A contribution to the study of mortars prepared with recycled sand

Uma contribuição para o estudo de argamassas preparadas com areia reciclada

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ABSTRACT
No one denies that today concrete is the most used material in the field of civil engineering. It is widely admitted that the production of concrete necessitates large quantities of fine aggregates, specifically river sand and crushed sand. Moreover, the excessive exploitation of river sand, which generally causes a multitude of environmental problems, has pushed the majority of governments around the world to issue rules for the purpose of limiting or preventing the illegal extraction of river sand. The present article aims primarily to make a contribution to studying the possibility of replacing natural sand (NS) and crushed sand (CS) with recycled sand (RS) in ternary mortars, at proportions ranging from 20% to 100%. The consistency of the mixtures, the densities in the fresh and hardened state, the compressive strength after 3, 14 and 28 days of hardening, as well as the
absorption of water by immersion and by capillarity at 28 days, were determined and discussed. It should be noted that the (W/C) ratio was set at 0.7 for all mixtures. The experimental results showed that recycled sand could be successfully used as an alternative to natural sand, up to a rate of 40%, for the manufacture of ternary mortars without significantly affecting their properties.

**Keywords:** mortar, recycled sand, compressive strength, absorption, consistency.

**RESUMO**

Ninguém nega que o concreto é hoje o material mais utilizado no campo da engenharia civil. É amplamente reconhecido que a produção de concreto necessita de grandes quantidades de agregados finos, especificamente areia de rio e areia britada. Além disso, a exploração excessiva de areia de rio, que geralmente causa uma série de problemas ambientais, levou a maioria dos governos de todo o mundo a emitir regras com o objetivo de limitar ou impedir a extração ilegal de areia de rio. O presente artigo tem como objetivo principal contribuir para o estudo da possibilidade de substituir a areia natural (NS) e a areia britada (CS) por areia reciclada (RS) em argamassas ternárias, em proporções que variam de 20% a 100%. A consistência das misturas, as densidades no estado fresco e endurecido, a resistência à compressão após 3, 14 e 28 dias de endurecimento, bem como a absorção de água por imersão e por capilaridade aos 28 dias, foram determinadas e discutidas. Deve-se observar que a relação (W/C) foi fixada em 0,7 para todas as misturas. Os resultados experimentais mostraram que a areia reciclada pode ser usada com sucesso como uma alternativa à areia natural, até uma taxa de 40%, para a fabricação de argamassas ternárias sem afetar significativamente suas propriedades.

**Palavras-chave:** argamassa, areia reciclada, resistência à compressão, absorção, consistência.

**1 INTRODUCTION**

No one denies that today concrete is the most used material in the field of civil engineering. It is widely admitted that the production of concrete necessitates large quantities of fine aggregates, specifically river sand and crushed sand. Moreover, the excessive exploitation of river sand, which generally causes a multitude of environmental problems, has pushed the majority of governments around the world to issue rules for the purpose of limiting or preventing the illegal extraction of river sand (Dong et al., 2022).

Crushed sand is generally produced by grinding stones using artificial processes. In addition to consuming natural resources, the production of crushed sand is also responsible for generating significant emissions of CO₂ (Reyes-sánchez et al., 2018). On the other hand, recently, it has been reported that
construction and demolition waste, resulting from the demolition of old or abandoned structures, has contributed to relatively large proportions of the total quantity of waste. It has been pointed out that the most common method of construction and demolition waste disposal in several developing countries is landfilling, which inevitably leads to contamination of water, atmosphere and soil, as well as saturation of discharges (Bourguiba et al., 2017). It has also been revealed that the construction industry is currently responsible for 39% of CO\textsubscript{2} emissions (García Del Angel et al., 2023). In addition, more than 50% of natural resources are consumed by the industrial sector (Jesus et al., 2023). In this regard, and with the aim of manufacturing more environmentally friendly concrete, it was deemed appropriate to use alternative cementitious materials (Cui; Chang, 2022), and to reuse solid waste from the demolition of buildings. This technique is highly beneficial to the environment as it allows to significantly reduce the exploitation of natural aggregates, and to limit CO\textsubscript{2} emissions that are released by machines and equipment transporting aggregates into the atmosphere.

