EFFECT OF THE PRESENCE OF CLAY AND LIMESTONE DUST PARTICLES ON THE PHYSICO-MECHANICAL CHARACTERISTIS OF CONCRETE

Zitouni Salim, Naceri Abdelghani and Maza Mekki
Geo-Materials Development Laboratory, Technology Faculty, Civil Engineering Department, M'sila University, Algeria.
Corresponding Author: salimzitouni5@gmail.com

ABSTRACT

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The effects of clay and limestone dusts in the aggregates on the physico - mechanical characteristics of concrete were investigated. The fine aggregates (dune sand) and coarse aggregates (crushed gravels) used in this study were washed, dried and sieved.Two different mineralogical compositions of dusts (clay and stone) were incorporated in different rates(0%, 5%, 10%, 15%, 20%, 25% and 30%) by replacementin weight of fine (dune sand) and coarse (crushed gravel) aggregates. The presence of clay and limestone dust particles in the fine and coarse aggregates in excessive quantities influenced the physico – mechanical properties of fresh and hardened concrete. The results obtained showed that the effect of clay dust content is more important compared to limestone dust content on the properties of concrete.

Keywords: clay dust, limestone dust, physico-mechanical properties, concrete.

INTRODUCTION

Fine and coarse aggregates are important constituents in concrete. They give body to the concrete, reduce shrinkage and has an economical effect. The fine and coarse aggregates are inert granular materials used for the manufacture of concrete. For a good concrete mix, fine and coarse aggregates need to be clean, strong and free of absorbed chemicals and other fine materials that could cause deterioration of concrete (Menadi *et al., 2009*; Goble and Cohen, 1999; ShyamPrakash and Hanumantha Rao, 2016; Donza, Cabrera and Irassar, 2002).

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Properties of aggregates affect the durability and performance of concrete. The shape and texture of aggregates particles could lead to improvements in the strength of concrete due to better interlocking between particles.Dust particles strongly influence the fresh and hardened concrete properties, mixture proportions, and economy (Sengul,Tasdemir2002; Nagabhushana and Sharadabai, 2011; Radhikesh, Amiya and Moharana, 2010).

The presence of dust particles (very fine particles) in excessive proportions in fine and coarse aggregates influences the characteristics of fresh (workability, air content and grading) and hardened (strength, shrinkage and durability) mortar and concrete (Zhou *et al*, 1995; Giaccio*etal*. 1992; Mesbah, Lachemi and Aitcin, 2002).

Concrete has a high degree of heterogeneity, which could be due to a multiphase material consisting of coarse aggregate embedded in mortar matrix and an interfacial zone between the particles of coarse aggregate and the hydrated cement paste. Thus, concrete properties are strongly linked to the characteristics of the solid aggregate, the performance of the cement paste, and the interfacial region.

Clay dusts are commonly present in natural sand (dune sand) and limestone dusts are presents in crushed coarse aggregates. Several properties of aggregates, such as chemical and mineral compositions, shape, roughness, degree of weathering, specific gravity, hardness, strength, physical and chemical stability, and pore structure are linked to the properties of the parent rock (De Larrard and Belloc, 1997; Sahin *et al*. 2003).

Moreover, some properties, such as mineralogy, surface area, surface texture, particle size and shape, elastic modulus, strength, grading and water absorption may have a significant effect on the performance of concrete (Ukpata and Ephraim, 2012; Hmaid Mir, 2015). Generally, it is considered that compressive strength is the major concrete’s characteristic required for structural design, since both normal and high-strength concrete are mainly designed to resist compressive forces.

The relationship between concrete mix proportions and compressive strength has been a matter of interest for several researchers (Aitcin and Mehta, 1990). For normal strength concrete, the w/c is the major factor controlling most of the mechanical properties of concrete, and fine and coarse aggregates is considered as the strongest phase. Therefore, it is not only sufficient to relate mechanical strength to the water-cement ratio of concrete, but also to other parameters that have a considerable influence on the development of concrete mechanical properties.

In such a case, fine and coarse aggregates must be properly selected depending on their physical and mechanical properties (Cetin and Carrasquillo, 1998; Denis *et al*., 2002; Singh*etal*, 2015). Several studies were carried out to investigate the effect of types, proportions, physical and mechanical properties of dusts on concrete mechanical strength. However, researches focusing on the effect of dusts in coarse aggregate are still limited and its effect is not yet well established.

