Optimizing Physical and Mechanical Properties of Recycled Filler and Fiber Sand Concrete: A Full Factorial Design Approach

Ikram Souici*, Leila Zeghichi†, Abdelhalim Benouis§

1 Department of Civil Engineering and Hydraulic, May 8, 1945 University, Guelma, Algeria
2 Department of Civil Engineering and Hydraulic, Mohamed Khider University, Biskra 07000, Algeria

Corresponding Author Email: souici.ikram@univ-guelma.dz

https://doi.org/10.18280/rcma.340107

Received: 13 November 2023
Revised: 4 December 2023
Accepted: 11 January 2024
Available online: 29 February 2024

Keywords:
date palm waste fibers, factorial plane, optimization, recycled fillers, sand concrete, valorization

1. INTRODUCTION

Sand concrete, resembling traditional concrete in production scale, has been the subject of renewed interest as a construction material. Despite considerable advances in understanding its behavior through existing studies, a comprehensive grasp of sand concrete's properties remains elusive. Recent investigations have delineated sand concrete's economic benefits and technical properties [1], typically comprising sand, fines, cement, and water. To tailor this basic mix for specific applications, additions such as gravel, fibers, additives, and other components are considered [2].

The performance enhancement of sand concrete often involves the integration of mineral fillers. Among these, limestone fillers—with their high affinity for cement hydrate crystals—have been extensively utilized and researched for sand concrete production [3]. These fillers are primarily employed to improve the compactness of the concrete by refining its granular structure and to mitigate the use of costly cement. The cohesion of the mixture, influenced by the mineralogical nature, fineness, and reactivity of the fillers, has also been found to benefit from such additions [1].

A significant increase in demand for natural aggregates for the construction and public works sectors has been reported in recent years [4]. The existing supply of these aggregates is struggling to meet the burgeoning demand, and the establishment of new quarries is increasingly constrained by stringent regulations aimed at environmental preservation.

Concurrently, demolition and construction waste, derived from the deconstruction of outdated buildings, present a growing environmental issue when disposed of in landfills or used merely for embankments [5]. In light of this, research has been directed toward the utilization of recycled aggregates in concrete, despite their initially inferior properties. The crushing of recycled concrete blocks produces a quantity of fines, which, as some studies have suggested, can be effectively incorporated into various cementitious materials (Table 1).
Table 1. Summary of data about the use of fine recycled concrete (FRC) in cementitious materials

<table>
<thead>
<tr>
<th>Ref.</th>
<th>% of Recycled Fillers</th>
<th>Mixture</th>
<th>Properties</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[4]</td>
<td>10, 20, 30, 50 and 100</td>
<td>Concrete</td>
<td>Compressive strength</td>
<td>The compressive strength results have shown that it is possible to create FRC concretes that have high performance properties, as the concrete made with 100% of FRC presented compressive strength of about 55 MPa.</td>
</tr>
<tr>
<td>[6]</td>
<td>0, 25, 50, 75 and 100</td>
<td>Ultra-high performance (UHPC)</td>
<td>Mechanical behavior</td>
<td>The compressive and flexural strength and tenacity of UHPC decreased as more FRC was introduced. Generally, there is strength reduction of 15 – 30% for concrete containing FRC. However, concrete incorporating up to 50% FRC exhibits similar long-term strength to that of the control. Even at 100% replacement of fine aggregate with FRC, the reduction in strength is only 10%.</td>
</tr>
<tr>
<td>[7]</td>
<td>0, 25, 50, 75 and 100</td>
<td>Concrete</td>
<td>Mechanical properties</td>
<td>The carbonation depth reached a minimum and the resistivity reached a maximum when 50% contents of fine recycled masonry aggregates were used. The use of FRC instead of normal aggregates reduced the compressive and splitting tensile strengths in both normal and high strength concrete. The reduction in the splitting tensile strength was more pronounced than for the compressive strength. The results reveal that Herschel-Bulkley and modified Bingham models provide well defined rheological representations for SCC with FRC. The self-compatibility characteristics of the concretes are remarkably improved by the replacement levels of FRC used in SCC mixtures.</td>
</tr>
<tr>
<td>[8]</td>
<td>0, 20, 50 and 100</td>
<td>Concrete</td>
<td>Compressive strength</td>
<td>For 100% replacement of natural fine aggregate (NFA) by RFC, the compressive, splitting tensile and flexural strengths were found to decrease by 13·51, 6·46 and 22·62% respectively.</td>
</tr>
</tbody>
</table>

