**International Journal of Emerging Engineering Research and Technology**
**Volume 6, Issue 12, 2018, PP 1-16**
**ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)**

# Evaluation of the Grain Crushing Rate by the Concept of Fractal Dimension into the Proctor Test

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## ABSTRACT

*Our work is a part of an experimental study of the grain of local sandstone and schist materials subjected to the Proctor test using the notion of fractal dimension. It has been determined that with an increase in the fines content, the fractal dimension increases. This has allowed us to relate the fractal dimension to the compaction energy (number of blows to the Proctor test). These relationships were compared in terms of the quantity of produced fines or the hardness of the material and the size of the grains. Knowing that the fractal theory remains a good way to quantify the characteristics of the soil (roughness and dimensional of grain distribution), which are two parameters affecting the behavior of granular materials.*

**Keywords:** *Local materials, Proctor test, Crushing, Granulometric curve, Fractal dimension.*

## INTRODUCTION

In granular media, breaks occur during compaction. Depending on the shape, strength and compaction mode, soil grains can be degraded even during the first compaction. When the grains are solid, hard and fairly rounded, they can withstand high stresses that require the use of heavy equipment or compactors in the construction of high earth and rockfill dams to meet high density requirements. On the other hand, the angularly shaped grains of freshly extracted quarry materials endure a fragmentation due to the breaking of asperities under lesser stresses and reach higher densities [1]. A gradual crushing during compaction indicates a gradual change in the void index which subsequently influences the soil carrying capacity. The importance of grain fragmentation may not influence the design and stability of structures. Excessive crushing during compaction will improve the density which should be a consideration in evaluating the benefits of heavier compaction equipment. The advantage of crushing must not only break down weaker grains but it also improves the performance of granular media by reducing its compressibility and improving its permeability [1].

The structure of a granular material is described as an assembly of elements or grains of various sizes comprising infinity of details. It becomes essential to study the form's irregularities to better understand them. The study of these forms (angularity and roughness) plays a very important role in understanding the mechanical behavior of granular media [2] and it affects their strength and compactness.

Since a long time, soil physicists have measured the size of a grain with an equivalent diameter, which is not enough to describe the behavior of a material constituted by irregular shape grains. To understand these effects, a new technique was developed by [3] based on fractal geometry. The fractal dimension is a number that measures the degree of irregularity or fragmentation of a geometric or natural object [4] or the measurement of a surface's roughness [5] and this notion of fractal dimension is applied to invariant scale objects [6]. It is for this purpose that several methods have been developed [7] to calculate the fractal dimension of a granular material. In this study, two methods were used: the box method and the mass method. The Box counting method, which is a method of counting boxes [8], is one of the most, widely used methods [9]. It gives the grain level detailed information and more or less precise measures. The mass method (at the scale of a set of grains or a sample) is calculated using the results of the particle size analysis of the sample. The advantage of this method is that the granulometric curve data can be used, and the fractal dimension takes into account all the diameters of the measured sample.

The aim of our research is to use these two methods to study the crushing phenomenon of the grains of two local materials (shiny schist and sandstone), for different and well chosen grain forms; By characterizing the quantities of fines produced during the production of the various Proctor tests at different compaction energies. Two-dimensional image analysis techniques are applied to the grains of the samples in order to study the variation of their shape or size during compaction.

## GRAIN CRUSHING

To understand the behavior of granular materials, it is important to define the crushing grains's degree and to be able to quantify it. The crushing rate of the grains is measured by comparing the grain size curves before and after each test [10]. Breaking the grains lead to a reduction in their size which causes an increase in the percentage of fine particles (particles smaller than the smallest diameter of the sieving) and, consequently, a modification of the particle size distribution. The shape of the grains is a significant factor. The grain breakage increases with their angularity. This rupture is limited to the points of contact but may extend into the grain. Indeed, the angular shape obtained by crushing favors the concentration of the stresses (the contact surfaces being very weak) and the breaking strength of the grains is more quickly reached [11]. The smaller is the crush resistance, the higher is the friction angle of the mineral and the lower is the crushing stress. In addition, the smaller the particle size, the slighter the sphericity of the grains, the lower the crushing stresses [12].

The phenomenon of grain breakage is linked to the physical and mechanical properties of the latter as well as to the stress paths applied. [13] Classified grain breakage according to three modes: fracture, flaking and abrasion.

## METHODS OF CALCULATING THE FRACTAL DIMENSION

Fractal theory remains a good way to quantify soil characteristics such as roughness and dimensional distribution of grains, which are two parameters influencing the behavior of granular materials. There are several methods for quantifying the irregularity of grains.

In this study, two methods were used: the box method and the mass method. The Box counting method gives detailed information and more or less precise measurements at the grain level. The mass method (at the scale of a set of grains or a sample) is calculated using the results of the particle size analysis of the sample.

### The Box Counting Method

This is the most widely used method in the case of fragmentation. The value of the fractal dimension gives us an idea of thegrain's dimensional distribution in the soil and the fragmentation process. Mandelbrot has shown that the distribution of rock fragments is a fractal distribution. As he also suggested that fractal fragmentation could be measured by developing the fractal dimension of equation (1). This method is based on a theory that the number of grains smaller than a predetermined size can be exponentially formulated:

$$N(X > x) = Kx^{-FD_R} \quad (1)$$

Such that x is a dimension of the predetermined grain size; X is the number of the grains greater than the size x; N is the number of grains (fragments); K is a constant of proportionality obtained by the slope of the trend line; and the $FD_R$ is the fractal dimension of fragmentation [5], [14].

By plotting a predetermined size as a function of the number of boxes contained in this surface (fig. 1), the fractal dimension is determined by the following equation:

$$FD_R = -m \quad (2)$$

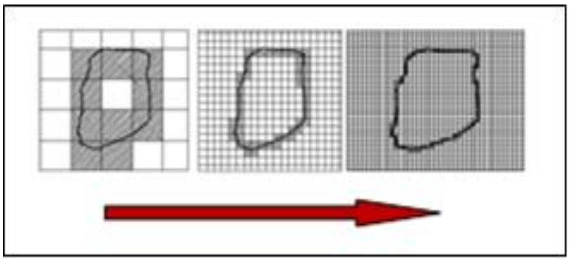

**Figure1:** *Application of the fractal dimension by Box Counting*

According to the study by [9], using the areas of the grains, an equation similar to equation (2) can be obtained. In this case, the fractal dimension is equal to (-2m).

Figure 2 (fig. 2a and fig. 2b) illustrates, as a function of the size of the grains, the values of fractal fragmentability with respect to the fragmentation process which took place when the compaction energy varies from 25 to 100 blows. The fractal dimension value is obtained by adjusting the point cloud describing the logarithm of the perimeter as a function of the logarithm of the surface by a linear function. The value of the correlation coefficient expresses the quality of the fit. The trend curves shown in Figure 2 (fig. 2a and fig. 2b) shows good fit of the data and the power law with a high degree of correlation ($R^2$> 0.90).

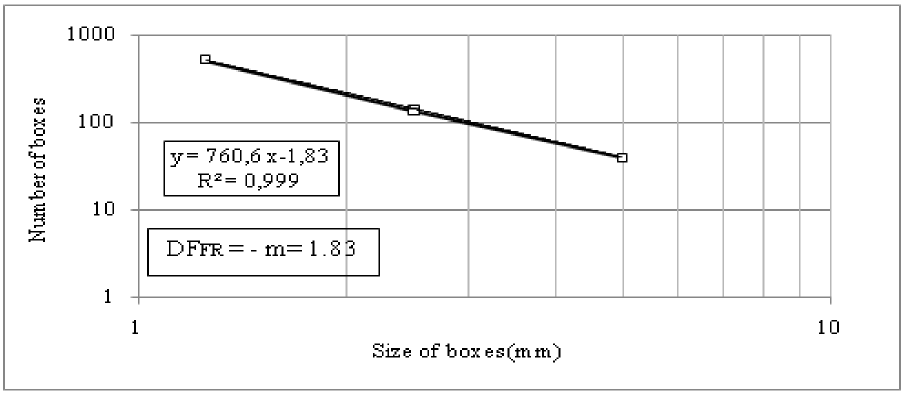


**Figure2a:** *Determination of the fractal dimension with the box method of the grains of 20 mm of the sandstone material*

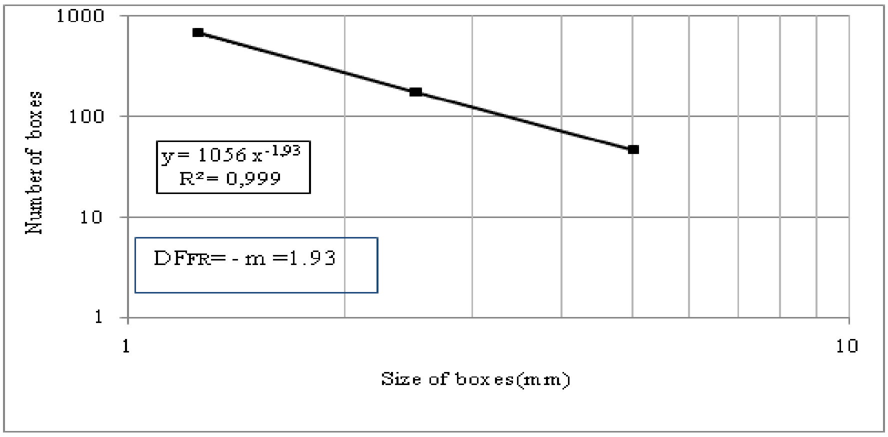


**Figure2b:** *Determination of the fractal dimension with the box method of the grains of 20 mm of the shiny schist materials*

## Mass Method

This method is based on the distribution of the grain sizes of the material sample. [15] Developed a formula using granulometric analysis for the calculation of fractal fragmentation $FD_{FR}$. This method of calculation uses the mass retained in sieve and its corresponding diameter. This equation is defined as follows:

$$\frac{M(R<r)}{M_T} = \left(\frac{r}{r_L}\right)^{3-FD_{FR}} \quad (3)$$

Where M (R <r) is the cumulative mass of grains; the size R is smaller than a given comparative of class r;

$M_T$: total mass of the grains;

r: Size of sieve opening;

$r_L$: maximum grain size defined by the largest opening of the sieve size;

$FD_{FR}$: fractal dimension of fragmentation.

