the reduction in drying shrinkage observed in concrete mixtures containing 30% alluvial sand (AS) and 70% oil well sand (OWS) with fiber contents of 1 and 1.5 kg/m³, compared with plain concrete made entirely of 100% OWS after 90 days. Error bars (mean ± standard deviation, n = 3) are presented in Fig. 7 to indicate variability in the results. The relatively narrow error ranges confirm the reproducibility of the shrinkage measurements. Statistical analysis (ANOVA, $p < 0.05$) verified that shrinkage reductions for both fiber dosages are statistically significant compared with the control mixture. Moreover, the mixture with 1.5 kg/m³ of fibers exhibited a greater reduction than that with 1 kg/m³, indicating that shrinkage mitigation improves with increasing fiber content. This effect is attributed to the formation of fiber networks that restrain shrinkage deformation by bridging microcracks, thereby lowering the overall shrinkage rate. These findings are consistent with earlier studies [17–20], which reported that fiber incorporation reduces drying shrinkage, and with the observations of Feldman et al. [21], who highlighted the effectiveness of polypropylene fibers in mitigating shrinkage.

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

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/m^3)	Specific density (Kg/m^3)	Sand equivalent (SE) (%)	Fineness modulus (FM) (%)
Oil well sand (OWS)	1370	2450	74	2.35
Alluvial sand (AS)	1640	2700	80	1.87

Table 3 *: Physical and mechanical properties of polypropylene fibers*

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)	Superplasticizer (Kg)	W/C
100% Oil well sand	1394.85	464.95	278.97	/	9.30	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
	1431.78	477.26	286.35	1.5	4.77	0.6

