Used Foundry Sand in Cement Mortars and Concrete Production

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Abstract: Used foundry sands represent the highest amount of solid wastes generated by foundries. Classified by European Union regulations as non hazardous waste, they represent a relevant source to be reused in several industrial sectors, in building construction primarily.

In present paper, the properties of mortars and concretes containing different dosages of used foundry sand (UFS) as partial replacement of sand were investigated in both fresh and hardened conditions. In particular, higher percentages of addition, but lower if referred to the whole aggregate (fine and coarse), were considered in concretes than in mortars. Both mortars and concretes were evaluated with respect to consistency of the fresh mixture and compressive strength of the hardened material. Elastic modulus determination of the hardened material was carried out on concretes.

A low (10%) amount of used foundry sand does not change the mortar's performances. In the presence of higher additions a workability decreasing can be outlined, and then a higher dosage of superplasticizer is required in order to keep it constant. Mechanical performances lower of about 20-30% than those of the conglomerate without used foundry sand are observed. The higher penalization it seems to concern to the conglomerates of better quality (i.e. lower water-cement ratio).

INTRODUCTION

Used Foundry sand (UFS) is a discarded material coming from ferrous and nonferrous metal-casting industry. It's a mixture of high quality size-specific silica sand, few amount of impurity of ferrous and nonferrous by-products from the metal casting process itself and a variety of binders.

The silica sand is used as moulding material, for ferrous (iron and steel) and nonferrous (copper, aluminium, brass) metal castings, mainly because of its thermal conductivity. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. In the casting process, moulding sands are recycled and reused multiple times, small residues of ferrous and non-ferrous by-products often come from the recycling process. Before to be reused, silica sand needs to be cleaned by means of screening systems and magnetic separators to segregate reusable sand from other wastes and to separate particles of varying sizes [1, 2].

As moulding material, the sand is compacted and shaped according to the mould pattern that is going to be produced, as well as to create cavities that are not practical to produce by normal moulding operations, the cores. Because of that, UFSs contain a variety of binders (a binder is required to give binding action to the incoherent sandy mixtures) depending on the specific application for which they were used.

Although UFS is partially a recycled material itself, as successfully recycled and reused through many production cycles, after many times it loses its characteristics especially the cleanliness and the uniformity ones. Becoming unsuitable in the manufacturing process, it's discarded as waste.

Typically, the automotive industry and its parts suppliers are the major generators of foundry sand (about 95% of the estimated UFS). They employ about 1 ton of foundry sand for each ton of iron or steel casting produced, with a non negligible impact especially from a sustainable development point of view. According to the American Foundry Society (AFS), a metal casting industry group, the metal-casting process generates 9.4 million tons of foundry sand annually (2007 data) [3].

At present, although a great attention to environmental issues, the general trend is still to dispose UFSs in landfills, sometimes utilised as landfill daily cover. The American Foundry Society estimates that 6.8 million tons of foundry sand (2007 data) [3] was disposed in landfills, approximately the 2/3 of the total production. Several evident drawbacks could be listed due to this trend:

− early closure of the material life cycle with consequently more consumption of virgin raw materials;

− saturation of existing landfills and soil pollution in unmanaged landfill cases;

− release of leachable contaminants, absorbed by the sand during the moulding process and casting operations, like heavy metals (cadmium, lead, copper, nickel, and zinc) and phenols;

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– economic impact, referring in particular to logistic costs in UFS transportation (sometimes landfill is not so close to the foundry);

– environmental impact, linked to the climate change, due to CO_2 emission because of the previous drawbacks.

Furthermore, according to EC regulations [4, 5], UFS is classified as non-hazardous waste and, consequently, it has an important intrinsic economic value, especially in terms of iron and steel. Recently, a numbers of applied researches [6-9], including the patent [10], addressed to investigate the feasibility to re-employ UFSs in other industrial sectors than ferrous. The most suitable one seems the construction industry, because of UFS employ in several construction materials, like: Portland cement clinker, structural concrete, brickworks, building conglomerates, road base, structural fill, flow-able fill, soil amendment, or as the fine aggregate portion of concrete or hot-mix asphalt [11-13]. In addition, some sand can be used as a high-end additive to industrial materials, such as plastics, to provide specific textures and colours [12].

