Concrete and mortar properties prediction by cement fineness

S A Zogo Tsala [1,2], P Bame Che[3,4], H L Ekoro Nkoungou [1], E YAMB BELL[3]
[1]*Department of Civil Engineering, ENSET of Ebolowa, University of Ebolowa, Cameroon.*
[2]*Laboratory of Technology and Applied Science University of Douala, Cameroon.*
[3]*Laboratory of Mechanics, University of Douala, Cameroon.*
[4]*University of Bamenda, Bamenda, Cameroon.*

Abstract: The cost of characterisation tests, storage conditions, climatic hazards and the poor state of the road network generally lead to the use of partially solidified cement. The objective of this work was to predict the mechanical characteristics of concrete and mortar, the main components of civil construction, by estimating the fineness modulus of cement, which can be easily implemented by medium-level workers. To do this, particle size analysis and classical geotechnical characterisation tests (compression, slump), at monthly frequency, were deployed for ten months on a classical cement (Dangote CPJ 42.5). The results confirmed the considerable loss of mechanical capacities after three months of storage, as predicted by standard cement characterisation tests. The correlation between the stress curves in concrete, mortars and the increase in lump content resulted in logarithmic relationships between lump content and the different stresses (concrete, mortars and walls). The formulas established showed that mortars can be prepared for a maximum lump content of 16.5%, that a maximum lump content of 13.8% in the cements can be used for the processing of concrete, and that the remaining wall elements can be constructed from elements with a maximum lump content of 20% in the cement. The implementation of this simple and quick approach, with results similar to those of standard tests, could be used to predict the mechanical properties of mortars, concretes and walls prior to their implementation on site by low-level personnel.

Keywords: *lumps, cement, mortar, concrete, mansonry*.

I. Introduction

Some work has shown that the compressive strength and workability of concrete increases with the fineness of the cement [1,2,3], however, storage and transport conditions lead to partial hydration of the cement, which manifests itself in the formation of lumps that reduce the mechanical characteristics. For this reason, it is generally advisable to use the cement no later than three months after it leaves the factory [4]. The weathering of cement, which leads to a reduction in fineness modulus, is studied using standardised tests (grinding fineness, compression tests, normal mortar, loss on ignition, etc.) [5]. However, these tests are not financially accessible to small construction sites, and the results are not usable for the usual construction workers, [6]. In view of this situation, it seems essential to develop a method for assessing cement quality based on simple and accessible measurements, leading to results similar to conventional tests.

Based on these observations, which often lead to the ruin of structures in poor or developing countries, we plan to correlate the fineness modulus of cement, materialized by the proportion of lumps, with the mechanical characteristics of the structural elements of constructions, which include cement. This correlation must be made on the basis of classic geotechnical tests, easy to interpret, (granulometric analysis, slump tests, simple compression test), with a view to guiding the site personnel in the use of cements according to their condition, not exclusively linked to the duration of storage, in the absence of the financial means necessary for standard characterisation tests.

In order to achieve this objective, at the end of the general introduction, the principles of the classical geotechnical tests used, i.e. the grain size analysis, the slump test and the compression test, as well as the necessary equipment and the principles of calculating the stresses of the mortar and then of the wall from the stress values of the concrete, are presented. We will present the results obtained at 7, 14 and 28 days, carried out each month, during ten months on a Dangote CPJ 42.5 cement, commercialised in several poor countries. On the basis of these results and the formulas derived, we will conclude on the impact of this approach on the prediction of the mechanical properties of concretes and mortars from the modulus of fineness (lump rate) and the possible orientations for the use of cement in small building sites.

II. Materials and methods

2.1 Cement

The cement used was Dangote Portland Cement, CPJ 42.5, whose characteristics are presented in Table 1. All cements collected were fresh cements and were stored between 150mm to 200mm above ground level at 600mm from the walls and covered with a plastic sheet [7]. The temperature of the store was room temperature. Cement for storage was collected from local building material suppliers on the same day it arrived from the Dangote cement plant.