The incorporation of agricultural waste, particularly date palm waste which constitutes an environmental challenge in regions like southern Algeria, into concrete is gaining traction. Maintenance of date palms, necessary for waste reduction, generates significant by-products: each palm yields 26 kg of waste annually, including 9.8 kg of midribs, 8 kg of leaflets, 7 kg of spadix stems, and 1.2 kg of mesh [12]. The reinforcement potential of natural plant fibers in cementitious composites has been confirmed, with date palm fibers being a focus for reinforcement applications. The results are summarized in Table 2.

Table 2. Summary of data about the use of date palm fibers (DPF) in cementitious materials

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Percentage of DPF</th>
<th>Mixture</th>
<th>Properties</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[13]</td>
<td>5%, 10%, 15%, 20%, 25% and 30%</td>
<td>Mortar</td>
<td>The density and thermal conductivity of the mortar decrease with increasing DPF; the compressive strength of the mortar decreases with increasing DPF.</td>
<td>DPF increased the water absorption and porosity of the mortar. Thermal conductivity of the mortar was also reported to decrease with addition of DPF.</td>
</tr>
<tr>
<td>[14]</td>
<td>0% to 51%</td>
<td>Mortar</td>
<td>DPF increased the water absorption and porosity of the mortar. Thermal conductivity of the mortar was also reported to decrease with addition of DPF.</td>
<td>The ductility of the mortar increased with increment in DPF content; however, the flexural and mechanical strengths of the mortar decrease with increment in DPF addition.</td>
</tr>
<tr>
<td>[15]</td>
<td>0% to 51%</td>
<td>Mortar</td>
<td>The ductility of the mortar increased with increment in DPF content; however, the flexural and mechanical strengths of the mortar decrease with increment in DPF addition.</td>
<td>The compressive strength at all ages decreased with increase in fiber addition and length. The flexural strength, which was measured in terms of load-deflection, also decreased with increase in fiber volume.</td>
</tr>
<tr>
<td>[16]</td>
<td>2% and 3%</td>
<td>Concrete</td>
<td>The thermal conductivity increased with increase in the fiber length and decreased with increment in fiber volume due to escalation of void content in the cement matrix.</td>
<td>They reported a decrease in workability and compressive strength with increment in fiber dosage and length.</td>
</tr>
</tbody>
</table>

However, the combined use of mineral waste (recycled filler) and organic waste (date palm fibers) in sand concrete has not been adequately explored. This study, therefore, seeks to fill this gap by assessing the effects of filler and fiber incorporation on sand concrete's physical and mechanical properties. Date palm fibers, derived from palm spines and available in 2 cm and 6 cm lengths, were added in volumes of 0.1% and 0.2% (Figure 1). Recycled concrete fillers were substituted for limestone fillers in proportions of 50% and 100% by weight.
A comprehensive three-level factorial design was employed to optimize the parameters of fiber length (FL), fiber percentage (FP), and recycled filler percentage (RFP). The response surfaces and model predictions yielded by this design in JMP Trial 16 were meticulously analyzed. This study aims to evaluate and optimize the effects of recycled fines content and waste fiber content at varying lengths on the physical and mechanical properties of sand concrete using a full factorial design methodology.