Detailed quantitative data on the various beneficial applications of foundry sand have not been well documented in the past. Recently, a preliminary survey has been conducted by AFS [14] pointing out that a small amount of UFS is still used in Portland cement clinker. This seems due to the transportation costs to joint the final destination plant, especially considering the high amounts daily production of the foundry. However, according to the Portland Cement Association foundry sand is being used by a number of North American cement kilns [15-17].

As far as Europe it concerns, data are pointing out an increasing interest on UFS technical properties in conglomerates production and performances [18, 19]. Moreover, the environmental aspects and compatibility have been investigated in order to point out the prerequisites for the USF utilisation [20, 21].

The present work aims to contribute at studies on the UFS usability as construction material. In particular, it focus on structural concretes and mortars, by investigating the feasibility to partially replace natural sand with UFSs, and by characterising the new conglomerate mixtures in both fresh and hardened conditions.

BASIC LITERATURE REVIEW ON USED FOUNDRY SAND PROPERTIES

Due to the foundry sand high concentration and annually production of metal industries – especially in USA – applied research on UFS start since 1980. In particular, UFS has extensively investigated as a constituent material for controlled low-strength materials [1, 2, 9, 22, 23].

The classification (physical and chemical) and the behaviour of foundry sand strictly depend on the type of casting process and the industry sector from which it originates, and especially from the type of binder systems used in the process. Typically, two types of binder systems, with different physical and environmental characteristics, are used: clay and chemical binder. Accordingly, foundry sand is categorised as: clay bonded system (green sand) and chemically bonded system. Generally, green sand is the most

commonly used: it constitutes about the 90% of casting volume [24].

Green sand is composed of:

– high quality silica sand (85-95%) – the bulk medium that resists high temperature;

– bentonite clay (4-10%) – used as binder;

– carbonaceous additive (2-10%) – added to improve the casting surface finish;

– water (2-5%) – to adjust plasticity.

Green sand has a clay content that results in percentage of material that passes at 75µm (sieve n.200, ASTM C136 - 06 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates) and adheres together due to clay and water. Due to carbon content, it looks black in colour, or sometimes gray. It also contains trace chemicals such as MgO, K_2O, and TiO_2 [24].

Chemically bonded sand consists of silica sand and chemical binder that is activated by a catalyst. Generally, chemically bonded sands are 93–99% silica and 1–3% chemical binder. There are various types of chemical binder systems used in the foundry industry (chemical composition usually proprietary). Most consists of organic, like phenolic-urethanes, epoxy-resins, furfyl alcohol, although some systems use inorganic binders (i.e. sodium silicates).

Commonly, they are used in core making where high strengths are necessary to withstand the heat of molten metal, but also in mould making. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. The chemically bonded sand is typically a medium tan or off-white colour.

Used foundry sand is generally sub-angular to round in shape. The grain size distribution is uniform: 85–95% of the material ranging between 0.6 and 0.15mm; 5–12% can be smaller than 75µm. The specific gravity of the foundry sand can vary according to the category; often it ranges between 2200 and 2600 kg/m^3. Used foundry sand has low absorption capacity and is non-plastic [25].

MATERIALS AND METHODOLOGY

The present work concerns the investigation of UFS utilisation effect on both mortars and concretes. In particular, the performances of conglomerates (mortars and concretes), at different water/cement (w/c) ratios, are investigated. The aims is to establish the amount of used foundry sand that can be added in mixture without too heavy penalizations, principally in terms of workability, mechanical performances (i.e. compressive strength and dynamic elastic modulus) and drying shrinkage.

A commercial Portland-limestone blended cement type CEM II/A-L 42.5 R in accordance with European Standards EN-197/1 is used.