The present paper investigates the influence of the proportion of dusts on the physico-mechanical properties of concrete using different types and rates of dusts (clay and limestone).The main objective of thisstudy was to clarify the influences of type and proportion of dust particles on the physico-mechanical properties of concrete and to suggest a rational use of these very fine particles.

MATERIALS AND METHODS

Two series of concretes were made by incorporating different rates (0%, 5%, 10%, 15%, 20%, 25% and 30%) of dusts (clay and limestone) by replacement in weight of washed, dried and sieved fine and coarse aggregates.

The fine aggregates (dune sand) and coarse aggregates (crushed gravels) used in the current study were obtained from locally available sources in Algeria. The fine aggregates (dune sand) and coarse aggregates (crushed gravels) used in this study were washed, dried and sieved. The concrete mixtures were prepared at the laboratory of the Civil Engineering Department, M'sila University, Algeria, using the following materials:

Crushed coarse aggregates (natural crushed manufactured gravel)

Crushed manufactured, washed, dried and sieved gravel was used in the concrete mixes. In this study, three size fractions of crushed limestone coarse aggregates (3/8 mm, 8/15 and 15/25 mm) were used. Gravel was obtained during the production of coarse aggregates through the process of crushing rocks in crushing units of rubble. In this study, the manufactured limestone aggregates used were crushed gravel generated by the crushing plant.

The coarse crushed gravels used was angular and irregular in shape. The surface of the particles was rough with uniform color. Sample of this natural aggregates (calcareous gravels) utilized in this study is shown in Fig.1.The particle size composition is an important indicator of the physical properties and structure of the coarse aggregates used in this study. Classification and grading limits are generally expressed as the percentage of material passing each sieve.

There are several reasons for specifying grading limits and nominal maximum aggregate size, as they affect relative aggregate proportions as well as cement and water requirements, workability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from one batch to another.

The sieve analysis curves of 3/8 mm, 8/15 and 15/25 mm fractions crushed coarse aggregates are shown in Fig.2 and their physical properties and chemical compositions are summarized in Tables 1 and 2. Porosity of fine and coarse aggregates was calculated from the absolute density and bulk density values using the formula:

$$P(\%) = (1 - \frac{\rho}{\gamma}).100 \qquad (1)$$

Where P is the porosity as the content of pores and voids in the specimens (wt. %), ρ is the absolute density ofaggregates (g/cm^3) and γ is the bulk gravity (g/cm^3). The analysis of the results obtained concerning the physical properties of manufactured crushed gravel are summarized in Table 1. Crushed gravel (3/8 mm, 8/15 and 15/25 mm fractions) had a high porosity and water absorption, which may be attributed to its angular and irregular shape and particles surface was smooth.

Table 1. Physical properties of manufactured crushed gravel (CG).

Physical properties	$CG_{3/8}$	$CG_{8/15}$	$CG_{15/25}$
Apparent density (g/cm^3)	1.33	1.34	1.35
Porosity (%)	50.19	49.81	49.05
Water absorption (%)	1.60	1.33	1.15
Abrasion resistance (L.A)	22.36	22.36	23.36

$CG_{3/8}$: crushed gravel (3/8 mm), $CG_{8/15}$: crushed gravel (8/15 mm)
And $CG_{15/25}$: crushed gravel (15/25 mm).

Table 2. Chemical composition of crushed gravel used.

Compounds	% by weight In crushed gravel
Lime	50.66
Silica	4.40
Alumina	1.39
Ironoxide	1.13
Potassium oxide	0.11
Sodiumoxide	0.02
Sulfite	0.43
Magnesia	0.75

Figure 1.Sample of crushed coarse aggregates.

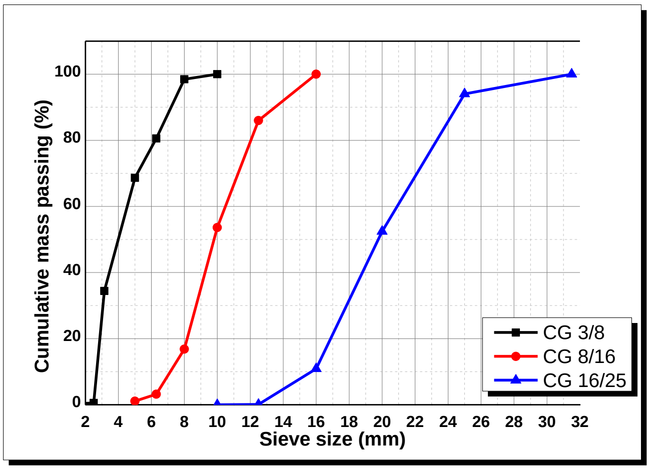


Figure 2. Particle size distribution curve of the crushed coarse aggregates studied.

