Strength performance of mortar with artificial sands

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Abstract: Natural sands exploited from alluvial deposits are commonly used for making mortar. However, this extraction activity has been the cause of several negative impacts on the environment. Erosion processes associated with sand dredging from alluvial plains and channels have forced Brazilian environmental offices to forbid sand extraction, mainly near urban centres. As a consequence, the price of sands to be used in civil construction has continuously grown since the producers are being pushed away from cities' neighbourhoods and transportation has a strong influence over final sand prices.

On the other hand, quarries producing coarse aggregate have generated considerable volumes of inert residues derived from rock crushing activities. It is characterized by a fine material lower than 4.8 mm in diameter and that is often disposed on stockpiles. These residues can sometimes be easily eroded and deposited in channels causing flooding.

Modern environmental management systems prescribe a non-generation of residues. However, if technological processes do not permit this achievement, then some form of waste re-use is required.

Artificial sands derived from crushing of four different rock types and other two natural alluvial sands were sampled and characterized from a geological point of view. Specimens of mortar were prepared using all these sands and unconfined compressive strengths were measured after 7, 14 and 28 days of hardening. Specimens prepared with artificial sands produced a better performance than those made with alluvial sands. This finding suggests that artificial sands could potentially replace natural sands.

Résumé: Les sables naturels exploités des alluvions, sont utilisés dans la production de mortiers. Malheureusement, cette exploitation a été la cause de plusieurs impacts négatifs sur l'environnement. L'érosion associée au dragage du sable des plaines et canaux fluviaux, a amené les services Brésiliens pour l'environnement, à interdire l'extraction de sables, principalement aux environs des centres urbains. Comme conséquence, les prix des sables utilisés dans la construction civile ont continué d'augmenter, parce que les producteurs sont poussés hors du voisinage des villes, alors que le transport a une forte influence sur les prix finaux des sables.

D'autre part, les carrières qui produisent les agrégats grossiers ont généré des volumes considérables de résidus inertes, dérivant du concassage des roches. Ces résidus sont caractérisés par des matériaux fins qui ont moins de 4,8 mm de diamètre et qui sont souvent déposés en tas. Ces résidus peuvent être parfois, facilement érodés et déposés dans les canaux fluviaux, entraînant des inondations.

Les systèmes modernes de gestion de l'environnement, imposent la non-génération de résidus. Mais, si les techniques de productions ne permettent pas d'atteindre cet objectif, alors une certaine réutilisation des déchets est requise.

Des sables artificiels dérivés du concassage de quatre types de roches différentes et deux autres sables naturels d'alluvions ont été échantillonnés et caractérisés d'un point de vue géologique. Des échantillons de mortiers ont été préparés en utilisant tous ces sables, et leurs résistances en compression simple ont été obtenues après 7, 14 et 28 jours d'endurcissement. Les échantillons a base de sables artificiels ont produit une meilleur performance que ceux a base de sables d'alluvions. Ces résultats suggèrent que les sables artificiels peuvent potentiellement remplacer les sables naturels.

Keywords: aggregate, geomaterials, mechanical properties, quarries.

INTRODUCTION

The aggregate production for civil construction is one of the biggest industries in the world. In the United States alone the per capita consumption reached around 7.5 tons in the year 2000. In Europe the value was 8.0 tons in the same period (Valverde 2001). The total Brazilian production of aggregates was close to 320.4 million of tons only in 2003.

In spite of its great economic and social importance, the activity of coarse aggregate production is potentially a waste generator in Brazil. The reasons for that are related to the domestic industry profile, whose techniques are rudimental and inappropriate. As a consequence, fines generating crushing procedures are almost unavoidable.

Natural sands exploited from alluvial deposits are commonly used in civil construction. However, this extraction activity has been the cause of several negative impacts on the environment. Erosion processes associated with sand dredging from alluvial plains and channels have forced Brazilian environmental offices to forbid sand extraction, mainly near the urban centres. As a consequence, the price of sands to be used in civil construction has continuously grown since the producers are being pushed away from cities' neighbourhoods and transportation has a strong influence over final sand prices.