Cement is characterized by Blaine fineness of 0.415 m^2/g (UNI EN 196/6) and density of 3100 kg/m^3. The chemical composition of cement is shown in Table **1**. The UFS, object of this research, is green sand (Fig. **1**) coming from the metal-casting moulding process of an Italian foundry which produces metal component for the automotive industry.
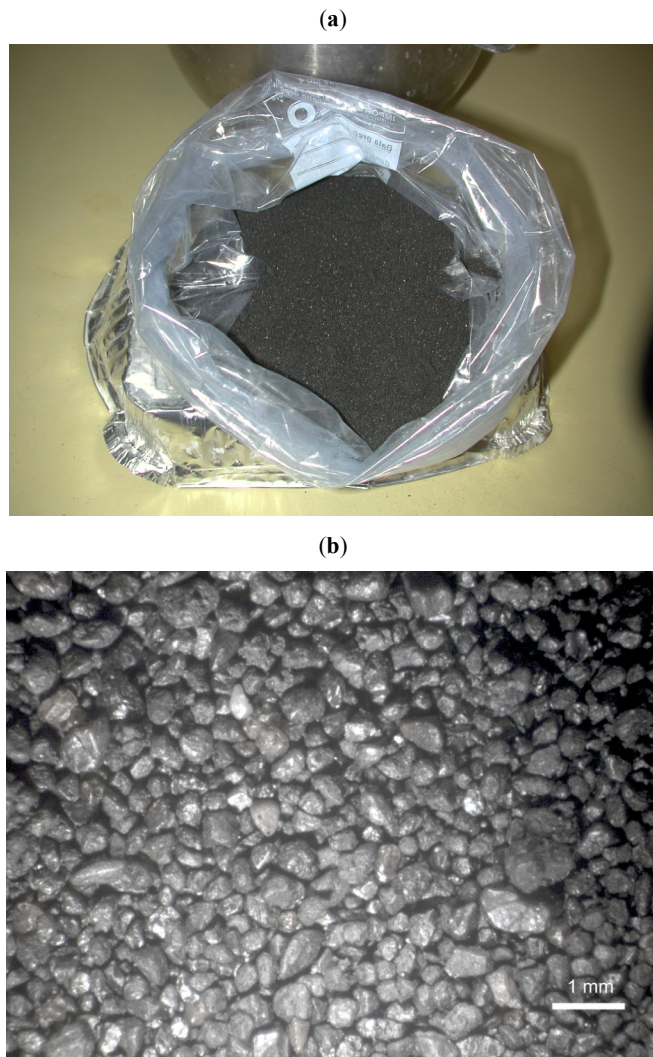
(a)

(b)

1 mm

Fig. (1). Used Foundry Sand (UFS) – an Italian foundry green sand: **a**) normal view **b**) magnified in optical microscopy.

According to the European Union and National regulations [26-28], the industry dispose it as non-hazardous waste. The chemical analyses (including leaching tests) confirm the non-hazardous nature of the discarded sand (Table **2**). As far as the organic content it concerns, the measured dissolved organic carbon (DOC) results under the Italian low limit (i.e. < 80 mg l^{-1}).

The UFS was physically and chemically characterized in terms of specific weight (UNI EN 1097-6:2002), X-Ray

diffraction analysis (on the fraction finer than 75µm) and Differential Thermal Analysis. Particle-size distribution was evaluated by sieve analysis (UNI EN 933-1).

About UFS physical properties, the specific weight is equal to 2260 kg/m^3. Sieve analysis shows a high rate of material finer than 75µm, due to the large amount of binder present in the sand (Fig. **2**).
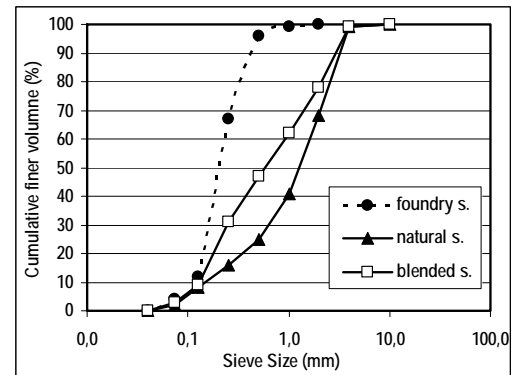

Fig. (2). Sieve analysis curves of the foundry, natural and a blended (with 30% of UFS) sand.

