VALUATION OF FOUNDRY SAND IN THE CONSTRUCTION SECTOR

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ABSTRACT

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The purpose of this work is to find out the possibility of valorizing the green foundry sand from the foundry of EPE-ALFE, Tiaret, Algeria in construction. Mortars which are based on this sand were made and their mechanical behavior was evaluated. The first results showed that the strengths of these mortars represent approximately 74% to 80% of the resistance of the control mortar based on quarry sand from Guelta, Algeria, so, the mixture of 30 to 50% of quarry sand with the Foundry green molding sand increases this interval and gives an ordinary mortar with compressive strengths varying between 25 and 30 MPa which allows an extended use of this sand meeting the 206.1 standard of concrete. This solution represents an economic choice in construction which makes it possible to recycle around 50% of the quantity of foundry sand for any concrete production and it will help with the elimination of waste and the rapid release of storage areas at the level of foundries as well meet the requirements of the quality assurance plan.

Keywords: mortar, foundry sand, green sand, strengths, resistance, recycling.

INTRODUCTION

Foundry sand is a high quality silica sand (Eknath et al., 2009). There are two main types of foundry sand: sand at green (often called molding sand) which uses clay as a binding material and chemically bonded sand which uses polymers to bind the grains of sand together (Foundry Industry Recycling Starts Today [FIRST], 2004). Sands at Green are black, or gray, while chemically bound sands are off-white (Kewal et al., 2015). Foundry sand waste consists mainly of silica sand, covered with a thin film of burnt carbon, residues and dust (Dushyant et al. 2013, Jadhav et al. 2017). They are combined with a binder (bentonite, resins, cement, sodium silicate or oils) to make molds and cores for ferrous and non-ferrous molded parts (Eknath et al., 2009, Jadhav et al. 2017, Shyam & Yashwantsinh, 2015). Foundry sand can also contain metal fragments from previous castings when the sand is recycled (Australian

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Government Publishing Service Canberra [AGPSC], 1989). Their particle size distribution is uniform: 85 to 95% of the material between 0.6 and 0.15 mm and about 5-12 to 20% less than 0.075 mm (Chesner et al., 1997; Fawaz et al. 2017; Dominique, 2017), its typical density varies between 2.3 to 2.6 (Fawaz et al. 2017; Dominique, 2017), it has a low absorption capacity and is not plastic (Fawaz et al. 2017). The used properties of foundry sand vary depending on the preparation process (Smyksy et al., 2010), the type of equipment used for processing in foundries, the types of additives (coal powder or sea charcoal, cellulose, iron oxide and water), the number of reuse of sand, the type and the quantity of binder (Dushyant et al. 2013). The pH of foundry sand is around 4 to 12 depending on the binder and the type of metal cast (Craig et al., 2011). Excessive concentrations of respirable free crystalline silica dust during conditioning of the sand for reuse may cause respiratory problems and lung disease (AGPSC, 1989), however, studies of the concentrations of metals in the leachate under a test fragment of foundry sand revealed concentrations comparable to those of natural soils and that the concentrations measured were below the limits (Craig et al., 2011).

In the casting process, the molding sand will be burned, recycled and reused several times, it is the old sand, then it degrades to the point that it can no longer be reused in the casting process and will be rejected in storage areas at the foundry level (Dushyant et al. 2013, Pathariya et al., 2013). So, faced with this situation, it is important to find solutions for their uses and to expeditiously release these storage areas to avoid any contamination and the diseases mentioned above. Among which we can cite the various engineering applications, in particular for the manufacture of materials based on hydraulic binders (concrete, mortar and grout, etc.), roadworks, etc. Foundry sand waste can be used in concrete as a partial or total replacement for fine aggregates (Pathariya et al., 2013; Pathariya et al., 2013; Jadhav et al. 2017) to obtain various sought properties. According to the literature, some sands used have given an economical, light concrete with good resistance (Pathariya et al., 2013), we note here that the result depends on the type of foundry sand used, also, it is mainly used for public works: up to 15% as fine aggregates in hot mixed asphalt pavements (Chesner et al., 1997), a source of high quality silica used in the manufacture of Portland cement, as well as in the manufacture of fiberglass (FIRST, 2004).

