ANALES de Edificación

Anales de Edificación
Vol. 9, Nº3, 6-10 (2023)
ISSN: 2444-1309
DOI: 10.20868/ade.2023.5374

Received: 20/10/2023
Accepted:10/11/2023

Propiedades mecánicas del mortero con residuos de arena de fundición

Mechanical properties of mortar containing waste foundry sand

Ahlem Akeb; Souad Kherbache; Abdelkader Tahakourt

[a] Laboratory of Construction Engineering and Architecture, Faculty of Technology, University of Bejaia, Algeria.

Resumen-- **El uso de los residuos industriales en hormigón y mortero abarata su coste y la reutilización de residuos se considera la alternativa más respetuosa con el medio ambiente para hacer frente al problema de los vertederos. Entre estos vertidos se encuentra la arena de fundición residual, que puede utilizarse en hormigón y mortero en lugar de la arena natural de río o de cantera. Este trabajo investiga el uso de la arena de fundición de residuos (WFS) en el mortero y su influencia en las propiedades mecánicas. En este estudio, se presentan los resultados de las pruebas de fluidez, resistencia a la compresión y flexión del mortero que contiene WFS. El WFS se utilizó como sustituto parcial de los áridos finos del 0 al 20% en incrementos del 5%. Se ha observado que la sustitución del WFS mejora en cierta medida las propiedades mecánicas del mortero, luego se observa una disminución de la resistencia, pero simultáneamente disminuye la trabajabilidad al aumentar el porcentaje de sustitución del WFS.**

Palabras clave— Residuos de arena de fundición; mortero; valorización; trabajabilidad; propiedades mecánicas.

Abstract—**The use of the industrial waste in concrete and mortar makes it cheaper and the reuse of waste is considered the most environmentally friendly alternative to deal with the problem of waste landfills. Among these discharges, waste foundry sand which can be used in concrete and mortar instead of natural river sand or quarry sand. This paper investigates the use of the waste foundry sand (WFS) in the mortar and its influence on the mechanical properties. In this study, the results of tests on the flow, the compressive and flexural strength of mortar containing WFS are presented. The WFS was used as a partial replacement of fine aggregates from 0 to 20% in 5% increment. It has been observed that the WFS replacement to some extent improves the mechanical properties of mortar, then a decrease in strength is observed, but simultaneously decreases the workability by increasing WFS replacement percentage.**

Index Terms— Waste foundry sand; mortar; valorization; workability; mechanical properties.

I. INTRODUCTION

The problem of the depletion of renewable and also non-renewable natural resources and the scarcity of raw materials has become, in a few decades, a major concern on a global scale. Resources are threatened by the growth of human settlements, industrialization, and the development of activities as well as by certain ecological phenomena (Nouri et al., 2018). In addition, the livelihood of the construction industry has been severely affected due to restrictions in the extraction of sand from the river, leading to an increase in the price of sand (Bhardwajet et al., 2017). The foundry industry produces many by-products during the casting process of ferrous and non-ferrous metals. Over 70% of the total by-product material is sand as molds and cores are usually made of waste foundry sand (WFS), which is readily available, inexpensive, resistant to thermal damage and easily bonded to binder. This foundry sand waste can be used in concretes and mortars instead of natural river or quarry sands (Ahmad et al., 2022). The WFS is accounted for as siliceous material and having even physical standards. It is an incidental waste product most obtained from metal casting firms (Singh et al., 2022).The foundry industry

---

A.A, S.K AND A.T are assistant professor at Laboratory of Construction Engineering and Architecture, Faculty of Technology, University of Bejaia, Algeria .

