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Research Article

The effect of using recycled materials (sand and fine powder) from demolished concrete waste in alluvial sand mortar

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Abstract

This article evaluates the possibility of a mortar preparation incorporating recycled demolition concrete waste (RDCW). These allow mortars to be produced in two ways: the first in the form of recycled aggregates (RA) to partially replace alluvial sand (AS) (natural sand) and the second in the form of the fine fraction of the waste concrete powder (CWPF) obtained by screening recycled sand (RS) from construction and demolition waste (CDW) to replace Portland cement in the production of composites. The CWPF fraction used is composed of particles having a diameter of less than 0.08 mm. Mortar mixtures were designed with three different RS replacement ratios (0%, 15% and 25%) and varying percentages of CWPF (5%, 10% and 15%). The W/C ratio was designed in 0.53 for all mixes. Mechanical properties such as compressive strength and theological properties (shrinkage) of the prepared mortars were studied. The results show that the material studied has lower mechanical properties than an ordinary mortar, but these are acceptable and indicative, except that the mixture prepared with 75% A Sand 25% Reregister an increase in mechanical resistance at (long term) 90 days. The reverse is true for shrinkage, where adding RS and CWPF with percentages up to 15% and 10% respectively has a positive effect on the mortars studied. These results contribute to the use of FCPW in composites products.

1. Introduction

Over the last few decades, concrete has been estimated to be the second most used material in the world after water [1]. This consumption will continue to grow in the future due to increased urbanization. But this urban development poses environmental problems in terms of preserving natural resources. Indeed, the construction and demolition (C&D) industry in the civil engineering sector accounts for a significant proportion of waste production.

Each year, it is estimated that around 300 million tonnes of construction waste are produced in the United States and almost 80 million tonnes in Japan; over 500 million tonnes are produced in Europe; 200 million tonnes of concrete waste are produced in China [2], 300 million tonnes in France [1] and 70 million tonnes in Brazil [3]. The situation is the same as in France, where landfill costs vary widely and recycling rates are still very low.

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In the UK, the average cost of landfill is estimated at £15/t (around €18.8/t), representing a total cost to the cement industry of £11.25 million/year (around €15.5 million/year). These figures are currently set to rise due to the observed increase in energy prices. In Australia, inert construction waste accounts for 82% of construction and demolition waste, of which 43% is landfilled. The cost of landfilling in Western Australia has been estimated at between $6 and $10/t . Reliable statistics are also a problem in Malaysia, where the identification of construction and demolition waste is not yet effective, and even more so in Kuwait, where up to 33% of landfills are illegal.

In Algeria, and given the development of the building and public works sector in recent years, as well as the growing number of construction sites and deconstruction of illegal sites, the said building and public works sector constitutes the 1st source of massive flows. According to 2016 estimates, the quantity of construction waste generated amounted to 11 million tonnes.

Any construction or deconstruction site affects the environment through the construction materials themselves, the production of waste and the discharge of pollutants into the air and water, and, indirectly, through the energy requirements of the structures built and the spaces they occupy. Through the Stratégie Nationale de Gestion Intégrée des Déchets à l'horizon 2035, the French government aims to reduce the environmental impact of inert waste by installing crushers and sorting destroyed materials.

Studies [4] have shown that recycled gravel can be reused without difficulty in the formulation of concrete. Recycled sand, on the other hand, is more difficult to use. The latter is rich in fines (<0.063 mm), which have a negative impact on workability and increase mix absorption. To avoid this problem, several solutions are applied, such as sieving the fine part of the recycled sand or adding admixtures.

However, for economic reasons, these solutions are not satisfactory. In fact, the use of recycled sand is not authorized for the production of structural concrete, nor is it permitted for the production of prefabricated elements. However, during the demolition waste crushing phase, the quantity of sand by mass can reach half the total quantity of recycled aggregates, so work is needed on incorporating the fines fraction (0.08-5mm) of recycled aggregates into mortars and concretes.

In addition to the problem of generating demolition concrete waste CDW, the environmental impact of cement manufacture, cement production emits a very large quantity of carbon dioxide gas [5 and 6], with CO2 emissions having a negative impact on the environment. According to several studies, the cement industry is responsible for around 75% of global CO2 emissions [7]; [6]; [8]; [9]; to reduce this problem, a solution has been proposed by several studies such as , which use materials partially replacing cement in their work [10], this solution a way to reduce CO2 emissions from clinker and cement production plants and or used recycled waste as a cement additive [6]; [9]; [11,12 and 13];.

In the same context [3] note in their work that there is a need for work on the use of this fraction of recycled fine aggregates. Several studies have been aimed at replacing sand or gravel, but few at replacing cement with CDW. For this reason, the present work aims to produce a new binder from the screening of recycled sand to separate the fine fraction < 0.08mm and use it as a substitute for portland cement. Moreover, in the context of the circular economy, this research is intended as a solution to reduce CO2 emissions from cement manufacturing plants, and also to the difficulty of disposing of CDW. Mortar, by its very nature, is made up of an essential internal element: fine sand.