Some studies have been discussed in (Sowmya et al., 2015; Kherbache & Bouzidi, 2019) such as: the effect of foundry sand as partial replacement of natural or quarry sand on the strength, ultrasonic pulse velocity, permeability of concrete as well as durability properties of concrete mixtures: it was signed that there is a systematic loss in workability observing the percentage decrease in slump, as the foundry sand content increases. Maria and Lawrence, (2019), used foundry sand as a chemically bonded composite material (polymer resin binder). The results showed that this tested chemically bound foundry sand could replace regular concrete sand fully, giving highly workable mixes with good mechanical properties (compressive, splitting and flexural strengths and static modulus of elasticity) similar to those of mixes with regular concrete sand. Neslihan (Neslihan, 2018) has been successful in making a geopolymer activated by chemical binders (sodium hydroxide: NaOH and sodium silicate: Na2SiO3) material from foundry sand (as a cement less technology) which can be used as a building wall material. Currently, studies are focused on composite materials and many problems have been addressed using non-recycled materials such as: Studies on composite disks: reinforced thermo-elastic disk (Al-Furjan et al. 2020a), hybrids nano-composites disk

(Al-Furjan et al. 2020b), électriquement FG-GPLRC disk (Al-Furjan et al. 2020c); hybrid disk resting on nonlinear elastic foundation (Shariati et al., 2020). Studies on composite beam and plates: SW-CNT reinforced concrete beam resting on elastic-foundation (Bourada et al., 2020), carbon nanotube Single-Walled, double-Walled and Multi-Walled embedded in an elastic medium (Dihaj et al. 2018; Hamidi et al., 2018; Belmahi et al. 2019), CNT-RC beams (Bousahla et al., 2020), micro-composite beam (Alimirzaei, 2019), nanobeam in a polymeric matrix (Belmahi et al. 2018b), functionally graded porous plates (Zine et al.2020), FG-CNTs reinforced composite plate (Tayeb et al., 2020, Zerrouki et al. 2020), sandwich doubly curved nanocomposite panel (Al-Furjan et al., 2020d) and soil-retaining wall system (Bourdim et al.2016).

In Algeria, there are three large foundry companies (ALFEL Foundry of El Harrach, ALFON Foundry of Oran, ALFET Foundry of Tiaret) grouped under the name of the Algerian company: FONDAL Spa Group "National Company of Algerian Foundries", by abbreviation “EPE FONDAL SPA”, ISO 9001-2008 certified (EPE FONDAL Spa, 2018). These latter have been producing and marketing foundry products for over 50 years with a production of more than 18,000 T / year of cast iron and 5,500 T / year of steel in addition to mechanical machining and industrial sheet metal work. In fact, we do not have exact figures on the quantity of foundry sand waste; but this duration of more than fifty years of production, the indicated rates as well as the absence at the present time of a remarkable valuation in Algeria, indicate the importance of stocks of this waste near production units, hence the need to initiate studies and think of effective solutions for their recovery.

Therefore, the aim of this research and thanks to experimental tests consists in particular of collecting and synthesizing data and information on the sand waste of the EPE-ALFE foundry; Tiaret and the find the optimum value in percentage of the quantity of foundry sand which gives a mortar with at least the same mechanical characteristics of a mortar made with quarry sand. So, for a first step, a mortar based on sand at green from the EPE-ALFE foundry Tiaret was manufactured and compared with a control mortar based on quarry sand (Guelta sand). Subsequently, substitutions and mixtures of foundry and quarry sands were studied to find the optimum values of sand at green and the ideal composition with regard to resistance; cost and rate of consumption.

It is clear that our procedure is to directly use the foundry sand as aggregates for mortar or for concrete; contrary to some research works cited (Sayeed, 1992; Eknath et al., 2009; Elizabeth et al., 2010; Dushyant et al. 2013; Kewal et al., 2015; Shyam & Yashwantsinh, 2015; Attar & Gupta, 2016; Jadhav et al. 2017; Fawaz et al. 2017; Belmahi et al., 2018a), which used foundry sand as an addition to improve some physical and mechanical properties.