In Fig. (**2**) the UFS sieve analysis is also compared with that of the natural sand. An example of how the blend with both natural (70%) and foundry (30%) sand modifies the sieving curve is also shown in Fig. (**2**).

The binder constituents are better pointed out in Figs. (**3**, **4**). In particular, Fig. (**3**) relates to the X-ray analysis, carried out on the material fraction finer than 75µm, and reveals the presence of quartz and carbonates (calcite and dolomite) as well as montmorillonite. Fig. (**4**) relates to the Differential Thermal Analysis (DTA), carried out on UFS as received, and quantifies the amount of carbonaceous additive as about 2.8% by weight.

As far as to the mortars and concretes preparation it concerns, firstly reference mortars and concretes (control mix) are proportioned without used foundry sand (i.e. with only natural sand). For both mortar and concrete mixtures the natural aggregates consist of:

–   coarse aggregate with a 22mm maximum size and specific weight of 2660 kg/m^3 ;

–   fine aggregate (natural sand) with a 4mm maximum size, specific weight of 2620 kg/m^3.

The experimental stage plans to employ used foundry sand as a partial replacement of the fine aggregate. A set of

Table 1.   Chemical Composition of the Cement

Oxide	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	TiO$_2$	CaO	MgO	SO$_3$	K$_2$O	Na$_2$O	L.O.I.
%	29.67	3.74	1.80	0.09	59.25	1.15	3.25	0.79	0.26	11.62

L.O.I. = loss on ignition.

Table 2.   UFS Leaching Cation Content and Dissolved Organic Carbon (DOC)

Ion	Na	K	Mg	Ca	Al	Zn	DOC
mg l^{-1}	340	10.8	2.5	9.1	36.0	0.16	< 80

mortar specimens is manufactured by replacing the 10%, 20%, 30% by weight of natural sand with UFS. On the other hand, concrete specimens were manufactured by replacing the 7-10% of the whole aggregate weight, which corresponds to replace of about the 20-30% of the only sand weight, with UFS.
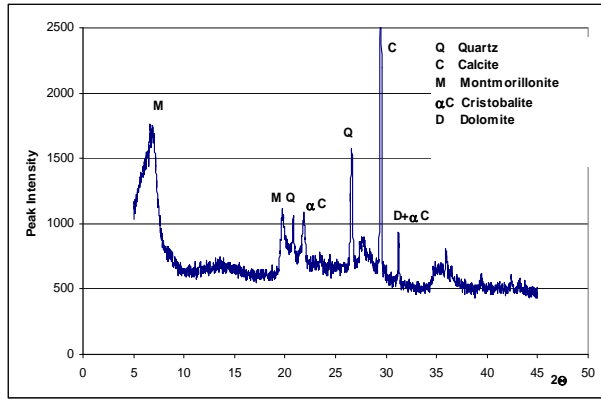

Fig. (3). X-Ray diffraction pattern of UFS finer than 75μm.

Mortars (M1, M2 and M3) are manufactured with a water-cement (w/c) ratio of 0.45, 0.50, 0.55; concretes (C1, C2) are proportioned with a water-cement ratio of 0.46 and 0.50. Compositions, including workability, are shown in Tables **3** and **4**.
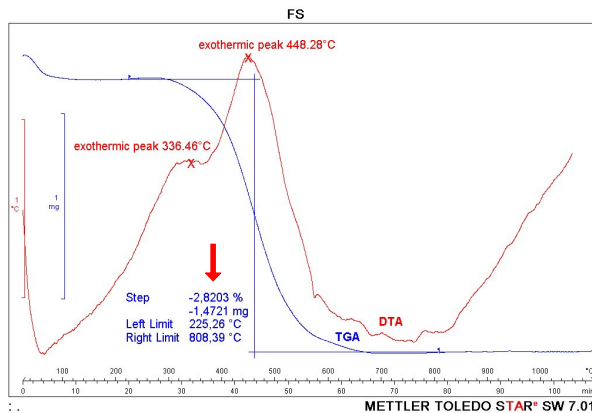

Fig. (4). Differential Thermal Analysis of UFS as it is.