Oil Wells Sand (OWS) **Alluvial Sand (AS)** **Polypropylene Fibers**

Figure 1. *Raw materials*

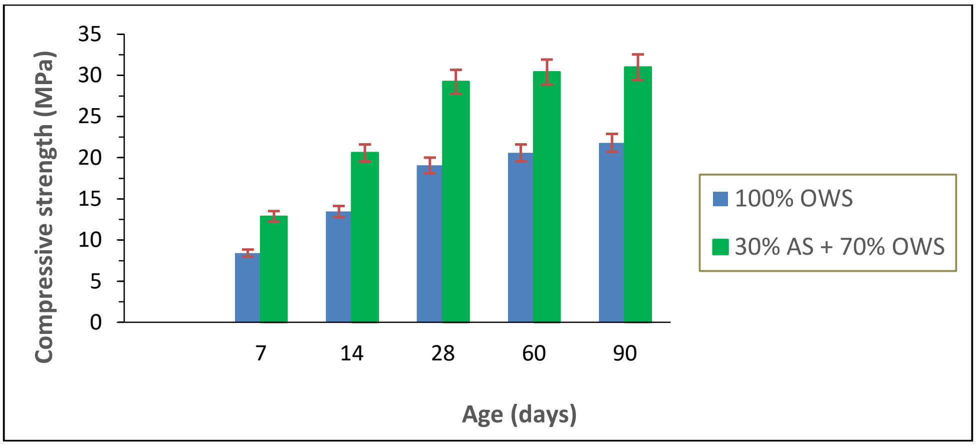

Figure 2. *Compressive strength as a function of age*

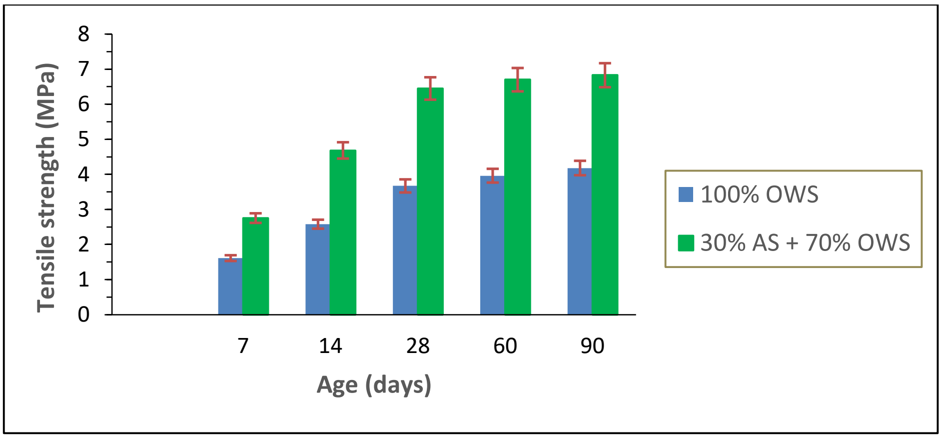

Figure 3. *Tensile strength as a function of age*

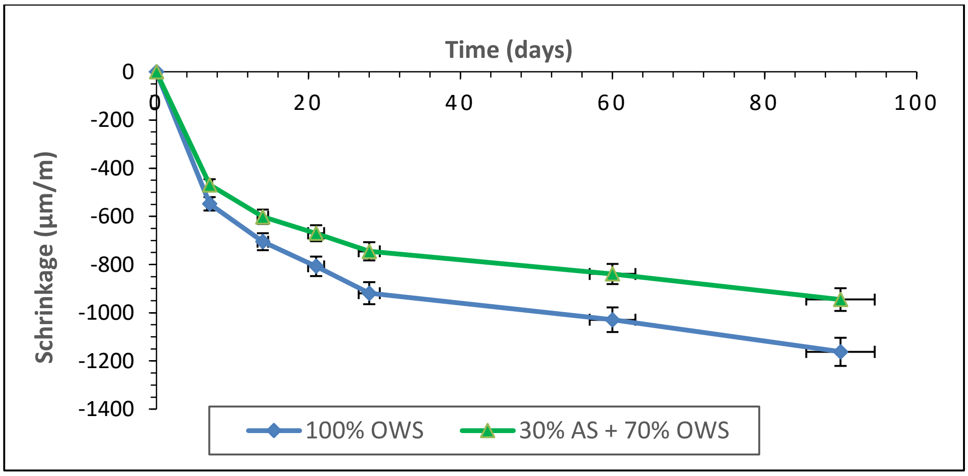

Figure 4. *Shrinkage as a function of age*

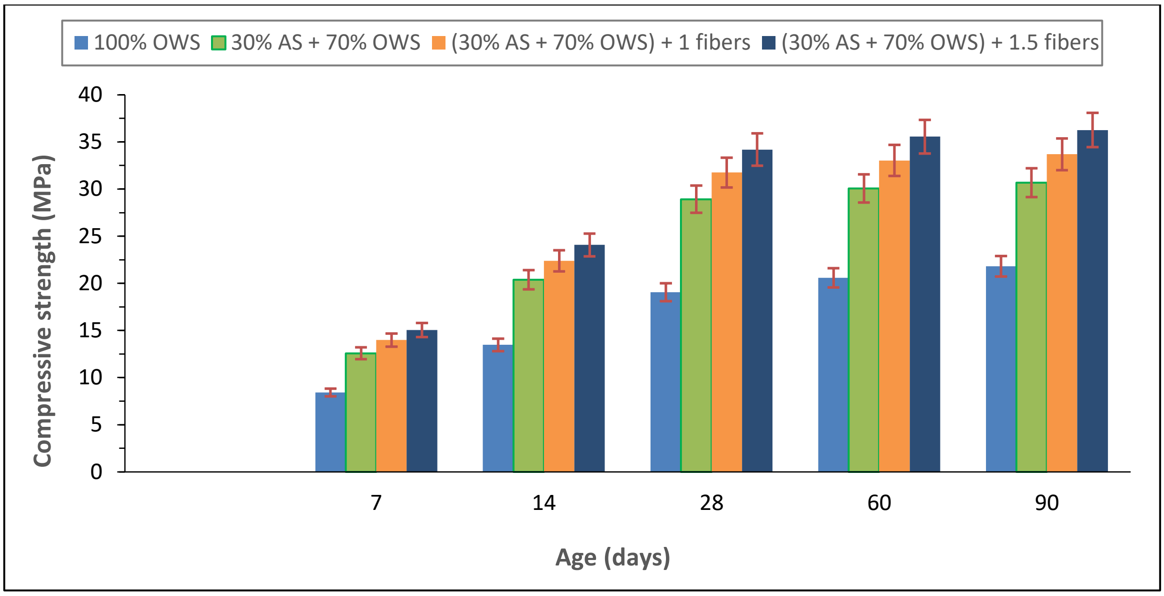

Figure 5. *Effect of polypropylene fibers on compressive strength*

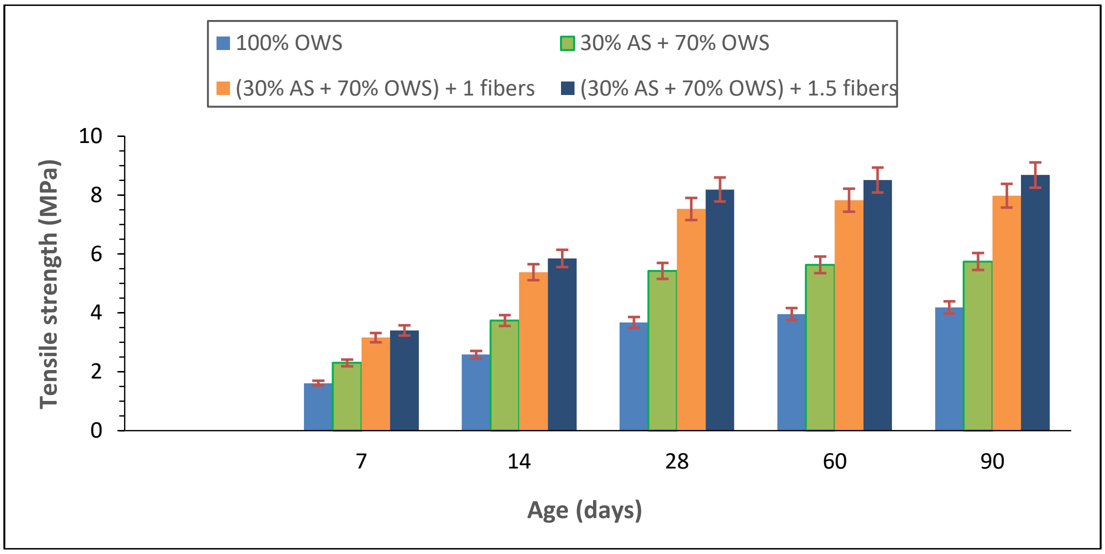

Figure 6*. Effect of polypropylene fibers on tensile strength*

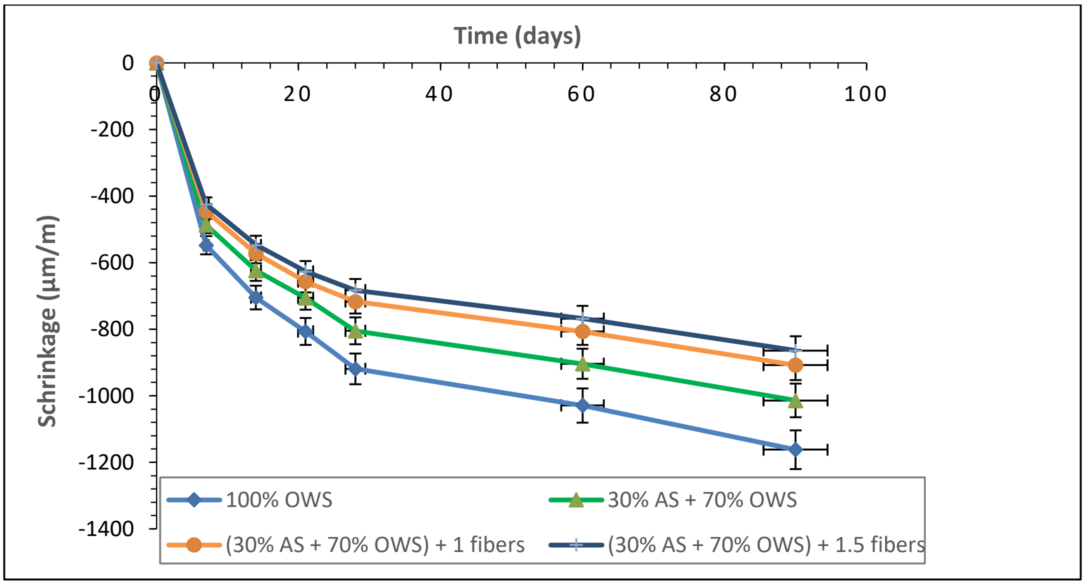

Figure 7. *Effect of polypropylene fiber on shrinkage*

5. Conclusions

Based on the experimental results obtained, the following conclusions can be drawn:

- The increase in compressive strength observed in concrete containing a blend of alluvial sand (30% AS) and oil well sand (70% OWS), compared to concrete made exclusively with oil well sand (100% OWS), can be attributed to several factors. These include the reduction in oil content present in the OWS, as well as differences in granular grading and surface smoothness of the sands used.
- Similarly, the tensile strength of sand concrete containing 30% alluvial sand and 70% oil well sand (30% AS + 70% OWS) is higher than that of concrete made entirely with oil well sand (100% OWS). This increase in strength is attributed to the larger particle size of AS, which promotes better packing and interlocking, reduces voids, and enhances overall mechanical performance.
- The shrinkage of concrete mixtures containing 30% alluvial sand (AS) and 70% oil well sand (OWS) was found to be lower than that of plain concrete made entirely with 100% OWS. This reduction is primarily due to differences in the granular gradation and surface smoothness of the sands used in these mixtures.
- The compressive strength of sand concrete improves when alluvial sand is mixed with oil well sand in a 30:70 ratio (30% alluvial sand (AS) and 70% oil well sand (OWS)) compared to using 100% OWS. This improvement is observed at various fiber contents (1 and 1.5 kg/m³) after 90 days. The addition of polypropylene fibers, particularly when properly oriented, significantly enhances compressive strength.
- Similarly, the tensile strength of sand concrete derived from oil wells increases when alluvial sand is incorporated (30% AS and 70% OWS) rather than using 100% OWS. This enhancement is primarily due to the fibers aligning along the length of the specimens.
- A reduction in drying shrinkage was observed in concrete mixtures containing 30% oil well sand (AS) and 70% oil well sand (OWS), with fiber contents of 1 kg/m³ and 1.5 kg/m³, compared to plain concrete made entirely of 100% oil well sand. The addition of fibers helps minimize drying shrinkage in reinforced sand concrete, with the effect becoming more significant as the fiber content increases.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
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- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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