On the other hand, quarries producing coarse aggregate have generated considerable volumes of inert residues derived from rock crushing activities. It is characterized by fine material less than 4.8 mm in particle diameter and that is often disposed on stockpiles. These residues can sometimes be easily eroded and deposited in channels causing flooding.

Modern environmental management systems prescribe a non-generation of residues. However, if technological processes do not permit this achievement, then some form of waste re-use is required.

Artificial sands derived from crushing of four different rock types and another two natural alluvial sands were sampled and characterized from a geological point of view. Specimens of mortar were prepared using all these sands and unconfined compressive strengths were measured after 7, 14 and 28 days of hardening. Specimens prepared with artificial sands produced a better performance than those made with alluvial sands. This finding suggests that artificial sands could potentially replace natural sands.

OBJECTIVES

The purpose of this paper is to compare the performance of mortars made with natural fluvial sands and mortars with those made with sands derived from rock crushing. Taking into account that artificial sand properties are extremely dependent on characteristics of parental rock (mineralogy, chemical composition and physical properties), besides the rock crushing process, a special attention was given to geological features of lithological types used to produce sands. Petrography, X-ray diffraction, conventional particle size distribution and laser diffraction analysis for the powder fraction (diameter lesser than 0.075 mm) were the analytical techniques applied for the purpose of materials characterization. For this research two fluvial sands and five artificial ones were used. From a mechanical point of view, specimens of mortar were prepared using all these sands and unconfined compressive strength were measured after 7, 14 and 28 days of hardening.

GEOLOGICAL CHARACTERIZATION

The fluvial sands were sampled in the Paraíba do Sul river, in the vicinity of Campos dos Goytacazes City. The artificial sands were produced from the following rock types: (a) charnockite, (b) porphyroblastic gneiss 1, (c) porphyroblastic gneiss 2, (d) garnet gneiss, (e) granitic gneiss and (f) nepheline syenite.

Binocular Microscope

All sand types were analysed under a binocular microscope. In each case, the particle roundness and sphericity were recorded and classified according Pettijohn (1973). The results are presented in the Table 1.

Table 1. Roundness and sphericity (Pettijohn, 1973) of fluvial and artificial sands.

Aggregates	Roundnesss	Sphericity
Fluvial Sand 1	subrounded to subangular	low
Fluvial Sand 2	subangular to angular	low
Charnockite	angular to very angular	low
Porphyroblastic Gneiss 1	angular to very angular	high to low
Porphyroblastic Gneiss 2	Angular	low
Garnet Gneiss	angular to very angular	high to low
Granitic Gneiss	angular to very angular	low
Nepheline-syenite	angular	low

As expected, the natural sand grains are more rounded than the grains produced by rock crushing. Referring to sphericity, almost all sands have low sphericity grains. Only the Porphyroblastic Gneiss 1 and the Garnet Gneiss have highly spherical grains. This fact should be related to the mineral characteristics and to rock processing, including extraction and comminution.

Grain shape has an important influence on the workability and strength of mortar. The greater the amount of angular particles, the higher is the water volume necessary to lubricate the grains and as a consequence it can result in a porous mortar.

Petrographic Microscope

Samples of studied rocks were collected directly from quarries and thin-sections were prepared and analysed. The method applied was transmitted light microscopy and digital images were acquired. The main purposes were to investigate the mineral weathering features and the presence and distribution of microcracks. Such characteristics are considered of relevance when the aggregates are to be used in civil construction. The results are described in Tables 2 to 6. The fabric of each studied rock is illustrated in Figure 1.

Table 2. Charnockite data.

Mineralogy	Plagioclase (46%), Quartz (33%), Orthopyroxene (11%), Alkali-feldspar (4%), Biotite (3%) & Opaques (3%).
Description	In a general sense, the mineral grains have few microcracks filled with iron oxide. It is possible to notice a slight discoloration on the surfaces of biotite grains. Changing from biotites and orthopyroxenes into chlorite occur sparsely. No other weathering aspects could be observed.
Positive Aspects	•Grain surfaces have no signs of intense weathering. •Microcracks present on mineral surfaces are filled.
Negative Aspects	•Sparse grains of biotites and orthpyroxenes changing into chlorites.

Table 3. Porphyroblastic gneiss 1 data.