At occasion UFS is pre-treated mainly to reduce the amount of binder finer fraction and to improve adhesion. In this research UFS has been cleaned by washing in water and

sieving at 75μm. A mortar specimen with 20% by weight of cleaned UFS has been set up in order to compare results and test the benefits to clean the UFS (see Table **3**, M2-20$_c$).

Mixtures are proportioned maintaining, as close as possible, the same workability with and without foundry sand. To this aim, when needed, an acrylic based super plasticizer is added in the mixture to adjust workability.

The consistency test gives a slump flow - measured by vibrating table (UNI EN 1015-3) – of 110 – 145mm for mortars, and a slump value – measured by Abrams cone (UNI EN 12350-2) – of approximately 120-160mm for concretes.

Prismatic mortar specimens (4 × 4 × 16cm) and cubic concrete specimens (15x15x15cm) are prepared with each mixture in order to test compressive strength (UNI EN 1015-11 and UNI EN 12504-4) and dynamic elastic modulus (UNI EN 1015-11 and UNI EN 12504-4) and then to deduce the mechanical performance of the specimens. Compressive strength of both mortar and concrete mixtures, made with and without UFS, is determined at 1, 3, 7, 14 and 28 days of curing in order to point out the mechanical performances trend, depending on the hydration kinetic, versus time.

Moreover, concrete beams (10x10x50cm) are appositely performed to test drying shrinkage (UNI 11307), in order to report the effects of UFS replacing on the concrete drying shrinkage.

During the first day of curing time, all mixtures are conserved into formworks. After de-moulding, they are cured in a saturated environment to prevent water evaporation. For drying shrinkage measurements, concrete beams are conserved, during all curing time, in a controlled environment, at relative humidity of about 60%. The temperature is kept constant at about 20°C.

RESULTS AND DISCUSSION

The fresh mixture data of both mortars and concretes (Tables **3** and **4**) show that UFS reduces the workability when added as natural sand replacement (at same w/c); higher amount of superplasticizer is required in order to maintain the same workability.

The control mortar sample with w/c equal to 0.50 requires an addition of 0.5% by cement weight, while mortars containing UFS need an addition up to 1.8%. Similarly, concrete mixture containing UFS needs a

Table 3. Mortar Composition and Fresh Mixture Workability

MIX	M1	M1-10	M1-20	M1-30	M2	M2-20	M2-20$_c$	M2-30	M3-30
cement (kg)	500	500	500	500	480	480	480	480	510
natural sand (kg)	1500	1350	1200	1050	1445	1155	1155	1010	1065
foundry sand (kg)	-	150	300	450	-	290	290	435	455
water (kg)	250	250	250	250	265	265	265	265	230
water/cement (w/c)	0.50	0.50	0.50	0.50	0.55	0.55	0.55	0.55	0.45
superplasticizer (%)	0.5	0.5	1.5	1.8	-	0.9	-	1.2	2
slump flow (mm)	142	130	115	110	145	123	130	118	116

c = Used Foundry Sand (UFS) cleaned by washing and sieving.

superplasticizer dosage. The dosage ranges from 1.4% to 1.7% by cement weight, depending on the w/c ratio utilised. This increase in superplasticizer addition should be considered quite high when compared to that introduced in ordinary conglomerate.

Fresh mixture unit weight (UNI EN 12350-6) and entrapped air content (UNI EN 12350-7) do not point out any relevant differences with and without foundry sand (i.e. shown on Table **4**).