In Algeria, large quantities of alluvial rolled silica sand are used to manufacture concrete and mortar. However, excessive extraction of these sands has contributed significantly to resource depletion, while also having a detrimental impact on the environment. Parts of the world are experiencing this situation, and must now look for alternative materials to meet the growing demand for concrete and mortar aggregates.

There is another type of sand, available in large quantities locally and presenting no major environmental problems: dune sand, which despite its abundance remains relatively unknown in the construction industry. Its quantity amounts to billions of m3, it is available on nearly 60% of the territory and some of its physico-chemical characteristics suggest that it could be adopted as a building material, thus striking a balancé between environmental protection constraints and economic and social considerations.

This study will then consider proposing a more atypical alternative : the crushing of recycled sand for incorporation into cementitious materials as a mineral input. According to the literature, this idea has been applied by replacing part of the cement with the fine sand obtained. To test the influence of this incorporation on the mechanical strength of cementitious materials (particularly compressive strength) [14].

The aim of this study is to evaluate the potential of crushed concrete sand and crushed concrete fines recovered from the demolition and maintenance of old reconfigured houses, as well as from construction waste, to be incorporated as sand and substituted in cementitious materials, In order to reduce the cost of using natural materials on the one hand and on the other hand to save the environment.

2.Study Materials

2.1. Sand

The recycled sand used as a corrector in this study comes from the residues of a concrete landfill. This recycled sand (0/4 mm) is obtained by crushing concrete waste and sieving fig. 3. The results of the physical characterization of this sand are presented in Table 1. The particle size analysis curve for this sand is illustrated in figure 1. This recycled sand is a coarse sand with a uniform particle size (Uc = 7.8) still spread out (Rc= 1.98). Their fineness modulus is 3.36.

The sand equivalent value (80.50%) shows that sand is suitable for mortar making. alluvial sand (AS) was taken from career of Hassi Sayah in the area of Ouargla (Algeria). From the results shown in Table 1, we note that the water absorption of recycled sand is almost three times higher than that of alluvial dune sand. This can be explained by the high porosity induced by the presence of a certain proportion of cement in the recycled sand, in addition to the fines from the crushing of concrete waste having a high proportion (> 5%) with a very high specific surface area.

The determination of sieve analysis and calculation of fineness modulus (FM) were carried out in accordance with NF P 18-560, sand equivalency (SE) was measured by NF P 18-598. The specific and apparent density and the absorption test were conducted in accordance with NF P 18-555.

Fig. 1 Preparation of recycled sand by sieving

Fig. 2 photo of sand used

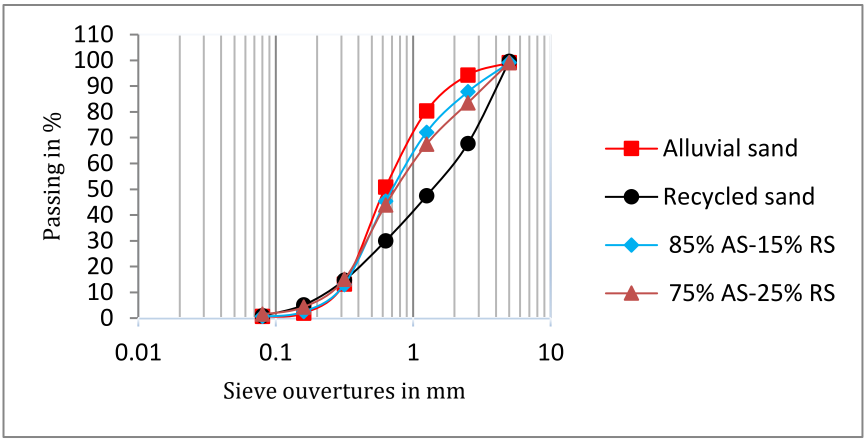


Fig. 3 Grain size distribution of used sand

Table 1. Physical properties of the sands used.

	Alluvial sand (AS)	Recycled sand (RS)	Corrected sand formulations	
			85% AS + 15% RS	75% DS + 25% RS
Specific density (g/cm³)	2,51	2,50	2,58	2,66
Apparent density (g/cm³)	1.47	1,63	1,57	1,58
Water absorption (%)	0.6	8,20	///	///
Fineness modulus	2.60	3,36	2,78	2,80
Sand equivalency (%)	73	80,50	///	///

2.2. Cement

The cement used is a CPJ-CEM II 42.5 N artificial Portland cement, according with standard NF EN 197-1. It has a density of 3.10 g/cm3 and a specific surface area of 3240 g /cm^2

Tables 2 and 3 present the chemical analysis and physical and mechanical properties of this cement, respectively. In compliance with standard NF P 15-301194.