Dune sand (natural fine aggregates)

The natural fine aggregates washed, dried and sieved used were dune sand with particles ranging from 0.08 mm to 3 mm in size. Sample of the natural fine aggregates (siliceous dune sand) utilized in this study is shown in Fig.3.

Figure 3. Sample of dune sand.

The fineness modulus (M_f),wascalculated as 2.36. This natural sand was taken from Boussâada, Algeria. The absolute density and porosity were 2.54g/cm^3 and 28.35%, respectively. Its physical characteristics are summarized in Table 3.

Table 3. Physical properties of dune sand.

Properties	Specific weight (g/cm^3)	Water absorption (%)	Sand equivalent (sight/test)	Porosity (%)	Fineness modulus
Dune sand	2,54	1.88	74/76	28.35	2.36

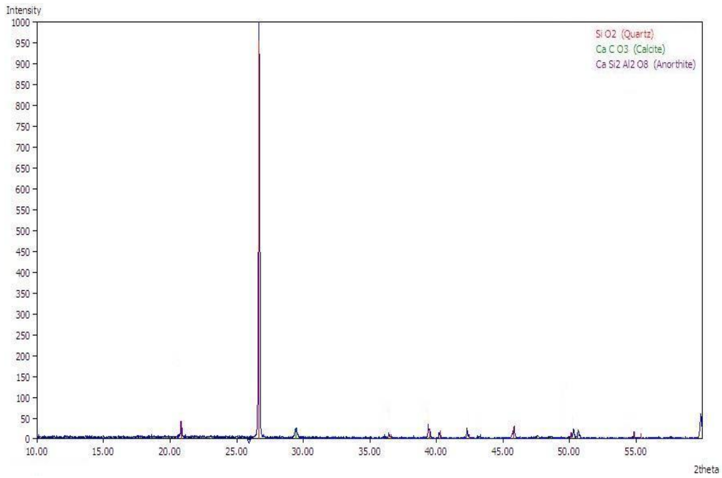
The chemical composition of siliceous sand is shown in Table 4. Silicate is predominant in terms of chemical composition that also indicates the presence of lime, alumina, iron and magnesia in small quantities. The mineralogical composition (mineral phases) of the dune sand was investigated by X-ray diffraction (XRD).

The crystalline mineral phases identified for the dune sand (Fig. 4) was mainly composed of quartz (SiO_2), calcite ($CaCO_3$) and anorthite ($CaSi_2Al_2O_8$),with a small but evident band ranging from 20° and 30°, indicating the presence of amorphous materials.

Table 4. Chemical composition (%, by weight) of fine aggregates (dune sand) used.

Compounds	% (by weight)
Lime	2.94
Silica	88.25
Alumina	0.71
Ironoxide	0.96
Potassium oxide	0.30
Sodium	0.01
Sulfite	0.08
Magnesia	0.17

Intensity of X-rays



Angle 2θ (°)

Figure4. X ray diffraction of dune sand.

The thermal analysis (TG/DTG) curves for dune sand are presented in Fig. 5. A finely ground sample was introduced into a furnace where the temperature was increased from 0°C to 1000°C with a rate of 10°C/min. The loss in mass was equal to 4%. The curve shows two main endothermic peaks:

(i) Endothermic peak (P1) at 100°C indicates the evaporation of water.

(ii) Endothermic peak (P2) at 640°C corresponds to the decomposition of carbonates ($CaCO_3$).

(iii) The grain size distribution of natural fine aggregate (dune sand) used is presented in Fig. 6. The sieve analysis was obtained according to AFNOR standard NE EN 933-1. From the sieve analysis result, the studied sample of the fine aggregates used (DS) was compared to fine upper limit (F.U.L.) and fine lower limit (F.L.L.).