The fractal dimension is calculated using the following equation:

$$FD_{FR}=3-m \quad (4)$$

With 'm' is the exponent of the power law of equation (3) representing the regression line best suited to the cloud of points representing the different diameters.

Figure 3 (fig. 3a and fig. 3b) shows an interesting connection with the fractal dimension of the resistance to fragmentation of the two materials. The trend curves show a good fit of the data and the power law with a high degree of correlation ($R^2$> 0.90). Indeed, the nature and the mineralogy of the material play a very important role in the values of the fractal dimension. The fragmentation of the schist material gave rise to a small amount of fine particles compared to the friable sandstone material, which modified very little its fractal dimension.

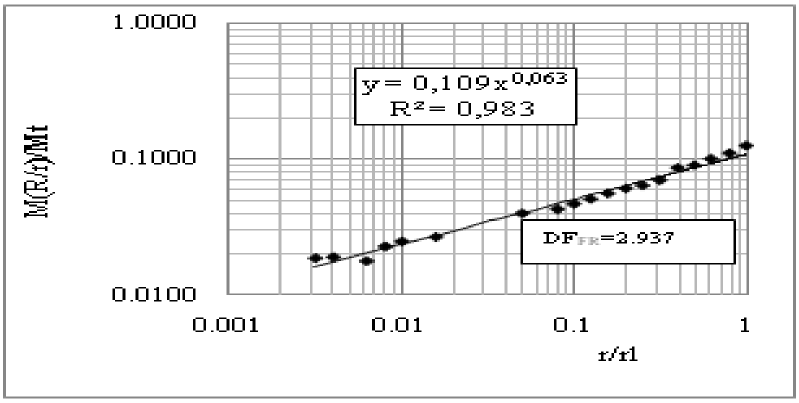


**Figure3a:** *Trend curves obtained after 25 blows with the masses method of the sandstone material*

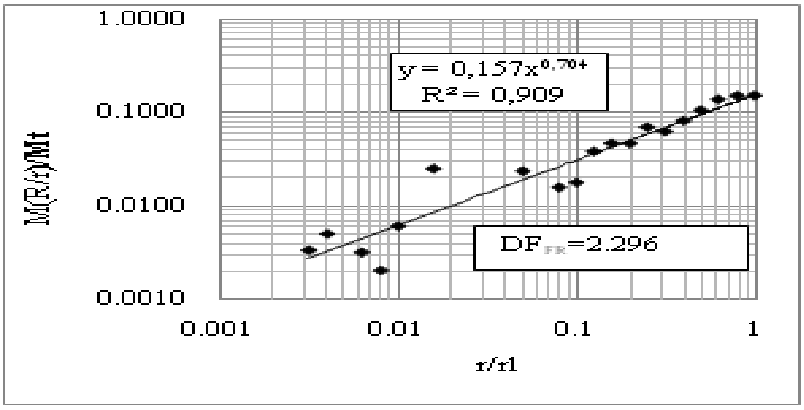


**Figure3b:** *Trend curves obtained after 25 blows with the masses method of the shiny schist material*

For the mass method, it is calculated using the particle size analysis of a soil sample. The advantage of this method is that the granulometric curve data can be used. Another advantage of this method is that fractal dimension takes into account more points in the granulometric curve (on a sample scale) than the other methods. Consequently, the value of fractal dimension which is determined may represent a distribution of more precise quantities. Moreover, it is noted that when the value of fractal dimension is small, it indicates that the size distribution is not completely fractal. This usually occurs on a sample that has not yet been subjected to high stress.

## CHARACTERISTICS OF MATERIALS USED

The Tizi-Ouzou region has several deposits of materials (sandstones, schists ...) located on the surface and close to the national roads, making their operation easy and at a lower cost. Their choice is justified by the very important place they occupy in the realization of several projects in civil engineering such as dams, roads, railways, etc.

The two materials are extracted at the level of the Tizi-Ouzou region, the sandstone at the place called "Yakourene" located 70 km to the east of the chief place Tizi-Ouzou and the schists are extracted in the deposit located at the place called " Candle Bridge "located 7 km east of Tizi-Ouzou. The results of the chemical analysis to determine the various minerals of the sandstone are grouped in Table 1 and the petrographic study of the schist was carried out on thin plates and the main results are represented in Table 2 [16].

**Table1:** *Mineralogical composition of the sandstone material*

| Compositions / Matérial | Quartz % | calcium oxide % | Alumina % | Iron Oxide % | Loss to fire |
|---|---|---|---|---|---|
| Sandstone | 46 à 65 | 12 à 15 | 9 à 14 | 1 à 3 | 12.58 à 13.69 |

**Table2:** *The various mineralogical components of shiny schist [16]*

| Texture | Structure | Quartz (%) | Biotite (%) | Muscovite (%) | Tourmaline (%) | Secondary Minéral |
|---|---|---|---|---|---|---|
| Schist with two micas | Schistose | 45-50 | 20-25 | 20-25 | 8-10 | fine shell mica |

The schist studied is shiny schist who contains 65 to 75% of stable minerals (quartz and tourmaline) and 40 to 50% of unstable minerals (micas: biotite and muscovite). The results of the main geotechnical identification characteristics are summarized in Table 3 and the aggregate test results in Table 4 for both sandstone and shiny schist materials.

**Table3:** *The physical characteristics values of the sandstone and schist materials*

| Charactéristics | W (%) | γd (gr/cm$^3$) | γh (gr/cm$^3$) | γs (gr/cm$^3$) | e | Sr (%) | n | $\gamma d_{opt}$ (gr/cm$^3$) | $W_{opt}$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| Sandstone Values | 4.3 | 1.75 | 2.30 | 2.74 | 0.56 | 21 | 0.36 | 1.72 | 8.0 |
| Shiny schist Values | 4.9 | 2.34 | 2.46 | 2.79 | 0.19 | 72 | 0.16 | 2.21 | 6.5 |

The physical characteristics of the sandstone are quite similar to those of the sand. The shiny schist recorded the highest densities unlike the sandstone; this reverts to its massive and compact texture, which explains why it has the lowest indices of voids and porosity in relation to sandstone.

The sandstone is slightly more fragmentable than the shiny schist: the fragmentability coefficient, FR (NF P94-066), of the two materials is less than 7, so they are not very fragmentable. The degradability coefficient, DG (NF P94-067), of both materials (sandstone and shiny schist) is less than 5, so they are not degradable (Table 4). The Micro-Deval coefficient (MDE) (NF P18-572), of the sandstone is higher than that of the shiny schist. The two coefficients are between 25 and 45, these two materials can be used for the shaped layers (Table 4). For sandstone, the coefficient Los Angeles, (LA) (NF P18-573), is slightly higher than that of shiny schist. The coefficients LA and MDE of the two materials are simultaneously less than 45, so these materials can be used only for shape layers (Table 4), thus [17] classifies the sandstone used in subclass $R_{41}$ and the shiny schist in subclass $R_{61}$.

**Table4:** *Aggregate tests results of the materials*

| Tests | LA (%) | MDE | FR | DG |
|---|---|---|---|---|
| Sandstone results | 32.6 | 37.6 | 6.9 | 3.27 |
| Shiny schist results | 25.5 | 29.2 | 6.4 | 2 |

## APPARATUS AND PROCEDURE

The Proctor's equipment is simple and includes a Proctor mold and a Proctor lady. The procedure of this test is a set of mechanical operations, which lead to increase the density in place of a soil. This action increases the compactness of the soil, thus tightens the texture of the material, reduces the possibility of deformation of the ground and improves its bearing capacity.

The principle of the Proctor test consists in placing the material in several layers in the Proctor mold. Each layer must be compacted with the same energy. The test is repeated several times by varying the water content of the soil. For each water content considered, the dry bulk density of the soil is determined and the curve of the variations of this density is established as a function of the water content. The two main characteristics are deduced: optimal dry density and optimum water content.