Table 1 Physical Characteristics of the cement used

Physical Characteristic	Average results
Apparent density	0.95 t/m^3
Consistency	29%
Specific density	3.14 t/m^3
Specific surface area	3425 cm^2/g
Expansion	2mm
Manufacturing date	None
28^{th} day Compressive Strength	45 Mpa
28^{th} day tensile Strength	13 Mpa

1.1. Aggregates, water

The sand used for the surveys is natural sand from the Wum River bed collected from local suppliers. The gravel were air-dried in the laboratory room. The aggregates were sieved and stored in a dry place in the laboratory room as presented in Table2

The water used for the implementation of the concretes came from the drinking water distribution company of Cameroon.

Table 2 characteristics of the aggregates

Characteristics	Sand 0/5	Gravel 5/15	Gravel 15/25
Diameter	0/5	5/15	15/25
Specific gravity	2.60	2.77	2.75
Apparent density	1,86	1,91	1,86
Sand equivalent	88.8	-	-
Finesse modulus	2.7	-	-
Water absorption	0.51	2.21	2.21

2.2 Granulometric analysis (Cement, aggregates)

The purpose of this test is to study the distribution of grains according to their size in a sample. It was used to study the modulus of fineness of cements and aggregates. The granulometry of cements were carried out on cement with different storage times to know the percentages of fines retained on a sieve of 0.08 mm diameter. The granulometry of sands was carried out on the following sieve sizes of 5.00 mm, 2.5 mm, 1.25mm, 0.63 mm, 0.315mm, 0.16mm, 0.08mm, [8] , as can be seen in figure 1.

The granulometry of the gravels retained was those generally used in the construction in Cameroon which are of diameters 5/15 and 15/25 or a combination of two different sizes.

Figure 1: Sieve

1.2. Concrete tests

1.2.1. Slump test

The slump test which is the simplest and easiest to perform to measure the workability of milled concrete was performed on a cone with a small radius of 100 mm, a large diameter of 200 mm and a height of 300 mm. The cylindrical molds used were 150 mm in diameter and 300 mm in height [9].

1.2.2. Compression test

It was performed to compress the specimen with increasing force until cracks appeared in order to determine its resistance to concrete compression[10] . The concrete cylinders were tested for compressive strength at 7 days, 14 days and 28 days. For each shelf life, 3 samples were prepared [11]. The compression press of *GTHS Bamenda*, [12], presented in Figure 2, was used in this study.

1.3. Estimation of mortar compressive strength with concrete test

In a dry stack of particles loaded with compression, it is known that coarse particles tend to “pick up” stresses. They thus act as hard points in the soft medium constituted by the porous mixture of the finer particles. The distance between these aggregates is called the maximum thickness of paste $e_{p\max}$, it is a function both of the maximum size of the aggregate and of the degree of separation of the grains by the cement paste [13].

$$e_{p\max} = D\left(\sqrt[3]{\frac{g^*}{g}} - 1\right) \quad 1$$

- With: d and D are the minimum and the maximum of the dimensions of the aggregate corresponding to 10 and 90% of the passage, respectively;
- g is the volume of the aggregate per unit vol ume of concrete (before expansion);
- $g*$ can be obtained by using formula 2, [14].

$$g^* = 1 - 0.39\left(\frac{d}{D}\right)^{0,22} \quad 2$$

Figure 2: Compression test apparatus

The compressive strength of the mortar given by formula 3 [15], is defined as the product of the compressive strength of the mortar , and a term describing the effect of the maximum thickness of the concrete.

$$\sigma_{mortar} = \sigma_{concrete} \times e_{p\max}^{-0,13}$$

Different categories of mortars are distributed on th e basis of their average resistance measured accordi ng to, [16]. The conventional mortar envisaged for t his study should have an average compressive stren gth after 28 days greater than 20N/mm².

The compressive strength of the masonry walls can then be determined from formula 4 [16] ,

$$F_k = K.f_b^{\alpha}.\sigma_{mortar}^{\beta}$$

Avec :

- F_k : Compressive strength characteristic of masonry, in N/mm²;
- α et β : Parameters of Table 3.

