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Influence of stone dust as fine aggregate replacement on concrete compressive strength using an analysis of variance (ANOVA)

Abstract

The use of stone dust in concrete provides environmental benefits by reducing the impacts produced by the extraction of natural sand. The use of this material can also offer economic advantages, since the product is less costly than natural sand. In this way, the present work evaluated the compressive strength of concretes made with stone dust in different replacement levels (30% and 100%) compared to the use of natural sand. The results were analyzed statistically using the Analysis of Variance (ANOVA) in order to verify the statistical influence of replacement levels and the mix proportioning in the resulting compressive strength. It was found that the compressive strength of concrete with 30% of replacement level presented similar behavior to reference concrete, showing that the use in structural concrete is feasible.

Keywords: concrete, stone dust, compressive strength, analysis of variance

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Introduction

It is known that the construction industry is responsible for the consumption of a large quantity of raw material in cement production (limestone and clay), red and white ceramic materials (clays), and natural aggregates. However, due to the increasing number of legal restrictions in conjunction with the need for sustainability in production processes, new alternatives are being tested to minimize the environmental impacts associated with the manufacturing of the products employed in the constructions. In order to manufacture 1m^3 of Portland cement concrete, typically between 75–80% of aggregates in volume are employed, mostly natural sand.[1] The extraction of natural sand from rivers reaches a volume of approximately 320million m^3 per year.[2] It is estimated that between 10 and 11 billion tons of aggregates are consumed per year.[3] These numbers express the vast amount of material that is removed from the environment each year; it is estimated that in a medium and/or long term a scarcity of natural resources will happen, leading to a demand for replacement alternatives for these materials. Besides, investigations are necessary to identify suitable substitutes that are eco–friendly, inexpensive and better for strength and durability performances.[4] It must be considered that good quality aggregates are not always available in all regions of the countries. In some cases the natural sand is scarce, leading to the evaluation of transporting the material from other localities, even with the associated costs. Thus, the reuse of the waste rock processing employed for the manufacture of aggregates in structural concrete is an alternative that can contribute to the minimization of both the waste disposed in landfills and the exploitation of natural aggregates. Considering the significant volume of stone dust generated during the rock crushing process, some investigations have been developed in order to use such material as fine aggregate in concrete. Kanning et al.,[5] used agricultural limestone in partial substitution of natural aggregate (10%, 20% and 30%) in mortars. The characterization tests of mortars in the fresh and hardened states showed that the better performance was obtained with a 30% replacement level of aggregate with 300μm diameter. Bastos[6] investigated four replacement levels (15%, 30%, 50% and 70%) of natural sand by stone dust in concretes, evaluating the mechanical properties (compressive and tensile strengths), water absorption by capillarity and carbonation. The results showed that with 70% of replacement there was a reduction of 30% in relation to reference due to the shape of lamellar artificial sand. In addition, for the same replacement content the increased resistance was of the order of 56%.

Çelik et al.,[7] carried out an experimental program in order to investigate the influence replacement of natural sand by stone dust (5%, 10%, 15%, 20%, 25% and 30%) in workability, air content, compressive strength, impact strength, permeability and retraction of concrete samples. It was found that the 10% of replacement increased the compressive strength of concrete; however, 5% of stone dust was adequate considering the impact resistance of the material. Topçu A Ugurlu[8] used 5 replacement levels (3%, 7%, 10% and 15%) of natural sand aggregate by fine particles (sizes smaller than 2mm). The authors observed an increase in compressive and splitting strength, as well as minimized permeability, porosity and absorption of concrete. The results showed that concretes with replacement levels between 7% and 10% showed better performances in relation to the properties analyzed. It should be emphasized that in the surveys conducted the stone dust presented a high content of fine material in its composition, which carried an improvement of properties due to the packing effect typical of fine material. Ho et al.,[9] conducted analysis in order to compare the rheology of self–compacting concrete and pastes with the use of limestone powder. The authors found particle shape and the aggregates composition have influence over the concrete behavior, leading to a different amount of plasticizer required to maintain the same consistency. Besides the technical issues, the use of stone dust is very important from a sustainability point of view, considering the depletions of sand natural reserves and/or the increase of natural aggregate transportations costs due the availability only in large distances. Thus, this paper presents a investigation to verify the effect of mix proportioning and stone dust replacement levels in compressive strength of concretes, whose results were analyzed through an Analysis of Variance (ANOVA), to verify the statistical significance of controlled parameters in response to the experiment.