The materials used were extracted as large blocks. The latter are crushed using a hammer for large diameters and a jaw crusher for small diameters. The grains thus obtained are of irregular shape. The Proctor tests carried out on these two materials showed the following curves in figure 4.

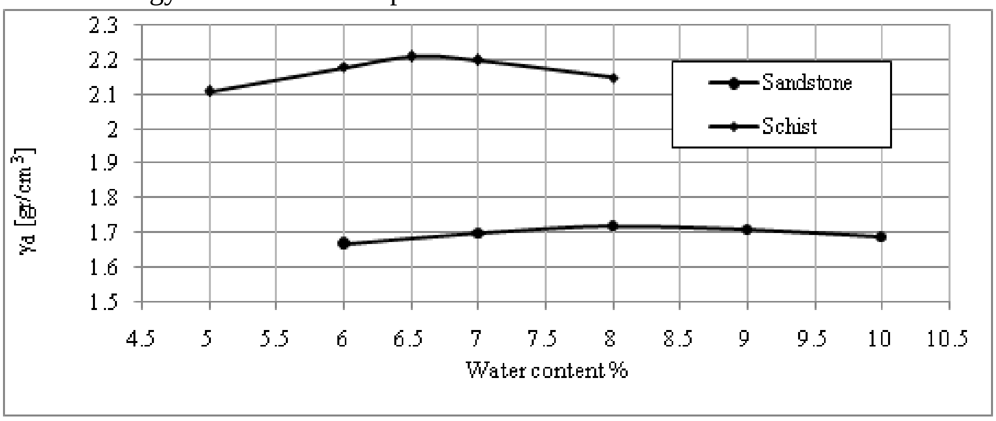


**Figure4:** *Proctor's Curves for the sandstone and schist materials*

The Proctor curves have a slightly flattened appearance for both materials, indicating that they are not very sensitive to water, since a fairly large variation in moisture has little effect on dry density.

To better demonstrate the influence of the shape of the grains, the selection of forms: shape under rounded for sandstone (Fig. 5) and elongate shape for shiny schist (Fig. 6), is done manually.

**Figure5:** *The sub-rounded form for the sandstone*

**Figure6:** *The elongated form for the schist*

A grain of each diameter is colored with a color distinct from the other diameters in order to follow its crushing and deduct its fractal dimension during the Proctor tests. Two types of samples were made: samples in a single layer of 15.2 cm and samples in 4 layers of 3.8 cm separated by a fine tissue (fig. 7). The colored grains are positioned in the modified Proctor mold as a function of depth; at 3.8 cm, 7.6 cm, 11.4 cm and at 15.2 cm. We have limited ourselves to 4 layers instead of five recommended for the mold CBR because the size of the two biggest grains exceeds 3 cm. All colored grains of the same layer have the same numbering as the layer position to facilitate recovery after testing. Photos were taken for the colored grains to study their variations in size and shape and to deduce their fractal dimension with the box method.

After each test, the colored grains are recovered and then photographed for the calculation of the fractal dimension with the box method. Then, a particle size analysis will be carried out for the whole sample for the calculation of the fractal dimension with the mass method.

In order to compare the results obtained with the Proctor test, the same initial particle size curve is used for all samples for both single-layer 15.2 cm and 4-layer 3.8 cm samples (Fig. 7). The fines were defined as the particles having a smaller diameter than the smallest diameter of the particle size curve.

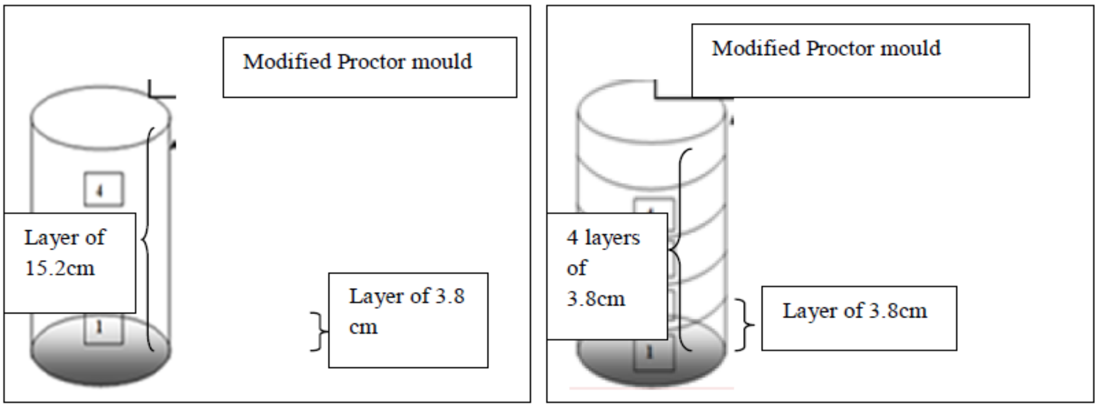


**Figure7:** *The layers arrangement in the sample in the Proctor mold*

## Results and Discussion

There are many factors influencing the fragmentation of granular material in the sample: coordination number, grain size, layers number and applied stress are the main ones. Thus, a higher coordination number indicates that the force is distributed through contacting grains to higher degree. This phenomenon also reduces the stress on the grain, causing a higher chance of the grains surviving the impact.

In addition, the type of the crushing (fracture) must be considered in order to fully understand the crushing behavior, which produces fragmentation.

### Case of a Test with a Single Layer of 15.2 Cm

The granulometric curve is plotted before test (fig. 8) and for each compaction energy, the corresponding crushing rate is then calculated and the fractal dimension by the mass method is deduced simultaneously. We can thus evaluate the evolution of the fractal dimension as a function of the rate of crushing.

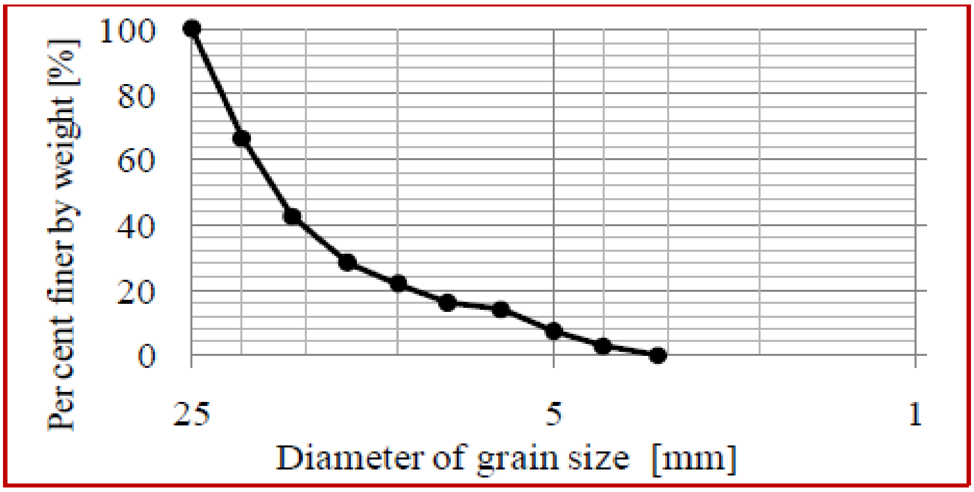


**Figure8:** *Initial grain size distribution*

Figure 9 respectively shows the particle size distribution for the different compaction energies (25, 50, 75 and 100 blows) before and after Proctor test for sandstone (fig 9a) and shiny schist (fig. 9b).

The rate of crushing has a direct relationship with the number of blows; Which results in the spreading of the granulometric curves obtained after each compaction energy (25-50-75-100 blows); Both for sandstone and schist (Figure 9).