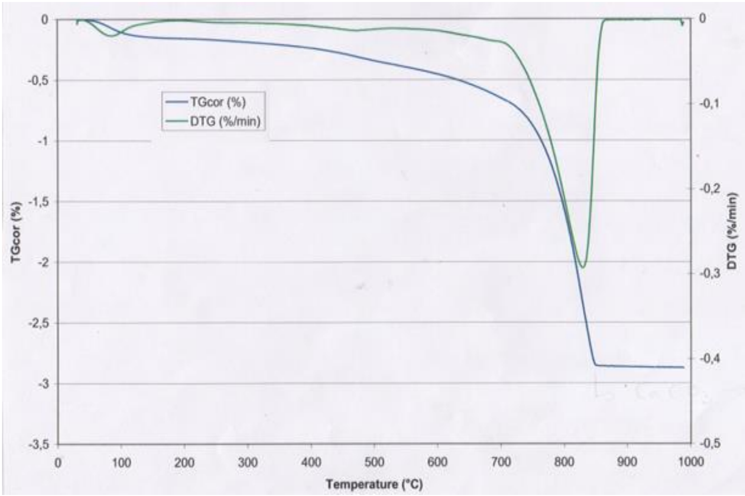


Figure 5. The thermogravimetry (TG) and the derivative thermogravimetry (DTG) curves of dune sand.

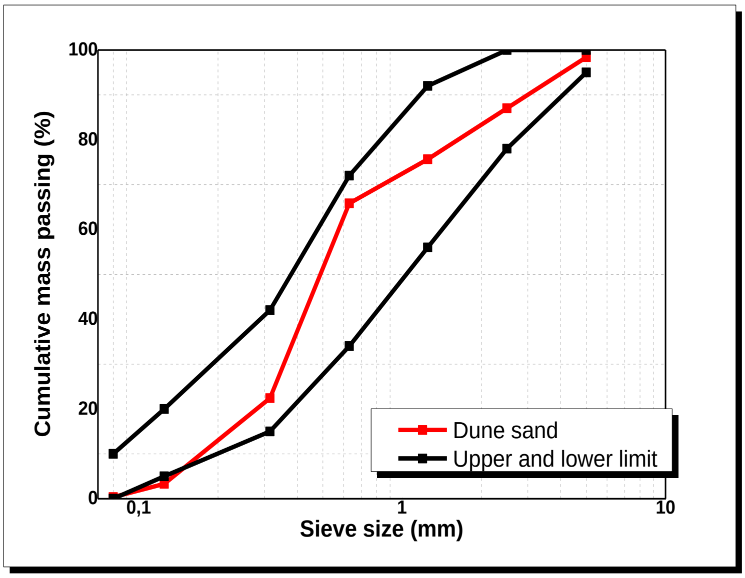


Figure 6. Particle size distribution curve of the dune sand studied.

Cement

The Portland cement type CEM II/A 42.5 from Hammam Dalâa local factory was used in this experimental study. The absolute density, bulk density and porosity were 3.1

g/cm^3, 1.9 g/cm^3 and 41.93%, respectively. The Blaine specific surface area (fineness) was 3800 cm^2/g. The fineness (specific surface area) of the cement studied was determined by an air permeability apparatus and the chemical composition wasdetermined by X-ray fluorescence spectrometry (XRF). Chemical and mineralogical compositions of the cement used are shown in Table 5.

Table 5. Chemical analysis and Bogue calculation of cement mineral composition.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	C_3S	C_2S	C_3A	C_4AF
22.1	4.57	3.95	66.34	1.60	0.54	65.70	16.85	5.42	12.03

Mixing water

Water is an important ingredient of mortar as it actually participates in the chemical reaction with cement. Since it helps to form the strength, giving cement tobermorite gel. The quantity and quality of water is required to be looked into very carefully. Potable tap water was used for mortar mixing in all through the study and contains none harmful impurity.

Dusts (clay and limestone)

The very fine particles (micro-fines) studied in this work are clay and limestone dusts. The dusts were sieved with 0.116 sieve and the samples were taken in the M’sila region (Algeria). The physical characteristics of these dusts are presented in Table 6. Samples of the dust particles (limestone and clay dusts) utilized in this study are shown in Figs 7 and 8.

Table 6. Physical properties of dusts (very fine particles).

Properties	Specific weight (g/cm^3)	Apparent Density (g/cm^3)	Compactness (%)	Porosity (%)
Clay	2,57	1.06	41.01	58.99
Limestone	2.66	1.25	46.99	53.01

Figure 7. Sample of limestone dust.

Figure 8. Sample of clay dust.