MATERIALS AND METHODS

Cement

The cement used is a Portland cement of class CEM II / B-L 32.5R, named by CHAMIL, marketed and manufactured by the LAFARGE-Algeria cement plant. Chamil is

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certified in accordance with the Algerian standard NA442-2013, (Institut Algérien de Normalisation [IANOR], 2013) and the European standard EN197-1 (Association française de normalisation [AFNOR], 2013). The setting time was determined using the Vicat device standard EN 196-3 and standards NA 228 and 229 (AFNOR, 2013; IANOR, 2013) which gives two practical marks: the start and the end of setting.

Sands

The sands used are:
Natural sand from the Guelta quarry - Laghouat, Algeria (Figure 1):

Figure 1. Quarry sand used.

sand at green or at clay from the EPE-ALFE foundry, Tiaret (Figure 2): It consists mainly of grains of pure silica (quartz), mixed with a bentonite (1 to 1.5%), mineral black (0.3 to 0.5%) and water. sand at green is widely used for making molds for cast iron parts, called "molding at green".

Figure 2. Sand at green or at the clay (after several uses).

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The main composition in mass percentages of the molding material for sand at green or at the clay is as follows:

- ***Basic sand (old sand)***: around 86 to 97%.
- ***New sand***: New sand is a white sand with the chemical composition indicated in table 1 below:

Table 1. Chemical composition in percent of new sand.

SIO_2	*AL_2O_3*	*Fe_2O_3*	*MgO*	*CaO*	*TiO_2*	*CuO*	*H_2O*	*L.O.I*
98.36	*0.474*	*0.074*	*0.0039*	*0.0138*	*0.317*	*0.0020*	*4.71*	*0.38*

- ***Bentonite:*** Foundry bentonite is a hydraulic binder, delivered in bags of 30 to 45 kg. It is used in the molding of sand at green for the manufacture of foundry molds; it represents a swelling volume of 2g / 100ml and humidity from 10 to 14%.

- ***Mineral black***: Mineral black for foundries is an additive used in the mixture of molding sand at green in order to improve the surface condition of the castings and to avoid the appearance of defects caused by thermal expansion of the silica sand. It represents the following characteristics (Table 2):

Table 2. Characteristics of mineral black for foundries.

Characteristics	**Limit Values**
Volatile matter of humidity	≥ 30%
Shiny carbon	≥ 9%
Sulfur	≤ 0.8%
H2O content	≤ 3.0 %
Refusal on sieve 0.21 mm	0 %
Refusal on sieve 0.21 mm	10 %

Then, these components with the mass percentages indicated above and summarized in table 3, are mixed with water for a preparation time of approximately 7 minutes.

Table 3. Mass percentages of molding material for sand at green.

Components	**Masse (%)**
basic sand (old sand)	86 à 97 %
new sand (quartz)	2 à 3 %
bentonite	(1 à 1.5%)
coal powder (mineral black)	0.3 à 0.5%
water	2 à 5%

The final physical and mechanical characteristics obtained are indicated in table 4.

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Table 4. Physical and mechanical characteristics of Sand at green.

Characteristics	Limit Values
Gas permeability (units)	$100 \leq P \leq 250$
Compressive strength	≥ 0.050 (N/mm^2)
Shear strength	≥ 0.012 (N/mm^2)
Humidity (%)	2.8 – 4.2 %

After several uses, up to three times, this sand will no longer be usable by the EPE-ALFE foundry, Tiaret and will be rejected in the discharge and storage areas in the form of loose and consolidated rock. For our work this sand will be crushed and sieved to return it to a grainy state (Figure 3).

Figure 3. Foundry sand (sand at green) after recycling. A: Sand grinding (Los-Angeles machine), B: Sieving sand.

The sands were identified in accordance with the Algerian IANOR (2013) standard and the European and French standard AFNOR (2013).

