THE USE OF GRANITE BY-PRODUCTS DERIVING FROM TUNNELING EXCAVATIONS FOR ROAD CONSTRUCTION PURPOSES

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ABSTRACT

The purpose of the research presented in this paper is to verify the possibility of using granite by-products deriving from tunnel excavations for road construction. This case study refers to the granite deriving from tunnels excavated on the south east coast on the island of Sardinia, which are part of major road works for the realization of the new road S.S.125. The road project consists on the realization of three main galleries, total length 4.1 km, plus 2 service tunnels. Two excavation techniques were used on this site: Tunnel Boring Machine (TBM) method for the excavation of the service tunnels and Drilling and Blasting (D&B) for the galleries, these techniques produced two different types of granite by-products. Both materials were tested and compared to verify physical and mechanical characteristics for road sub-base purposes and for soil-cement mixtures. Particle size distribution, Atterberg's limits, Los Angeles abrasion test, sand equivalent test and physical and chemical tests were carried out on the aggregates, also tests were conducted on aggregate specimens for soil-cement mixtures. The test results indicated that the physical and mechanical properties of the aggregates are suitable for road base and sub-base, also the compressive strength tests conducted on the soil-cement mixture were in the limits imposed by the specifications using low percentages (2-3 %) of Portland cement.

Keywords: granite by-products, tunnel excavation, road construction, aggregates reclaim.

INTRODUCTION

In recent decades, the growth in industrial production and consequent increase in consumption has led to a fast decrease of available natural resources (raw materials or energy sources). On the other hand, a high volume of production has generated a considerable amount of waste materials which have adverse impacts on the environment. Many countries and international establishments have been working for new regulations on how to minimize and reuse the generated waste, Hüseyin and Cahit (2007) . In order to reach these objectives it is fundamental to minimize quarry wastes and plants production, by means of a rational exploitation starting with a correct planning, and the systematic treatment and reuse of rock wastes, Dino and Fornaro (2005). While this problem is getting more common, in the quarry industries where by-products are being studied to be reused in several applications, in the construction industry only recently it has begun to receive the right attention. New projects like the Gotthard tunnel are reusing the millions of tons of material excavated during the construction of the galleries, Pepino (2009). In a smaller scale this research aims of evaluating the granite by-products deriving from the excavation of three galleries and two service tunnels.

These tunnels are being excavated on the south east coast on the island of Sardinia, which are part of major road works for the realization of the new road S.S.125. The three main galleries called: Marapintau (1.290,00 m), Istellas (212,50 m) and Murtineddu (2.590,50 m) were excavated for a total length of 4.1 km, also two service tunnels were constructed for the Marapintau and Murtineddu galleries these had nearly the same length of the main galleries. Galleries were excavated on compact and homogeneous granite bodies. Two excavation techniques were used on this site: Tunnel Boring Machine (TBM) for the service tunnels and Drilling and Blasting (D&B) for the galleries. The maximum daily advance using D&B was of 5 m but in some cases it could drop to 0.5 m, the average daily advance progress of the TBM was of 30 m, but at times peaks of 45 m were reached. These techniques produced two different types of granite by-products. Both materials were tested and compared to verify physical and mechanical characteristics for road sub-base purposes and on soil-cement mixtures for base layers. Particle size distribution, Atterberg's limits, Los Angeles abrasion test, sand equivalent test, determination of specificity gravity and chemical composition were carried out on aggregates. Also the modified Proctor test and Californian bearing ratio (CBR) index were performed in order to evaluate mechanical properties of granite by-product aggregates.

Finally, granite by-product aggregates were tested to be used for bounded layers with Portland cement. A total of 40 samples, prepared using five different content of Portland cement (0.5%, 1.5%, 2%, 3% and 3.5%), and granite by-product produced with TBM and D&B were analysed with compressive strength tests. In this paper results from all the tests are reported. Results both aggregates deriving from TBM and D&B have shown a high bearing capacity for bound and unbound conditions in terms of CBR Index and Compressive strength.

RESEARCH OBJECTIVE AND SCOPE

The main objective of this research is to verify the possibility of using granite by-products deriving from tunnelling works for road construction purposes. Material deriving from two different excavation techniques: TBM and D&B. These materials were studied and compared with the scope of verifying in which way different excavation techniques influence physical and mechanical characteristics of by-products deriving from the same material. Once the materials were studied and results compared a second phase started with the scope of verifying if they could be used in the road construction industry. For this reason two potential applications were studied: road sub-base and soil-cement mixtures for base layers. This paper describes methods and tests conducted on both materials.