Water requirement for the different mixtures with and without dust

The very fine particles (dusts) studied in this research are clay and limestone. Two series of mixtures were studiedseparately: the first concerns 6 mixtures containing different rates (0%, 5%, 10%, 15%, 20%, 25% and 30%) of clay dust with a control mixture, the second series concerns 6 mixtures containing different rates (0%, 5%, 10%, 15%, 20%, 25% and 30%) of limestone dust with a control mixture. These percentages being substituted by weight of aggregates (sand and gravel).

Tests of water requirement, fluidity, density, w/c ratio and strength are developed for both series of mixtures in order to determine the influence of these dusts on the rheology and the mechanical characteristics of the concretes investigated (Tables 7 and 8). The water requirement for the different mixtures with and without clay and limestone dusts is shown in Fig. 9 and was calculated using formula 2.

$$R_w(\%) = \frac{\left(\frac{W}{C}\right)_m - \left(\frac{W}{C}\right)_{cp}}{2}.100 \qquad (2)$$

$(W / C)_m$: Water / cement ratio for mortar with or without dust
$(W / C)_{cp}$: Water / cement ratio for Cement paste with or without dust

Table 7. Water requirement for different mixtures with and without clay dust.

Sample	W(ml)	C (g)	$(W/C)_{cp}$	$(W/C)_m$	Flow	R_w(%)
Cement paste	265	900	0.29	---	16.50	----
Mortar + 0%Dust	110	250	0.29	0.44	16.80	7.50
Mortar + 5% Dust	126	250	0.29	0.50	17.00	10.50
Mortar + 10%Dust	138	250	0.29	0.55	17.50	13.00
Mortar + 15%Dust	157	250	0.29	0.63	17.00	17.00
Mortar + 20%Dust	165	250	0.29	0.66	16.80	18.50
Mortar + 25%Dust	175	250	0.29	0.70	17.80	20.50
Mortar + 30%Dust	187	250	0.29	0.75	17.50	23.00

Mortar was prepared with 1/3 cement CEM II/A 42.5 and 2/3 Dune Sand washed and dried.

Table 8. Water requirement for the different mixtures with and without limestone dust.

Sample	W (ml)	C (g)	$(W/C)_{cp}$	$(W/C)_m$	Flow	R_w(%)
Cement paste	265	900	0.29	---	16.50	----
Mortar + 0% dust	110	250	0.29	0.44	16.80	7.50
Mortar + 5% dust	120	250	0.29	0.48	17.00	9.50
Mortar + 10% dust	132	250	0.29	0.53	17.10	12.00
Mortar + 15% dust	141	250	0.29	0.56	16.80	13.50
Mortar + 20% dust	148	250	0.29	0.59	17.00	15.00
Mortar + 25% dust	155	250	0.29	0.62	16.80	16.50
Mortar + 30% dust	160	250	0.29	0.64	17.20	17.50

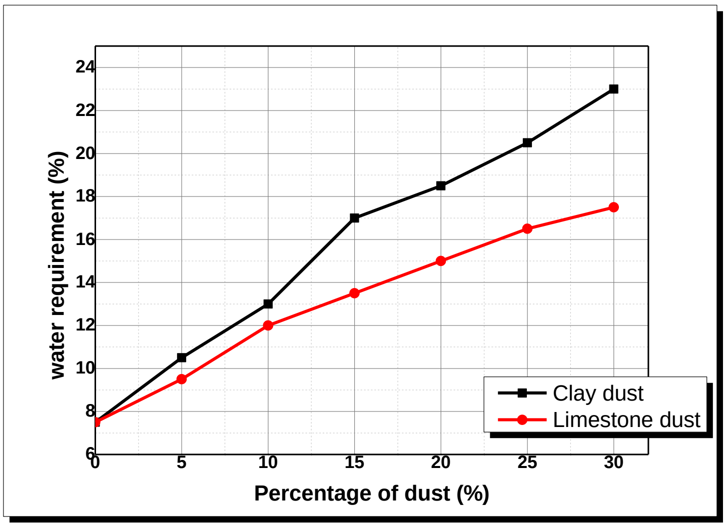


Figure 9. Water requirement for the different mixtures with and without clay and limestone dusts.

Increasing the percentage of fine dust in the mortar mixture increases the water requirement of the mixture due to the increase of specific surface; the higher the percentage of fine particles, the greater the need for water to envelop these fines.