Mineralogy	• Thin section 1: Quartz (59%), Alkali-feldspar (17%), Plagioclase (12%) and Biotite (12%). • Thin section 2: Alkali-feldspar (39%), Quartz (25%), Plagioclase (19%) and Biotite (17%). • Thin section 3: Quartz (60%), Plagioclase (16%), Biotite (14%) and Alkali-feldspar (7%)
Description	Slight signs of weathering on mineral surfaces. Biotite grains show discoloration on its surfaces and isolated grains transformed into chlorites. Feldspars have saussurites distributed over its surfaces. Alkali-feldspars and plagioclase have intragranular microcracks filled with iron oxide. Mineral orientations and recrystallization were observed.
Positive Aspects	• Mineral microcracks are filled with iron oxide. • All mineral surfaces with only sparse signs of weathering, with the exception of plagioclase.
Negative Aspects	• Mineral orientation can impose anisotropy and affect the form of aggregates. • Minerals changing from biotites into chlorites and from feldspar into saussurites.

Table 4. Porphyroblastic gneiss 2 data.

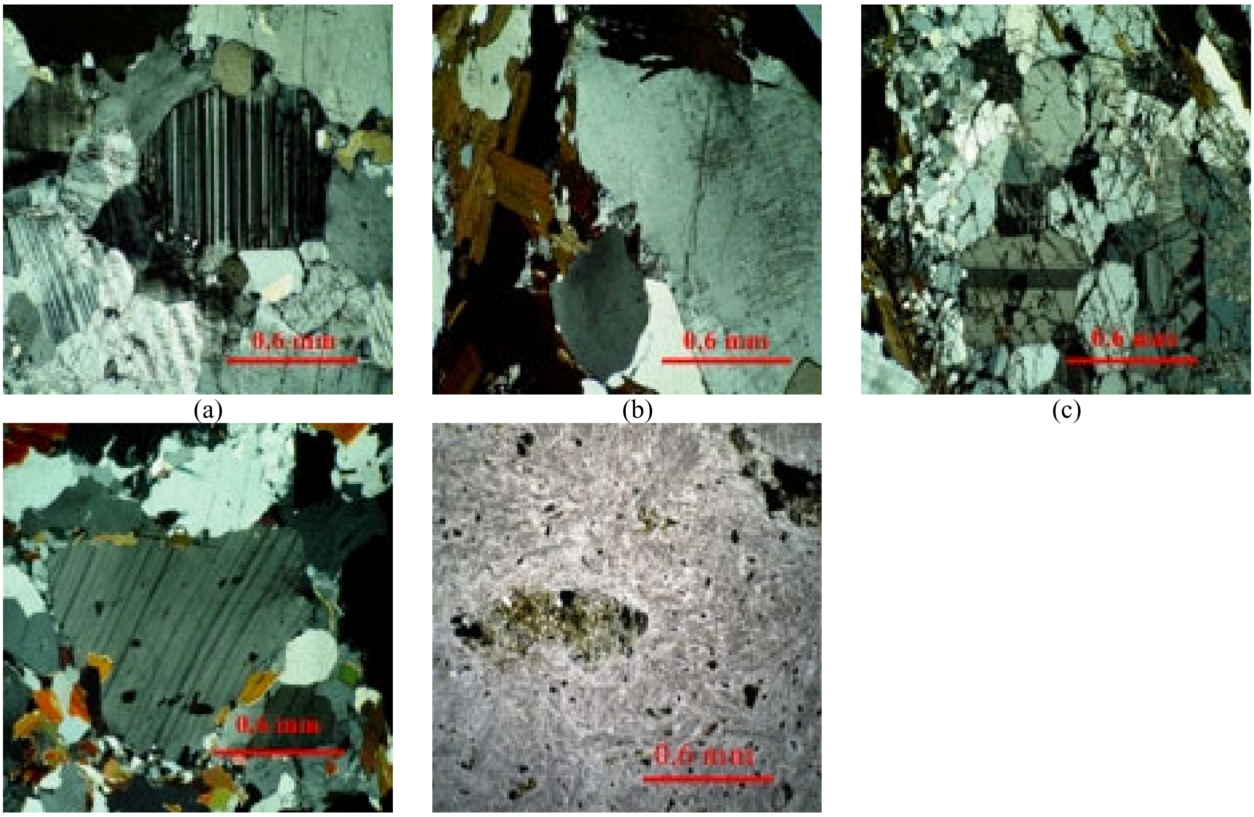
Mineralogy	• Thin section 1: Quartz (57%), Plagioclase (23%), Alkali-feldspar (12%), Biotite (7%) & Opaque Minerals(1%); • Thin section 2: Quartz (37%), Plagioclase (33%), Alkali-feldspar (12%), Biotite (17%) & Opaque Minerals (1%)
Description	Feldspar and plagioclase grains have cleavage traces conspicuously marked and microcracks filled with iron oxide. Rock alteration can be noticed by edge discoloration of biotite and the great amount changing from biotite into chlorite. There are evidences of mineral orientation and coexistence between metamorphic and magmatic textures.
Positive Aspects	• Microcracks are filled with iron oxide.
Negative Aspects	• The strong cleavage on feldspar grains tend to weaken mineral grains. • Bands of mineral orientation. • The weathering of biotites.