Table 3: Current mortar parameters

	K	α	β
Group 1	0,6	0,65	0,25
Group 2	0,5	0,65	0,25
Group 3	0,45	0,65	0,25

The normalized average compressive strength (f_b) of masonry blocks can be determined by equation 5, [17].

$$f_b = \delta.\delta_c.f_{mean}$$

With:

- $\delta_c = 0,8$, for limestone masonry;;
- $\delta = 1,25$, for the agglos of 15x20x40;
- f_{mean} : Aglos characteristic strength (4MPa for B 40)

2. Results and discussion

2.1. Cement fineness modulus (lumps)

The passage through a 0.08 mm sieve made it possible to separate the solidified lumps of cement powder, on a 100 Kg sample. The results of the tests are presented in Figure 3, which shows a percentage of very fine particles below 10% up to three months with a net increase in the 5th month to 11.80%, it reaches a rate of 29% in the 10th month probably marking the deterioration of cement [18]. Overall, as expected, partial hydration with aging was observed by an increase in the lump rate approaching thirty percent of the cement weight after ten months.

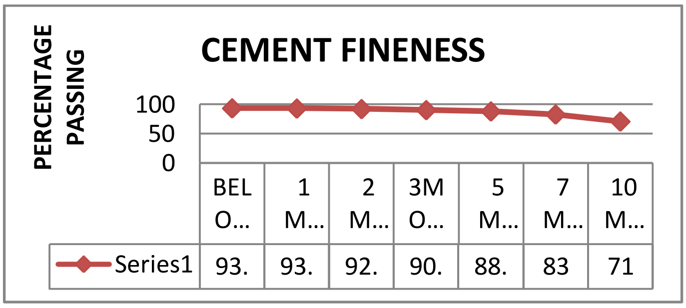

Fig.3 Fineness of cement

2.2. Concrete tests

2.2.1. Slump test

For each month, the slump tests gave the following slumps recorded in table 4, showing a slump of less than 9cm until two months corresponding to the plastic concretes before passing to the range of soft concretes at three months (slump of 10.3). This concrete becomes liquid from the 5th month (slump higher than 14cm), [19].

Table 4: Slump test results

Shelf life of cement	Mean Slump (cm)
<1 month	6.20
1 month	6.70
2 months	8.10
3 months	10.30
5 months	16.80
7 months	Shear
10 months	Shear

2.2.2. Concrete compressive test

The compressive strength of concrete was tested at 7, 14 and 28 days. The compressive strength of the concrete decreased with the aging of the cement was observed as for the previous tests, [16] ,[20].

As can be seen in Figure 4 corresponding to the 7-day compressive test, the concrete goes from 15.6 Mpa for less than one month storage and 14.21 Mpa at three months before dropping to 10.2 Mpa at 7 months and reaching 8.13 Mpa at 10 months. A loss of compressibility resistance is observed at 9% below the threshold set at 10% at the third month.

The 14-day compressive test using cements less than one month old increases to a value of 20.48 Mpa, reflecting the hardening of the cement as these values are higher than the 07-day compressive strength values. These values are relatively stable until three months with a compressive strength of 19.15,Mpa. A drop in compressive strength is observed at month 5 to 17.01,Mpa and it decreases to 11.2,Mpa at month 10.

These results show that the acceptable rate of loss of compressibility is reached after the 3rd month but with a value lower than the previous value (7%), [21] ,as can be seen in figure 4.