Table 2. The chemical analysis of the cement used revealed the existence of the elements which are presented

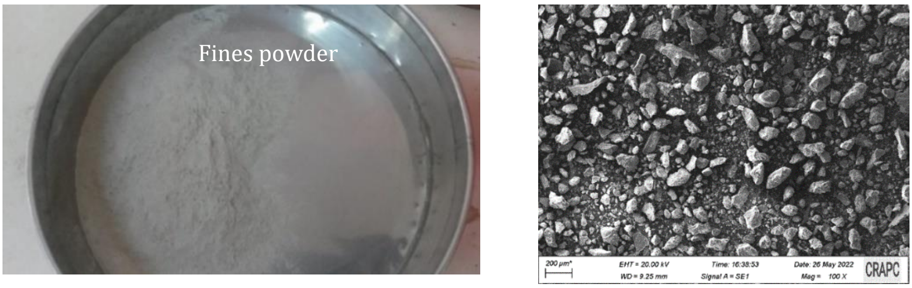
Chemical analyzes	Lossonignition (NA S042) (%)	Sulphate content (SO3) (%)	MgO magnesium oxide content (%)	Chloride content (NA S042) (%)
Value	10,0 ± 2	2,5 ± 0,5	1,7 ± 0,5	0,02 – 0,05

Table 3. Physical and mechanical characteristics of cement used

	Start setting (min)	End of setting (min)	Cs_{28} (MPa)	Cs_{2} (MPa)
CPJ-CEM II	150 ± 30	230 ± 50	≥ 42,5	≥ 10,0

2.3. The Fines Powder

In this study we used the fines powder from recycled concrete (CWPF) obtained by crushing concrete and sieving in the laboratory fig. 4 (a and b) these fines the idea was applied



(a) (b)

Fig. 4 (a) Photo of the fine powders used, (b) SEM images of the fine powders used

in this work by substituting part of the cement by the fine.

Table 4. Absolute density and specific surface of the CWPF and CPJ-CEM II used

Materials	Portland cement	Fine powder
Absolute density ρabs (g/cm3)	3.10	2.43
Blaine specific surface (cm2/g)	3240	6520

These results show that the Blaine specific surface area of fine powders is higher than that of CPJ-CEM II 42.5 N cement. This can be explained by the effect of successive crushing and the friability of the raw material, rich in limestone and cementitious materials.

2.3.1 Method of Manufacturing Fines

Recycled aggregate fines powder from crushed concrete waste (RAF): "recycled aggregate fines". A crushing-screening method is used to obtain fines of less than 80μm. In the case of concrete, the 16 x 32 cm cylindrical and 4 x 4 x 16 cm prismatic specimens were previously crushed by compression and traction melting to obtain pieces smaller than 5 cm. This facilitated processing in the crusher. The recycled RA 0/4 aggregates were fed directly into the crusher. The small granular size of the selected sample saved time and energy. The machine used is a jaw crusher.

The method consists of successively crushing materials with decreasing jaw opening. At the end of each crushing stage, the material is sieved to 80 µm. All particles rejected at this sieve are reintroduced for a new crushing stage, while those passing at 80 µm are retained fig. 5. These operations are repeated until the jaw opening can no longer be reduced. We have chosen to screen at 80 µm because this size is close to the D_{max} conventionally used for mineral additions.

Fig. 5 Preparation of fines by sieving

2.4. Water

The water used for mortar production in this study is potable water. Its quality complies with the requirements of standard NFP 18-404.

3. Experimental Methods

3.1 Characterization of Study Sands

Sand specific gravity, apparent density and absorption were determined in accordance with standard NF P 18-554. Sand particle size analysis by sieving was carried out in accordance with standard NF P 18-560, on aggregate samples ranging in size from 4 to 0.08 mm. Sand equivalence (SE) was carried out in accordance with standard NF P 18-598.

3.2. Fines Characterization Methods

The absolute density is measured by the pycnometer method in accordance with standard EN 1097-6. The specific surface (Ss) is measured by the Blaine method standardized according to NF EN 196-6. Scanning Electron Microscope (SEM) analysis is performed on a field effect microscope.

The SEM is coupled to an energy dispersive spectrometer (EDS). The advantage of using this device is to visualize particle structure on polished sections on polished sections or pellets, to carry out spot chemical analysis of each mineralogical phase and finally to quantify the proportions by image analysis. The tests are secondary electron mode and backscattered electron mode.

3.4. Mortar Formulation and Sample Preparation

The formulation method adopted is the same as for normal mortar (standard NF EN 196-1). Determination of water content is based on the workability test. The "Water/Cement" ratio (W/C= 0.53) was obtained from this test table 5.

Four alluvial sand mortar formulations were prepared and studied, designated as follows:

M-AS: mortar based on alluvial sand (natural sand) and 0% fines (control).