Table 5. Garnet gneiss data.

Mineralogy	Quartz (60%), Plagioclase (21%), Garnet (15%), Biotite (3%), Alkali-feldspar (1%) & Opaques (1%).
Description	The grains are fresh and with no evidence of weathering features. Only a very diffuse discoloration is observed on the edges of biotite grains. The intragranular garnet microcracks are filled with iron oxide.
Positive Aspects	• Mineral surfaces are clean and free of microcracks. • Microcracks present in the garnets are filled.
Negative Aspects	Absent.

Table 6. Nepheline syenite data.

Mineralogy	Alkali-feldspar (77%), Nepheline (16%), Clinopyroxene (3%) & Opaques (4%).
Description	The rock is composed of microphaneritic agglomerations of feldspar grains in a trachytic texture, in which are widespread fresh porphyry grains of feldspar and nepheline, besides opaques and weathered pyroxene grains.
Positive Aspects	• Porphyry grains are fresh and the microphaneritic matrix is very homegeneous.
Negative Aspects	• Weathered clinopyroxenes.



(a) (b) (c)

(d) (f)

Figure 1. Rock types used to produce fine aggregate by crushing: (a) charnockite, (b) porphyroblastic gneiss 1, (c) porphyroblastic gneiss 2, (d) garnet gneiss and (e) nepheline syenite.

The petrographic examinations indicate the presence of alteration minerals like saussurites, chlorites and carbonates in most part of the rocks and conspicuously in Porphyroblastic Gneiss 1, Porphyroblastic Gneiss 2 and Nepheline-Syenite. Those minerals have probably been generated by both weathering and hydro-thermal processes. In addition, they commonly fill microcracks inside the grains, whose presence indicates mechanically weakened surfaces that can affect the mortar strength properties. Thin-sections of Garnet Gneiss show no mineral alteration. It should be mentioned that it was not possible to prepare and study thin sections of Granitic Gneiss. In spite of this problem, grains observed under binocular microscope seemed to be very fresh.

One fact should be emphasized among the results of microscope analysis: the amount of mica present in each sand studied. According to Smith & Collis (1993), “the decreased bulk density of a micaceous aggregate will mean a lower weight of aggregate will be required to make up a certain volume of water but more cement paste will be required to fill the voids and coat the particles. The increased water absorption of the mica will mean that water requirement of the mix will increase. Furthermore, the increase in water requirement of the mix with the mica as a result of water being used to spread the cement paste further over the increased surface area of the particles and into the increased void space, will produce a diluted cement paste and a weakened mortar”.

In this context, it was verified that both porphyroblastic gneisses have amounts of biotite greater than 10%, whereas all the other rock types have less than 3% of biotite.

X Ray Diffraction Analysis

A dry mass of 50 g material finer than 0.075 mm in diameter was taken from each sample of sand. Ten millilitres of NaOH were added to the sand and the mixture was then shaken and left to rest for 24 hours. After this period a vigorous agitation was applied to the mixtures for 5 minutes. The material was then sieved and the clay fraction was collected from the passant.