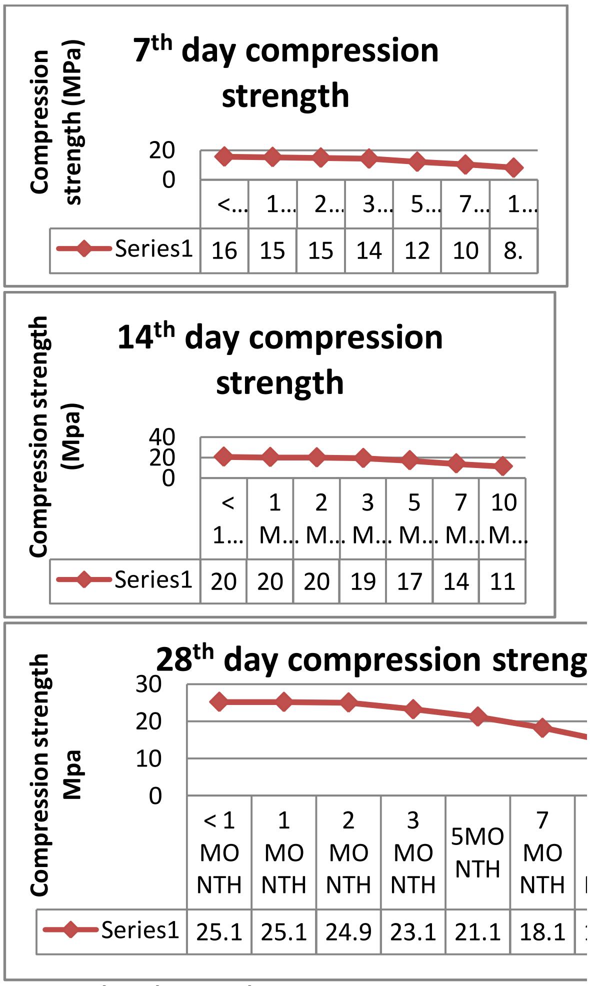

Fig.4: 7^{th}, 14^{th} and 28^{th} days compression strength of concrete

Compressive strength tests at 28 days showed higher values than the compressive values at 7 days and 14 days, figure 4, which confirms the hardening of the concrete. The compressive strength is 25.1 Mpa for cements less than one month old, 23.14 Mpa for cements three months old and reaches 14.56 Mpa for cements ten months old. Once again, a loss of more than 10% of compressive strength is observed after three months, reaching a rate of 16% at the fifth month.

Overall, we found that the cement loses more than 10% of lumps of its capacity after three months of storage under the conditions of the experiment by turning into a liquid state.

The compressive strength is 8% after three months compared to the factory outlet. It achieves a 15% drop in compression resistance after 5 months of storage. We find that the liquidity limit, the compressive strength and the lump rate vary excessively at the same time after three months, which is why, in the absence of laboratory results, the dealers advise to keep the cement for a maximum of three months.

2.3. Mortar constraint

The value of sand equivalent obtained being 88.8% shows that this sand is very clean with a low proportion of fines which may induce a plasticity defect, to correct this deficiency we increased the dosage of water to obtain high strength concrete [22].

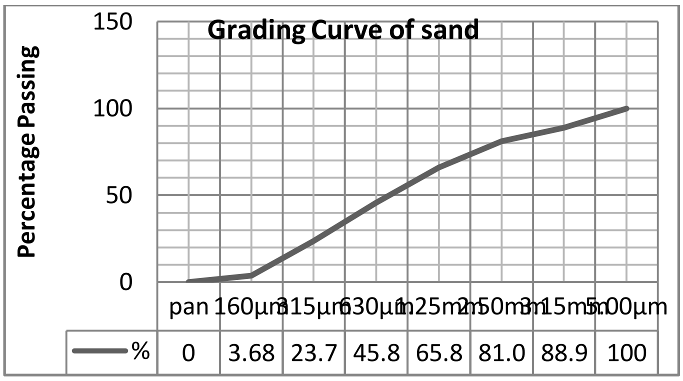

Figure 5: Sand granulometric analysis curves

The sand granulometric analysis, presented in Figure 5, showed a graded pattern of well graded sands with a fineness modulus of 2.7 which suggests satisfactory workability and good compressive strength with limited risk of segregation [18].

Formulae 1 and 2 and the results of particle size analysis give the grain spacing value shown in Table 5.