M1-ASRSF0: mortar based on 85% alluvial sand and 15% recycled sand.

M2-ASRSF0: mortar based on 75% alluvial sand and 25% recycled sand.

The rate of massive fines participation (CWPF) was varied from 5% , 10% and 15% for each mortar formulation.

Details of the composition of the different formulations tested are given in Table 5.

Table. 5. Composition of the formulations studied

Formulation (1 m^3)	Alluvial Sand (kg)	Recycled Sand (kg)	Cement (kg)	Fines powder (kg)	Water (l)	W/C
M-AS	1425.9	0,00	444.9	0,00	217.8	0,53
M-ASF5	1425.9	0,00	444.6	35.1	217.8	0.53
M-ASF10	1425.9	0,00	421.2	46.8	217.8	0.53
M-ASF15	1425.9	0,00	397.8	70.2	217.8	0.53
M1-ASRSF0	1193.4	210.6	479.7	0,00	217.8	0,53
M1-ASRSF5	1193.4	210.6	444.6	35.1	217.8	0.53
M1-ASRSF10	1193.4	210.6	421.2	46.8	217.8	0.53
M1-ASRSF15	1193.4	210.6	397.8	70.2	217.8	0.53
M2-ASRSF0	831,37	554,25	461,87	0,00	217.8	0,53
M2-ASRSF5	1053	351	444.6	35.1	217.8	0.53
M2-ASRSF10	1053	351	421.2	46.8	217.8	0.53
M2-ASRSF15	1053	351	397.8	70.2	217.8	0.53

The mortar samples prepared were 4 x 4 x 16 cm3 in size. Sand and cement were dry-mixed for 60 s, then water was added. The molds were filled in two layers, each vibrating for 30 s. After 24 h of curing, the mortar specimens were removed from their molds and kept fully immersed in water at a temperature of 25 ± 2°C for 14 days. Then removed from the water and exposed to laboratory conditions (Temperature = 30 ± 5 °C, Humidity = 25 ± 2 %). Figs 6-7 show the photos of the mixed constituents and the test specimens of the mortars prepared respectively.

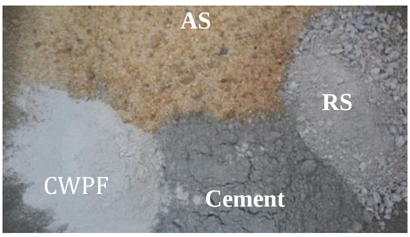


Fig. 6 Dry material mixtures

Fig. 7 Mixture specimens

3.5. Workability

The workability of mortars is measured with a workability meter according to standard NF P 15-437, the test for measuring the flow time of fresh concrete exposed to vibrations.

3.6. Mechanical Testing Techniques

The compressive strength of the mortar samples was measured with the prepared mortar samples (three per age) at ages of 28 and 90days according to the recommendations of NF

EN 196-1 using a hydraulic press with a displacement speed of 0.2 mm/min. The sample is placed between two metal plates in the compressive test machine, shown in Fig.8.

Fig. 8 Compressive test showing the crushing of specimen.

3.7. Shrinkage Test

The unstressed shrinkage test was carried out according to NF P 15-433 (AFNOR, 1994). The results presented are average values of three measurements. These were carried out using a shrinkage meter Fig.9 with an accuracy of ± 5 mm/m. The first shrinkage reading was taken after demolding the specimens at 24 hours followed by further measurements up to 90 days of age. The shrinkage meter can be reliably calibrated with an invar bar before each measurement. The weight loss of the specimens over time was studied along with the shrinkage measurements.

Fig. 9 Shrinkage measurement

4. Results and Discussion

4.1. The Surface Texture of Recycled Sand and Fine Powder

Fig. 10 show the surface texture of RS, which is extremely porous and rough), which may contribute to an increase in the surface area bound to the aggregate-rock interface [15].

An energy dispersion spectroscopy (EDS) analysis of the surface of the RS Fig.10 and table 5 revealed the presence of several elements such as dominant silicon, calcium and aluminum Table 6. This, explained by the presence of old mortar pate coated the RS grains. The same has been observed in several studies [15-16]. From the results obtained by the energy dispersive spectroscopy (EDS) analysis shown in fig. 11 and table 7, it can be seen that CWPF is rich in limestone and cementitious elements such as calcium, aluminum and silicon, with percentages close to those of portland cement, which justifies its use as a replacement for cement in the manufacture of mortars and concretes.

