Relationships between mineralogical and physico-mechanical properties of granitic aggregates

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Abstract. Several parameters are involved in the choice of the aggregates for concrete with good features: size, texture, quality, mineralogy, shape ... This work presents a study to characterize these materials through their geometrical properties (size, shape and size distribution), mechanical (uniaxial compressive strength and modulus of elasticity), physical (porosity, water absorption) and finally chemical and mineralogical properties. The relationships between mineralogical and physico-mechanical properties of granitic rocks from the Haute Garonne, France, were investigated. The relationships between these properties are described by simple regression analyzes. The results indicate that feldspar, chlorite and quartz contents of the studied rock-types significantly influence their physico-mechanical properties. Additionally, we find that the mechanical properties in compression are much higher when the mass percentage of quartz is important.

1 Introduction

These The aggregates play an important role in the behavior of concrete. Their influence is very strong in terms of mechanical performance. For concrete with good features, several parameters are involved in the choice of aggregates: quality, mineralogy, shape and granulometry … [1]. The aggregates intended for the concrete come from careers of massive rocks, alluvial layers or productions of lightweight artificial aggregates (expanded slag, expanded clay, expanded shale, etc.) [2].

As well as the mineralogical composition, the structure of the rocks is an important element in their classification, since it constitutes an indication on the way for the mineral assemblages are made in the rock.

In this research, we focused our choice on six types of aggregates of different mineralogical nature: two siliceous (crushed and rolled), a crushed granite, diabase, sandstone and limestone. This work describes the testing campaign conducted to characterize these materials through their geometrical properties (size, shape and granulometry), mechanical (uniaxial compressive strength and modulus of elasticity), physical (porosity, water absorption) and finally chemical and mineralogical properties. The comparative analysis of the results between different aggregates will be performed to estimate the influence of the mineralogical composition on the mechanical performance of aggregates, in particular the granitic aggregates.

2 Experimental characterization

In our study, six types of aggregates which differ in their mineralogical nature and shape were tested. Thereafter, these aggregates will be named according to the terminology introduced in Table 1.

The first two letters refer to the mineralogical nature of the aggregate. The last letter distinguishes the shape of aggregates: Rolled (R) and Crushed (C). The numerical values indicate the size range d/D where d (mm) is the minimum diameter of the aggregates and D (mm) maximum diameter. These size ranges slightly vary from one aggregate to another because of the origins distinct from materials. Nevertheless, they remain relatively comparable.

Table 1. Summary of the aggregates used.

Aggr-egate	**SiR**	**SiC**	**GrC**	**DiC**	**SaC**	**LiC**
Size range	4/10	6.3/10	4/10	6.3/10	6.3/10	4/12.5
Nature	Siliceous		Granite	Dia-base	Sand-stone	Lime-stone
Shape	Rolled	Crushed				

2.1 Physical Properties

2.1.1 Granulometric analysis

The granulometry is one of the most important parameters to consider in establishing a concrete formulation [1,3]. His knowledge allows for precise dosing of aggregates to optimize the granular skeleton and reduce its compactness according to the usual methods of formulation. The granulometric analysis also makes it possible to evaluate the content of fine elements through the value of the fineness modulus, the continuity and the regularity of the granularity.

This test is performed according to the standards (NF EN 933-1, 1997; XP P18-545, 2008).

The values are then plotted on a graph with cumulative percent passing on the y axis and logarithmic sieve size on the x axis. This graph is drawn continuously and semi-logarithmic in figure 1.

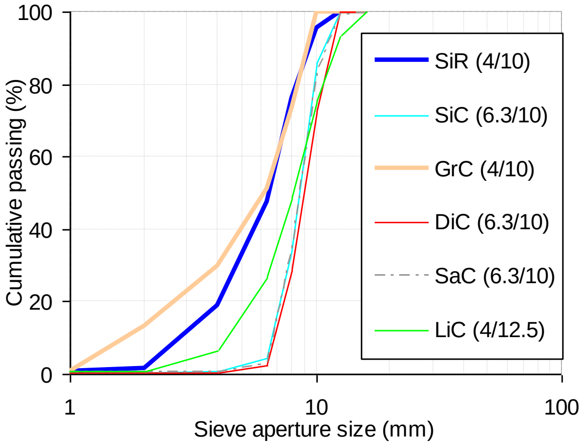

Fig. 1. Particle size distribution curves of the aggregates used.