MATERIALS AND METHODS

The three main galleries called: Marapintau, Istellas and Murtineddu were excavated in granite using the D&B method, special jumbos equipped with automated georeferenced hydraulic drilling systems were involved. Also two service tunnels were constructed for the Marapintau and Murtineddu galleries, using a TBM. In total 800.000 m^3 of granite was excavated. During the excavation of the tunnels the materials were always divided in different stockpiles without mixing materials deriving from TBM with those from D&B. For this reason it was very easy to sample them without having any problems (Figure 1 A-B).

The difference in the excavation techniques is highlighted by the dissimilar particle size and shape of the granite by-products as shown in Figure 1 A-B.

Figure 1- A Granite by-product deriving from TBM

Figure 1- B Granite by-product deriving from D&B

Samples were collected using UNI EN 932-1 procedures for stockpiles. Once in the laboratory they were reduced according to UNI EN 932-2 specifications.

Aggregates were characterized from the physical point of view measuring first specific gravity reported in Table 1.

Table 1 Specific gravities of aggregates

Aggregates	Specific gravity (g/cm^3)
Granite from TBM	2.65
Granite from D&B	2.66

The Inductively Coupled Plasma with Optical Emission Spectrometry (ICP- OES) technique was used in order to determine detailed information about the chemical composition as reported on Table 2. The granite by-products were reduced to a granular size of 0.063 mm in order to perform such test.

As expected the two materials had almost the same percentage of chemical compounds, there is only a slightly difference in the limited oxygen index (LOI) that gives a percentage of the lost in fire, results are reported on Table 2, Ribeiro et al. (2008).

Table 2 Chemical composition of granite by-products

Component	Granite from TBM (%)	Granite from D&B (%)
Al_2O_3	14.43	14.58
Fe_2O_3	3.53	4.46
MnO	0.07	0.08
MgO	1.20	2.07
K_2O	3.75	3.50
Na_2O	3.00	2.82
TiO_2	0.39	0.52
P_2O_5	0.12	0.15
SiO_2	69.69	66.64
CaO	2.84	5.09
LOI	1.55	4.09

The pre-characterization face continued with conducting particle size distribution tests for both granite by-products, the UNI EN 933-1 protocol was followed. Also measurements were focused on determining Atterberg's limit, both materials as expected resulted non-plastic. The results of the particle size distribution are shown in Figure 2. It is possible to see that the granite deriving from TBM excavation method has a higher percentage of fine particles than the granite deriving from D&B. This due to the excavation technique, TBM cutters pulverise huge amounts of granite. This type of results can be compared with other of the same kind, the Alp Transit project, the new railway link throw the alps with the realisation of the Gotthard Base tunnel. Similar granite by-products were compared and a 12% increase in fine materials was observed in granite deriving from TBM excavation in respect of granite from D&B, Pepino (2009).

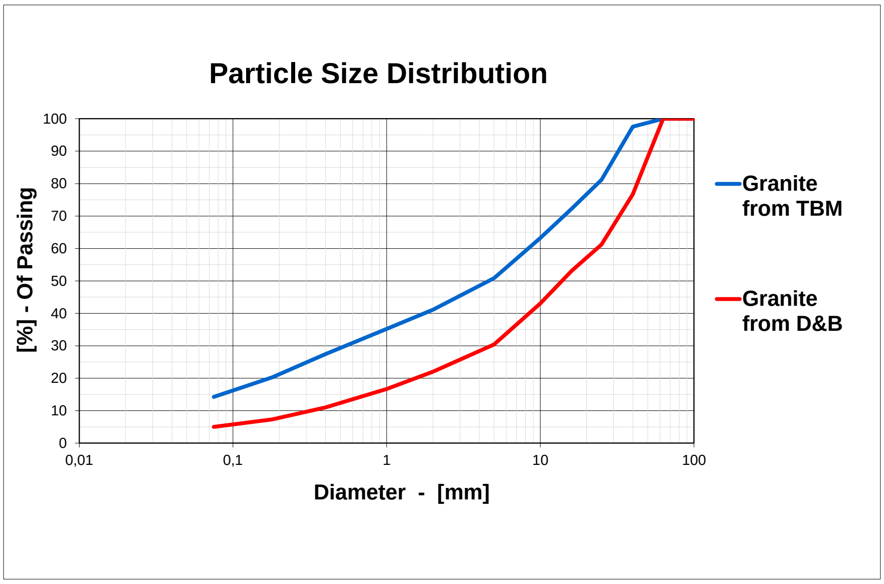

Figure 2 Particle size distribution of granite by-products

Once the particle size distribution for both materials was obtained it was possible to compare it with the grading that soil-cement mixtures and road sub-base must have. In Figure 3 it possible to see that both granite by-products do not fulfill the specification in terms of aggregates size for soil-cement mixtures. Granite deriving from D&B is mostly inside grading, but between 20 mm and 50 mm percentage for retained particles is too high. Granite by-products deriving from TBM have a larger quantity of fine materials than those derived from D&B.