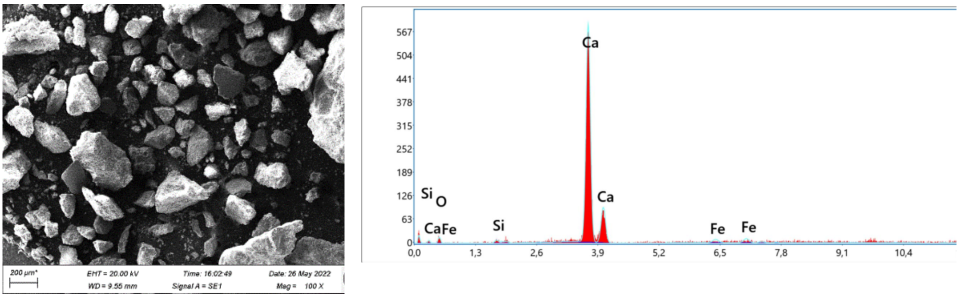


Fig. 10 Analysis of the surface texture of RS

Table 6. Smart quantitative results

Element	OK	SiK	CaK	Fek
% of mass	9.57	0.56	86.69	3.118

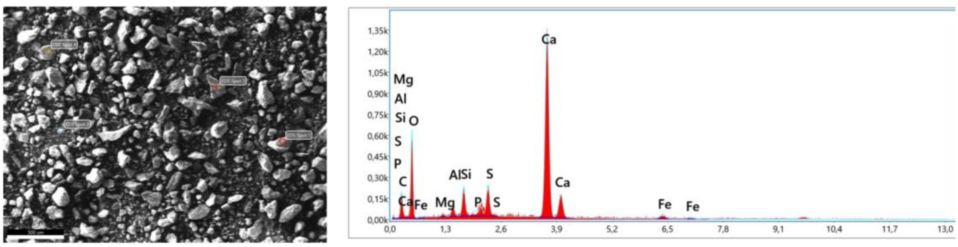


Fig. 11 Analysis of the surface texture of CWPF

Table 7. Smart quantitative results

Element	CK	OK	MgK	AlK	PK	SK	SiK	CaK	Fek
% of mass	7.19	41.76	0.51	1.35	2.88	0.63	3.82	39.68	2.19

4.2. The Effect of Adding Recycled Sand on Mechanical Strength

Fig. 12 shows the compressive strength of M-AS, M1-ASRS and M2-ASRS specimens over time. The compressive strength of the three mixes after 28 days of curing was around 45.1 MPa, 42.2 MPa and 36.3 MPa respectively. The M-AS mixture showed a higher strength than the M1-ASRS and M2-ASRS mixtures, with increases at 28 days of 6.43% and 19.51% respectively. This can be explained by the fact that the presence of RA increases the porosity of the mixture, which translates into a decrease in the strength of mortars containing RS compared to mortars without added RS (control).

Similar observations by [17] who observed in their work that mixes with waste incorporation show reduced compressive strength compared to mixes without incorporation. At 90 days, the compressive strength pattern changed, as the M1-ASRSF0 mortar recorded a decrease in strength of 7.95%, compared to M-ASRSF0, while the M2-ASRSF0 mixture gave more strength than the mixture of a percentage 1.04%, this a slight increase in the resistance of M2-ASRS compared to M-ASRS is due is that the recycled sand, rich in particles of diameters between 0.08 mm and 0.63 mm and containing anhydrous cement, in the presence of water in the long term, the latter reacts to form new hydrates by pozzolanic reactions, which have a positive effect on the resistance [18], while the void-filling effect of these fine RS grains minimizes the percentage of pores. On the other hand, the increase in resistance is probably also due to the nature of the recycled aggregates and the resistance of the demolition concrete which produces these aggregates.

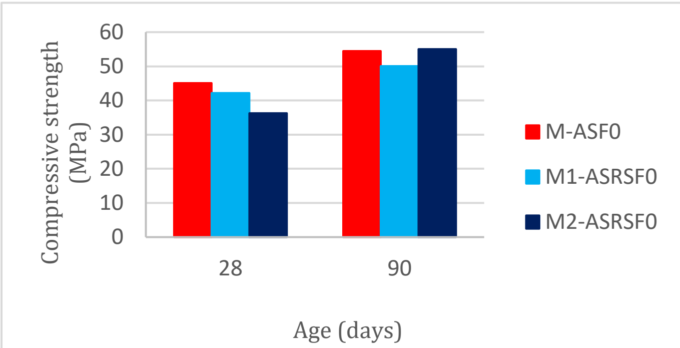


Fig. 12 compressive strength of mixtures without adding CWPF

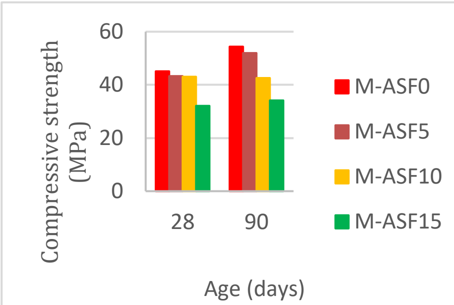
4.2.2. The Effect of Adding Recycled Fine Powder on Mechanical Strength

The results of the compressive strength of mortars prepared with different sands used and with contents of Portland cement replacement by (CWPF) are presented in figure 13. The results obtained show a decrease in compressive strength in all mortar types studied compared to the mortar (control) without replacement (0%).