Fig. 1 Photography of WFS. Left: WFS cores; mid: WFS crushed; Right: Morphology of WFS particles (from SEM)

recycles, and reuses sand several times in foundries. When it can no longer be reused, it is withdrawn from the industry and called used or spent foundry sand, which is the major issue in the management of foundry waste. This waste has the potential to be used in concrete and mortar and influence the mechanical properties due to its characteristics (Mavroulidou et al., 2019). This material is essentially a fine aggregate; it can be used in the same way as natural or manufactured sands. Foundry sands could also be used in embankments, construction of barrier layers, road construction. The greatest volume of foundry sand is used in geotechnical applications, such as site development fills and roadbeds (Guney et al., 2010). The SF had a variable effect (increase or decrease in resistance). The good resistances may be due to a more round, uniform, and fine sand filling effect, reducing the void ratios (Mavroulidou et al., 2019). An increase in the percentage of FS resulted in a decrease in the compressive strength of the concrete, which is attributed to the high surface area of the FS particles which led to the reduction of the water-cement gel in the matrix, resulting in a poor bond between aggregates and cement paste (Gholampour et al., 2021). The objective of this research responds to the concern for the recovery of industrial waste (foundry sand waste (WFS)) from the BCR unit Ain-Kbira Setif (Algeria), in the civil engineering field. To answer this concern, we carried out the characterization of raw materials for the manufacture of mortars to enhance WFS in the manufacture of mortars, and to study its behavior and its influence on the physico-mechanical characteristics of mortars. To achieve the objective, we have replaced the sand by the WFS in the mortars in multiple contents (5%, 10%, 15% and 20%).

II. METHODOLOGY

A. Materials used

The cement used is Portland cement (CEM II/A 42.5) produced at the Ain Kebira cement plant, Setif (eastern Algeria). Its Blaine specific surface is 3200 cm^2/g,the mineralogical composition of the cement is represented in Table 1. Two types of sand are used, natural sand (SN) crushed 0/4 from the LAFARGE quarry, El Mehir; the WFS is bounded chemically (sand + resin + catalyst) resulting from the crushing (grinding) of the foundry sand moulds in which the molten metals of the BCR unit of AIN KEBIRA SETIF are poured (Fig. 1). The characteristics of the two sands are presented in (Table 2). Despite its finer size, the WFS had lower water absorption than SN, possibly due to remnants of water-repellent binder. Fig. 2 represents the particle size distribution of the tow sands, WFS is uniform contrarily to the natural sand which is well-graded. According to the chemical analyses of the natural sand, we notice that the CaCO3 content is 93%, on the other hand, the WFS has a SiO2 content of 90%, so the sand studied is silica sand. However, the fraction 0/2 of the foundry sand is cleaner than that of the crushed sand 0/4, the MB <1, so it's a non-clayed sand. The chemical composition of crushed and foundry sands is summarized in table 3(Kherbache et al., 2019).

TABLE I
MINERALOGICAL COMPOSITION OF CEMENT

Element	%
C3S	55.46
C2S	18.85
C3A	8.56
C4AF	12.43

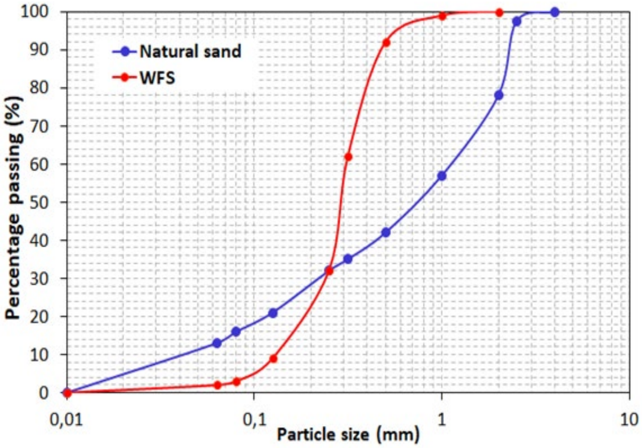

Fig. 2: Particle size analysis

TABLE II
PHYSICAL PROPERTIES OF THE TWO SANDS

Physic properties	Natural sand	WFS
Fineness modulus	2.69	1,69
Methylene blue value	1	0.35
Absolute density (kg/m^3)	2.73	2.58
Sand equivalent	71	82

TABLE III
CHEMICAL ANALYSES OF THE TWO SANDS

Elements (%)	$CaCO_3$	SiO_2	Cl	Al_2O_3	MgO
Natural sand	93	3	0	0	0
WFS	3	90	0	7	0