Formula 3 associating the constraints of the concretes and the maximum spacings between grains, obtained previously, allows us to draw the constraints of the mortars whose results are presented in Table 5. A loss of compressibility of 8%, compared with the value obtained for the cements used at the outlet of the factory, is observed after three months of storage, it is approximately 16%, at 5 months of storage.

Considering the Class B40 Blocks, generally implemented in developing countries, combined with the previous results on mortars, Formula 5 allows us to arrive at the values of resistance to compression of walls, the results of which are presented in Table 5. We find a breaking stress for walls of 2.30 Mpa in the first two months. There was a drop of 8% in the third month, then of 16% in the fifth month before reaching 42% in the 10th month.

The variations in stresses on the mortars and the walls once again show a sudden drop in stress beyond three months of conservation. We note that the same variations were observed for compression tests, slump test and fineness module study. These different results confirm the considerable loss of the mechanical characteristics of the cement after three months, established from the standardized tests. Furthermore, the correlation between, the results of the standardized tests, the percentage of lumps, the tests for the characterization of concretes and mortars shows that the mechanical characteristics of concretes and mortars can be estimated from the fineness module, the results of which can be refined by the standardized tests.

Table 5: mortar constraint calculation and maximum space of grains in mortar

time (month)	**<1**	**1**	**2**	**3**	**5**	**7**	**10**
$\sigma_{concrete}$	25,12	25,1	24,95	23,14	21,18	18,15	14,56
σ_{mortar}	22,01	22,00	21,87	20,28	18,56	15,91	12,76
F_K	2,30	2,30	2,30	2,26	2,21	2,12	2,01
Variation	0%	0%	1%	8%	16%	28%	42%

D(mm)=3.15; d(mm)=0.25; G=0.4; g*=0.87; $e_{p\max}$=3.31

2.4. Correlation of results

2.4.1. Concrete properties by lumps

The correlation curve of concrete compressibility and the fineness modulus obtained from the 0.08mm sieve rejects for 28-day preserved concretes, [14], implemented with cements preserved at various dates for 10 months, resulted in Equation 6. The value of the coefficient of determination close to unity shows that the point cloud is close to the logarithmic regression line, as can be seen in the figure 6.

$$\sigma_{concrete} = -7,41 \times \ln(Lumps) + 39,49 \qquad 6$$

The use of formula 6 shows that the accept able limit stress, which is generally 20 MPa for con cretes, is reached for a lump content of 13.87%, i.e. for the present case a shelf life of 4.5 months.This result shows that cements can be used in certain cas es for concretes beyond the conventional three mon ths.This result is an important one in view of the en clavement of the roads of the developing countries, used for the transport of cement, which generally in duces important times.

2.4.2. Mortar properties by lumps

The correlation curve again results in an a pproximate function having a determining paramet er close to unity, the equation linking the various pa rameters of which is given by formula 7:

$$\sigma_{mortar} = -7,40 \times \ln(Lumps) + 42,08 \qquad 7$$

Given that the mortars envisaged in the context of this study are those whose stresses are greater than 20 MPa, [24], the corresponding required rate of lumps is limited to 16.5%, it is conceivable for cements preserved under similar conditions to implement mortars without major risk with cements preserved for six months.

2.4.3. Mansonry properties by lumps

As can be seen in figure 6, the trend curve which best matches the point cloud is again a logarithmic curve with a coefficient of determination close to unity, governed by the formula 8. Taking into account the work of [14], the permissible rate of lumps has been limited to 20% for the implementation of other elements of the walls (agglos), i.e. a limit constraint of 2.2 MPa corresponding for the present case to a maximum conservation period of 6 months.