Materials and methods

In this study, Brazilian Pozzolanic Portland cement (similar ASTM C 595 Portland Pozzolanic) was used in the concrete specimens. The density, specific surface, and compressive strength of the cement were 2.74g/cm^3, 1230g/cm^2, and 38.7 MPa at 28 days, respectively. River siliceous sand and stone dust were used as fine aggregate, with the coarse aggregate being basaltic, whose physical characteristics are presented in Table 1 (Figure 1). It can be observed that the stone dust presents a high fineness modulus, greater than the limit recommended by Brazilian standard NBR 7211.[10] Nevertheless; such material can be used, provided that the test results show that such material is suitable for use in concrete. Bastos[6] found a value of 3.17 for the fineness modulus of the stone dust used in the manufacture of concrete. Menossi[11] found that the fineness modulus used in experimental work was equal to 2.48, very close to the value obtained with natural sand. Schumacher[12] obtained a fineness modulus value equal to 2.77 for the stone dust, while with river sand it was equal to 2.11. In this way, it is clear the relationship between the employment conditions of the material is related to the mineralogical composition of the aggregate and the preprocessing conditions (which will determine the shape and texture of constituent particles) and the size particle distribution. In this case the stone dust was added to concrete without any processing or adjustment. So, concrete samples were made by replacing varying percentages of natural sand by stone dust in 30% and 100% by weight. All the concrete mixtures were performed using IPT/EPUSP's method.[13] The workability was fixed at 80±10 mm based in the slump test method and the mortar content (α) was equal to 53% for all concretes. The procedure for test specimen molding and curing was performed according to Brazilian standard NBR 5738.[14] the mixtures used in this investigation is presented in Table 2. The compressive strength test was performed with cylindrical test specimens (10 × 20cm) of each mixture, according to Brazilian standard NBR 12655[15] at 3, 7 and 28 days. To determine whether the stone dust content and the mix proportioning had a statistically significant effect on the concrete compressive strength, an ANOVA was conducted. The F–test in the ANOVA analysis determined the existence of significant differences between the properties investigated. If the p–value of the F–test was less than 0.05, the factor had a significant effect over the analyzed property at a confidence level of 95%; conversely, if the p–value was greater than 0.05, the variables investigated did not show a significant effect.

Table 1 Physical characterization of aggregates

	Stone dust	Natural sand	Coarse aggregate
Apparent specific gravity (kg/dm^3)	2.71	2.64	2.95
Bulk density (kg/dm^3)	1.52	1.57	1.43
Fineness modulus	4.2	1.87	6.76
Maximum size (mm)	4.75	1.18	19

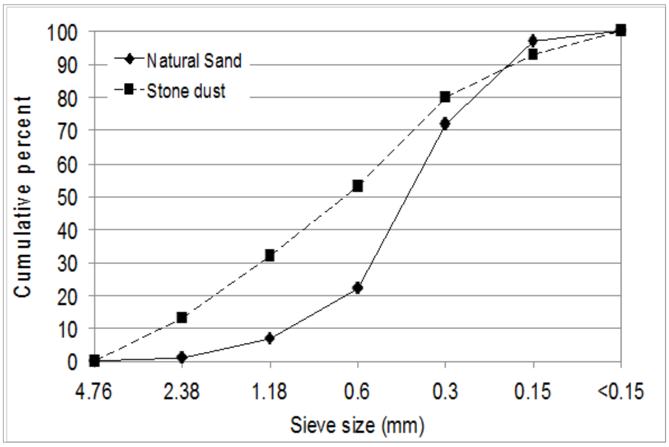

Figure 1 Grading curve for aggregates used.