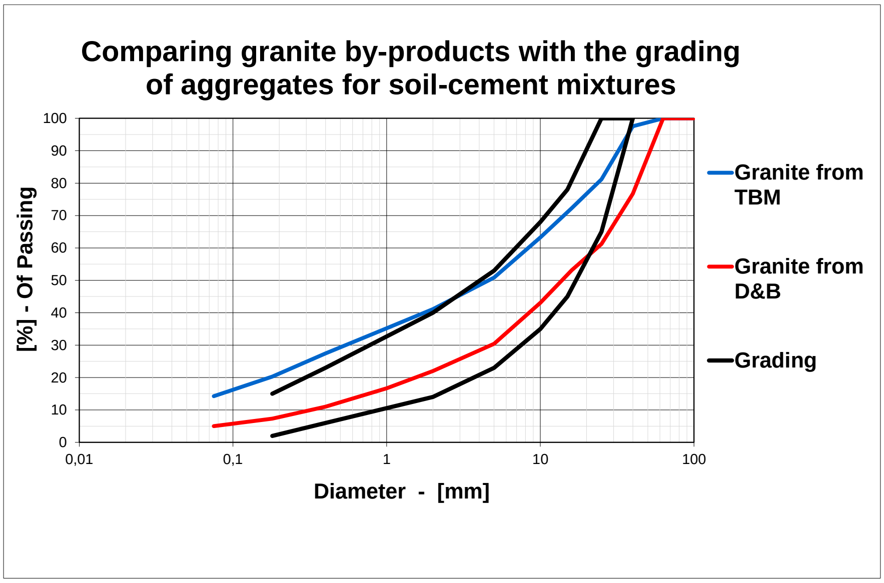

Figure 3 Comparing granite by-products with aggregates grading used in soil-cement mixtures

In Figure 4 the grading for road sub-base is compared with the particle size distribution for both granite by-products. In this case obtained grading curves are almost inside the grading with small differences.

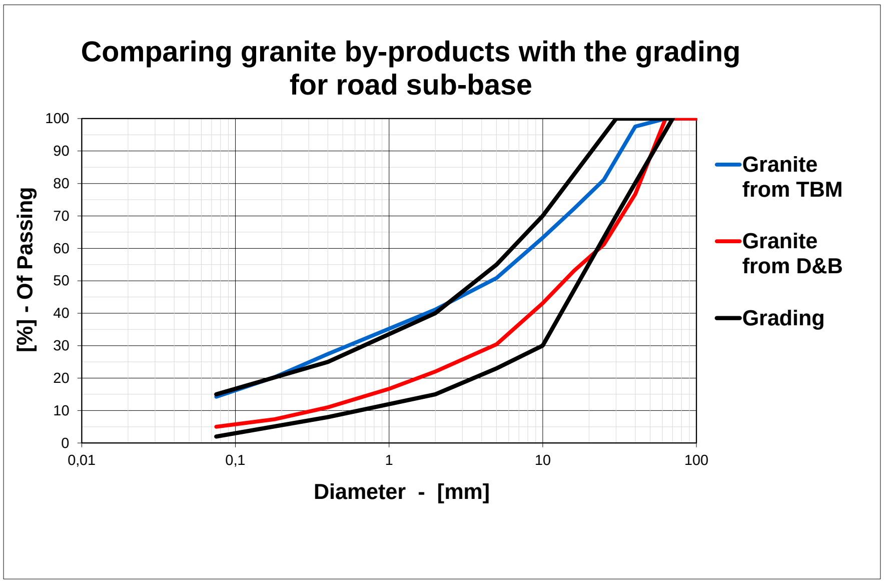

Figure 4 Comparing granite by-products with aggregates grading for road sub-base

In this research the materials were used as they were sampled from the stock piles, without trying to create blends that would fit the soil-cement and sub-base grading but only compare them.