$$F_K = -0,21 \times \ln(Lumps) + 2,834$$

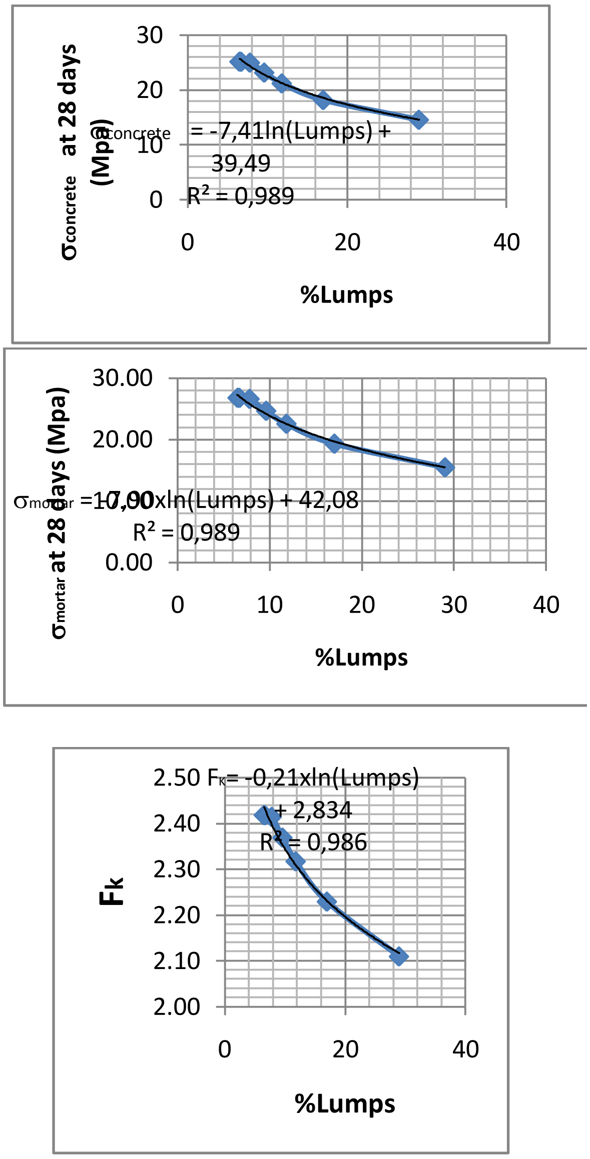

Figure 6: Correlation curves

III. Conclusion

The cost of cement characterisation tests and the complexity of their interpretation makes them inaccessible to modest construction sites, despite the multiple ruins observed in the constructions, induced by the use of damaged cements. The objective of this work was to develop an approach to predict the mechanical characteristics of concrete and cement mortar. The correlation between the variations of the fineness modulus, the slump test, the stresses of the concrete and mortar showed a clear decrease after three months of storage, in accordance with the conventional considerations established by the standard tests, a relationship between the proportion of lumps and the mechanical characteristics of the concrete and mortar was established.

- The results obtained by this approach for common cements marketed in several poor countries (Dangote 42.5), combined with correlation relationships, led to the following conclusions:The concretes can be used for a lump content of 13.8% corresponding to a limit stress of 20 MPa and a storage time of 4.5 months. However, after this period, this concrete can be used for filling, whose characteristic strength must be 9MPa, which is achieved for a proportion of lumps in the order of 60%;
- The mortars (joints, plaster) can be used with a maximum lump rate of 16.5%, which in this case corresponds to a storage period of 6 months;
- The rest of the wall elements can be used with a lump rate of 20%, corresponding to a shelf life of 6 months.

These different results show that this approach, whose results are consistent with standardised cement tests, makes it possible to obtain an acceptable estimate of the mechanical behaviour of concretes and mortars by sieving with 8 mm mesh. The simplicity of implementation and interpretation of these results makes them accessible to ordinary site personnel.

Aknowledgment

We are grateful to the authorities of GTHS Bamenda for allowing us to use the civil engineering labouratory for the tests.

References

[1] Higginson, E. C. (1970). “The effect of cement fineness on concrete”, ASTM STP 473 American Society for testing and materials

[2] Qadir, W., Ghafor, K., & Mohammed, A. (2019). Characterizing and modeling the mechanical properties of the cement mortar modified with fly ash for various water-to-cement ratios and curing times. Advances in Civil Engineering, 2019.