### 2. MATERIALS USED

#### 2.1 Sand

It is the main constituent of the sand concrete skeleton. This is local river sand that was brought from Lioua region in the Wilaya of Biskra (Algeria). Its absolute density is 2.58 g/cm³ with a fineness modulus equal to 2.38.

#### 2.2 Cement

Portland cement CEM I 42.5 N SR3 LH (CRS cement resistant to sulphates), manufactured by the cement factory "Biskria Cement SPA" in the Wilaya of Biskra (Algeria), was used in this work. Its absolute density is equal to 3.12 g/cm³.

#### 2.3 Limestone filler

This natural limestone filler comes from the quarry of the Wilaya of M'sila (Algeria). The average grain diameter of this limestone filler is \( \phi = 80 \mu m \). As for its specific surface, it is 6000 cm²/g, with an absolute density equal to 2.68 g/cm³.

#### 2.4 Fine recycled concrete

Resulting from the crushing of concrete specimens, its absolute density is equal to 2.51 g/cm³, its specific surface is about 6000 cm²/g.

Chemical analysis and the X-ray fluorescence spectrometry of fine materials: Cement, limestone filler and recycled filler are presented in Table 3 and Figure 2 respectively.

Figure 2 illustrates the X-ray fluorescence spectra of fines, cement, limestone filler, and recycled fillers. It is clearly seen that the peak corresponding to the limestone filler is larger than those of the other elements.

### 2.6 Date palm fibers

These vegetable fibers have an apparent density equal to 1.84 g/cm³, an absolute density of 1.55 g/cm³, and an absorption coefficient of 1.85%. They have two lengths, i.e., 2 cm and 6 cm, but the same diameter of 1 mm. The procedure followed to obtain the date palm fibers is illustrated in Figure 1.

### 3. EXPERIMENTAL METHOD

The experimental study was carried out on 3 types of sand concrete, namely the control sand concrete without fibers whose composition is well presented in Table 4, the fiber sand concrete, and the fiber sand concrete incorporating recycled fillers. We prepared these three types of sand concrete as follows:

First, dry mix sand, cement, limestone filler and recycled fillers for 1 minute.

Table 3. Chemical composition of cement, limestone filler and recycled filler

<table>
<thead>
<tr>
<th>Fine Materials</th>
<th>Cement</th>
<th>Loss on fire</th>
<th>MgO</th>
<th>( SO_3 )</th>
<th>Cl</th>
<th>Insoluble residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone filler</td>
<td>( SiO_2 )</td>
<td>1.64</td>
<td>0.56</td>
<td>0.24</td>
<td>53.13</td>
<td>MgO</td>
</tr>
<tr>
<td>Recycled filler</td>
<td>( SiO_2 )</td>
<td>8.31</td>
<td>2.59</td>
<td>1.65</td>
<td>47.57</td>
<td>MgO</td>
</tr>
</tbody>
</table>

Figure 3 illustrates the morphology of the particles of the limestone filler and the recycled filler. The limestone particles are very fine with a round shape, while the grains of the recycled filler are covered by the hydrated products of the cement.

Figure 3. SEM image: (a) Limestone filler, (b) Recycled filler

**Figure 2. X-ray fluorescence spectrometry of cement, limestone filler and recycled filler**

**Figure 3.** SEM image: (a) Limestone filler, (b) Recycled filler

2.5 Adjuvant

This adjuvant is a MEDAPLAST 40 type high range water-reducing superplasticizer. It is a brown colored liquid, with a dry extract of 40% and a PH = 8.2. Its density is equal to 1.2.

2.6 Date palm fibers

These vegetable fibers have an apparent density equal to 1.84 g/cm³, an absolute density of 1.55 g/cm³, and an absorption coefficient of 1.85%. They have two lengths, i.e., 2 cm and 6 cm, but the same diameter of 1 mm. The procedure followed to obtain the date palm fibers is illustrated in Figure 1.
Next, add water and adjuvant, and mix for 2 minutes. Then, incorporate fibers, and mix by hand until obtaining a homogeneous mixture.