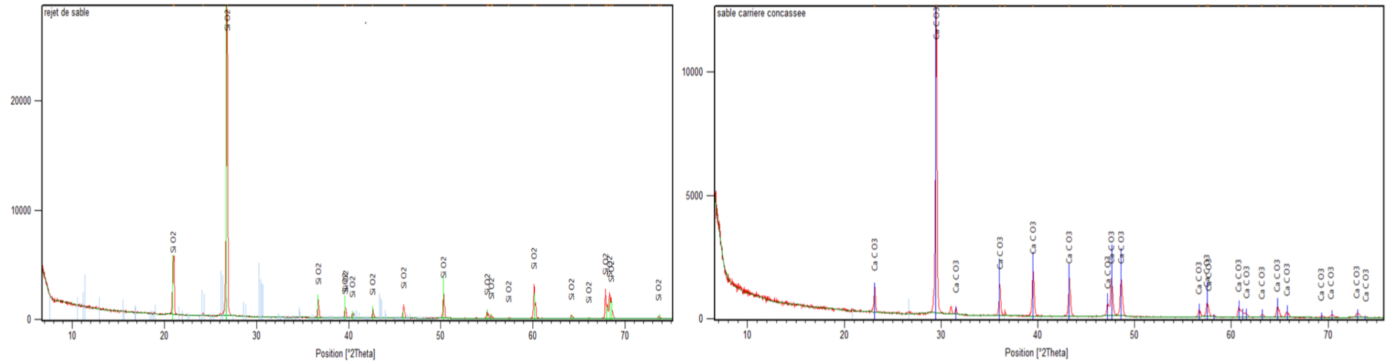

Fig.3. X-Ray diffraction Left: foundry sand; Right: Natural sand.

B. *Mortar formulations*

In the case of the preparation of three test specimens 40 x 40 x 160 mm, natural sand was partially replaced by 5%, 10%, 15% and 20% of WFS. The formulations of the various mixtures are given in (Table 4), the water/cement ratio (w/c) was kept constant for all the mixes (w/c = 0.5). The mortar samples were made according to the EN 196 standard [9], The constituents were introduced from coarsest to finest inside a 5-liter capacity propeller mixer. The filling of the prismatic molds was performed on a jolting table (Fig. 4. b).The manufactured samples are kept in a climatic chamber (relative humidity > 95% and T = 20°C ± 2°C) for 24 hours until demoulding(Fig. 4. c), then they are kept in water at a temperature of 20°C± 2°C until their use.

TABLE IV
PROPORTIONS OF THE MIXTURE OF MORTARS BASED ON WFS

Name	Natural sand (g)	WFS (g)	Cement (g)	Water (g)
M0	1350	0	450	225
M5	1282.5	67.5	450	225
M10	1215	135	450	225
M15	1147.5	202.5	450	225
M20	1080	270	450	225

To determine the flow, the consistency is appreciated by a cone of mortar subjected to a series of shakes. Then, the value of the flow is done by reading the diameter on the plate (Fig. 4. a).

C. *Tests procedures*

Flexural strength was performed on three prismatic mortar specimens 40 x 40 x 160 mm for each variable according to NF EN 196-1 [9]. This test is performed on a three-point bending press of 5KN capacity.

After recording the value of the rupture force Fr, the value of the bending strength can be calculated by the formula (1):

$$R_t = \frac{3\,F\,L}{2\,a^3} \qquad (1)$$

Where :

- Rt: is the flexural strength, in megapascals or newtons per square millimetre;
- F: is the rupture force, in Newtons;
- a: is the dimension of the section (a=40 mm).
- L: is the range of the element (L=110 mm)

Compressive strength is the most frequently measured property of mortar. To carry out the compression crushing of the specimens in accordance to NF EN 196-1 [9], the half-prism is placed lying in the centre of the two plates of the press between two square metal plates to transmit the force of the press to the compression faces of the mortar specimen as shown in (Fig. 6.a). The machine is run until the half-prism is crushed, and the value of the breaking force Fr is noted. Fig. 6.b shows the failure of a half-prism in compression.