Tests used

The concrete mixture is prepared with three fractions (3/8 mm, 8/15 mm and 15/25) of crushed coarse aggregates. The percentage of fraction manufactured crushed aggregates was fixed constant at 20% (3/8), 40% (8/15) and 40% (15/25) in all concrete mixtures studied.

Both fine and coarse aggregates were used in saturated surface-dry conditions. The concrete mixtures were designed in accordance with Dreux - Goris method.

The following fresh and hardened properties of concrete were selected for testing:

- Slump test (Properties of fresh concrete).
- Testing of dry density (Hardened concrete).
- Testing of compressive strength of Hardened concrete

Slump test (properties of fresh concrete*)*

The slump test is a method of testing the workability of the fresh concrete. A standard metal slump cone is to be filled with 4 layers of concrete; each layer is to be thoroughly compacted with a steel rod. The last layer which fills the cone to the top is to be trowelled flat. The cone is then removed and the height reduction (slump) of the concrete is measured. The slump test is used for evaluation of rheological behavior of a mixture. All concrete mixes was used to maintain a constant slump of 6 ± 1 cm. Workability is a property of fresh mortar and it is measured by the slump test and is described as a measure consistency.

Mechanical tests

The concrete samples were subjected to compressive mechanical tests. Mechanical strength was determined at 7, 14 and 28 days. Seven concrete mixes were prepared with different rates (0%, 5%, 10%, 15%, 20%, 25% and 30%) of each type of dust. All the concrete specimens were cast in three layers into 100 x 100 x 100 mm cubic steel molds; each layer consolidated using a vibrating table. The main objective of this paper is to evaluate the experimental characterization of the performance of concrete made with natural coarse aggregatesand clay dust or limestone dust at fresh and hardened states, and to find a percentage threshold of dust to which dust-laden aggregates will not be allowed for the manufacture of concrete.

RESULTS AND DISCUSSION

Effect of dust on the slump test of concrete

The percentage of dust significantly affects the fluidity of the concrete. The increase in the percentage of dust is followed by an increase in the mixing water. The dust absorbs water and reduces the water-binder reaction and also slows down the fluidity of the concrete.The increase of the mixing water is 11 to 39% for clay dust, and from 7.8 to 18.9% for the limestone dust. This is explained by the fact that absorption of clay is greater than that of limestone.

Effect of dusts on the water-cement ratio

The results of the reduction of water cement ratio for various rates of dusts of fresh concrete are presented in Figure 10. The concrete made with limestone dust presents low water-cement ratio content. Concretes with clay dust and limestone dust had a larger w/c ratio than the control concrete. The increase of dust content was followed by an increase in the w/c ratio of 24.2% for clay dust and 10% for limestone dust.

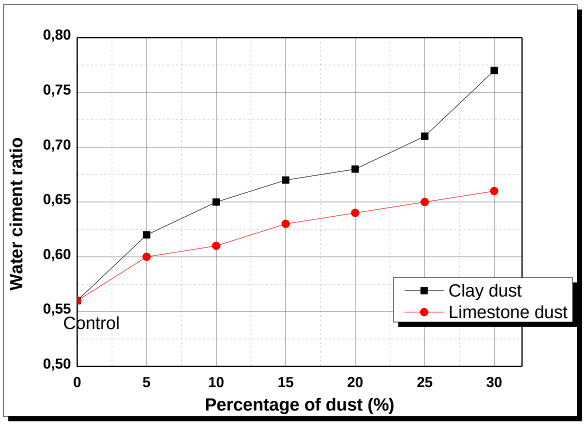


Figure 10. Reduction of water cement ratio for various percentages of dusts

Effect of dusts on the mix density of hardened concrete

The density tests for concrete mixture with dusts are shown in Fig.11.The density at 28 days decreased with increasing dusts content.

The dry density of hardened concrete was calculated as follows:

$$\rho(Kg/l) = \frac{M}{V} \qquad (3)$$

Where
M: weight of specimen (Kg),
V: volume of specimen (l).

On the other hand, the difference in the density of concrete mixes was mainly due to the difference in specific weight of the dusts used. Consequently, the density of concrete with clay dust was higher than that of concrete with limestone dust.The study showed that the increase in the dust content in the concrete mix decreased the density of the concrete because of the low density of dusts (very fine particles) compared to the densities of the constituents of the concrete and because of the high voids present caused by the dusts. In fact, a certain percentage of fine particles are embedded between the grains of sand and gravel to fill the voids, a surplus of fine particles itself created voids because of their almost uniform size.