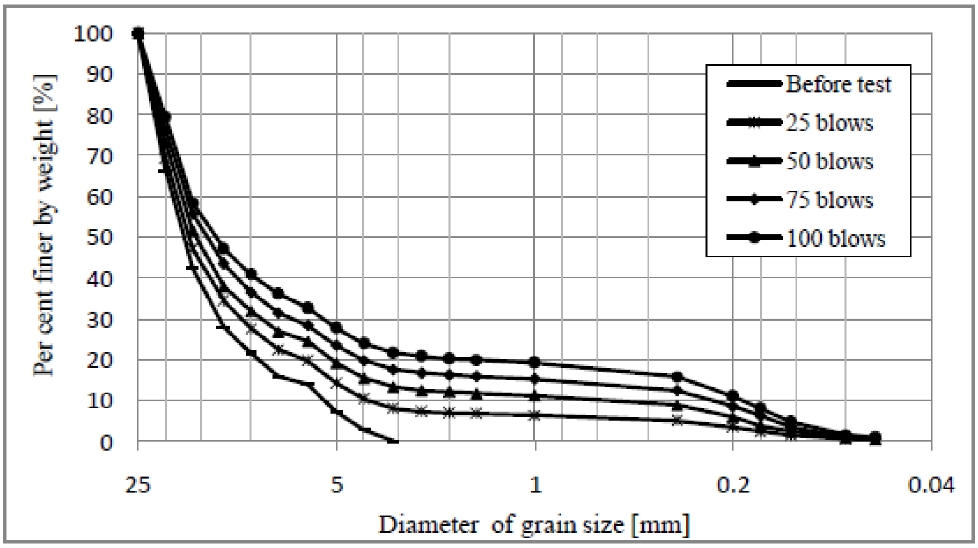


**Figure9a:** *Spreading of the grain size distribution curves of the sandstone under 25-50-75 and 100 blows*

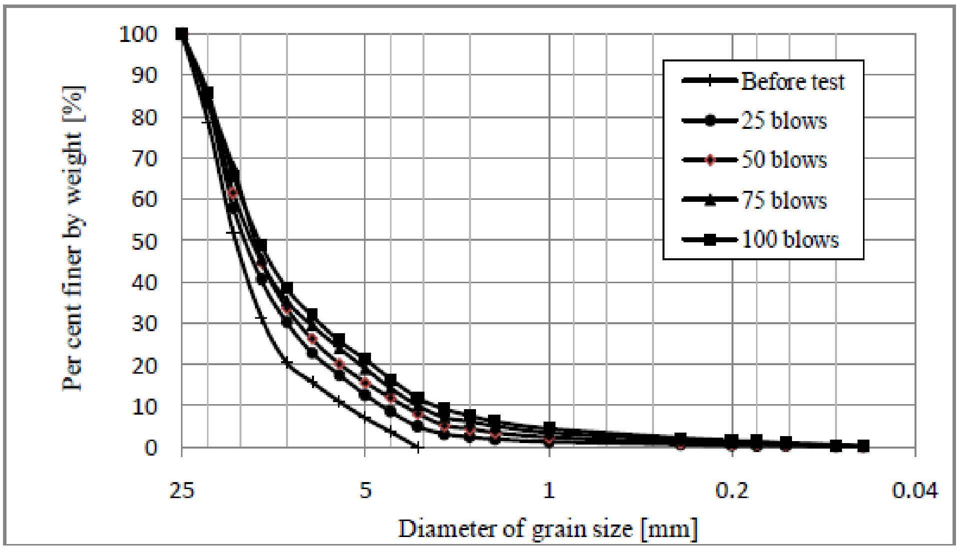


**Figure9b:** *Spreading of the grain size distribution curves of the shiny schist under 25-50-75 and 100 blows*

Indeed, for compaction energy of 25 blows, the granulometric curves of the two materials are very close (figure 10a). A deviation is significant for energy of 100 blows (Fig. 10b). This difference in grain size spread between these two materials is due to the crushing rate of the grains, which is more important for the sandstone than for the shiny schist, which results in a variation of the fractal dimension. The latter is higher for sandstone than for shiny schist because the quantity of fine particles produced, after each compaction energy, is more important for sandstone than for shiny schist. This is due, no doubt, to the internal structure of each material. The sheet form of the grains of the shiny schist renders its crushing rather difficult as for the grains of the sandstone which have a shape under rounded.

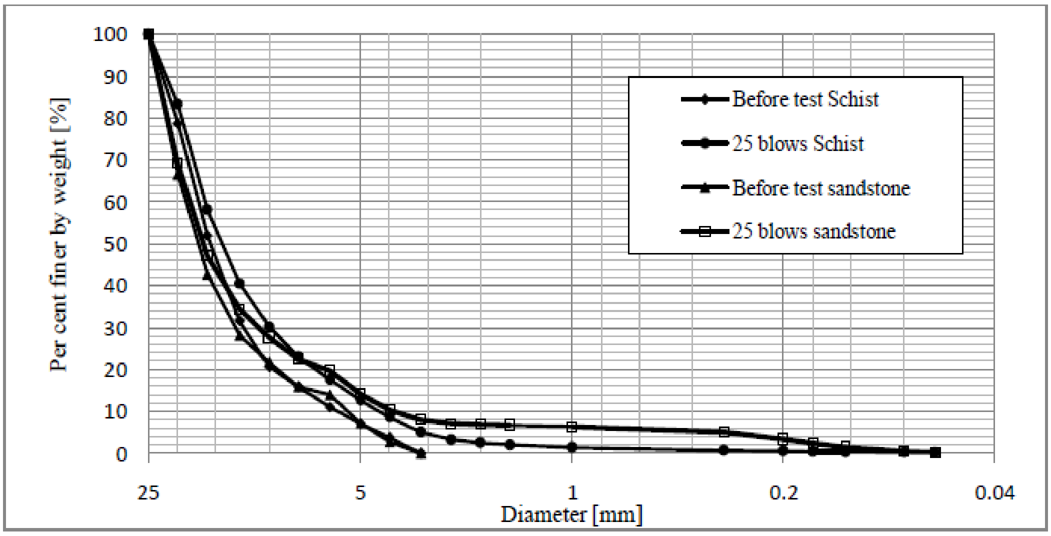


**Figure10a:** *Spreading comparison of grain size distribution curves of sandstone and shiny schist material subjected to 25 blows*

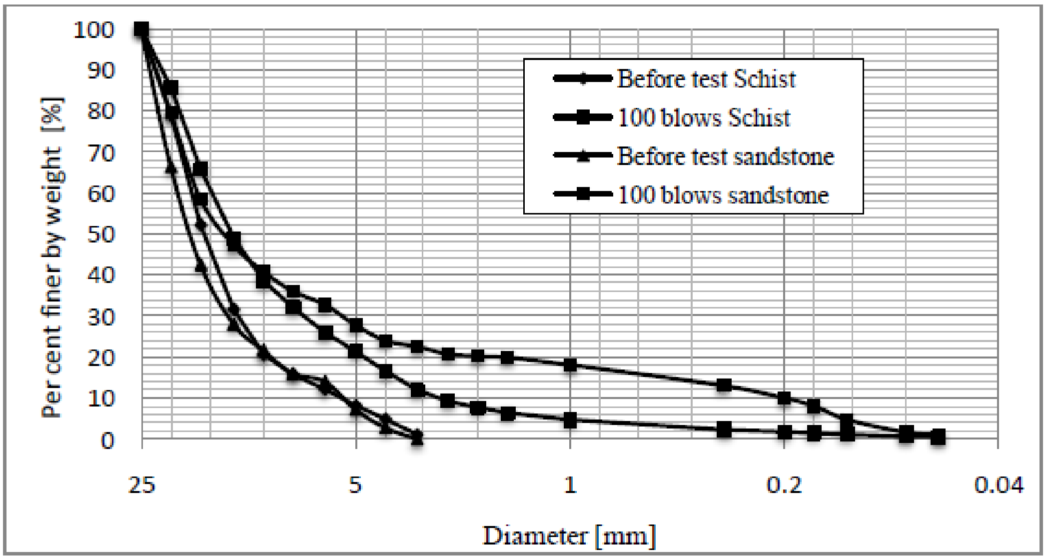


**Figure10b:** *Spreading comparison of grain size distribution curves of schist and sandstone materials subjected to 100 blows*

Consequently, the energy transmitted at depth does not damage the grains of the lower sub-layers of the shiny schist, so crushing of the schist grains occurred only in the 3.8 and 7.6 cm deep sub-layers. Unlike sandstone, the energy transmitted in depth causes displacements and rotations of the grains which are facilitated by their shape under rounded. These rotary movements take place in various directions and cause contact between the grains; Causing more crushing and a production of fine particles in the under layers that reaches up to 11.4 cm deep.

The grains of the two materials, under the effect of compaction energies, degrade and produce quantities of fines. The reduction of this size is thus evaluated with the fractal dimension. In the case of the whole sample (mass method), figure 11 shows the evolution of the fractal fragmentation dimension of the sandstone and the shiny schist as a function of the compaction energy. Consequently, as the compaction energy is increased, the crushing rate of the grains will be higher and will lead to an evolution of the fractal dimension. This fractal dimension tends to stabilize for the shiny schist, whereas it is evolutive for the sandstone.

This fractal dimension calculated after the Proctor tests, using the mass method (fig. 11) for the sandstone material, is between 2.45 and 2.73, while it varies from 2 to 2.66 for the shiny schist. It can therefore be deduced from the quantities of fines produced that the sandstone crushes more than the shiny schist.

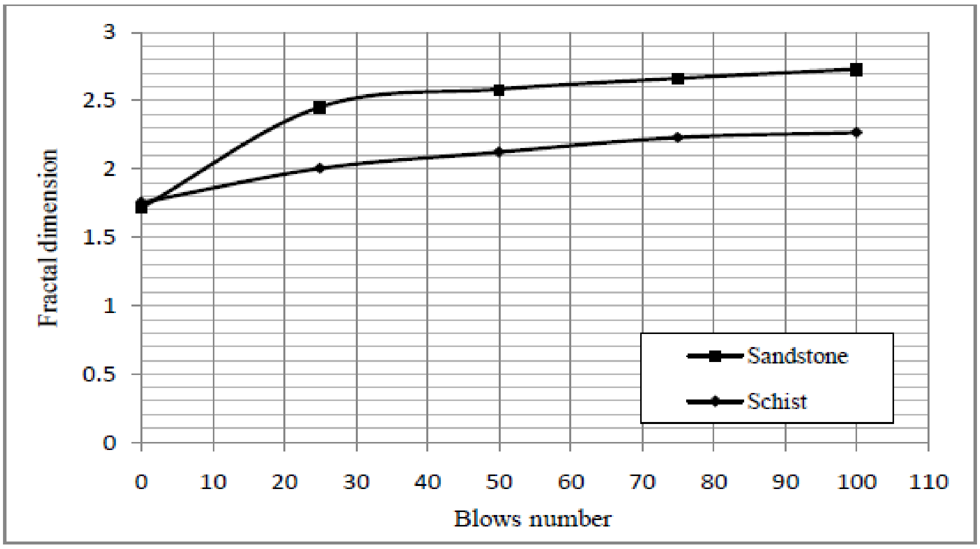


**Figure11:** *Comparison of the fractal dimension as function of the blows number of the two materials with the masses method*

This increase in the crushing rate of the grains depends on the intensity of the compaction energy and the shape of the grains. According to [18], a sample has reached a total crush (all grains are broken) when the fractal dimension is greater than or equal to 2.5. The fractal dimension values obtained show that the sandstone grains are "totally crushed" from an energy of 50 blows.