Fig.4. Manufacturing of specimens. Left: Flow table test; Mid: Jolting table; Right: Mortar specimen.

III. RESULTS AND DISCUSSION

A. Workability

Fig. 5 presents the flow results of all the types of mortar. The results show that the workability of the mortar decreases with increasing WFS, which is attributed to the larger surface area of the WFS compared to the sand used. This shows that the lower flow values of the mixtures containing WFS are not entirely explained by the presence of binders but also by the sand itself. The WFS has finer particles, and this increases water demand and reduces flow values. Moon et al (Moon et al., 2005) found the similar results.

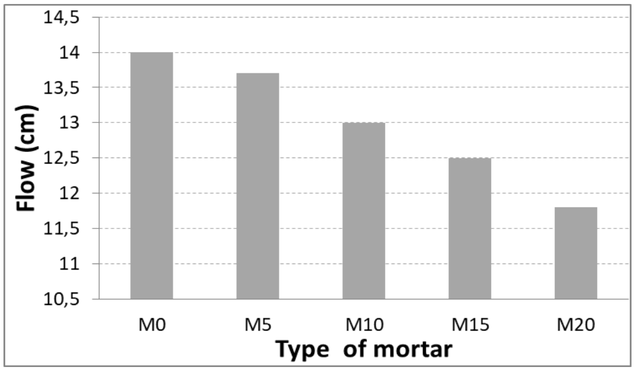

Fig. 5. Workability results.

B. Compressive strength

The Fig. 6 shows the compressive strength of the different types of mortar at 28 days. It is observed that it is affected by the rate of replacement of the WFS, it is noted that the M10 gives better results. The WFS had a variable effect (increase or decrease in strength). The good strengths can be due to some filler effect of the rounder, uniform and finer WFS reducing the void ratios [5,6]. The results obtained show that the compressive strength of 5% (M5) and 10% (M10) replacement rates of the WFS compared to the control mortar (M0) is 45.7, 46 and 44 MPa respectively. The WFS contributes to the reduction of the porosity given its grain size (fineness modulus equal to 1.69). We reached the same conclusions as those of other studies (Singh et al., 2012;2012; Sidiqqe et al., 2015), namelythe increase of the WFS attributes to the increase in surface area of fine particles which may have led to reduction of water cement gel in matrix hence led to inadequate bending.

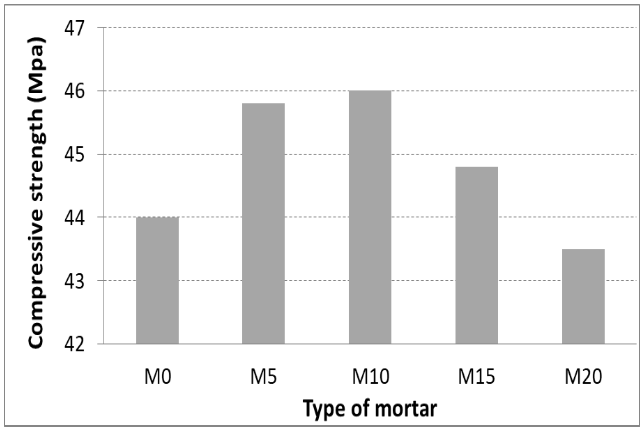

Fig. 6. Compressive strength results.

C. Flexural strength

Fig. 9 illustrates the flexural strength of several types of mortar after 28 days. The effect of partial replacement of natural sand by the WFS on flexural strength is very similar to what was observed in the compressive strength. An increase of around 10% and 32% forM5 and M10 respectively compared to M0.A replacement rate of 10% is therefore the optimal rate for better resistance. Guney et al. (Guney et al., 2010) reported increase in strength up to 10% replacement by WFS then it decreased further at 15% substitution.