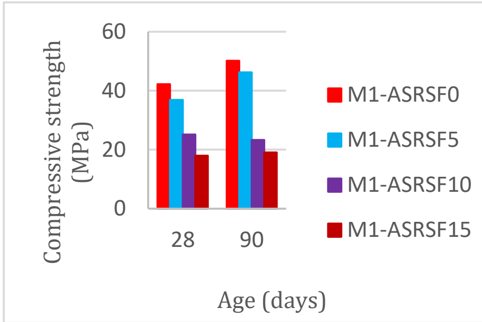
Figs.13 (a, b, c and d) show that the addition of fine demolition concrete waste in substitution of Portland cement resulted in a decrease in compressive strength compared with mortars without replacement (0%). However, the mortars produced have acceptable strengths for making mortars to NBR 16697 [19]. These results encourage the use of fine CW fractions as cement substitutes for both economic and environmental reasons. We also note that the control concretes M-ASF, M1-ASRS and M2-ASRS show the best strength results compared with mortars made with recycled fine concrete.

Fig. 13.a shows the strength of M-AS concretes with and without the addition of CWPF at 28 and 90 days. It can be seen that the strength of M-ASF5, M-ASF10 and M-ASF15 mixtures decreased by 3.97%, 4.43% and 28.82% respectively, and by 4.46%, 21.73% and 37.17% at 90 days respectively, compared with the M-AS control mortar. Fig. 13.b shows a similar decrease in strength of M1-ASRS mortar (85%AS-15%RS) at 28 days, compared with M1-ASRSF5, M1-ASRSF10 and M1-ASRSF15 mixtures.

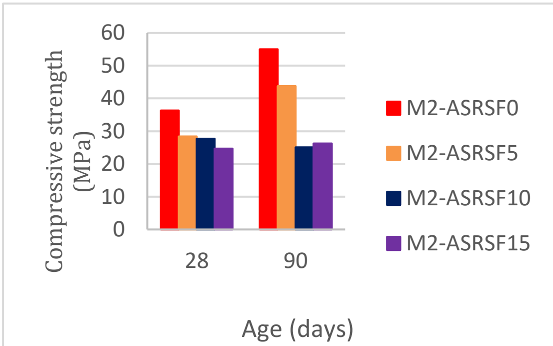
This difference is of the order of 18.12%, 44.3% and 60.24% respectively. Figure 13.c also shows a decrease in strength of M2-ASRS (75%AS-25%RS) compared with M2-ASRS, M2-ASRS and M2-ASRS mortar at 28 days of the order of 37.1%, 38.62% and 45.28% respectively.



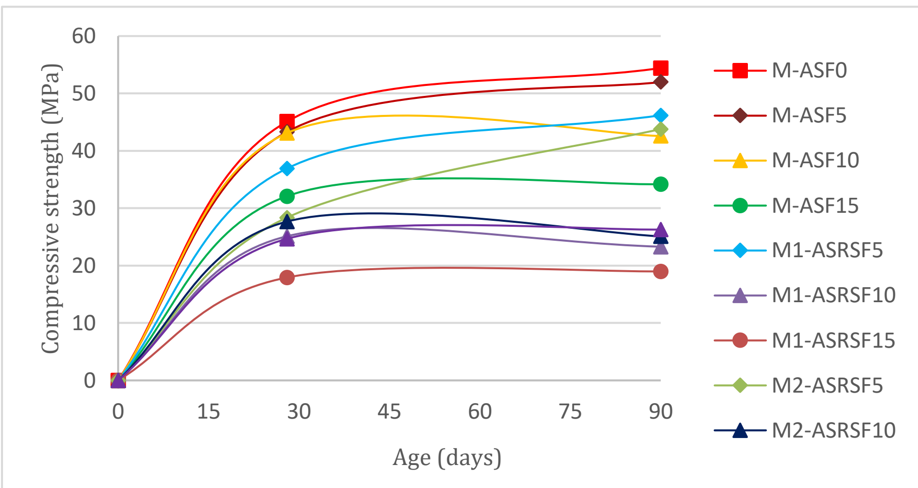
(a) M-AS with and without CWPF



(b) M1-ASRS with adding CWPF



(c) M2-ASRS with adding CWPF



(d) compressive strength of all mixtures studied in comparison

Fig. 13 Compressive strength of mixtures with and without addition of fine powder as a function of time