Several research projects have been carried out to study the possibility of using recycled aggregates as a partial or total replacement for natural aggregates for the manufacture of new types of concrete. In this context, Khatib (2005) conducted a series of experiments to study the effect of replacing natural aggregates with recycled fine aggregates at different rates on the mechanical properties of concrete. They then found out that the compressive strength decreased by 15% and 30% for replacement rates of 25% and 100%, respectively. Regarding Evangelista et de Brito, (2007), they indicated that no significant compressive strength reductions could be observed for recycled sand substitution percentages up to 30%. As for Khoshkenari et al. (2014), they discovered that the use of recycled sand reduced the tensile and compressive strength of concrete, but this reduction could be compensated by the incorporation of fine natural aggregates of size between 0 and 2 mm. With regard to Pereira et al. (2012), they suggested that the mechanical properties of concrete prepared with recycled sand and incorporating a superplasticizer exceeded those of the control concrete. On the other hand, Fan et al. (2016), introduced two types of recycled sand with different fineness moduli. The results of the tests they carried out indicated that
recycled sand, which has a low fine modulus and a low water absorption rate, tends to help maintain the mechanical strength of concrete.

Regarding Jesus et al. (2019), they showed that mortars made with construction demolition waste, and ground to 0.149 mm, as a replacement for 20% natural sand, saw their mechanical resistance increase. For their part, Azevedo et al. (2020) replaced natural sand with the mentioned above waste at the rates of 25, 50 and 100% to produce mortar. They then found out that the 25% substitution rate was the most appropriate to achieve mortars with better compactness and the highest mechanical strengths.

Despite all the above research achievements, the use of recycled sand in concrete production still remains limited due to its unique physical property which gives relatively low compressive strength and poor workability (Carro-López et al., 2017).

The present work aims to examine the possibility of replacing natural sand (NS) and crushed sand (CS) with recycled sand (RS) in a ternary system of mortar, at proportions ranging from 20% to 100%. The consistency of the mixtures, the densities in the fresh and hardened state, the compressive strength after 3, 14 and 28 days of hardening, as well as the absorption of water by immersion and by capillarity at 28 days, were then investigated and analyzed. The water-to-cement (W/C) ratio was set at 0.7 for all mixtures.

The results showed that the incorporation of recycled sand reduced the workability of mortars and increased their absorption coefficient due to the high water absorption of recycled sand. Concerning the physical properties of mortars, it turned out that the density decreased and the water absorption increased for all replacement percentages. It was also found that the compressive strength significantly decreased when the replacement percentage was greater than 40 wt%.

2 EXPERIMENTAL PROCEDURES
2.1 THE MATERIALS USED

Cement: The cement used in this study is the Portland cement CEM II/A-L 42.5 N from the Cement Plant of Ain Touta (Algeria). Its specific surface area is 3371 cm²/g, and its chemical composition is given in Table 1
Table 1: Chemical composition of the cement used

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>P.A.F</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM II</td>
<td>20.34</td>
<td>5.37</td>
<td>3</td>
<td>61.69</td>
<td>1.80</td>
<td>2.20</td>
<td>5.03</td>
</tr>
</tbody>
</table>

Source: Authors

Sand: Three types of sand with fraction 0/5 were used, namely natural Wadi sand (NS), crushed quarry sand (CS), and recycled sand (RS). Their granulometric analysis curves are illustrated in Figure 1.

Figure 1: Granulometric analysis of sands used in this study

Source: Authors

2.2 COMPOSITION AND METHODS

The mix ratio 1/3 is used for the preparation of our mortar composition. In this mortar, natural sand (NS) and crushed sand (CS) are replaced by recycled sand (RS), at proportions ranging from 20 to 100%, as indicated in Table 2. The ratio (W/C) is set at 0.7.

Table 2: Composition of the mixtures under study

<table>
<thead>
<tr>
<th>Mix</th>
<th>% Natural sand (NS)</th>
<th>% Crushed sand (CS)</th>
<th>% Recycled sand (RS)</th>
<th>C (g)</th>
<th>(W/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>33.33</td>
<td>33.33</td>
<td>33.33</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>20</td>
<td>60</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>10</td>
<td>80</td>
<td>450</td>
<td>0.7</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>450</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Source: Authors
The mortar specimens, measuring (4×4×16) cm³, were prepared in accordance with Standard EN196-1. The samples were kept in water until the day of testing.

It should be noted that the mechanical tests were carried out after 3, 14, and 28 days, and the capillary absorption tests were carried out after 28 days of curing in water. The spreading test consisted of filling the mini cone (lower diameter: 100 mm, upper diameter: 70 mm, height: 60 mm) and placing it on a smooth horizontal surface. The cone was then exposed to 15 generative shocks by lifting the shaking table to a height of 10 mm and then letting it fall freely, according to the specifications of the European Standard EN 1015-3. Afterwards, the cone was lifted, and the spreading diameter of mortar was measured along two perpendicular directions. The average of the two measurements was then recorded.