The granite (GrC) having the proportion of material with the dimensions of aggregates is the lowest (13.1% for the sizes smaller than 2 mm).

The granularity determines the intergranular porosity of the mixture. In the extreme case where all the aggregates are the same size (discontinuous curve), the resulting porosity is important. Instead, the distribution along a continuous curve improves the granular arrangement and reduces the porosity of materials. Knowledge of these distributions is therefore essential for the determination of the proportions of different materials (aggregate, sand) to optimize the granular arrangement within the development of concrete formulations [1,3].

2.1.2 Densities, Water absorption and porosity

Different densities (apparent densities in bulk, real and absolute) can be defined for aggregates according to the procedure used in the laboratory and in accordance with the standard: NF EN 1097-6 (2001), NF EN 1097 (2006). These densities should provide information on the specific density of material and also the values of porosity accessible to water, closed and open pores.

Figure 2 shows the diagram of the porous structure of the aggregate.

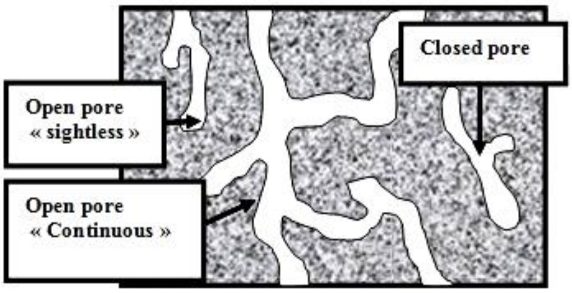

Fig. 2. Distinction of different pore of aggregates grain.

The measurements of the water absorption of the aggregates have been conducted according to the procedure of the standard NF EN 1097-6 (2001). The absorption water coefficient is defined as a ratio between an increase in the cumulative water flux at the material surface to the difference in the square root of time for which this increase was measured.

Table 2. Densities, Water absorption coefficients and porosities of different aggregates.

Aggregate	SiR	SiC	GrC	DiC	SaC	LiC
Density	2.7	2.7	2.6	2.6	2.8	2.7
Total Porosity (%)	5.3	5.4	3.9	5.5	3.2	4.6
Absorption (%)	1.2	1.1	0.9	1.6	1.0	1.3

The results of different porosities (Table 2) are presented as a histogram in Figure 3. We note significant differences in proportion for different types of porosities.

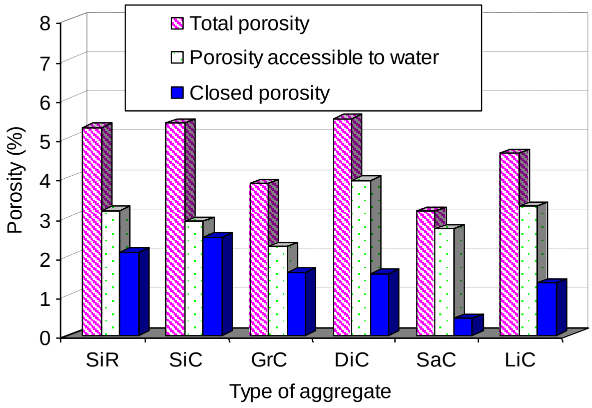

Fig. 3. Porosities of different aggregates.

The analysis shows that the values of total porosities higher are obtained for the diabase (5.5%) and siliceous aggregates (5.4% for SiC and 5.3% for SiR). We found in descending order: limestone (4.6%) and granite (3.9%) and sandstone (3.2%).