Table 2 Mix proportions for concretes investigated

Concrete	Proportioning (cement: aggregates)	w/c	NS[1] (%)	SD[2] (%)	Aggregates (kg/m^3)			C (kg/m^3)	Slump (mm)
					Sand	Stone dust	Coarse		
Reference	01:03.5	0.46	100	0	673.5	0	1022	484.5	85
	01:05.0	0.54	100	0	812	0	1051	372.5	80
	01:06.5	0.65	100	0	894	0	1056	300	80
30% stone dust	01:03.5	0.48	70	30	466	202	1014	481	90
	01:05.0	0.57	70	30	565	240	1042	369	80
	01:06.5	0.67	70	30	625	266	1052	299	85
100% stone dust	01:03.5	0.57	0	100	0	643	977	463	100
	01:05.0	0.66	0	100	0	784	1014	359	95
	01:06.5	0.82	0	100	0	858	1013	288	85

[1]NS, natural sand; [2]SD, stone dust

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Results and discussion

Figure 2 presents the Abrams curves for concretes evaluated at 28 days. It must be pointed out that the data presented corresponds to the average of the 3 specimens tested. It can be observed that concretes with 30% replacement levels of natural sand by stone dust showed resistance similar to reference concrete. Table 3 shows the Abram's equations for concretes evaluated at 28 days, which were obtained through the data presented in Figure 2. Based on these values the compressive strength for concretes considering different w/c ratios established by the Brazilian Standard NBR 6118[16] were estimated, as shown in Figure 3. The concretes with stone dust showed a slightly higher performance than the reference concrete, especially when considering the w/c ratios equals to 0.55 and 0.60. As for concretes with w/c ratios equal to 0.60 the difference is very small, showing the potential of stone dust use in concrete manufacturing. Considering the durability issues, the Brazilian standard NBR 6118[16] establishes that for a concrete exposed to urban areas the w/c ratio must be equal to 0.60, with minimum resistance of 25MPa. Considering concretes inserted in industrial environments the maximum w/c ratio must be equal to 0.55 associated with a minimum compressive strength of 30MPa. In this way, concretes must be proportioned establishing the w/c ratio, thus obtaining concretes that meet the durability requirements. To confirm the significance of the influence of the variables considered in compressive strength, an ANOVA was conducted and the results are presented in Table 4.

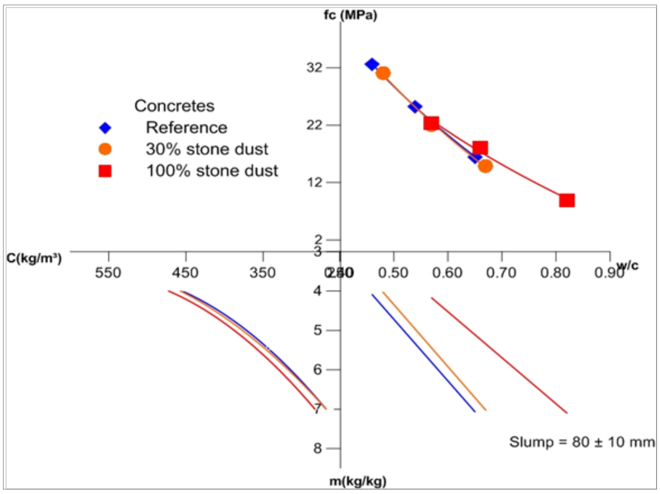

Figure 2 Concrete dosage diagrams at 28 days.

Table 3 Abrams equations for concretes at 28 days

Concrete	Equation	r^2
Reference	$f_c = -46.6174 \times \ln\left(w/c\right) - 3.56225$	0.9968
30% stone dust	$f_c = -48.4703 \times \ln\left(w/c\right) - 4.75435$	0.9974
100% stone dust	$f_c = -37.4716 \times \ln\left(w/c\right) + 1.77006$	0.9907