As for the water absorption test by immersion involved putting the mortar test pieces of dimensions (4x4x16) cm³ in the oven and then weighing them until they reached a constant weight. They were next immersed completely in water for a period of 72 hours, i.e. until the material was saturated, in conformity with the requirements of the European Standard EN 13369. The absorption coefficient by immersion \( A_b \) is given by the following relationship:

\[
A_b = \frac{M_a - M_s}{M_s} \times 100
\]  

(1)

Where \( M_a \) is the mass of the saturated sample and \( M_s \) is the mass of the dry sample.

The water absorption test by capillarity consisted of recording, by successive weighings, the amount of water absorbed by a previously dried test piece. This test may also be used for the indirect characterization of capillary porosity. It should be noted that several operating modes are proposed in the literature. In order to study the water absorption of mortars after 28 days of hardening in water, it was decided to adopt a variant of the operating method proposed by AFREM (AFPC-AFREM).

It is worth emphasizing that three samples of dimensions (4 × 4 × 16) cm³ were prepared from each formulation. The water absorption test was performed in order to measure the rate of water absorption by capillary suction of unsaturated
mortar specimens which were brought into contact with water without hydraulic pressure. The water absorption rate may be calculated using the following formula:

\[ C_{a_t} = \frac{M_t - M_0}{A} \]  

(2)

Where:

\( C_{a_t} \) (kg/m²) is the absorption coefficient at maturity (t), \( A \) (m²) is the cross-sectional area of the sample, \( M_0 \) (kg) the initial mass of the specimen, and \( M_t \) (kg) is its mass at the time t.

3 RESULTS AND INTERPRETATIONS

3.1 WORKABILITY TEST

Figure 2 shows the spreading results of mortars incorporating recycled sand. It is easy to notice that the workability of mortars decreases as the percentage of recycled sand increases. This due to the fact that the water absorption of recycled sand is higher than that of natural aggregates, i.e. natural sand and crushed sand. The results obtained indicate that the spreading diameter values vary between 13.4 and 23.5 cm for all the mixtures prepared.

![Figure 2: Spreading diameter of the different mixes](source)

The lowest spreading value was obtained for mix 8 (100% RS), which shows that recycled sands have a considerable effect on the workability of the mortars. In
this context, Gomes et al. (2018) showed that the quantity of water used must be
adjusted so as to obtain a spreading diameter between 16 and 17.6 cm, which
corresponds to excellent workability.

3.2 FRESH DENSITY

Figure 3 shows the variations in the apparent density of the mortar in the
fresh state for different percentages of substitution of natural sand (NS) and
crushed sand (CS) with recycled sand (RS). It is then noted that the density of the
mortars under study decreases as a function of the replacement rate of recycled
sand. This is certainly due to the low density of recycled sand and to its high water
absorption rate (Cartuxo et al., 2016). It is therefore necessary to increase the
amount of water in the mixture in order to achieve the desired consistency (Mora-
Ortiz et al., 2020). These results are in good agreement with those reported by
other researchers (Vegas et al., 2011).

3.3 DENSITY IN HARDENED STATE

The bulk density in the hardened state of all specimens prepared in this
study, measured at 28 days, is presented graphically in Figure 4.
This figure shows that the hardened density of specimens containing recycled sand is relatively lower than those of specimens containing natural sand. This density difference could be attributed to the fact that the density of the recycled sand used in this study is lower than that of natural sand, which confirms the results found by other researchers (Cuenca-Moyano et al., 2014; Tuaum et al., 2018).

3.4 WATER ABSORPTION TEST BY IMMERSION

The water absorption test by immersion was carried out in order to have an idea about the internal porosity of the material under study. This test was carried out at 28 days, in accordance with the recommendations of Standard NF EN 13369. Figure 5 shows the results obtained.
Figure 5 indicates that the inclusion of recycled sand in mortars increases the water absorption by immersion. This increase is due to the fact that recycled sand absorbs a significant amount of water. This result is in accordance with those found by other authors (Braga, et al., 2012). It was also shown that the maximum absorption rate recorded after \((72 \pm 2)\) h of immersion in water was 7.2% for Mix 8 (100% RS), and the lowest was 3.9%, for Mix 2 (100% CS). It is generally accepted that a good quality concrete must absorb water to less than 10% (Medina et al., 2014). The findings suggest that all the mixtures prepared as part of this research meet the current requirements, as they allowed producing good quality mortars.