The specimens were conserved in water at laboratory temperature (20°C), for 28 days.

The proportions of the different components used for the manufacture of the test specimens were selected in accordance with the recommendations of the experimental methodology proposed in the Sablocrete project [2]. This summarized as follows:

Set the quantities of cement and Water at 350 kg and 220 L, respectively.

Determine the quantity of sand in 1 m³.

Formulate the sand concrete without filler with a workability of 7 to 10 s.

For the purpose of increasing the compactness of sand concrete, it was deemed necessary to add the limestone filler so that the real apparent mass is identical to the theoretical apparente mass (RAM = TAM), while respecting the workability of 7 to 10 s.

It should be noted that the control sand concrete and the fiber sand concrete are considered as reference concretes. Their physical and mechanical performance is shown in Table 5.

4. MIXTURE DESIGN APPROACH

Factorial designs would enable an experimenter to study the joint effect of the factors xi (parameters) on a response y; Y = F(xi), rated 2k: 2 control levels (low level, and high level) and k factors. The choice of factors is as function to their effect on the response. The full factorial design 2ᵏ (define 8 trials) is used in this work. The main advantage of the factorial design is the precise estimation of the main effects of each factor and their interactions in fewer experiments [19]. The effects matrix for formulating recycled fiber sand concrete is shown in Table 6. As for Figure 4, it illustrates the flowchart that defines the experimental methodology adopted in this study.

The specimens prepared are preserved in water during the entire testing period.

Table 4. Composition of control sand concrete (c0)

<table>
<thead>
<tr>
<th>Components</th>
<th>Quantity (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>350</td>
</tr>
<tr>
<td>Limestone filler</td>
<td>150</td>
</tr>
<tr>
<td>Sand</td>
<td>1359</td>
</tr>
<tr>
<td>Water</td>
<td>220</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>3.5</td>
</tr>
<tr>
<td>W/C</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Table 5. Physical and mechanical properties of reference concretes

<table>
<thead>
<tr>
<th>Types of Sand Concrete</th>
<th>Workability (cm)</th>
<th>Density (g/cm³)</th>
<th>Compressive Strength (MPa)</th>
<th>Flexural Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control sand concrete</td>
<td>15</td>
<td>1.81</td>
<td>35.13</td>
<td>4.5</td>
</tr>
<tr>
<td>2 cm / 0.1%</td>
<td>15.5</td>
<td>1.9</td>
<td>34</td>
<td>4.75</td>
</tr>
<tr>
<td>6 cm / 0.1%</td>
<td>16.75</td>
<td>1.98</td>
<td>34.74</td>
<td>5.62</td>
</tr>
<tr>
<td>Fibersand concrete</td>
<td>2 cm / 0.2%</td>
<td>1.97</td>
<td>28.57</td>
<td>5.26</td>
</tr>
<tr>
<td>6 cm / 0.2%</td>
<td>18.25</td>
<td>1.94</td>
<td>34.45</td>
<td>6.75</td>
</tr>
</tbody>
</table>

Table 6. The effects matrix for formulating recycled fiber sand concrete

<table>
<thead>
<tr>
<th>Composition</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF (cm)</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>PF (%)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>RFP (%)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Cement kg/m³</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Limestone filler (kg/m³)</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Recycled filler (kg/m³)</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Fiber (kg)</td>
<td>1.58</td>
<td>1.58</td>
<td>3.16</td>
<td>3.16</td>
</tr>
<tr>
<td>Sand (kg/m³)</td>
<td>1359</td>
<td>1359</td>
<td>1359</td>
<td>1359</td>
</tr>
<tr>
<td>Water (kg)</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Superplasticizer (kg)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>W/C</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Optimization of the physical and mechanical properties of recycled fiber and sand concrete: A full factorial design approach

5. RESULTS AND DISCUSSION

5.1 Modeling of the physical properties of fiber sand concrete including recycled filler

5.1.1 Workability and density

The data depicted in Figure 5 show an increase in the workability of fiber sand concretes without recycled fillers. It has been revealed that the replacement of the limestone filler
by the recycled filler leads to a decrease in workability which remains comparable to that of the control concrete C0. In addition, increasing the content of fibers and their length contributes a significant increase in concrete workability. Likewise, the density of fiber sand concretes based on limestone filler also increases; it is greater than that of the control concrete due to the presence of water in the fibers. It should be noted that the incorporation of the recycled filler reduces the density of sand concretes.