In order to verify if the material was suitable for road sub-base and for soil-cement mixtures specific tests were carried out. First of all Los Angeles abrasion test was performed using UNI EN 1097-2 specifications. This test measures the deterioration of standard gradation of mineral aggregates through abrasion and impact (see Equation 1):

$$\left(\frac{5000-M}{50}\right) \quad (1)$$

M: is the amount of aggregate (kg) which passes a 1.6 mm sieve

The average loss of Los Angeles value was of 31.28% for the granite by-product deriving from TBM excavation and 26.18% for granite deriving from D&B, with a difference of 19.48% (Figure 5).

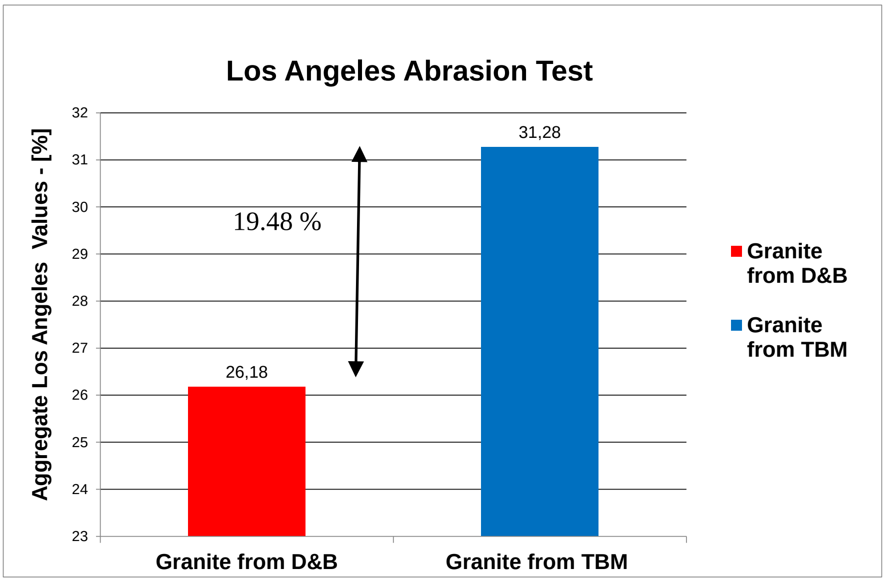

Figure 5 Los Angeles abrasion value of granite by-products

While the Los Angeles Abrasion value for granite by-products deriving from D&B was within the specified limits, for both road sub-base purposes and for soil-cement mixtures', the granite deriving from TBM was slightly over the specified limit of 30%.

Sand equivalent test was performed using CNR B.U. 27/72, slightly different to the UNI-EN 933-8 protocol, this test was performed only on granite by-products deriving from TBM excavation (Figure 6). The result obtained was 40.81% of sand equivalent, the value imposed by legislation for soil-cement mixtures must be in the range of: ≥ 30% ; ≤ 60%. In this case the value was well inside the limits.

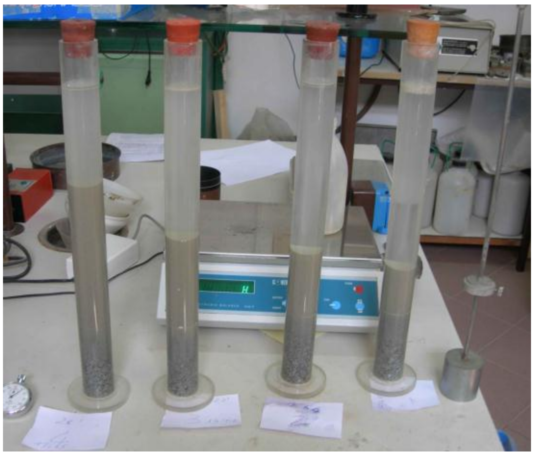

Figure 6 Sand equivalent test

In order to determine the optimum water content and the maximum dry density modified Proctor test using UNI EN 13286-2 specifications was performed. Optimum Water Content and Maximum Dry Density values obtained for the two by-products are shown on Figure 7. These 1% difference in optimum water content and maximum density can be explained by the larger percentage of fines particles of aggregates deriving from TBM then the D&B material, which tend to absorb more water and at the same time fine aggregates fill the voids in the coarse aggregate and act as a workability agent.