Whereas for shiny schist, the grains are "totally crushed" only from an energy of 100 blows. This is confirmed by figure 12 which shows the evolution of the fractal dimension of the two materials as a function of the quantity of fines produced during the Proctor tests where the quantity of fines produced by the shiny schist is only important for an energy of 100 blows.

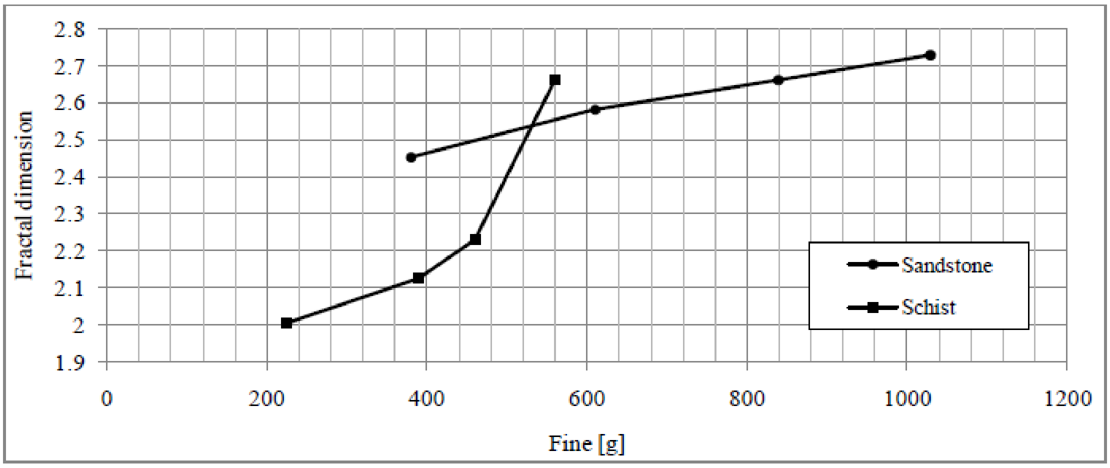


**Figure12:** *Evolution of the fines produced by the two materials as a function of Fractal dimension using the masses method*

Figure 13b shows that for almost all diameters the variation in fractal dimension tends to zero in the deep sub-layer (15.2 cm), which explains why the shiny schist grains of the deep undercoat are not subjected to Crushing during compaction. This variation gradually decreases from the surface sub-layer to the deepest sub-layer. Indeed, the fractal dimension tends to become constant from a depth of 11.4 cm, regardless of the diameter of the grains.

In the case of sandstone, the variation of the fractal dimension is important for the small diameter grains and it tends to become constant as from a depth of 11.4 cm (fig. 13a). On the other hand, for large diameters, it gradually decreases from the surface sub-layer to the deepest sub-layer. The larger the size of the sandstone grains, the smaller the variation in the fractal dimension and tends to merge with the depth of 11.4 cm. On the other hand, the fractal dimension of the grains increases with increasing grain size (grain diameter) for both shiny schist and sandstone. This result is explained by the fact that the larger grains have large surfaces that are more or less rough than small surfaces.

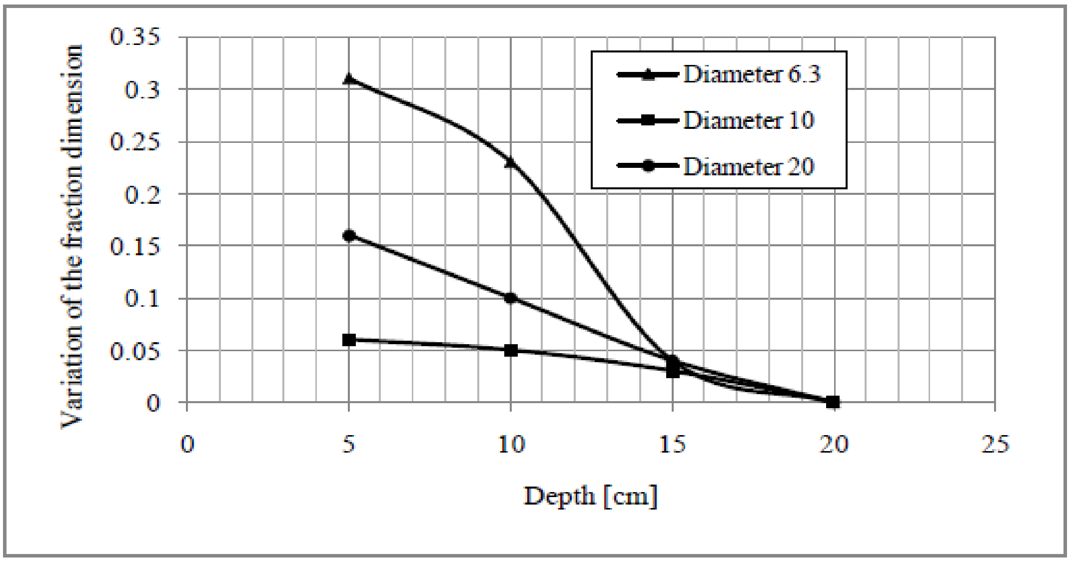


**Figure13a:** *Evolution of the variation of the fractal dimension as a function of the depth for the various diameters of the sandstone grains with box counting method and for a compaction energy of 100 blows*

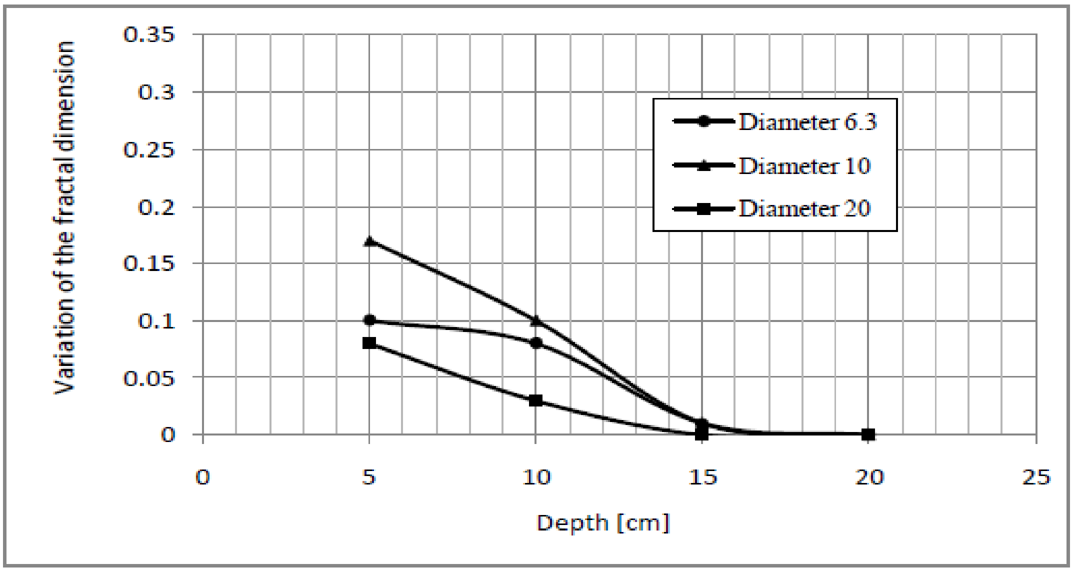


**Figure13b:** *Evolution of the variation of the fractal dimension as a function of the depth for the various diameters of the schist grains with box counting method and for a compaction energy of 100 blows*

For the shiny schist, according to the classification of [13], the most predominant mode of rupture is abrasion and then chipping by rupture of the asperities or by rupture of the angularities and only a few grains totally fragmented in the surface sublayer. The crushing rate by total fracture is significantly high in the first 3,8 cm depth and decreases to 7,6 cm depth. Unlike shiny schist, the modes of fracture by chipping and total fracture are dominant for the sandstone grains and the rate of crushing of the grains by total fracture reached 11,4 cm of depth.