Figure 5. Workability and density of different sand concretes

The statistical parameter analyses presented in Table 6 and Figures 5 and 6 indicate that Eq. (1) and Eq. (2) adequately represent the true relationship between the independent variables and responses. Moreover, the mathematical models generated by the software used in this study for the workability W and density D are given by the following Equations:

\[
W (\text{Cm}) = 14,8125 + 0,4375 \text{FL} + 0,4375 \text{FP} - 0,0625 \text{RFP} + 0,0625 \text{FL*FP} + 0,0625 \text{FL*RFP} - 0,1875 \text{FP*RFP} \quad (1)
\]

\[
D (\text{g/cm}^3) = 1.78 - 0.005 \text{FL} + 0.01 \text{FP} - 0.005 \text{RFP} + 0 \text{FL*FP} + 0 \text{FL*RFP} + 0 \text{FP*RFP} \quad (2)
\]

(2) Adjustment summary

The workability and density values, which were measured and recorded during the tests, are compared with the results predicted by the quadratic model (Table 7). In addition, the correlation coefficients \( R^2 \) and adjusted \( R^2 \) are close to 1 (0.99 and 0.936) for the workability. This coefficient is equal to 1 in the case of density. These results suggest that a good correlation exists between the responses obtained experimentally and those given by the generated model.

Table 7. Adjustment summary of physical properties

<table>
<thead>
<tr>
<th></th>
<th>W (Cm)</th>
<th>D (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R^2 )</td>
<td>0.99</td>
<td>1</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.936937</td>
<td>1</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.1768</td>
<td>0</td>
</tr>
<tr>
<td>Mean of response</td>
<td>14.8125</td>
<td>1.78</td>
</tr>
</tbody>
</table>

(3) Graphical representation of residuals versus predicted values

Figure 6 depicts the curves representing the evolution of the residues as a function of the predicted responses, for the workability and density of fiber sand concrete including recycled filler in the fresh state. Figure 6(a) clearly suggests that the diffusion is random, while Figure 6(b) indicates that the residuals are entirely consistent with 0, which implies that there are no outliers. This also means that the measured values are in good agreement with the calculated ones.

Figure 6. Diagram of residuals according to the predicted values responses: (a) Workability, (b) Fresh density

(4) Forecast profiler

The main effect shows the average variations between the highest and lowest values of each factor. The amplitude of the slope gives an idea about the magnitude of the effect of each factor. When the slope is positive, the response can reach quite high levels [20]. The mathematical model under consideration and Figure 7 explicitly indicate that the workability and density are mainly conditioned by the amount of incorporated fibers and their length. In this context, literature [21] showed that adding fibers to the cementitious matrix affects workability. Jaradat et al. [22] reported a reduction in the workability of sand concrete when increasing the percentage of sisal fibers. In our case, an increase in workability was noticed when the amount of incorporated fibers went up. This was certainly due to the presence of saturated date palm fibers. This has certainly favored the presence of free water in the mixture.