Specimens of clay were prepared in natural state, saturated in an ethylene glycol atmosphere and heated to 550ºC. The intention was identify the presence of any secondary minerals produced by weathering that could eventually be harmful to the mortars. Mineral identification was processed with the aid of a mineral powder x-ray diffraction chart (JCPDS,1980). X-ray diffracion results are shown in Table 7.

Table 7. X-ray diffraction results of clay fraction.

Agreggates	Minerals Identified in the Clay Size Fraction						
	Primary Minerals			**Secondary Minerals**			
	Feldspars	Mica	Quartz	Kaolinite	Mica/Illite	Smectite	Gibbsite
Fluvial Sand 1		X		X			
Fluvial Sand 2		X		X	X		X
Charnockite	X		X	X	X	X	
Porphyroblastic Gneiss 1	X	X		X		X	
Porphyroblastic Gneiss 2	X	X		X		X	
Garnet gneiss	X	X	X	X	X		
Granitic gneiss	X	X	X	X	X		
Nepheline-syenite	X		X	X	X	X	

The X-ray diffraction analysis showed the presence of kaolinite in all sands and gibbsite in Fluvial Sand 2. More problematic than those secondary minerals is the presence of illite and smectite because of their swelling properties. It should be noted that these were not quantitative X-ray diffraction analyses, but eventually high amounts of illite and smectite in the mix can restrict the use of mortar on external environments. The possibility of wetting and drying cycles can produce fractures in the mortar that will lead to weakening.

PARTICLE SIZE DISTRIBUTION OF SANDS

This analysis was carried out with the following series of sieves: 0.075 mm; 0.150 mm; 0.300 mm; 0.600 mm; 1.2 mm and 2.4 mm. Test procedures were based on that prescribed by the Brazilian Technical Standard Association (ABNT) – NBR 7217 (ABNT, 1987). Figure 2 shows the particle size distribution of sands.