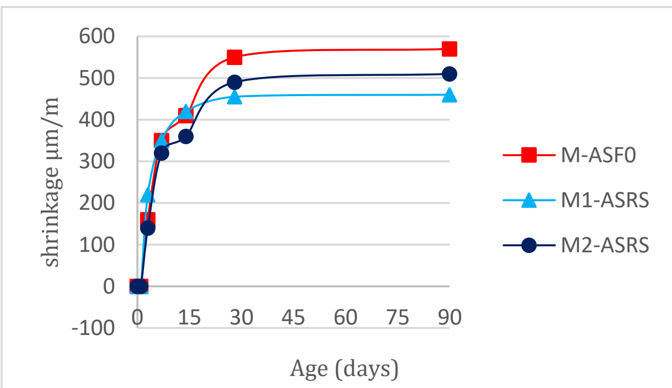
4.3. The Effect of Adding Recycled Sand and Fine Powder on Shrinkage

mixes is similar during the curing time, which resulted in an increase in drying shrinkage as a function of time, this shrinkage is greater in the first 28 days, this due to water evaporation, beyond this period a slight increase observed in all types of mortars studied, similar results were observed in the study of [20]. But the results obtained show a decrease in the shrinkage of alluvial sand mortars mixed with M1-ASRS and M2-ASRS recycled sand compared with mortars made with 100% M-AS alluvial sand.

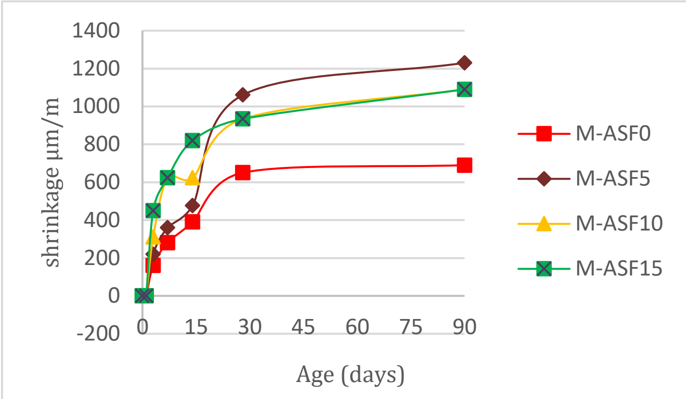
These decreases are respectively of the order of 17.27% and 10.90% at 28 days and of the order of 19.30% and 7.02% at 90 days. The same was observed in the work of [21-18], who found that the addition of AR had a positive effect on shrinkage. As a result, M1-ASRS mortar shows the lowest shrinkage relative to M2-ASRS. This increase in shrinkage is due to the presence of a large quantity of RS, which increases the W/C ratio during mixing, and also to the nature of RS, despite this, the shrinkage of M2-ASRS remains lower than that of M-AS. It can therefore be said that the incorporation of RS in percentages of up to 25% improves the shrinkage of alluvial sand.

The same was observed in the work of [22] where they stated that the addition of RA had a negative influence on the shrinkage phenomenon. Figs. 14 (b, c, d et e). show that incorporating up to 10% CWPF has a positive effect on shrinkage, where mortars M1-ASRSF5 and M1-ASRSF10% show a decrease in shrinkage, this decrease being 4.61% and 6.92% at 28 days and 2.9% and 10. 14% at 90 days on the other hand, above 10% CWPF, there is an increase in shrinkage compared with M-AS mortar.

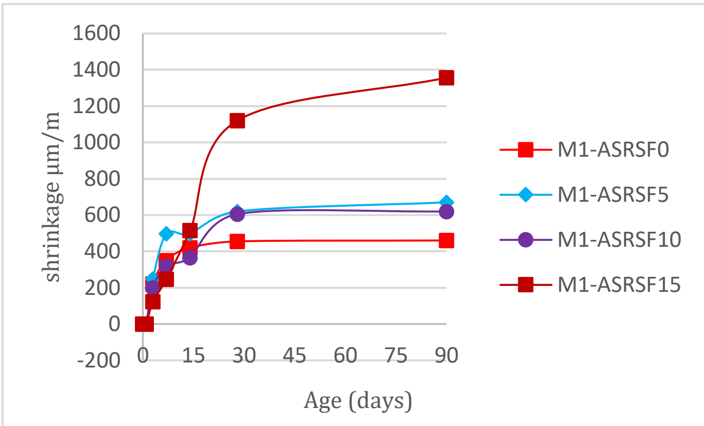
The probable reason for the improvement in the shrinkage phenomenon is the effect of filling the interstitial voids with CWPF, which creates a very dense microstructure which limits microcracking and internal movements of alluvial sand mortars, and also due to the presence of non-hydrated cementitious material, the latter forming hydrates in the presence of water, resulting in long-term internal hardening that limits shrinkage. These results show that the addition of up to 10%CWPF has a positive effect on the shrinkage of alluvial sand.