The p–value less than 0.01 indicate that the relationship between the variables and their interactions are statistically significant with a confidence level of 99% in concrete compressive strength. When comparing the p–values with the numerical results of the F–tests it can be verified that the influence of the mix proportioning and the age were greater than that replacement of stone dust, but it must be considered that such parameter has significant influence in compressive strength. The small difference in compressive strength observed between the reference and concrete with 30% of stone dust (Figure 2) could be related with the variability inherent in experimental procedures. However, the ANOVA results showed that this difference is statistically significant, i.e., the presence of stone dust has influence over the difference observed between the compressive strength of concretes evaluated. In this way, a mathematical model that represents the compressive strength behavior of concretes was obtained from the experimental data through a multiple non–linear regression analysis (Equation 1). After several adjustments the model was submitted to an analysis of variance (ANOVA), showing a coefficient of determination (r^2) equal to 0.922, indicating that the model explains 92.2% of the variability of the observed values for compressive strength of concrete. It should be pointed out that all the coefficients of the model developed showed statistical significance.

$$f_c = e^{\left(21{,}95 - 0{,}1855.Dust - 0{,}3465.Mix + 0{,}0248.Age\right)} \quad (1)$$

Where:

f_c = compressive strength (MPa);

Dust = replacement level of stone dust in concrete (Codes: reference = 101; 30% stone dust = 102; 100% stone dust = 103);

Mix = Mix proportioning of dry materials in concrete (Codes: 1:3.5 = 1; 1:5.0 = 2 and 1:6.5 = 3);

Age = Age of concretes (days).

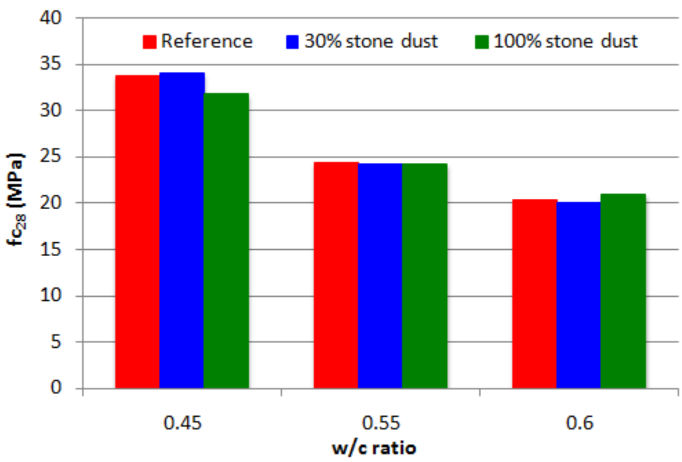

Figure 3 Influence of stone dust in compressive strength at 28 days.

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Table 4 ANOVA for compressive strength

Source of variation	DF	SS	MS	F-test	p value
Stone dust	2	594.25	297.13	879.88	0
Age	2	1799.18	899.59	2663.97	0
Mix proportioning	2	1681.4	840.7	2489.57	0
Stone dust × age	4	7.25	1.81	5.37	0.001
Stone dust × mix proportioning	4	65.13	16.28	48.22	0
Age × mix proportioning	4	132.41	36.1	98.03	0
Stone dust × mix proportioning × age	8	36.85	4.61	13.64	0
Error	54	18.24	0.34		

DF, degrees of freedom; SS, sum of squares; MS, mean square

Conclusion

It was observed that the use of the stone dust in conventional concrete is feasible. For this experimental study, it was found that the replacement content of 30% in relation to the natural sand presented a satisfactory performance in relation to compressive strength. It was also verified that mix proportioning, the replacement level and age were significant factors over the concrete compressive strength. Besides, the ANOVA is a powerful tool used to evaluate the effective influence of the factors in the response of an experiment. In order to ensure that the stone dust can be used in concrete in large scale, other investigations are needed. For example, it is important to perform tests in order to optimize the grading curve of the aggregate due to the variability that exists in the crushing process. In this way, the mixture of aggregates using other replacement levels, beyond the control of fine materials in the mix, are important initiatives in order to obtain concrete with adequate characteristics for specific uses. In addition, in order to completely validate the use of the material in structural concrete, larger studies should be carried out considering aspects of durability and deformations over time of concretes made with stone dust.

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Conflict of interest

The author declares there is no conflict of interest.

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