The highest open porosity is also observed for the diabase (3.9%). Those of siliceous and limestone aggregates are similar (between 2.9% and 3.3%). The minimum value is measured for granite (2.3%) and not for the sandstone (2.7%) in contrast to the total porosity. We can also note that the porosity accessible to water is 71 to 84% of the total porosity for limestone, sandstone and diabase, 59% and 60% respectively for the rolled siliceous and granites aggregates and 54% for crushed siliceous aggregates.

Finally, we note that the minimum value of the closed porosity corresponds to the sandstone aggregate, as the total porosity. The porosity of granite, diabase and limestone are comparable. The siliceous aggregates are characterized by the highest values of closed porosity.

2.2 Mechanical properties

The realization of the mechanical tests requires the preparation of rock specimens with sufficient size to ensure the homogeneity of the material and its representation about to the aggregate site. In addition, its size must be sufficient to enable instrumentation for the measurement of static modulus of elasticity. Among the various aggregates, three of them from a crushing (DiC, SaC and LiC) satisfy the three conditions. For the other aggregates, either it was unfortunately not possible to obtain sufficiently large carrots to allow the installation of a classical instrumentation, or the greatest dimension of the aggregates available on the site did not exceed the sufficient size.

The uniaxial compression tests are performed on a right circular cylinder. The diameter of the sample must be at least 20 times that of the largest grain [4]. A diameter of sample of 40 mm is chosen. The coring is done in wet condition, with a water jet. The direction of coring has no geological significance. In order to ensure a slenderness (height/diameter) of 2, the average height of the specimen is taken equal to 80 mm.

The press used to measure the uniaxial compressive strength has a maximum capacity of 3000 kN. This feature has been assessed following the recommendations NF P 18-412 (1981). The tests were carried out using the scale most appropriate force (600 or 1500 kN according to the estimated approximate resistance of the material), with a loading rate of 0.5 MPa/s.

We have chosen to evaluate the modulus and Poisson's ratio of the samples according to the Recommendations of the RILEM CPC8 (1972).

The density and porosity accessible to water were measured on these carrots before passing to the destructive tests.

The value of the bulk density, porosity accessible to water, the uniaxial compressive strength, the modulus and Poisson's ratio is the average values of a series of six samples. These values are given in Table 3 for the three aggregates.

Table 3. Mechanical resistance and Elastic characteristics of different aggregates.

Aggregate	**DiC**	**SaC**	**LiC**
Bulk density (standard deviation) in kg/m3	2620 (30)	2841 (83)	2676 (14)
Porosity accessible to water (standard deviation) in %	3.0 (0.8)	0.4 (0.1)	1.1 (0.5)
Mechanical resistance (standard deviation) in MPa	136 (55)	203 (61)	224 (25)
Static modulus of elasticity (standard deviation) en GPa	48 (6)	97 (3)	80 (2)
Poisson's ratio (standard deviation)	0.19 (0.02)	0.34 (0.09)	0.31 (0.01)

Initially, it is important to note the lower dispersion values of modulus of elasticity compared to the uniaxial compressive strength. This difference is probably due to stress intensities lower than those obtained at rupture (the damage mainly occurs at stress levels close to plastic deformation and fracturing).

The comparative study between the rocks shows that the elastic properties of aggregates are very different. The elastic modulus and Poisson's ratio of the diabase are lowest. The sandstone (97 GPa) presents an important modulus of elasticity compared to the diabase (48 GPa) and to the limestone for which the variation is less (80 GPa). This value is close to the value measured by de Larrard and Belloc, 78 GPa (limestone rocks of the same our career) [5]. The diabase studied by Cubaynes et al. resulting from the same our career, was characterized by a modulus of elasticity significantly higher of 102 GPa [6]. As the uniaxial compressive strength, we can consider to explain this discrepancy, the lithological variations and distribution of microcracks in the rock according to the localization within the same of extraction zone.

In view of our results, we note that the rigidities appear to increase when the total and closed porosities decrease. Thus, the sandstone is characterized by a high modulus and a low porosity. This tendency is consistent with the findings of Kováčik [7].

Figure 4 shows an excellent correlation obtained between the modulus of elasticity and uniaxial compressive strength.