Table 4. Concrete Composition and Fresh Mixture Performance

MIX	C1	C1-7	C1-10	C2	C2-10
cement (kg)	350	350	350	355	355
natural sand (kg)	645	515	460	655	456
coarse aggregate (kg)	1210	1210	1210	1230	1230
foundry sand (kg)	-	130	185	-	187
water (kg)	175	175	175	165	165
water/cement (w/c) (-)	0.50	0.50	0.50	0.46	0.46
superplasticizer %	0.75	0.95	1.4	0.95	1.7
slump (mm)	160	130	150	130	120
unit weigth (kg/m^3)	2378	2367	2356	2404	2389
air content (%)	1.8	1.9	1.8	1.5	2.3

Mechanical performance results, related to mortar mixtures at different water-cement ratio, are shown in Fig. (**5**) (see also Table **5**). A mechanical performance decrease can be noted at any UFS dosage; the decrease rate is quite comparable to the replacement amount.

Despite the absolute value of compressive strength, the negative influence ascribed to the presence of UFS in reducing the compressive strength seems greater when lower w/c is adopted.

In order to clarify this assertion, the mechanical performance of mortars at same UFS's rate is compared at three different w/c ratio (0.45, 0.50 and 0.55) in Fig. (**6a**). Although the absolute value of the compressive strength is high at low w/c ratio, as usual, it achieves negligible advantages when w/c is lower than 0.50. Consequently, the strength reduction due to the presence of UFS cannot be simply recovered by lowering the w/c. Therefore, this solution is not suitable below certain values due to the increasing in superplasticizer addition.

Another widen aspect is the binder effect by comparing the effect on compressive strength of UFS replace when cleaned. In Fig. (**6b**) the negative influence of binder in reducing the compressive strength seems upheld. Nevertheless, the complexity in pre-treat the UFS doesn't seem justifies the modest increase in mechanical performances; although the modest increase looks incomplete (see in Fig. **6b**, curves M2 *vs* M2-20c).
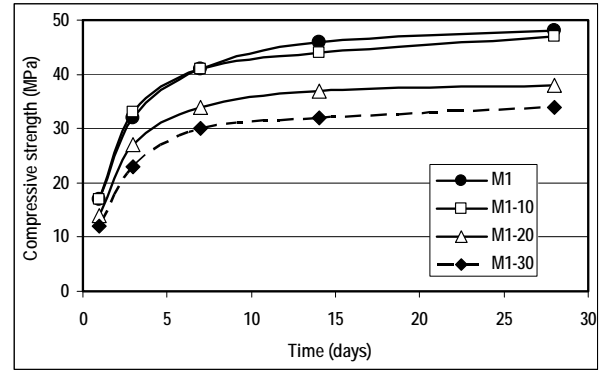

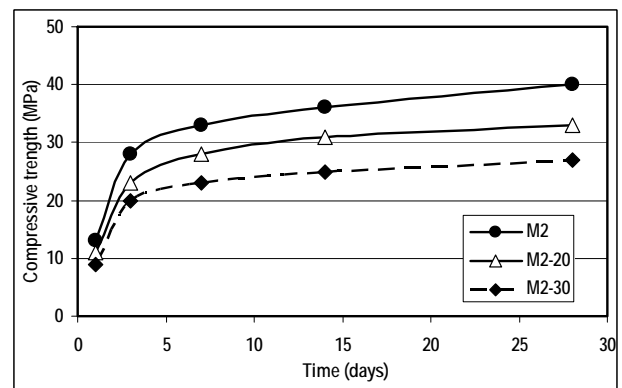**Fig. (5a).** Mortar compressive strength results at w/c=0.50.

Fig. (5b). Mortar compressive strength results at w/c=0.55.

As far as concrete mixtures at different water-cement ratio (0.46, 0.50) it concerns, they are shown on Fig. (**7**) (see also Table **6**). The considerations on compressive strength deduced from mortars can be extended to concretes mixtures, reinforcing previous results. The compressive strength penalization has to be ascribed to the presence of UFS, as partial replacement of natural sand, and depends on the amount introduced in the mixture.