• *Particle size analysis (Standard EN933-1)*

The results of the particle size analysis of the two sands are presented in the following figure 4:

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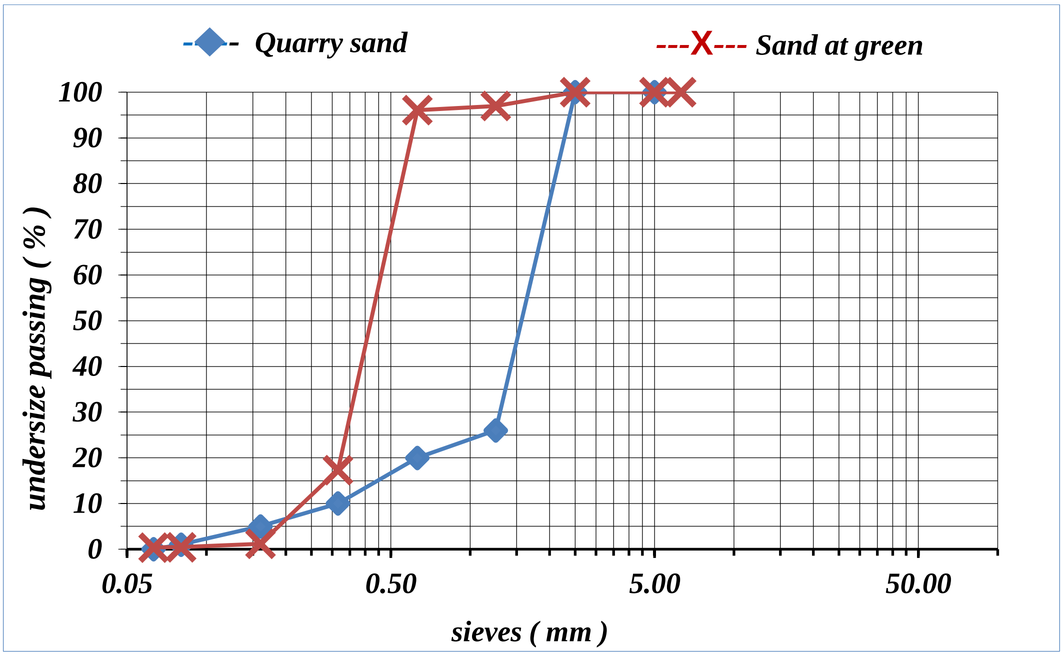

Figure 4. Particle size analysis curves: quarry sand and green sand.

- ***Sand equivalent (EN 933-8 and P 18-598).***

The sand equivalent tests carried out on the two types of sand (quarry and at green) are shown in figure 5.

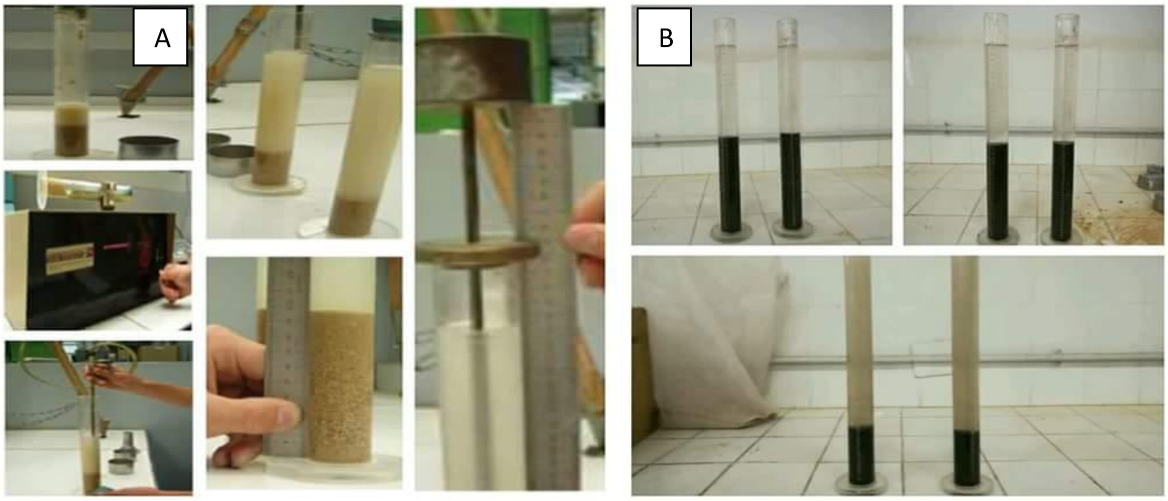

Figure 5. Sand equivalent tests. A: ***Quarry sand, B: Sand at green***

- ***Sand pH***

The Hydrogen potential (pH) expresses the degree of acidity or alkalinity of a medium (solid material or solution) on a scale of 1 to 14. A neutral and well balanced medium has a pH equal to 7, a pH lower than 7, characterizes an acid medium, whereas a pH higher than 7,