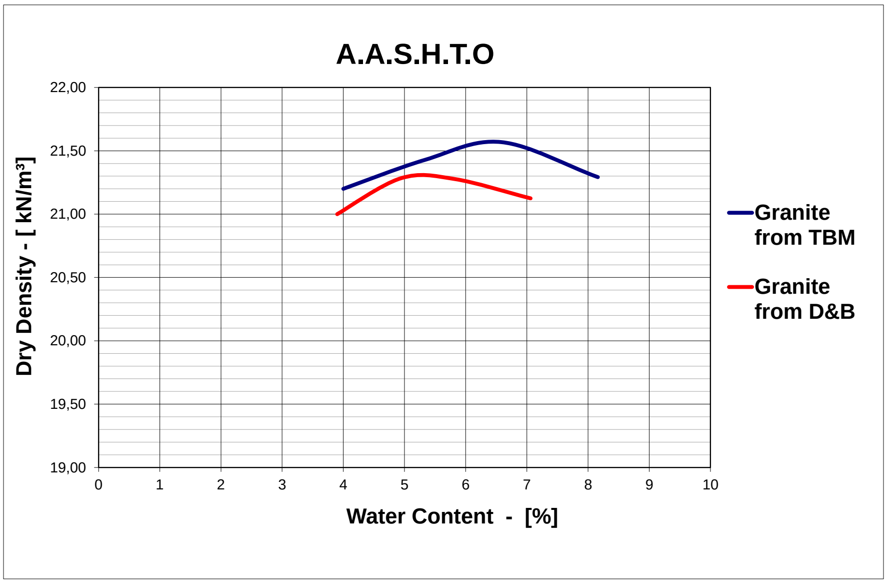

Figure 7 A.A.S.H.T.O Granite by products deriving from TBM

Also the Californian bearing ratio (CBR) test was performed using UNI EN 13286-47, to determine immediate bearing ratio and linear swelling. Test was carried out on granite by-products deriving from TBM, mixed with optimum water content, and a dry density value of 19.44 kN/m^3. The highest CBR index value obtained, carried out in soaked conditions, was 167%, as shown in Figure 8, and no swelling was measured. Further CBR tests are needed, especially on granite by-products deriving from (D&B) that in this phase of the research weren't performed.

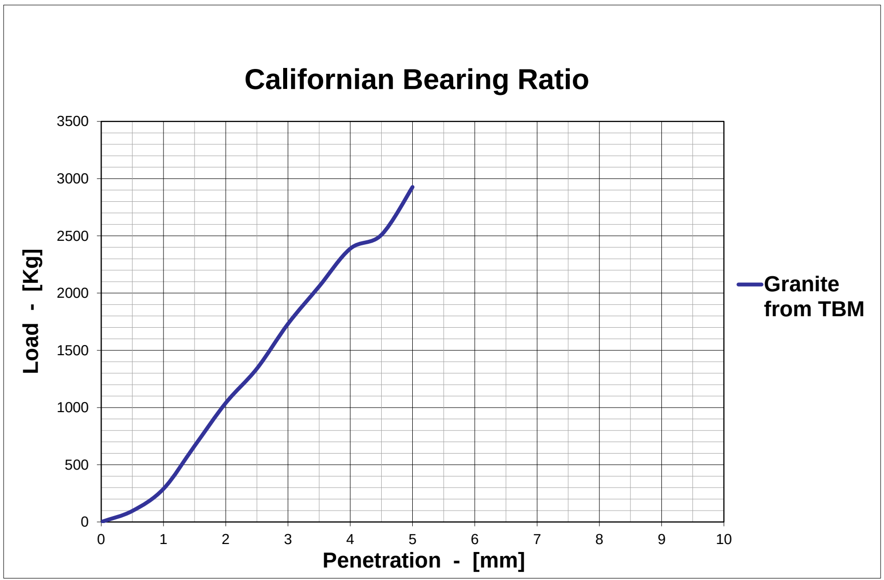

Figure 8 Californian bearing ratio test

The last test performed was the determination of compressive strength values conducted on soil-cement mixture specimens; the C.N.R. 29/72 protocol was used. These tests was performed on both granite by-products TBM and D&B, five mixes were tested using: a total of 40 samples with portland cement content ranging from 0.5%, 1.5%, 2%, 3% and 3.5% were tested. First of all TBM granite by-product was analysed, for each mix four specimens were prepared for a total of 20. Samples were mixed with the specified Portland cement percentage and a constant water content of 6% was used regardless the aggregate natural water content. Once the mixes were ready and compacted they were buried in wet sand to mature for seven days (Figure 9) before compressive strength tests were performed (Figure 10).