The compressive strength decrease in cementitious materials is due to the presence of binder in foundry sand, as pointed out in [20, 29, 30]. The binder, composed by a very

Table 5. Mortars Compressive Strength (MPa) as a Function of Time (Days)

MIX	M1	M1-10	M1-20	M1-30	M2	M2-20	M2-30	M3
1 day	17	17	14	12	13	11	9	16
3 days	32	33	27	23	28	23	20	27
7 days	41	41	34	30	33	28	23	32
14 days	46	44	37	32	36	31	25	35
28 days	48	47	38	34	40	33	27	36

fine powder of carbon and clay, causes a loose of contacts and links between the cement paste and the aggregate. In particular, in case of carbon's binder, a delay in cement hydration it's also possible. As a matter of fact the compressive strength decreases also at very low curing time (i.e. 1 and 3 days in Tables **5** and **6**). Moreover, as previously pointed out in mortars, despite the absolute value of the compressive strength, the negative influence ascribed to the presence of UFS seems greater in presence of low w/c. In effect, compressive strength of concretes with w/c=0.46 undergoes a heavy penalization of about 30%, instead of about 20% exhibited by concretes with w/c=0.50 (Fig. **7**). Fig. (**7**) states that negligible advantages are achieved when w/c goes under 0.50.
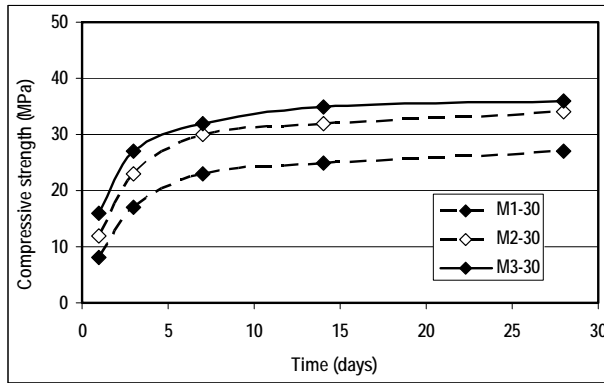

Fig. (6a). Mortar compressive strength at 30% of UFS dosage and different w/c ratio (M1=0.50, M2=0.55, M3=0.45).
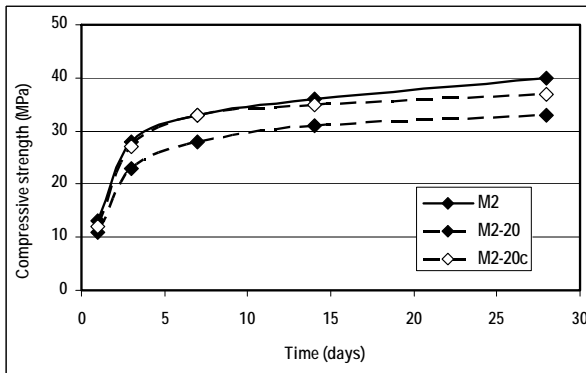

Fig. (6b). Mortar compressive strength at w/c=0.55 and different UFS employ (M2, M2-20, M2-20$_c$).

Table 6.   Concrete Compressive Strength (MPa) as a Function of Time (days)

MIX	C1	C1-7	C1-10	C2	C2-10
1 day	18	16	14	26	17
3 days	31	27	23	34	23
7 days	36	31	27	43	29
14 days	-	-	-	52	36
28 days	45	38	35	56	39

In general, the obtained values – ranging from 35MPa-40MPa – although not so performing, could be considered

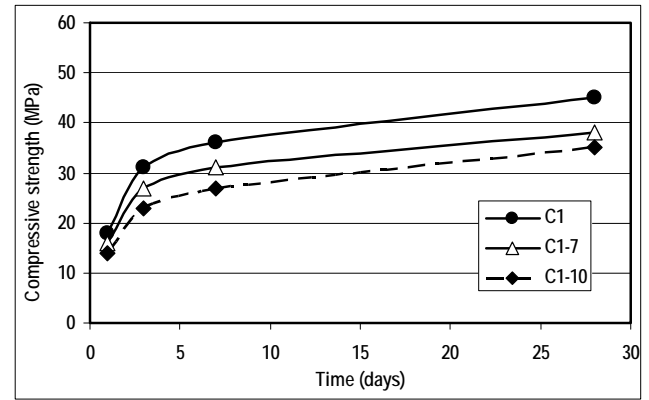acceptable when compared to those of ordinary conglomerates [31].