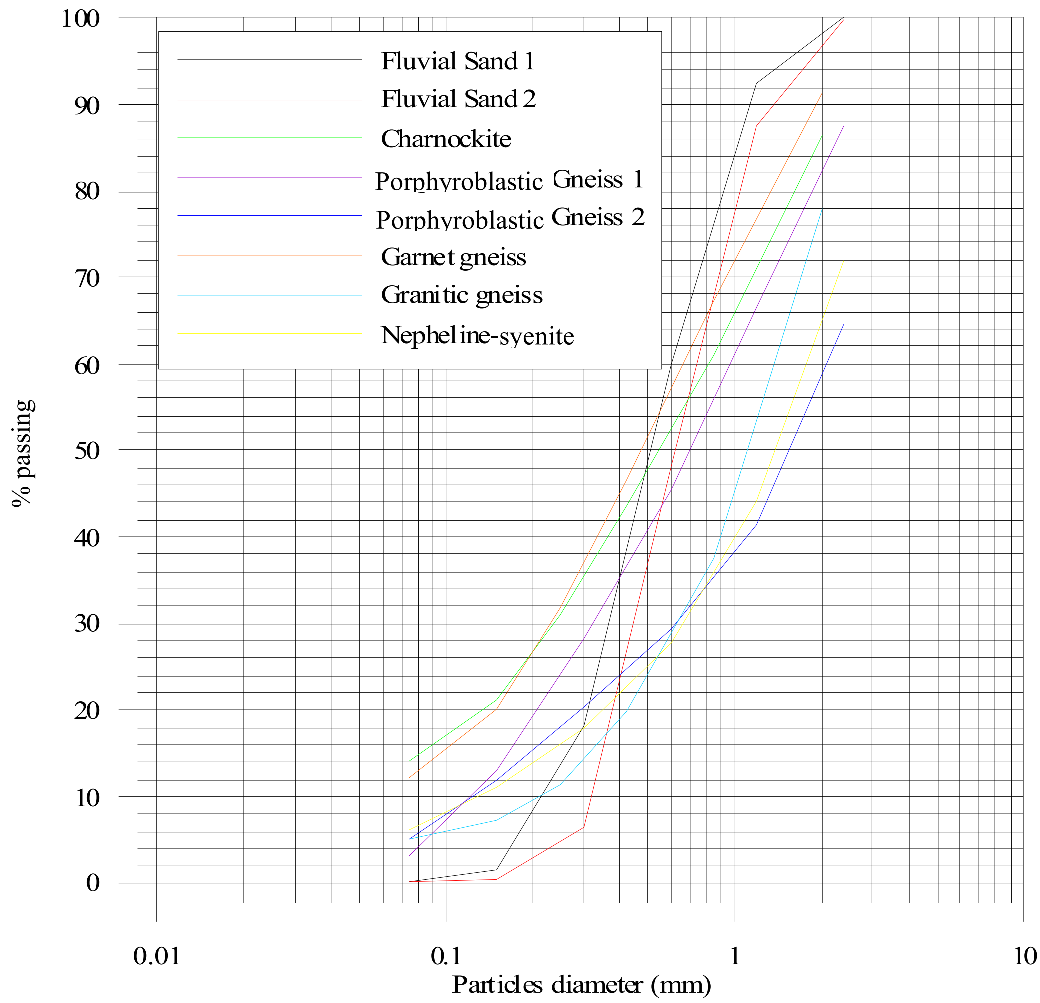


Figure 2. Particle size distribution curves of sands.

It can be seen from Figure 2 that the natural sands have a more homogeneous distribution of grain sizes (better sorted), whereas the artificial sands are well graded, meaning the presence of all sizes in the the distribution. It is well known that a well graded size distribution allows for a better filling of void spaces among coarse aggregates. It contributes to increasing strength of mortar and to the reduction of Portland cement to be used.

The particle size distribution of material finer than 0.075 mm was analysed using a laser diffraction technique. Results are shown in Figure 3.