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indicates a basic medium containing limestone. The test carried out and the device for measuring the pH is corresponding to figure 6.

Figure 6. Apparatus for measuring the pH of sand.

Thus, the results of the characterization and analysis of the sands used are summarized in the following table 5:

Table 5. Characteristics of the sands used.

Essais et mesures	Quarry sand	Sand at green
Granular class (d/D)	0/4	0/0.8
Apparent density (Kg/m^3)	1455	1405
Absolute density (Kg/m^3)	2500	2500
Sand equivalent	76,18	100 % (H2=H1)
Fineness module fM	2.34	2.09
Bulking water content	4%	not measured
pH	not measured	6.72

We notice in table 5 that the quarry sand with a fineness module equal to 2.34 is a bit coarse sand, of a granular class (d / D = 0/4 mm). It is a clean sand (ES = 76.18%) with the presence of a low percentage of clayey materials, it is perfectly suitable for making quality mortar or concrete. Its optimal water content of expansion is 4%. It meets the requirements of standard EN 12620 (2003, aggregate for concrete.)

Foundry sand at green has an apparent density of around 1404 Kg /m^3 and an absolute density of 2500 Kg /m^3, these are normalized values. The modulus of fineness equal to 2.11, which corresponds to a sand with a majority of fine grains. The equivalent of sand is a little difficult to measure given the black color of the sand (H1 = H2) which corresponds to an ES value equal to 100%. This result is contradictory with standard NF EN 933-8 which indicates that for ES = 100% corresponds to a total absence of clayey materials, but actually the mixture contains bentonite which itself contains clay which cannot be burnt during molding due to its heat resistance.

Mixing water (Standard en 1008)

This is the amount of total water added to the dry mortar mixture. It is necessary for the hydration of the binder, the wetting of the aggregates facilitates the placement of the mortar or concrete (AFNOR, 2013). The water used in this work is drinking water from the city of Tiaret. The chemical result of this mixing water is summarized in table 6.

Table 6. Composition of the mixing water (mg/l).

Components	Cl^-	NO_3^-	Zn^{+2}	SO_3^{-6}	pH
Values	75	0	0	0	7

The dosages of water and cement are two important factors. Indeed, workability and resistance are greatly affected by these two parameters. More the W/C ratio is high; more the workability will be high. The most often used average E/C mass ratio is around 0.50, it gives a concrete of good workability while retaining their strengths.

Concrete Admixture (En 480-15)

Concrete admixture used is the type of P Plastocrete 160, is a non-colored synthetic plasticizer, with a dosage of 0.2 to 0.35% of the weight of the binder or cement (i.e. approximately 0.20 to 0.34 liter per 100 kg of cement) allows hydration more complete grains of cement which leads to a gain and an increase in mechanical resistance from a young age, better hydration of the cement and decreases the capillary absorption by its deflocculation effect (AFNOR, 2013). Their properties are summarized in table 7 below:

Table 7. Characteristics of the Plastocrete 160 Concrete admixture.

Properties	Values
Aspect	Liquide
Color	non coloré
Density	1,02 ± 0,01
dry extract	8.5 ± 1%
pH	5 à 6
Chloride content	1g/l

It is recommended to add the admixture in the concrete or mortar, after 50 to 70% of the mixing water has already been introduced into the mixer tank.

METHODS

Preparation and characterization of mortars

The prepared mortars are of the type (1/2: one mass of cement / two masses of sand).
We started by the making of two witness or reference mortars:

- The first is made from Guelta quarry sand, cement, water and admixture.
- The second consists of the glass molding sand, cement, water and admixture.