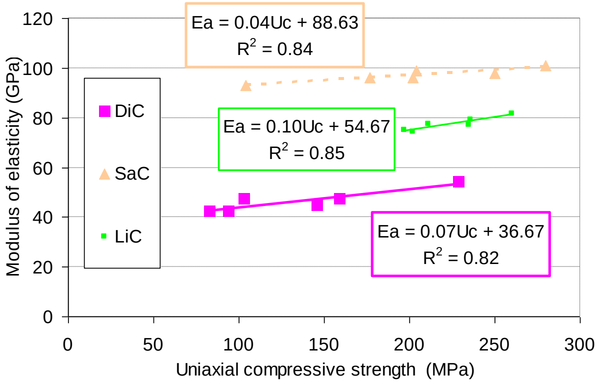

Fig. 4. Correlation between Young's modulus and uniaxial compressive strength of aggregates used.

This figure highlights a dispersion of the values of mechanical compressive strength translating the heterogeneity of materials. The limestone presents nevertheless differences between the measured values appreciably less important. As we previously mentioned, this dispersion can be correlated with the variations of the mineralogical nature of the aggregates within the same career and also with the quality of their structures and textures (microcracks, alteration ...).

2.3 Chemical and mineralogical properties

As we previously mentioned, texture, size, shape, chemical and mineralogical compositions of minerals affect the mechanical and physical properties of aggregates.

The chemical and mineralogical characterizations of the aggregates were made respectively by the means of a total chemical analysis and an X-ray diffractometric analysis (XRD). To carry out these analyses, the aggregates are crushed (particle size <63 µm).

Following these chemical and mineralogical analysis, we will try to detect the potential influence of the mineralogical nature on the mechanical properties of the aggregates.

Obtaining a representative powder sample from a bulk aggregate sample is an important step for effective chemical characterization. Analyzed volume is about some µm3. Elemental oxide weight percentages for all prepared aggregate powder samples were determined by X-ray spectroscopy and are presented in Table 4.

Table 4. Densities, Water absorption coefficients and porosities of different aggregates.

Composition	SiR	SiC	GrC	DiC	SaC	LiC
SiO2	64.5	63.6	61.2	49.9	64.9	0.7
Al2O3	12.8	12.4	15.3	15.9	6.0	0.4
Fe2O3	5.8	5.3	4.1	11.2	2.6	0.4
CaO	3.8	3.3	1.9	5.9	13.6	53.0
MgO	1.9	2.2	2.3	5.5	1.0	1.3
SO3	0.1	0.4	0.3	0.3	0.5	-
K2O	1.8	1.8	4.4	1.2	1.1	0.3
Na2O	1.8	2.5	3.4	3.8	0.6	0.1
P2O5	-	-	-	0.8	-	-
TiO2	-	-	0.8	2.4	-	-
Loss on ignition	1.6	1.6	2.2	1.2	2.3	42.3
TOT	94.1	93.1	96.0	97.6	92.5	98.3

The results reflect the dominance of SiO2 in siliceous aggregates (SiR and SiC), granite (GrC), diabase (DiC) and sandstone (SaC). The CaO is the principal element of limestone aggregate (LiC). It is also found in significant proportion in the sandstone. Alumina (Al2O3) is present in amounts ranging from 6.0 to 15.9% in siliceous aggregates, granite, diabase and sandstone. we observe a relatively high amount of iron oxide (Fe2O3) in the diabase. we find then a smaller percentages of magnesium oxide (MgO), potassium (K2O), sodium (Na2O) and other elements (Ti, S and P) in trace amounts (<1%).

In order to define with precision the minera-logical nature of the aggregates, we carry out diffractometric measurements.

From the study of these X-ray diffractograms, global chemical analyzes and other study based on the formulas of minerals detected on the diagrams, we can establish a semi-quantitative mineralogical composition. Thus, the proportions of the different minerals are detailed in Table 5 for each aggregate. Aggregates are classified according to the ascending order of the carbonate content and the second level in the descending order of their quartz content.