The decrease in density for concretes with clay dust was higher than that of concrete with limestone dust with the same content levels.

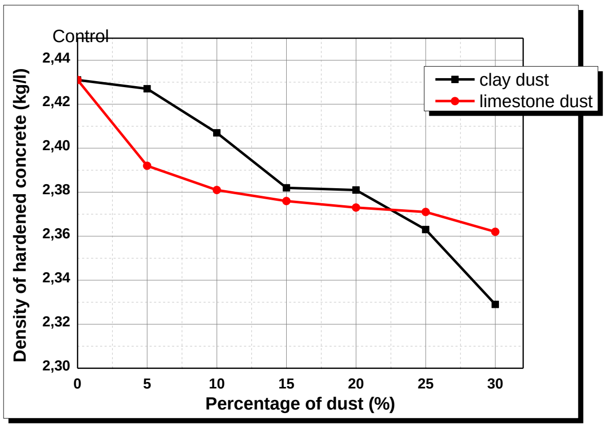


Figure 11. Density of hardened concrete for various rates of dusts content.

Effect of dusts on the compressive strength

The results of the compressive strength of the concretes with dusts (clay and limestone) at 28 days are plotted in Fig.12. Each presented value is the average of three measurements resulted in an increase in compressive strength.

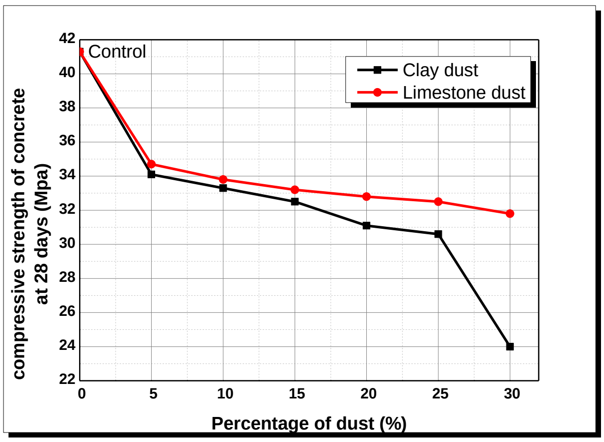


Figure 12. Variation of compressive strength of concrete at 28 days as a function of substituted dust content.

Concrete strength decreased with increase in dust content. This is likely to be due to the increase in the w/c (water-cement) ratio and decrease in density. The incorporation of dusts form a screen on aggregates prevents strong bonding between the aggregates and the binder. With 5% of limestone dust, mechanical compressive strength decreased by 19% compared with the control concrete and continued to decrease up to 29% at the rate of 30% dust.

The decrease of mechanical strength (compressive strength) was 21% and continued to decrease until 72% for a concrete made with 30% clay dust.Clay dust was more harmful to the concrete compared to limestone dust. The presence of these dusts caused significant drops in the concrete strength.Care must be taken to store the materials in places not exposed to wind, especially in arid regions.The very fine particles (dust particles) present in the aggregates must be eliminated either by washing or drying.

Discussion on Results

According to the results obtained, the percentage of 30% of limestone dust reduces the compressive strength by 29% compared to concrete control.

in strength compared to normal concrete and then decreases from Shyam Prakash and Hanumantha Rao (2016) has shown and concluted that 40% replacement of sand by quarry dust gives maximum result 50% replacement.

Nagabhushana and Sharada bai H. (2011). Confirms the results found by Shyam Prakash and concluded that the compressive strength, split tensile strength and flexural strengths of concrete are not affected with the replacement of sand by Crushed Rock Powder CRP as fine aggregate up to 40%. Hence, CRP can be effectively used to replace natural sand, without reduction in the strength of concrete with CRP replacement level up to 40%.

The percentage replacement of the sand is depending on the quarry dust location from where the quarry dust was taken.

Unlike limestone dust, clay dust is bad for concrete, it significantly reduces its mechanical resistance, and our study has shown that:

* The increase of dust content was followed by an increase in the w/c ratio of 24.2% for clay dust.

* The decrease of mechanical strength (compressive strength) was 21% and continued to decrease until 72% for a concrete made with 30% clay dust. Clay dust was more harmful to the concrete compared to limestone dust. The presence of these dusts caused significant drop in the concrete strength. Care must be taken to store the materials in places not exposed to wind, especially in arid regions. The very fine particles (dust particles) present in the aggregates must be eliminated either by washing or drying.

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