Figure 7. Main effect plot of: (a) Workability, (b) Fresh density

Furthermore, increasing the percentage of recycled filler during the preparation of concrete decreases its workability and its density, which is in agreement with the results reported by Celik and Marar [23] and Yaprak et al. [24]. These authors studied the effect of recycled fine aggregates on the fresh properties of concrete. Indeed, Celik and Marar [23] mentioned that when the percentage of fines (particles with size less than 250 µm) increased, the amount of water required to adequately wet the surface of the particles and to maintain a specified workability must be greater. With regard to literature [24], it has been revealed that the weight of fresh concrete decreased as the amount of recycled fine aggregate increased in the concrete mix. Such behavior was certainly, because the density of recycled fine aggregates was lower than that of natural fine aggregates and to the increasing air content in fresh concrete.

(5) Surface profiler

Figure 8(a) clearly shows that the workability of sand concrete follows a linear relationship, which depends on the percentage of fibers in the mixture and their lengths. A higher surface slope suggests that the effect of the parameter FL (cm) is greater than that of the parameter FP (%). Examination of the workability isoresponse surface allows deducing that the minimal response is reached for the minimal levels of FL (cm)
and FP (%), 3 cm and 0.14%, respectively. Likewise, the maximum workability is obtained for the maximum FL (cm) and maximum FP (%) levels, 5 cm and 0.15%, respectively. Moreover, the large profile of the surface model for the workability shows that the best-fitting model is linear in nature.

Figure 8(b) depicts the effect of the two factors FL (cm) and FP (%) on the response (density) of fresh sand concrete. It is noted that the factor FL (%) plays a very important role in the process. Moreover, it turned out that increasing this factor leads to an improvement in density. Furthermore, when the fiber content FP (%) increases and reaches 0.15%, the density of concrete increases too. The results showed that the mixture containing 0.15% fibers 5 cm long shows the highest density, approximately 1.798 $\frac{g}{cm^3}$. However, the minimum density, which is of the order of 1.762 $\frac{g}{cm^3}$, is obtained when the mixture contains 0.14% of fibers with a length of 3 cm.

The mathematical models that are represented by Eq. (3) and Eq. (4) generate statistical analyses of the mechanical responses:

$$
Cs (MPa) = 34.79375 + 0.71125 FL - 0.66125 FP + 0.02875 RFP - 0.03375 FL*FP + 0.03625 FL*RFP + 0.26875 FP*RFP 
$$  
$$
Fs (MPa) = 5.39 + 0.3529 FL - 0.3475 FP + 0.0425 RFP + 0.15 FL*FP + 0.05 FL*RFP + 0.01 FP*RFP
$$

(2) Adjustment summary

The results obtained for the mechanical strengths were compared with the ones predicted by the quadratic model (Table 8). The values of the correlation coefficients $R^2$ and adjusted $R^2$ (0.87 - 0.105) are relatively far from 1. However, the flexural strength values (0.99-0.99) are very close to 1. These findings show that there is a good correlation between the responses obtained experimentally and those generated by our model.

Table 8. Adjustment summary of mechanical properties

<table>
<thead>
<tr>
<th></th>
<th>Cs (MPa)</th>
<th>Fs (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.87</td>
<td>0.99</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.105752</td>
<td>0.99</td>
</tr>
<tr>
<td>RMSE</td>
<td>1.0925</td>
<td>0.0071</td>
</tr>
<tr>
<td>Mean of response</td>
<td>34.79375</td>
<td>5.39</td>
</tr>
</tbody>
</table>

(3) Graphical representation of the variation of the residuals as a function of the predicted values

The graphical representations of the residuals as a function of the predicted values depicted in Figure 10 show that the normalized residuals are greater than +0.4 and smaller than -0.4 (Figure 10(a)); they are also greater than +0.03 and smaller than -0.04 (Figure 10(b)).

Figure 10. Diagram of residuals according to the predicted response values: (a) Compressive strength, (b) Flexural strength at 28 days

The proposed model indicates a negligible difference between the experimental value and the adjusted value. It also signals that the points are uniformly distributed along the diagonal. It can therefore be concluded that the predicted model shows a significant convergence between the fitted value and the experimental value.