Figure 9 Soil-cement mixtures specimens after 7 days

Figure 10 Specimen during compression strength test

Compressive strength vales obtained on soil-cement mixture after 7 days are shown in Table 3. According to Italian specifications acceptable values are between 25 kg/cm^2 and 45 kg/cm^2, such values were achieved with a percentage of portland cement between 2 and 3 percent.

Table 3 Mean values of compressive strength tests on TBM granite by-products

Portland cement (%)	Water content (%)	Compressive strength test (kg/cm^2)
0.5	6	9.28
1.5	6	16.48
2	6	33.42
3	6	42.71
3.5	6	52.65

Aggregates deriving from D&B were mixed with three water content: three sets with 5.5% and two sets of with 7% and 8% of water content. Different water contents were needed due to the different percent of fine particles, since aggregates were collected from different stockpiles.

In Table 4 the mean values of the tests are shown, acceptable values were obtained with 2 and 3 percent of portland cement.

Table 4 Mean values of compressive strength tests on D&B granite by-products

Portland cement (%)	Water content (%)	Compressive strength test (kg/cm^2)
0.5	5.5	9.74
1.5	5.5	22.85
2	5.5	28.40
3	8	38.05
3.5	7	62.07

In Figure 11 compressive strength values from specimens deriving from TBM and D&B granite by-products are compared. In some cases values are very similar

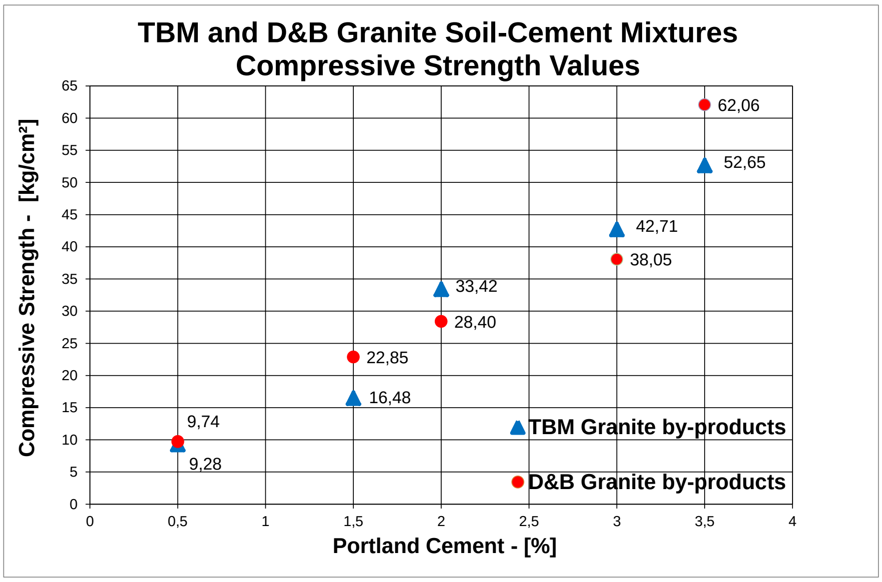

Figure 11 Values for both TBM and D&B soil-cement specimens compressive strength

CONCLUSIONS

In this research the use of granite by-products deriving from two different excavation techniques were studied and results compared, with the aim of verifying if such materials were suitable for road construction purposes. Specific tests to establish the potential application in road base and sub-base layers were performed on both aggregates and soil-cement mixtures. The two granite by-products resulted different in shape and in particle size distribution: aggregates deriving from TBM are regular in size with a flat and elongated shape, while aggregates deriving from D&B are more present a wider range of particle size and different shapes. The particle size distribution of granite by products deriving from TBM show a 10% increase in fine materials than aggregates deriving from D&B, this due to the TBM cutters that pulverize large quantities of granite. Both materials are non-plastic, same specific gravity and chemical composition was measured, as expected since they derive from the same rock.

The particle size distribution of both granite by-products is suitable for road sub-base, while a selection of aggregate size for soil-cement mixture is needed.

Test conducted on measuring the deterioration of standard gradation of mineral aggregates through abrasion and impact, have shown that aggregates deriving from TBM have higher values of LA in the range of 31% in respect of aggregates deriving from D&B 26%. This can be explained by the type of shape, flat and elongated, that aggregates deriving from TBM possess, that commonly tends to disgregate more easily. Sand equivalent test shows that such percentage is of 40.81% well inside for soil-cement mixtures specifications.

Both aggregates deriving from TBM and D&B have shown a high bearing capacity for bound and unbound conditions in terms of CBR Index and Compressive strength.

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