Then, we gradually carried out mixtures of the sands as follows:

- 70% sand at green and 30% quarry sand,
- 50% sand at green and 50% quarry sand

Whose purpose is to keep a consumption or considerable use of foundry sand to free up storage and depot areas? Indeed, a percentage of glass sand less than 50% is not advantageous for this study vis-à-vis the low consumption.

The final compositions are summarized in table 8 below:

Table 8. Selected compositions.

Mortars/ components	Cement (g)	Sand at green(g)	Quarry Sand (g)	Water (g)	Concrete admixture (g)
100% of quarry sand (witness)	675	//	1350	337.5	2.02
100% sand at green	675	1350	//	337.5	2.02
30% quarry sand	675	945	405	337.5	2.02
50% quarry sand	675	675	675	337.5	2.02

Mechanical tests

The mechanical behavior of sand at green mortars has been studied in order to better show the margin of its use and its recycling in the construction. Table 9 summarizes the different results of the two mechanical tensile and compression tests.

Table 9. Results of the flexural and compressive strengths of different mortars made up.

Mortars/ Strengths	Tensile strength (MPa)	compressive strength (MPa)
100% of quarry sand (witness)	6	31
100% sand at green	4,8	23
70% sand at green, 30% quarry sand	5,3	25
50 % sand at green, 50% quarry sand	5,7	28

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According to Table 9, the compressive strength of the control mortar produced by Geultat quarry sand has been estimated at 31 MPa and the tensile strength at 6 MPa. These results are satisfactory and can be used in various exposure classes according to standard EN 206.1 (AFNOR, 2013): (X0: no risk of corrosion attacking: (protected non-reinforced or weakly reinforced concrete); XC1 / XC2: reinforced concrete, risk of corrosion by carbonation (Protected concrete and permanently dry or humid environment), XF1 and XF2: (zone of weak or moderate frost without or with de-icing agent).

The comparison of the results has been visualized in figure 7 below:

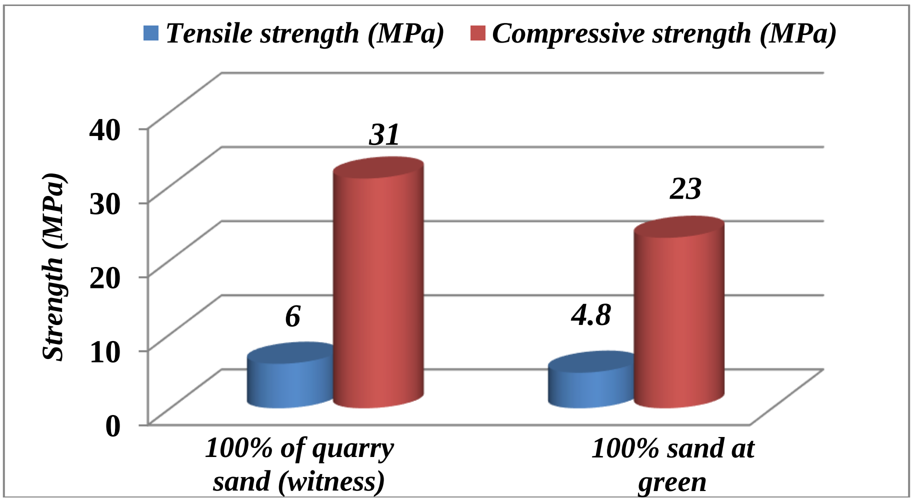

Figure 7. Comparison: mortar based on foundry sand at green and mortar based on quarry sand.

According to figure 7, the strengths of the foundry sand at green molding sand mortars (EPE-ALFE. Tiaret) are estimated at averages of 23 MPa for compression and 4.8 MPa for traction. We note that these results are moderately weak and that our sand at green mortar represents only about 74% of the compressive strength and about 80% of the tensile strength of quarry sand mortar.

So, we can say that the use of sand at green from the foundry (EPE-ALFE. Tiaret) will be limited to the manufacture and construction of elements that do not require great resistance, for example the case of plasters, mortar mounting; ground platforms; decorative elements and lintels.