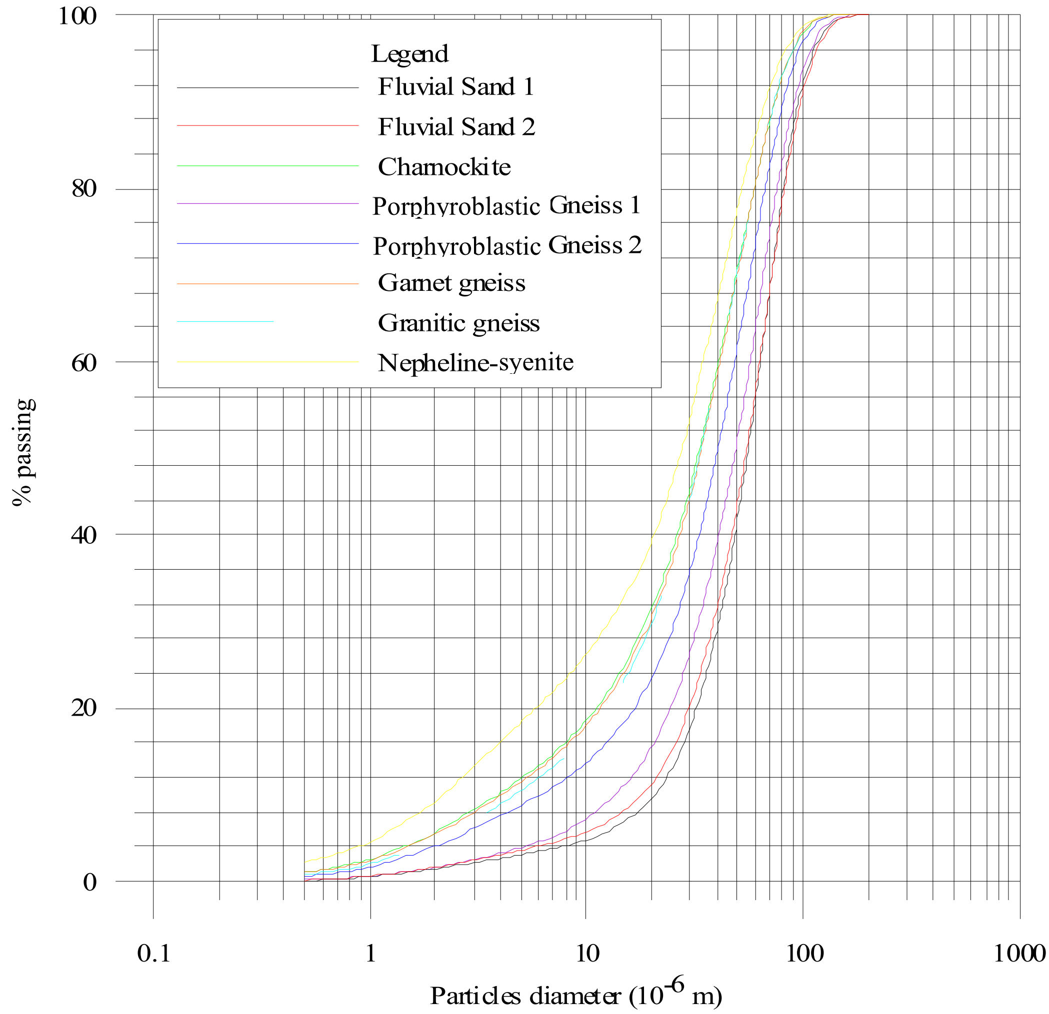


Figure 3. Particle size distribution of material finer than 0,075 mm.

The particle size distribution of particles smaller than 0.075 mm affects the workability of mortars (Smith & Collis, 1993). The presence of fines tends to make the mortar mixture more workable and also provide an easy final completion of mortar surfaces (McIntosh,1970). However, fines in excess can reduce the mixture consistence and then the workability.

It can observed that both fluvial sands have similar particle size distribution. This fact should be related to its geographical proximity in the same river channel and the same sedimentary process as a consequence. Some similarity is also observed among charnockite, garnet gneiss and granitic gneiss grading curves. The reasons may be related to textural features of those rocks, mainly a weak intrinsic anisotropy of their fabrics. Another possible explanation for this similarity may be related to the resemblance among crushing plants, however this possibility was not investigated.

Sands with similar particle size distribution could be used to evaluate the role played particles smaller than 0.075mm

BULK DENSITY IN THE LOOSE STATE

The test was carried out according NBR 7251 (ABNT, 1982) and the results are shown in Table 8. It should be noted that bulk density of the Porphyroblastic Gneiss 1 was determined with and without the material smaller than 0.075mm. The intention was verify the role played by the fines on the strength of mortars.

Table 8. Unit mass in loose state for sands studied.

Aggregate	Unit Mass (kg/dm³)
Fluvial Sand 1	1.50
Fluvial Sand 2	1.47
Charnockite	1.68
Porphyroblastic Gneiss 1*	1.50
Porphyroblastic Gneiss 1†	1,54
Porphyroblastic Gneiss 2	1.59
Garnet gneiss	1.75
Granitic gneiss	1.62
Nepheline-syenite	1.67

* With fines.
† Without fines.

SLUMP TESTS AND MORTAR MIXES

In order to compare the performances of natural and artificial sands, mortars were prepared according to the Brazilian suggested method NBR 13276 (ABNT, 2002) and observing a cement:sand volume ratio of 1:6 that was later converted to mass ratio according the unit mass of each sand presented in Table 8.

UNCONFINED COMPRESSIVE STRENGTH OF MORTARS

Mechanical tests were performed in accordance with procedures prescribed by NBR 13279 (ABNT, 1995), which suggests a 0.25 ± 0.05 MPa/s loading rate. Prepared specimens were tested after 7, 14 and 28 days of hardening. Four specimens of mortar were prepared for each sand for each hardening time. In total, 108 specimens were tested. The average strength values are presented in Table 9 and illustrated in Figure 4.

Table 9. Average strength values of mortars.

Aggregate	**Average Strength (MPa)**		
	7 days	14 days	28 days
Fluvial Sand 1	0.2	0.2	0.4
Fluvial Sand 2	0.3	0.4	0.4
Charnockite	2.8	3.9	4.7
Porphyroblastic Gneiss 1*	1.6	1.9	2.9
Porphyroblastic Gneiss 1†	1.0	1.3	2.1
Porphyroblastic Gneiss 2	2.3	3.2	4.3
Garnet gneiss	2.7	3.5	4.3
Granitic gneiss	2.3	3.6	4.2
Nepheline-syenite	1.4	2.1	3.0

* With fines.
† Without fines.