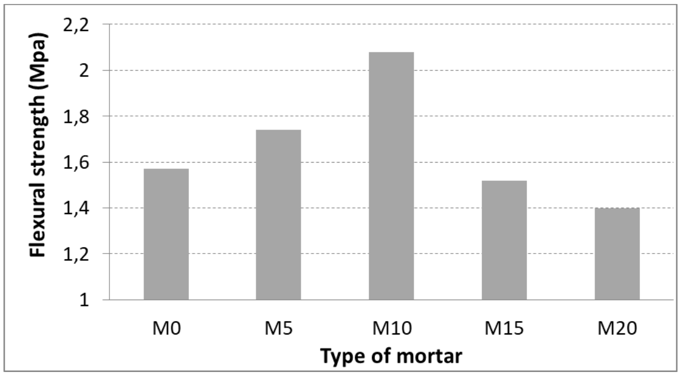

Fig. 7. Flexural strength results.

IV. CONCLUSIONS

This work is part of the general issue of sustainable development, improvement, and control of the properties of cementitious materials. By the economic importance of these materials based on industrial waste and by the fundamental aspect involved in their study. From the results of the experiments and their discussions, the following conclusions can be drawn:

- Waste foundry sand is characterized by a lower fineness modulus, a lower density and it's cleaner than.
- The workability is decreased by increasing WFS replacement percentage.
- The compressive and flexural strengths increase for the different rates of replacement of natural sand by WFS. For a replacement rate of 10% of WFS, the optimal resistance was found.
- Used foundry sand can be used very conveniently to make good quality concrete and building materials.

REFERENCES

Nouri. Ibtissem, Ait Habouche-Mihoub. Ouahiba, Limits of waste recovery in Algeria: Case of industrial waste recycling in Oran. Limites de la valorisation des déchets en Algérie: Cas du recyclage des déchets industriels à Oran, (2018).

B. Bhardwaj, P. Kumar, Waste foundry sand in concrete: A review, Construction and Building Materials 156 (2017) 661-674.

J. Ahmad, Z. Zhou, R. Martínez-García, N.I. Vatin, J. de-Prado-Gil, M.A. El-Shorbagy, Waste foundry sand in concrete production instead of natural river sand: A review, Materials 15(7) (2022) 2365.

J. Singh, V.K. Dhiman, Impact of Used Foundry Sand on Concrete's Characteristics-An Overview, Advances in Sustainable Construction Materials: Select Proceedings of ASCM 2020 (2021) 659-676.

M. Mavroulidou, D. Lawrence, Can waste foundry sand fully replace structural concrete sand?, Journal of Material Cycles and Waste Management 21(3) (2019) 594-605.

Y. Guney, Y.D. Sari, M. Yalcin, A. Tuncan, S. Donmez, Re-usage of waste foundry sand in high-strength concrete, Waste Management 30(8-9) (2010) 1705-1713.

A. Gholampour, J. Zheng, T. Ozbakkaloglu, Development of waste-based concretes containing foundry sand, recycled fine aggregate, ground granulated blast furnace slag and fly ash, Construction and building materials 267 (2021) 121004.

S. Kherbache, N. Bouzidi, Concrete properties made with machining reject (foudry sand), Journal of Materials and Environmental Sciences, 2019, Volume 10, Issue 11, page 1043-1052

EN 196-1: April 2006, Methods for testing of cement: mechanical strength. p. 24., 1987.

H.-Y. Moon, Y.-W. Choi, Y.-K. Song, J.-K. Jeon, Fundamental properties of Mortar and Concrete using waste foundry sand, Journal of the Korea Concrete Institute 17(1) (2005) 141-147.

G. Singh, R. Siddique, Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete, Construction and Building Materials 26(1) (2012) 416-422.

G. Singh, R. Siddique, Abrasion resistance and strength properties of concrete containing waste foundry sand (WFS), Construction and Building Materials 28(1) (2012) 421-426.

R. Siddique, G. Singh, R. Belarbi, K. Ait-Mokhtar, Comparative investigation on the influence of spent foundry sand as partial replacement of fine aggregates on the properties of two grades of concrete, Construction and Building Materials 83 (2015) 216-222.