[3] Granger, L. P., & Bazant, Z. P. (1995). Effect

of composition on basic creep of concrete and cement paste. Journal of engineering mechanics, 121(11), 1261-1270.

[4] IS 4082, 1996. "Recommendations on stacking and storage of construction materials and components at site." 2nd edition. Bureau of Indian standard. New Delhi.

[5] IS 4031:1988 "Methods for physical tests for hydraulic cement", 2ndediton. Bureau of Indian standard, New Delhi.

[6] Celik I.B. (2009) The effects of particle size distribution and surface area upon cement strength development. Powder Technol.

[7] Bethel Getachew, Tamene Adugna and Sintayehu Assefa.(2018).Investigation on the effect of storage time due to moisture absorption of cement on the properties of concrete, International Journal of Development Research, 08, (01), 18558-18561.

[8] Mambou Ngueyep et al.(2017) Analysis of Strength Hydraulic Concrete Produced with a Mixture of Crushed Gneiss and Alluvial Sand, Journal of Applied Mechanical Engineering, ISSN: 2168-9873, Volume 6 Issue 5.

[9] BS EN 12390-3. (2009). Testing hardened concrete. Compressive strength of test specimens. *British Standard Institution*.

[10] Gupta, B.L and Gupta, A.(2004): Concrete Technology. A.K. John Publishers for Standard Publishers Distributors, Nai Sarak, Delhi, India.

[11] Standard, B. (2009). Testing hardened concrete. *Compressive Strength of Test Specimens, BS EN*, 12390-3.

[12] European Standard NF EN 12390-3 (2003) Test for hardened concrete, Part 3: Compressive strength of test specimens", AFNOR.

[13] Zahra, T., Thamboo, J., & Asad, M. (2021). Compressive strength and deformation characteristics of concrete block masonry made with different mortars, blocks and mortar beddings types. Journal of Building Engineering, 38, 102213.

[14] Granger, L. P., & Bazant, Z. P. (1995). Effect of composition on basic creep of concrete and cement paste. *Journal of engineering mechanics*, *121*(11), 1261-1270.

[15] A. M. Neville (2002). "Properties of Concrete" Fourth and final edition.

[16] European Standard NF EN 12350-6 (1999) Test for fresh concrete, Part 6: Density", AFNOR.

[17] Fortes, E. S., Parsekian, G. A., Camacho, J. S., & Fonseca, F. S. (2017). Compressive strength of masonry constructed with high strength concrete blocks. Revista IBRACON de Estruturas e Materiais, 10, 1273-1319.

[18] Zhang Y.M., Napier-Munn T.J. (1995) Effects of particle size distribution, surface area and chemical composition on Portland cement strength. Powder Technology.

[19] Domone, P. (1998). The slump flow test for high-workability concrete. *Cement and Concrete Research*, *28*(2), 177-182.

[20] Xiaodan, F., Biao, J., Hong, W., Yuezhou, Z. H. O. U., Yi, J. I. A. N. G., & Hongtao, L. A. I. (2013). Axial compressive test and study on steel tube confined high strength concrete shear wall. *Journal of Building Structures*, *34*(3), 100.

[21] Lee J.H., Lee T.G. (2019) Effects of high CaO fly ash and sulfate activator as a finer binder for cementless grouting material. Materials.

[22] Tiecher F., Gomes M., Dal Molin D., Hasparyk N., Monteiro P. (2017) Relationship between degree of deformation in quartz and silica dissolution for the development of alkali-silica reaction in concrete. Materials.

[23] Wu, B., Yu, Y., Chen, Z., & Zhao, X. (2018). Shape effect on compressive mechanical properties of compound concrete containing demolished concrete lumps. *Construction and Building Materials*, *187*, 50-64.

[24] Bakolas, A., Biscontin, G., Moropoulou, A., & Zendri, E. (1995). Characterization of the lumps in the mortars of historic masonry. *Thermochimica Acta*, *269*, 809-816.