## Case of Test Specimens Consisting of 4 Layers of 3.8 Cm

The layers are prepared in the same manner so that the same granulometric curve will be maintained for each layer. Each layer is insulated from the others with a fine fabric. To simulate what is done in practice, the sample is prepared as follows: the 3.8 cm layer is poured, subjected to compaction (25 blows) and sieving. Then the layer will be put back into the mold which will be insulated by a fine fabric and a second layer will be poured into the mold which will be subjected to the same compaction energy as the first layer and which will also be insulated by a fine fabric. The same procedure is used until the fourth layer is reached. A granulometric analysis for each layer after testing is carried out followed by taking pictures of the colored grains to visualize the crushing rate of these grains. The same procedure was carried out fewer than 50, 75 and 100 blows. This process is carried out to study the influence of grain degradation as a function of depth.

### *Influence of Compaction Energy (Number of Blows) on Each Layer of Sandstone and Shiny Schist*

The granulometric curves obtained show a progressive spreading as the compaction energy (number of blows) increases at the level of the first layer both for the sandstone (fig. 14a) and the schist(fig. 14b). However, the spreading is much more pronounced for the sandstone. A quantity of the fine particles occurred during the crushing of the grains, which justified the spreading of granulometry for both the sandstone and the shiny schist.

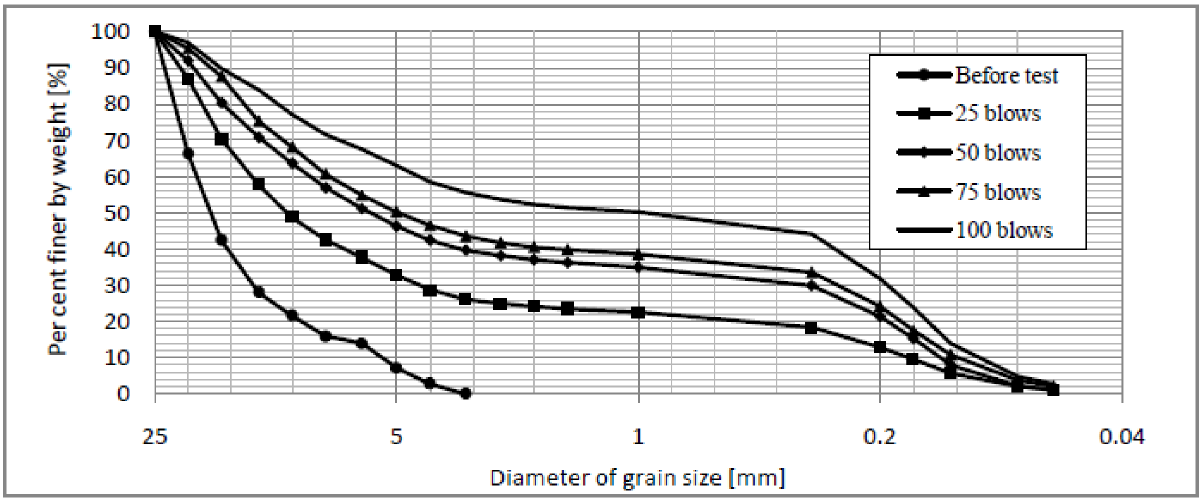


**Figure14a:** *Spreading of the grain size distribution as a function of the compaction energy of the first layer of sandstone material*

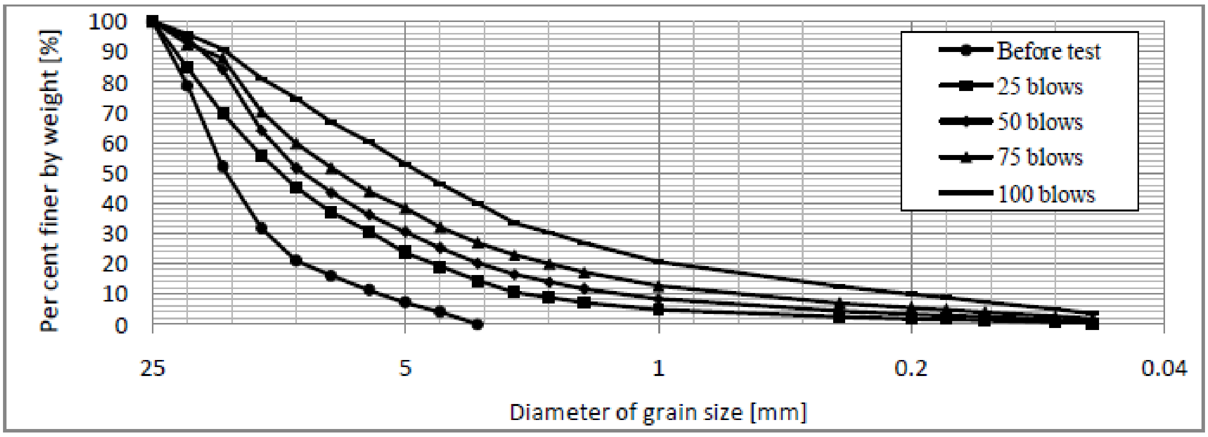


**Figure14b:** *Spreading of the grain size distribution as a function of the compaction energy of the first layer of shiny schist material*

### *Grain Size Distribution as a Function of the Depth of Each Layer of Sandstone and Shiny Schist*

The granulometric curves also show that spreading increases as a function of depth under constant compaction energy. Indeed, the crushing rate of the grains increases and the curves become more and more spread from the surface layer to the deepest, both for the sandstone (fig. 15a) and the shiny schist (Fig. 15b). This can be explained by the fact that the deep layer (first layer) is subjected not only to its compaction energy when it is placed but also to the energy of the upper layers when they are placed.

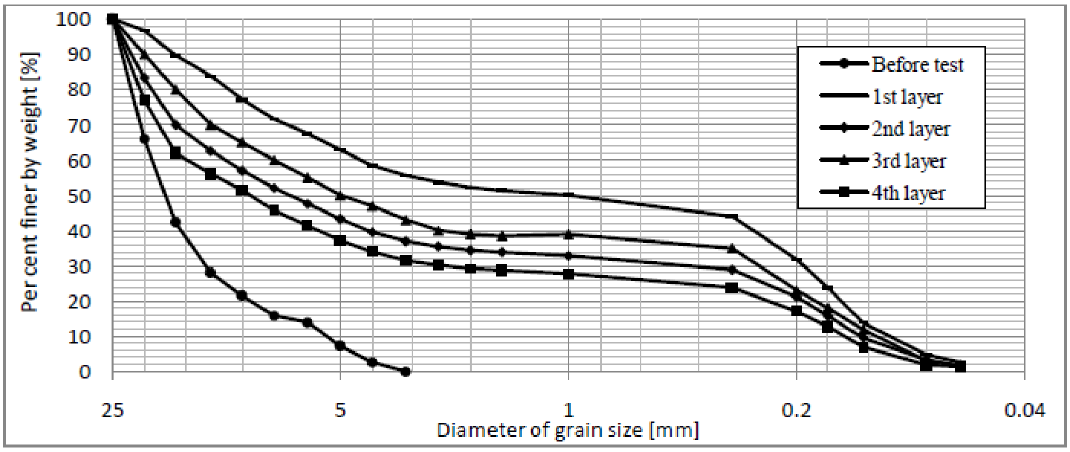


**Figure15a:** *Evolution of the granulometric spreading of the sandstone under 100 blows*

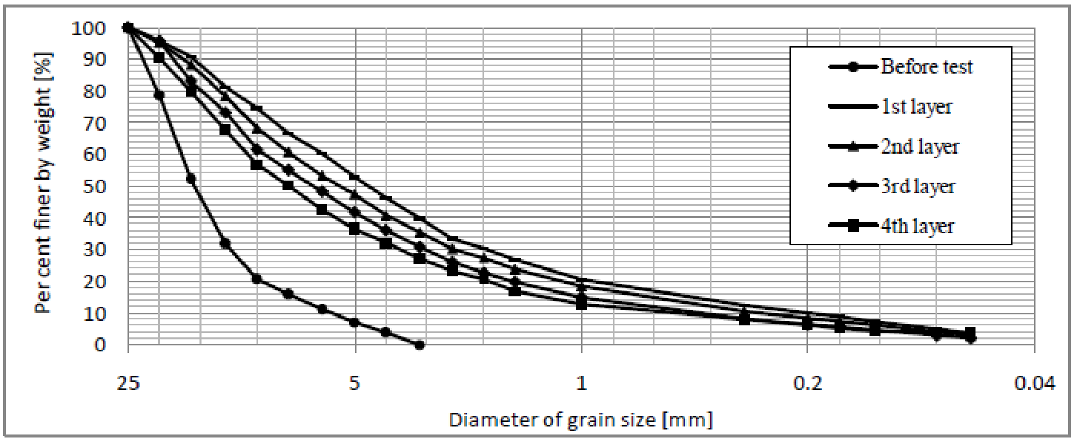


**Figure15b:** *Evolution of the granulometric spreading of the shiny schist under 100 blows*

## *Evolution of the Fractal Dimension as a Function of the Depth*

The crushing rate of the grains has a direct relationship with the number of blows and with the height of the sample. Indeed, the fractal dimension of each layer varies as a function of the number of blows. The quantity of fine particles produced after crushing of the grains in the first layer is the highest and then decreases from one layer to the other as it rises to the surface (fig. 16). This quantity of fines increases with compaction energy for both the sandstone and the shiny schist materials and is all the more important as the grain diameter is high in the first layer. The higher one goes back to the upper layers, the smaller the amount of fine particles. The smallest amount is obtained for the surface layer (4th layer). This quantity of fines produced is more important for the sandstone material (fig. 16a) than for the shiny schist material (fig. 16b). This is evident and is due to the mineralogical composition of the two materials (the shiny schist being harder than the sandstone).