To increase the resistance and have an acceptable use and consumption of foundry sand at green as indicated in the objective of this work, we mixed the latter with quarry sand which is itself inexpensive due to the manufacturing costs and transportation. The substitution was made by replacing foundry sand at green with quarry sand in parts of 30% and 50%. Above 50%, the objective will be completely different and the study will not be really advantageous given the low consumption of foundry sand in the mixture.

After the substitutions, the strengths of the mortars have been considerably increased, as shown in figure 8 that:

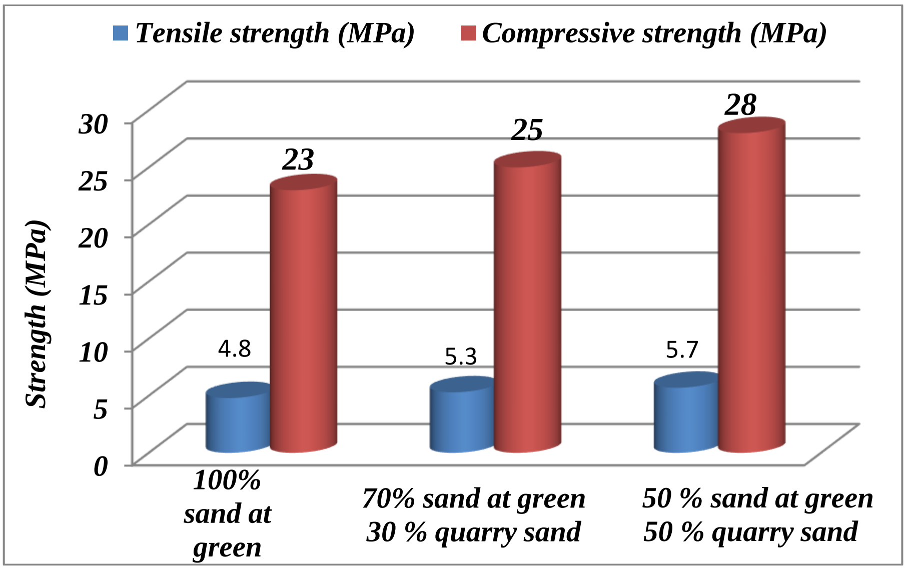

Figure 8. The compressive and tensile strength of foundry sand mortars and mortars substituted by quarry sand.

Mixing 30% quarry sand with 70% of sand at green improves the strength of sand at green mortars to around 10% (from 4.8 to 5.3 MPa) for Tensile strength and from about 9% (from 23 to 25 MPa) for compressive strength. This made it possible to widen the use of sand at green in the construction of resistance elements according to standard 206-1, such as columns, foundations and beams which do not support large loads (house or building with number of floors limited or semi-collective accommodation).

The addition of 30% to 50% of quarry sand further increases the strength of molded sand mortars to around 8% (5.3 to 5.7 MPa) for Tensile strength and 12% (25 to 28 MPa) for compressive strength.

In some works in the literature, the strengths of concrete obtained with other types and quality of foundry sands are greater than those made with quarry sand and the best values have been obtained for a replacement of natural sand by foundry of approximately 20% (Sowmya & Chaitanya Kumar, 2015), 25% (Kherbache & Bouzidi, 2019) and 30% (Maria & Lawrence, 2019).

In this case, we can say that the solution is always economical, for example: the quantity of quarry sand for a construction project will be reduced to half the quantity provided for in the calculation and the other half will be replaced by the foundry sand at green which has a lower price.

CONCLUSION

From this purely experimental work; we conclude that the use of foundry sand at green (EPE-ALFE. Tiaret) alone in the mixture will not be advantageous for the resistances and will

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be limited to the manufacture and the construction of elements which do not require large resistances; such as; for example; coating; decorative elements and lintels. So; replacing 30% to 50% foundry sand with quality quarry sand will be the ideal solution to obtain the minimum strength required by standard 206-1. It should also be noted that the use of 50% foundry sand in the mortar or concrete mixture will help with the elimination of waste and the rapid release of storage areas to avoid all costs and dangerous effects on the environment. Thus meet the requirements of the quality assurance plan.

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