3.5 DENSITY AND WATER ABSORPTION

Recycled materials generally have lower density and higher water absorption than natural materials (Nedeljković et al., 2021). This is certainly due to the fact that the hardened cement paste which adheres to the aggregates is porous and its density is lower than that of natural sands and aggregates. For this reason, it was found that the density of the recycled material gradually decreased as the bonded cement content increased (Skocek et al., 2024).

Figure 6, which depicts the variation of the water absorption rate as a function of dry density, confirms the above explanation. Finally, it was found that an overall and very strong correlation exists between the water absorption and dry density \((R^2 = 0.98)\), regardless of the size, type and origin of the recycled materials used.
3.6 CAPILLARY WATER ABSORPTION TEST

Water absorption by capillary action is an important indicator of mortar durability. Previous studies on concrete have shown that mortar specimens with high water absorption are less durable (Elbahi; Zeghichi, 2022). If the mortar has high water absorption, then the particles and substances carried by water decrease the durability of the mortar (Mora-Ortiz et al., 2020). It should be emphasized that the absorption of water by capillarity depends on the structure of the mortar, because the more compact it is, the smaller the pore network, which means, therefore, that denser mortars absorb less water (Cuenca-Moyano et al., 2020).

Figure 7 presents the water absorption values by capillary action for all mixtures. It is observed that the water absorption values of the mortar increase as the replacement rate of natural aggregates with recycled sand increases.

![Figure 7: Variation of the capillary absorption of mortars as a function of the square root of time](image)

It is generally observed that the water absorption of mortars increases with the value of the square root of time. However, two parts of the curve show distinct trends on the graph:

- the first part of the curve, which is characterized by a very high slope, corresponds to the filling of the largest capillaries. This is the initial absorption;
• the second part, which is characterized by a more or less smaller slope, corresponds to the filling of the finest capillaries. This is the sorptivity.

This figure shows that the mortars under study have almost constant initial absorption values for a replacement rate between 20 and 40%. The mortar with the highest capillary absorption rate corresponds to Mix 8 (100% RS).

3.7 COMpressive StRENGTH TEST

The compressive strength tests were carried out after 3, 14 and 28 days of water curing. Figure 8 depicts the evolution of the compressive strength of mortars as a function of the percentages of recycled sand.

Figure 8 shows that recycled sand-based mortars develop compressive strengths lower than that of the control mortar which contains natural sand. The difference is proportional to the rate of replacement of natural sand by recycled sand. The experimental results indicate that the compressive strength at 28 days decreased by 3.37%, 5.09%, 10.82%, 14.09%, 18.91% and 21.16% for the recycled sand replacement rates of 20%, 33.33%, 40%, 60%, 80% and 100%, respectively. The results obtained in this research are consistent with those reported by other authors (Kępniak et al., 2024; Mora-Ortiz et al., 2020).
4 CONCLUSION

The present study was conducted with the aim of exploring the possibility of replacing natural sand with recycled sand for the manufacture of mortars at proportions ranging from 20% to 100%. The consistency of the mixtures, the densities in the fresh and hardened state, the compressive strengths after 3, 14 and 28 days, as well as the absorption of water by immersion and by capillarity were examined. The results obtained allowed drawing the following conclusions:

- recycled sand has a considerable effect on the workability of mortars due to its high water absorption;
- mortar density decreases as the replacement rate of natural sand with recycled sand increases. This is mainly due to the fact that the density of recycled sand is lower than that of natural sand;
- the results show a strong correlation between the dry density and water absorption ($R^2 = 0.98$). This observation is independent of the size, type and origin of the recycled materials.
- mortars have almost constant initial absorption values for a replacement rate between 20 and 40%;
- the optimal rate for the replacement of natural sand with recycled sand is between 20% and 40%. This rate offers satisfactory compressive strength values, while it minimizes the costs of mortar and limits its environmental impact.

All the above findings allow asserting that recycled sand could be successfully used as an alternative substitute to natural aggregates, as it has clear environmental and economic benefits.

Finally, additional work is however necessary in the future to study other characteristics, in order to increase the percentage of replacement of natural sand by recycled sand without increasing the W/C ratio, while maintaining the same workability.
REFERENCES