(4) Forecast profiler

Figure 11 clearly shows that in order to increase the mechanical strengths (Cs and Fs), it is deemed necessary to increase the fiber length (FL), and reduce the fiber content (FP). Several studies [25-27] found out that the strength of concrete decreases with the addition of vegetable fibers. On the other hand, it was revealed that the amount of recycled filler (RFP) in fiber sand concretes has little influence on both the compressive and flexural strengths. In addition, some authors have investigated the effect of recycled fine
aggregates on various properties of concretes. In this regard, authors in literatures [7, 11, 28-30] have reported that the reduction in strength varies with the replacement rate of the recycled filler. The strength drop was equal to 6.7%, 11.1%, 31.3% and 50% for replacement rates of 10%, 30%, 50% and 100%, respectively. These results show that the compressive strength is quite sensitive to high replacement rates.

Furthermore, the strength reduction is mainly due to the increase in water content in concrete mixes with filler recycled concrete. It is also worth pointing out that a poor interface bond with the surrounding matrix forms due to the deposition of water in the interface zone [31].

Furthermore, it was revealed that the introduction of recycled fillers in sand concretes leads to an increase in their compactness due to the hydration of non-hydrated cement grains and to the creation of new dense C-S-H. Figure 12 illustrates the microstructure of sand concrete containing 100% and 50% recycled filler. The entanglement of C-S-H needles causes the filling of voids and space between the cement grains, which leads to the densification of the cementitious matrix.

Figure 11. Main effect plot: (a) Compressive strength, (b) Flexural strength at 28 days

Figure 12. Microstructure of sand concrete containing recycled filler

Figure 13. Isoresponse surfaces: (a) Compressive strength, (b) Flexural strength at 28 days

6. CONCLUSION

A predictive approach was adopted in this work to study the effect of recovered and recycled waste (recycled fillers from demolition concrete and fibers from date palm waste) on the physico-mechanical properties of sand concrete. These properties were modeled using a complete factorial plan, along with the software JMP 16.

Statistical analyses confirmed that the correlation coefficients of the physical responses, workability and density, were between 0.99 and 1, and between 0.87 and 0.99, for the two mechanical strengths, namely the compressive strength and flexural strength, respectively. The results obtained indicated that the factors under study (fiber length FL and fiber percentage FP) influence differently the physical and mechanical properties of the concretes prepared. Indeed, it was found that these two parameters (FL and FP) have a significant impact on the above properties. However, the recycled filler percentage (RFP) has little influence on these two properties. An increase in fiber length (FL) and fiber percentage (FP), along with a decrease in recycled filler content (RFP), resulted in increased workability and density of the concrete. These findings allowed concluding that the mechanical strength increase is conditioned first by the fiber length increase and the percentage of recycled filler and then by the decrease in the fiber content.

Likewise, the findings suggest that the introduction of recycled fillers in sand concretes causes an increase in their compactness following the hydration of the anhydrated cement grains along with the creation of new dense C-S-H.

Furthermore, it was found that the compressive strength of sand concrete incorporating recycled filler and fiber was greater than that of fiber sand concrete by 5%, while it was lower than that of the control sand concrete by 1%. On the other hand, it turned out that the flexural strength of fiber sand concrete including the recycled filler was smaller than that of fiber sand concrete by 4%, but was greater than that of control sand concrete by 19.5%.

The use of recycled products in the preparation of concrete has several economic, environmental and technical interests. The production of a resistant and environmentally friendly sand concrete can be achieved by simple recovery of recycled fillers and fibers.

Large amounts of date palm waste and demolition waste are widely available around us. These wastes can be used to prepare construction materials. The effect of their substitution rates on the physical and mechanical properties of the formulated sand concrete were investigated. The results obtained were quite satisfactory in general. It would be highly important that future research investigates the effect of other parameters, such as the water-to-cement (W/C) ratio, fiber treatment on the properties of sand concrete.
REFERENCES


[25] Ammari, M.S., Belhadj, B., Bederina, M., Ferhat, A.,