Table 5. Densities, Water absorption coefficients and porosities of different aggregates.

Type of mineral	SiR	SiC	GrC	DiC	SaC	LiC
Quartz	59	55	27	18	58	2
Carbonates	-	-	-	8	26	97
Calcite				8	26	91
Dolomite				-	-	6
Feldspar	33	34	47	20	5	
Micas	6	7	21	11	8	1
Chlorite	2	2	5	28	-	-
Pyroxene	-	-	-	5	-	-
Amphibole	-	1	-	5	-	-

The aggregates without carbonates are the granite and the siliceous gravels which have a granitic origin. The siliceous aggregates (SnR, SiR and SiC) have similar mineralogy resulting from the same career. They consist mainly of quartz in similar proportions (between 53% and 59%) and feldspar (37-33%) and secondary elements (micas and chlorites). The granite is characterized by a higher amount of feldspar (47%) compared to quartz (27%). It contains also more mica (21%) and chlorite compared to the siliceous aggregates.

Diabase, sandstone and limestone are materials containing carbonates unlike those of granite and siliceous aggregate. The diabase contains the lowest amount (8%). It consists also in descending order of chlorite (28%), of feldspar (20%), of quartz (18%) and of micas (11%). The sandstone consists mainly of quartz in proportions equivalent to those of siliceous aggregates (58%). Then, we find the carbonates (26%) and low percentages of micas (8%) and feldspar (5%). Limestone is the aggregate whose mineralogy is more distinguishes from the other aggregates. It is almost solely consisting of carbonates, mainly of calcite (96%), and a small proportion of dolomite (6%). There are some traces of quartz and mica.

3 Correlation between mineralogy and mechanical characteristic

It appears interesting to confront the results of the mineralogical analysis with the mechanical properties measured on carrots for limestone, the sandstone and the diabase. This study associated with analyses resulting from the bibliography can make it possible to estimate the influence of the mineralogical composition of minerals on the mechanical performances of the aggregates and to give indications with respect to the other aggregates for which the tests of mechanical characterization could not be realized. However, it must relativize these analyzes taking into account the uncertainty about the representativeness of the sample studied. Moreover, the textures aspect and structure of minerals was not the object of our study.

– Siliceous aggregate

Few data concerning the siliceous aggregates are available. Cubaynes and Pons studied the concretes incorporating of the siliceous aggregates resulting from the same career as the aggregate of our study and the elementary chemical composition rather near. They estimated a wide range of values of uniaxial compressive strength between 107 and 282 MPa, without citing the informations of the mineralogical composition and the values of modulus of elasticity.

– Granite

The compression strength resulting from the literature is between 159 and 193 MPa for the modulus of elasticity varying between 43 and 79 GPa. The Granite studied by Tugrul and Zarif (1999) approaching that of our study, mainly in terms of quartz content is characterized by a uniaxial compressive strength of 170 MPa and a modulus of elasticity of 52 GPa.

– Diabase

The diabase aggregate of our study is similar in terms of the uniaxial compressive strength (136 MPa) of those tested by Pomomis et al. (150 and 156 MPa) with the mineralogy is quite different [8]. Cubaynes and Pons worked with a diabase more preferment but we unfortunately do not have its mineralogical composition [6]. Nevertheless, it is clear that it is a siliceous diabase, which suggests a significant amount of quartz, which is not the case in our study diabase.

– Sandstone

The value of the uniaxial compressive strength of 203 MPa is comparable to the literature of 198 MPa [9- 10]. We do not have data of the modulus of elasticity and mineralogical compositions.

From this overview and a literature review, we can note the influence of certain minerals. Thus, we find that the uniaxial compressive strength increases with the increasing composition percentage of quartz (Figure 5).