Observing results from Table 9, it is possible to assess the influence of material with diameter smaller than 0.075mm. Mortars prepared with Porphyroblastic Gneiss 1 without the presence of fine particles (†) showed a slightly lower unconfined compressive strength when compared with mortars prepared with the same sand and with fine particles (*). The lack of fine particles is also noticeable a characteristic of fluvial sands that presented very low unconfined compressive strength values. Mortars prepared with sands containing percentages of fine particles greater than 5% (Charnockite, Garnet Gneiss, Porphyroblastic Gneiss 2 and Granitic Gneiss) had higher strength average values.

CONCLUSIONS

The better performance of sands derived from rock crushing when compared with fluvial sands can be explained by following reasons: (i) continuous particle size distributions that allow a better void filling and a mortar preparation with lower volumes of cement that add economic benefits to the work and (ii) the presence of particles smaller than 0.075 mm in diameter is one of the factors that contributes to an adequate workability. These two features explain the higher unconfined compressive strength data that were recorded by mortars prepared with manufactured sand.

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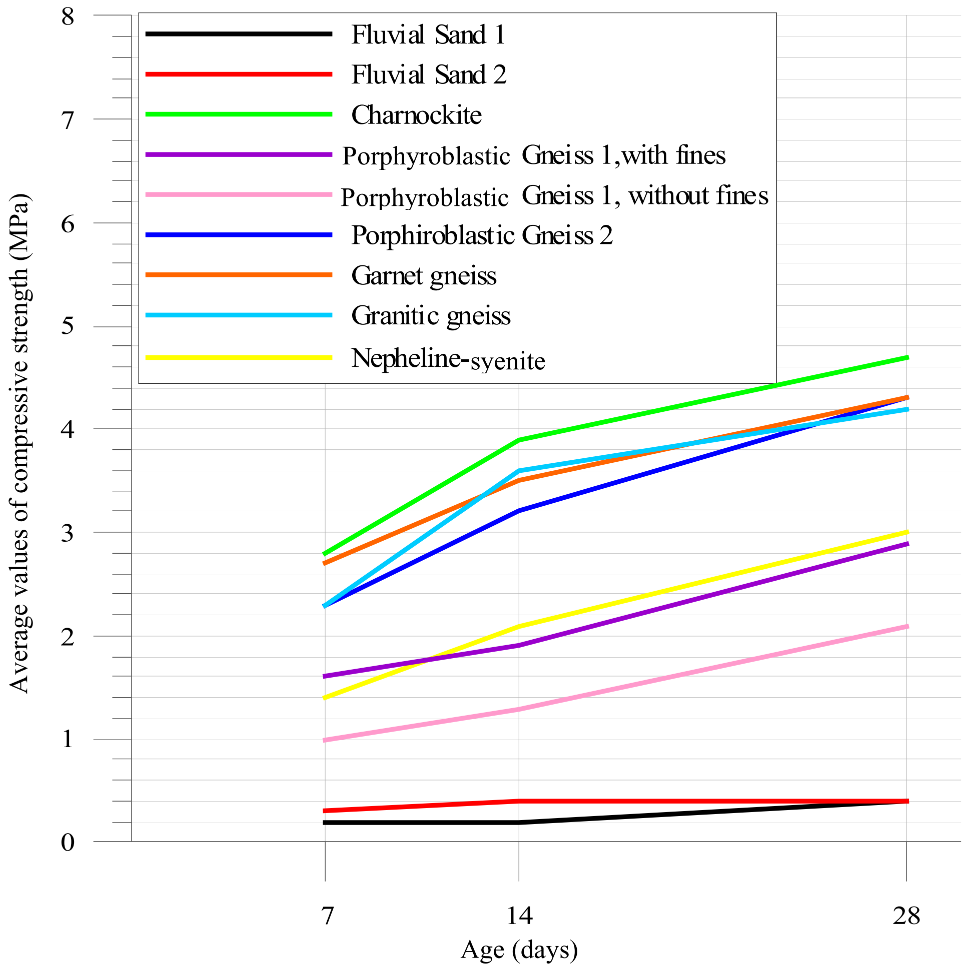

Figure 4. Variation of average strength values for each sand used in mortar mixes.

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