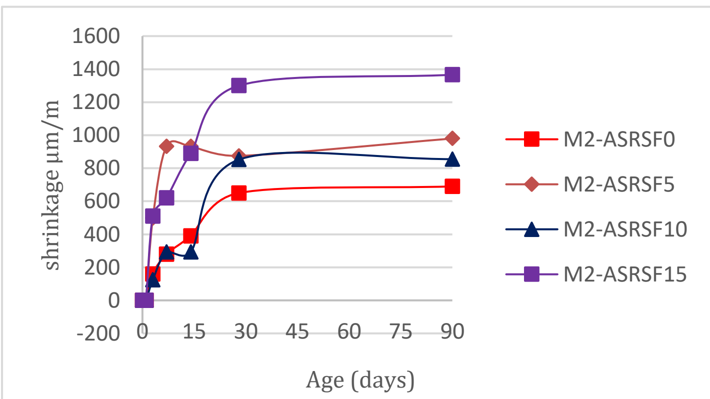
(a) M-AS, M1-ASRS et M2-ASRS without CWPF



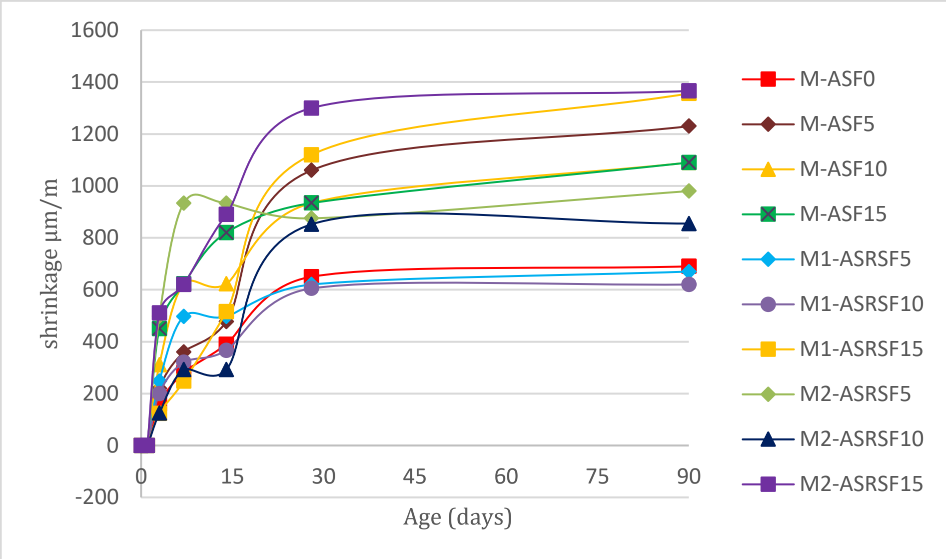
(b) M-AS with and without CWPF



(c) M1-ASRS with adding CWPF



(d) M2-ASRS with adding CWPF



(e) Shrinkage of all mixtures studied in comparison

Fig. 14 Shrinkage of mixtures with and without addition of fine powder as a function of time.

5. Conclusions

The study of all the results concerning the mechanical and rheological characteristics of alluvial sand mortars has enabled us to identify the main findings of this work:

- The addition of demolition sand, which contains a high proportion of fine elements to alluvial sand, helps to fill the voids between the grains of alluvial sand thanks to the fine elements. On the other hand, the alluvial sand grains fill the voids between the coarse demolition sand grains, resulting in a well-balanced grain gradient.
- Correcting the grading of recycled sand with silty sand had a positive effect on improving physical properties (fineness modulus).
- Replacing more than 30% of the natural sand with recycled sand, the mixed sand may lose certain physical properties such as fineness modulus.
- Incorporating recycled sand into the alluvial sand mortar mixture slightly reduces the mechanical strength of the mortar studied.
- Some samples made up of alluvial sand and demolition sand gave better strength results than the mortar sample made up of 100% alluvial sand, and this is of course due to the origin of the recycled aggregates and the strength of the demolished concrete.
- A mixture containing 25% recycled sand showed better compressive strength over the long term (90 days) than a 100% AS mixture.
- Some of the physical properties of CWPF were close to those of Portland cement, encouraging and enabling its use as a substitute for a percentage of synthetic cement to reduce carbon dioxide emissions from cement plants.
- The incorporation of RS and CWPF in the alluvial sand slurry mixture reduced the mechanical strength of the slurry studied.

- As for the effect of incorporating demolition aggregates on the shrinkage of the mortar studied, it varied between an improvement on some samples and an increase on others.
- The incorporation of 15% and 25% alluvial sand in the mortar showed improved shrinkage compared with the 100% AS mixture.
- Mixtures with 15% RS, 5% replacement and 10% CWPF showed improved shrinkage compared with the other mixtures.
- The addition of 15% recycled sand and 10% CWPF to alluvial sand mortar showed positive results, encouraging the use of recycled concrete waste as an alternative to sand and cement, for economic and environmental reasons as part of the valorization of construction waste.

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