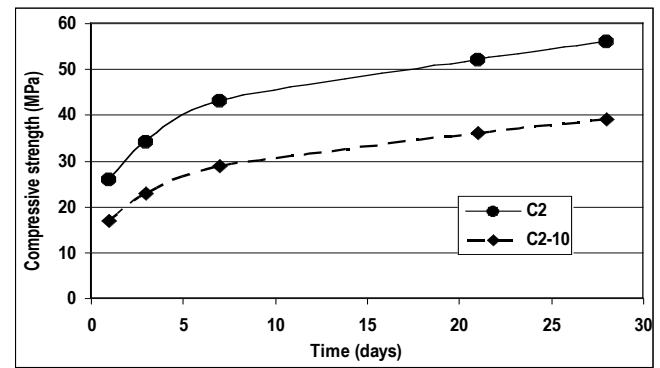**Fig. (7a).** Concrete compressive strength results at w/c=0.50.

Fig. (7b). Concrete compressive strength results at w/c=0.46.

Table **7** shows the dynamic elastic modulus of concretes at 28 days of curing time. Consistent with the compressive strength, the elasticity modulus of concretes with UFS is lower than that of concretes with natural sand. However, differences are very low at that curing time (i.e. 28 days) and don't exceed about 6%. More investigations are needed to justify these poor differences and to establish if they are still confirmed at low curing time (i.e. < 28days). Drying shrinkage results in concretes specimens (Fig. **8**) show, as expected that the contraction (due to water loss) is higher when UFS is present in the mixture instead of natural sand. The shrinkage suffers a moderate increase both at short and long curing time.

The increase in drying shrinkage fits well with the results obtained by compressive tests and elasticity modulus determinations. Generally, several factors can affect concrete shrinkage, including paste porosity, aggregate type and volume, modulus of elasticity. As the present study it concerns, an explanation could be find on a possible delay on the cement hydration due to carbon (graphite) particles and/or a loosening of the link between aggregate and cement paste, as above mentioned.

CONCLUSION

According to the obtained test results, it can be concluded that structural mortar and concrete can be manufactured with UFS as a partial replacement of natural sand. A suitable recycling of the discarded foundry sand as building construction material could be suggested.
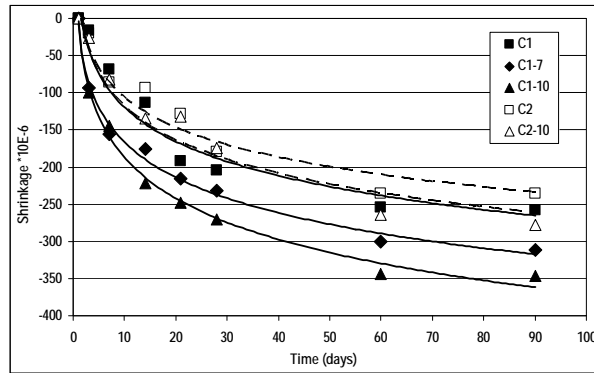
Fig. (8). Concrete drying shrinkage *vs* time results at w/c=0.50 (C1) and w/c=0.46 (C2).

Table 7. Dynamic Elastic Modulus (MPa) of Different Concrete Mixtures at 28 Days of Curing Time

MIX	C1	C1-7	C1-10	C2	C2-10
dynamic elastic modulus	40167	40052	37632	41920	39046

The fresh concrete data shows that all mixtures, containing UFS, require high superplasticizer dosage in order to maintain a good workability. Substantially, UFS addition gives low slump (or slump flow) mainly due to the presence of very fine binders. As far as mechanical performances it concerns, mortars containing UFS at water-cement ratio equal to 0.5 show a compressive strength lower by about 20-30% compared to that of the reference mix. Same percentage could be reached in concrete at the same water cement ratio. The modulus of elasticity doesn't vary significantly; in the highest penalization it is about the 94% of the elastic modulus of the control mix. Drying shrinkage increases with the decrease of mechanical performances.

More investigations are focusing to clarify the influence of UFS on the cement hydration kinetic and on the opportunity to clean UFS from the fine binder.

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