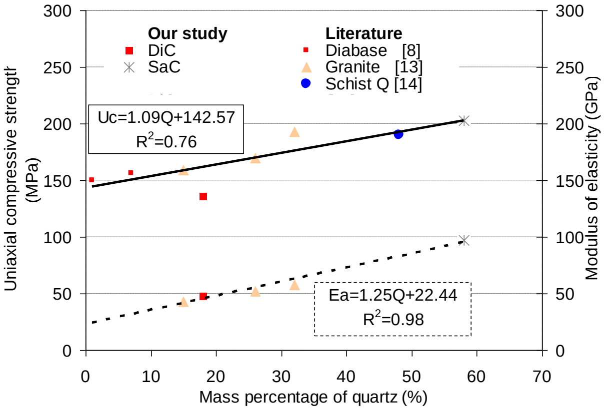

Fig. 5. Relationship between the mass percentage of quartz and mechanical characteristics of granitic rocks.

– Limestone

The limestone of this study is characterized by a uniaxial compressive strength of 226 MPa, this value is higher than those from the literature (between 130 and 178 MPa). However, it does not present the modulus of elasticity is higher. The maximum value of 105 GPa is that of a limestone studied by Cubaynes and Pons which does not correspond however to the maximum value of uniaxial compressive strength [6].

The limestone which is the aggregate mineralogy is the most distinct from other aggregates. It is composed almost exclusively of carbonates and from the literature, the mineralogy is characterized by excellent mechanical behavior when the porosity is low.

According to recent works [11-12], Some granular minerals such as quartz become the main stress-bearing skeleton and are able to accumulate large quantities of elastic strain energy and that is due to their higher strength than other flaky minerals (mica and clay). This observation can justify the high values of uniaxial compressive strength and modulus of elasticity measured on the sandstone (SaC) of our study.

According to work of Tugrul and Zarif, there is a linear relationship between the quartz to feldspar ratio and uniaxial compressive strength and modulus of elasticity of the rocks [13]. This relation is however not always significant because dependent on the degree of deterioration of feldspars. The latter can partly justify the mechanical characteristics of the lowest recorded for the diabase (DiC).

According Nasseri et al., The presence of mica of biotite type leads to the loss of connection between the grains and facilitates the primary cracks once the rock subjected to a load of compression [14]. The comparative study of schist and noted Ch Q-M differing only by the proportion of micas shows that the uniaxial compressive strength decreases by almost half (110 MPa to 50 MPa) when the amount of micas doubles (from 11 to 22%) [14].

The diabase aggregates are characterized by important chlorite concentrations which are characterized by a structure in layers and cleavage plans [14] being able to be at the origin of poor mechanical performances. Moreover, according to Yongsheng and al., for the diabases made up of feldspar, pyroxene and amphibole, their mechanical behaviors are controlled by feldspar and pyroxene when the content of amphibole is lower than 10% [15], which is the case of the diabase of our study. These observations could explain its higher deformability and its low uniaxial compressive strength. Moreover, as mentioned previously, the high mechanical performance of diabase identified by Cubaynes and Pons also tend to consider the possibility of alteration minerals (in particular feldspars and micas of our study).

4 Conclusions

Mineralogical composition is one of the main properties controlling the rock strength. Concerning the mineral composition, the variation in the quartz and feldspar contents is the most important factor affecting the mechanical properties in compression. The association between the dependent parameters and quartz and feldspar (as independent variables) is linear and, respectively, positive and negative.

This means that different minerals can have opposite effects on the strength parameters of the rocks.

Interrelationships between the mineralogical characteristics and the engineering properties of the granitic rock samples were determined by simple regression analysis. The conclusions of the study are as follows:

- A strong proportion of quartz, relatively high quartz to feldspar ratio, compared to the other aggregates of other studies, associated with a low content of mica, can give high mechanical properties for the siliceous aggregates.

- The granite aggregate consists of a moderate amount of quartz and characterized by a lower quartz to feldspar ratio, is relatively close to that studied by Tugrul and Zarif (1999) whose the values of uniaxial compressive strength and modulus of elasticity are respectively of 52 GPa and to 170 MPa. However, the strong quantity of micas and a higher proportion of feldspars could be at the origin of mechanical performances lower than these values.

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