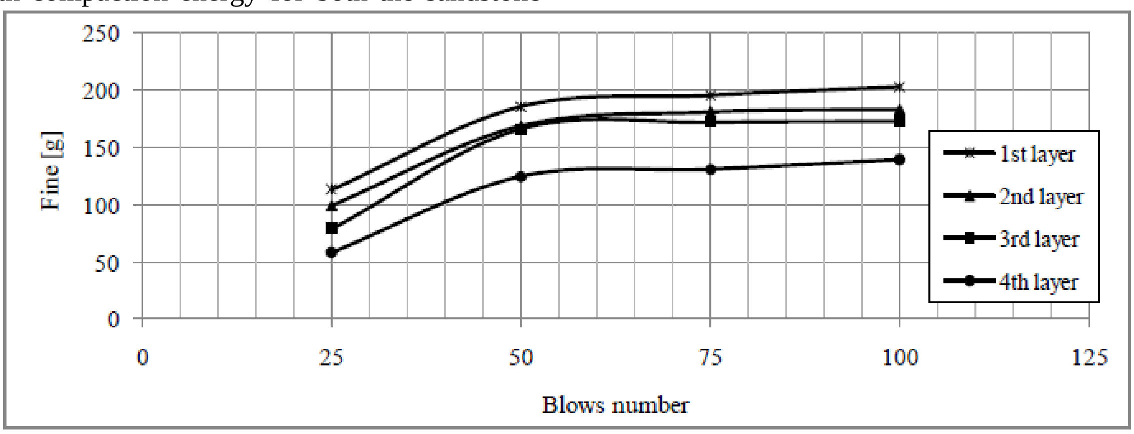


**Figure16a:** *Evolution of the fine particles after crushing as a function of the compaction energy of the sandstone material*

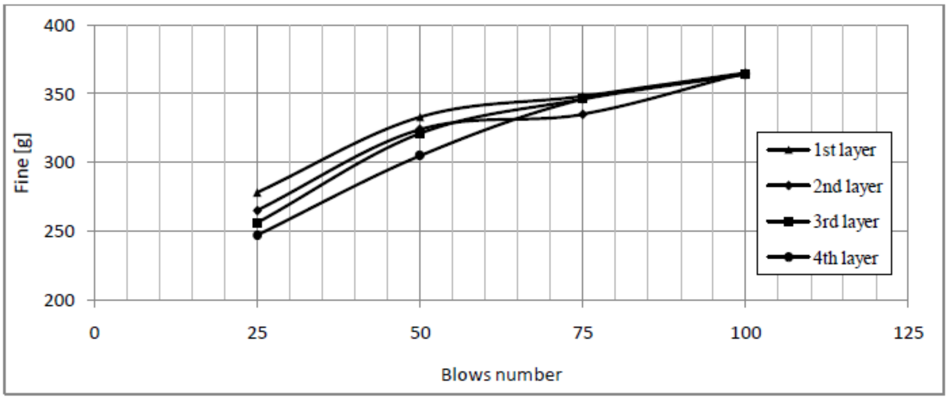


**Figure16b:** *Evolution of the fine particles after crushing as a function of the compaction energy of the shiny schist material*

In the four layers subjected to 25-50-75-100 blows respectively, a progressive increase in the fractal dimension of the surface layer to the deepest layer is noted (figs. 17a and 17b). This is confirmed by the granulometric curves which are increasingly spread out as a function of the depth of the layers (figs. 15a and 15b). It is interesting to note that the granulometric curve of the 4th layer is close to that of the third layer; hence the fractal dimensions are quite close. This means that the crushing rate of the grains in the fourth layer is almost identical to that of the third layer. Indeed, in the three superficial layers, the compaction energy is absorbed by the movement and crushing of the grains; On the other hand, the first layer (base layer) is subjected not only to the effect of the upper layers but also to the reaction of the base of the mold. The fractal dimension increases as a function of compaction energy and as a function of the depth of the layers. Since the first layer is compacted 4 times, the second layer is compacted 3 times, the third layer is compacted 2 times, and the fourth layer is compacted only once.

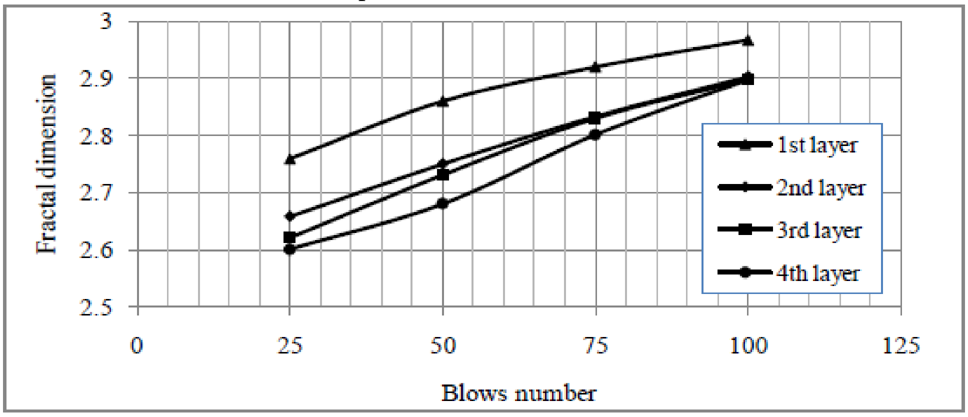


**Figure17a:** *Evolution of fractal dimension with masses method for each layer of the sandstone material under different energy*

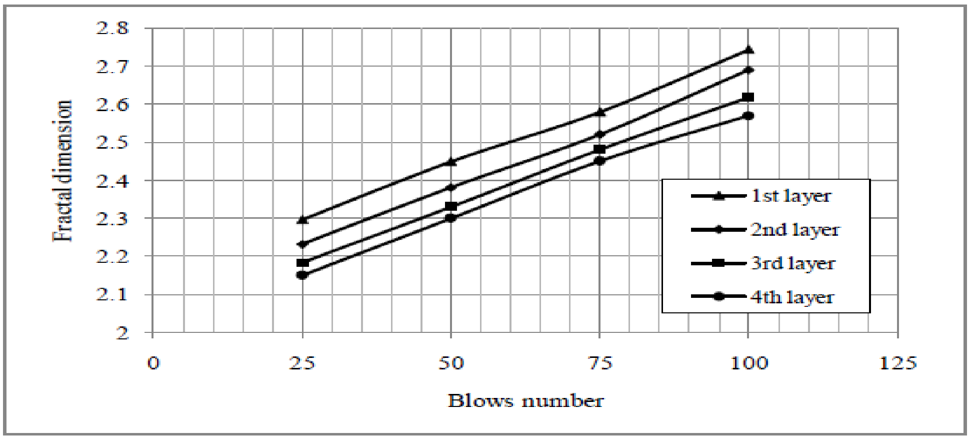


**Figure17b:** *Evolution of fractal dimension with masses method for each layer of the shiny schist material under different energy*

In order to find the link between the fine particles obtained after crushing the Proctor grains and the fractal dimension, figure 18 confirms that the first bottom layer has the highest fractal dimensions and the surface layer the fractal dimensions Lower. These results are valid for both sandstone and schist. Therefore, the greater the quantity of fines, the higher the fractal dimensions.

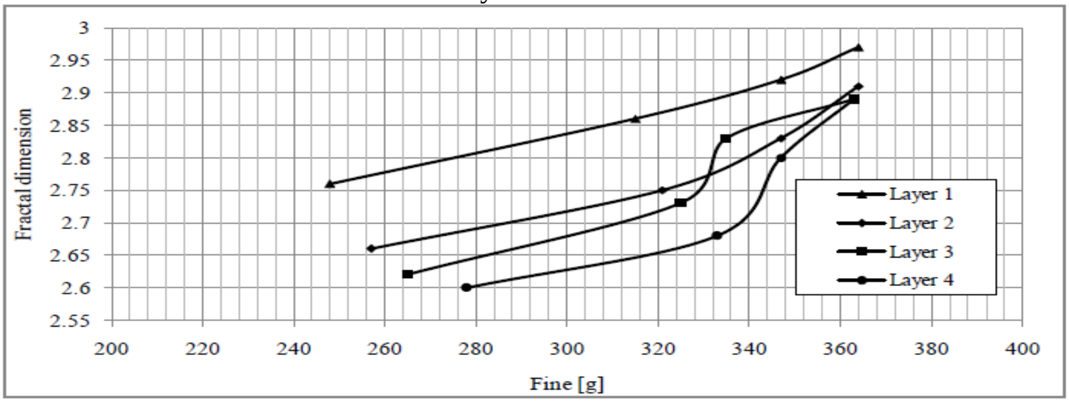


**Figure18:** *Evolution of fractal dimension as a function of fines of sandstone produced under different energy compaction*

Indeed, in the first three superficial layers, the compaction energy is absorbed by the movement and crushing of the grains; On the other hand, the first layer (base layer) is subjected not only to the effect of the upper layers but also to the reaction of the base of the mold. In the four layers subjected to 25-50-75-100 blows respectively, there is a progressive decrease in the fractal dimension of the deeper layer to the surface layer. The granulometric curves are increasingly plotted as a function of the depth of the layers (figs. 15a and 15b).

### *Calculating the Fractal Dimension with the Box Method*

By taking the grains individually from the deepest layer to the surface layer, all the diameters of the colored grains of the first layer subjected to 100 blows have shown that their fractal dimension has decreased. Indeed, for the 20 mm grains, the fractal dimension in the first layer decreases from 1.89 to 1.85 under the effect of 100 blows and continues to decrease to 1.83 under the effect of a second layer subjected to 100 blows and then Stabilizes at 1.78 under the effect of the 3rd and the 4th layer subjected to 100 blows. For the other diameters, the effect of the upper layers on the first layer showed a slight increase in the fractal dimension corresponding to a greater roughness. Knowing that the fractal dimension of the grains by the Box Counting method depends on the mode of rupture they undergo. Indeed, the fractal dimension decreases in the case of "splitting" and / or "rupture of the asperities" and it increases in the case of "chipping" which causes the increase of surface irregularities. For grains larger than 8 mm, the grain angles were broken; On the other hand, for diameters less than 6.3 mm, abrasion and flaking occurred. The effect of the upper layers on the first layer did not show any significant deviations of the fractal dimension; only the effect of the second layer on the first caused small deviations of the fractal dimension (Figs. 19a and 19b).

Figure 20 show that the grains of the first layer have undergone more degradation than those of the 4th layer. This resulted in an increase in the fractal dimension of the first layer grains. The difference in the crushing rate of the grains of the two samples between the first and the fourth layer is greater for the sandstone than for the schist.

The calculated fractal dimension decreases progressively with increasing compaction energy for the sandstone and the four layers (fig. 19a); Whereas for shiny schist, the fractal dimension increases to an energy of 75 blows and then decreases with a high energy of 100 blows (Fig. 19b). However, the evolution of the fractal dimension for the sandstone grains is more significant for the 1st layer, whereas the fractal dimensionspacing for the other three layers is not very important. This can be explained by the fact that the layer 1 plays the shock-absorber for the layer 2; the layer 2 for the layer 3 and the layer 3 for the fourth layer. For the shiny schist, the difference of fractal dimension between the first and the fourth layer is significant; while the fractal dimension spacing of the second and third layers is small or insignificant up to energy of 75 blows. For energy of 100 blows, fractal dimension of the grains of the 1st, 2nd and 3rd layer are quite close.

By comparing the fractal dimension of the two materials, figure 20 clearly shows that the fractal dimension of the sandstone grains of the first layer has a large deviation from the fourth layer and that the fractal dimension of the fourth layer of the sandstone grains presents results as close as those of the schist grains for energies of 25 and 100 blows; whereas for 50 and 75 blows, the fractal dimension values are different between the grains of the two materials. However, for shiny schist, the difference of fractal dimension between the 1st and the 4th layer is insignificant except for the energy of 100 blows where the difference is more or less important. This can be explained by the hardness of the two materials, where the shiny schist is harder than the sandstone. In addition, the rounded shape of the sandstone material collapses more than the elongated shape of the schist material after testing.

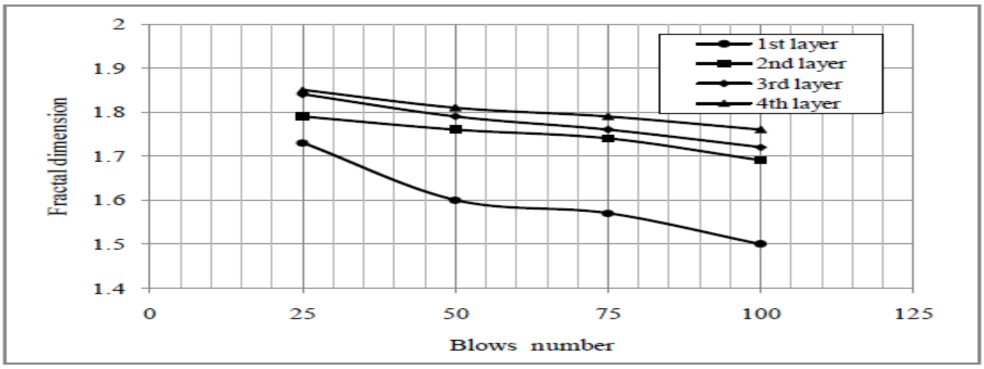


**Figure19a:** *Evolution of fractal dimension for each layer depending on the energy of compaction for grains 12.5 mm of sandstone material with the box counting method*

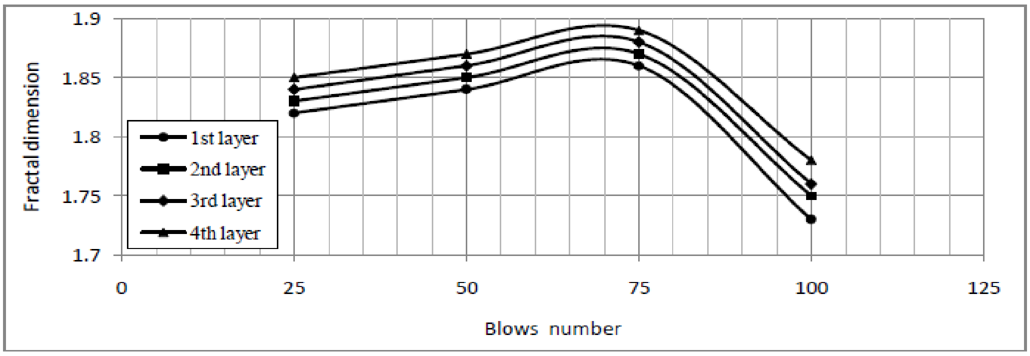


**Figure19b:** *Evolution of fractal dimension for each layer depending on the energy of compaction for grains 12.5 mm of shiny schist material with the box counting method*

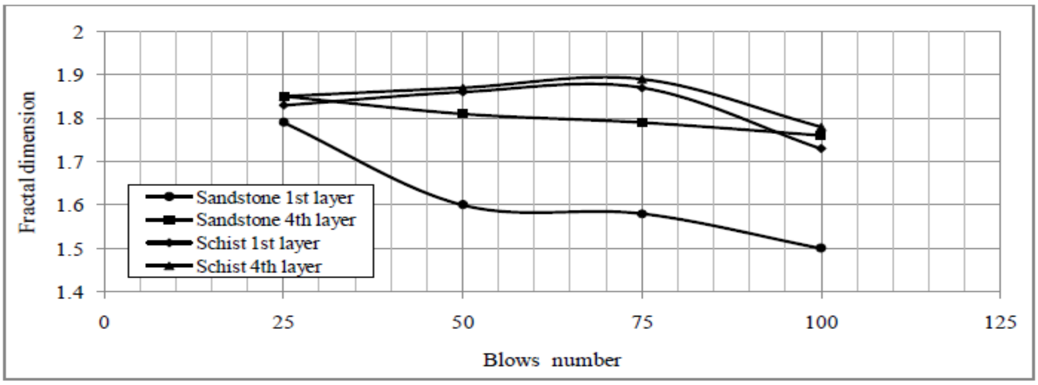


**Figure20:** *Fractal Dimension of the 1st and the 4th layer of sandstone and schist materials as a function of the compaction energy.*

## CONCLUSION

The evolution of the granulometric spread due to the crushing phenomenon gives rise to a new granular structure, leading to a modification of the Proctor characteristics which are different from the parent structure.

The results obtained show that the greater the degree of crushing of the grains, the greater the fractal dimension determined with both the mass method and the box method. Furthermore, the influence of the compaction energy on the crushing phenomenon as a function of depth differs in the following two cases:

- In the case of a specimen made up in a single layer of 15,2 cm, the crushing of the grains allows the production of fine particles which is important in the surface sublayer and decreases as we go down to the Under deep layers for both sandstone and shiny schist. The fractal dimension (mass method) generated decreases according to the depth of the specimen. The fractal dimension (box method) of the different grains arranged at different depths confirms this thesis.
- In the case of a specimen made up of 3,8 cm layers, the results show that the most degradable layer is the first (deepest) layer for both materials (sandstone and shiny schist) and the least degradable layer is 4th layer (surface layer), but the crushing rate is quite large for sandstone than for shiny schist. The fractal dimension (mass method) is more important in the first layer and decreases as we go up to the surface. On the other hand, with the box method, the crushing of the grains is well demonstrated by the notion of fractal dimension, particularly with the three modes of rupture observed during the tests.

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**Citation:** *Bachir Melbouci, Abdelmadjid Chafa, "Evaluation of the Grain Crushing Rate by the Concept of Fractal Dimension into the Proctor Test", International Journal of Emerging Engineering Research and Technology, 6(12), pp.1-16*