Rombi J., Maltinti F., Coni M. (2022), Sardinia Granite Scraps Application in Road Pavement Layer. In: Gervasi, O., et al. (Eds.) Computational Science and Its Applications – ICCSA 2022 Workshops, Lecture Notes in Computer Science, Vol.13382, 2022, pp. 613-623..

Rombi J., Maltinti F., Coni M., Lecture Notes in Computer Science, Springer Nature Switzerland, 2022, pp.613-623 .

http://dx.doi.org/10.1007/978-3-031-10592-0_44

Sardinia Granite Scraps Application in Road Pavement Layers

J. Rombi, F. Maltinti(✉), and M. Coni

Department of Civil Environmental Engineering and Architecture, University of Cagliari, 09042 Cagliari, Italy
maltinti@unica.it

Abstract. Sardinia is the second-largest island of Italy after Sicily, in this region, large volumes of granite scraps deriving mainly from the ornamental quarry industry, lie abandoned in stockpiles. The ornamental query industry, very active in the region since the late 1900s, has produced large volumes of granite scraps causing several environmental and landscape issues. Therefore, there is a need to find potential applications for such materials, previously extracted, for which energy has already been consumed and CO_2 emitted. This research focuses on the possibility of introducing granite scraps for road construction processes. Achieving several benefits, ecological by restoring landscape integrity and reducing CO_2 emissions, economical by decreasing road construction costs. For this reason, three types of granite scraps, obtained from the same granitic body using two types of excavation methods and treatment, were studied. In the first phase of the research the evaluation of the environmental compatibility of the scraps, based on Italian regulations, was investigated. Also, chemical, and mineralogical analyses were performed to establish the correct granite family. Mechanical properties were evaluated to assess the possibility of using them to their fullest extent in booth unbound and hydraulically bound pavement layers. From the test conducted useful information were obtained showing how granite scraps, can achieve good physical and mechanical performances if compared with those of natural aggregates normally used in road pavement layers. The test conducted demonstrated how granite scraps can be used with high performances in road pavement structures, contributing to the reduction of quarrying new materials, and introducing a circle economy approach with several benefits for the Sardinian Island.

Keywords: Granite scraps · Recycle · Pavement layers · Circular economy · Quarry waste

1 Introduction

Large volumes of scraps are produced each year during manning and quarrying activities, generating high environmental impacts. The possibility of using quarrying waste materials to create a new product or as admixtures so that natural sources can be preserved or used more efficiently is becoming a challenging field [1, 2]. Many of these

O. Gervasi et al. (Eds.): ICCSA 2022 Workshops, LNCS 13382, pp. 613–623, 2022.
https://doi.org/10.1007/978-3-031-10592-0_44

materials are considered waste and are not used to the fullest extent for construction purposes, limiting their potential use.

In Sardinia, one of the largest islands of Italy, quarrying activity of marble and granite, used as ornamental and building stones, has been very active in the region for decades [3].

There are 11 types of commercialized granite [4], that differ not only in colour but in some cases for physical and mechanical properties.

Commercial ornamental granite is subjected to many processes like excavation, cutting, polishing and grinding. The yield wastage ratio during processing varies between 65% and 50% depending on the type of granite. It is very important to understand and evaluate what must be considered a waste or what can be considered a by-product evaluating their possible application. Analyzing the data of Sardinia granite quarrying production for ornamental use (see Fig. 1), obtained from the Italian National Institute of Statistics (ISTAT), the estimated average annual production between 2015 and 2019 [5] has been 361000 m^3.

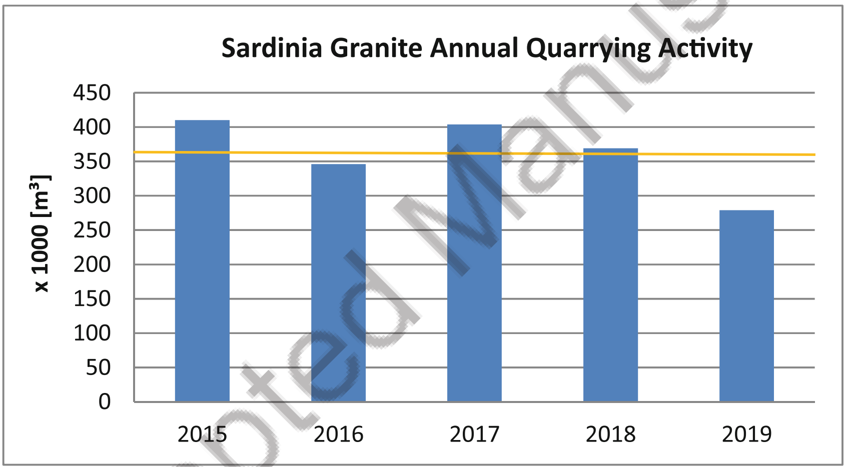

Fig. 1. Sardinia annual granite quarrying activity (source ISTAT)

Assuming that in the next 10 years Sardinian production will remain at the actual average, assuming a yield wastage ratio during the processing of 50%, there will be approximately 1,5 million m^3 of suitable granite scraps. Also, there are over 40 million m^3 of large and medium size shapeless granite by-products already stockpiled, belonging to the past granite query activity. All this stockpiled material, an example can be seen in Fig. 2, is subtracting and will continue to consume land if a solution isn't found. There is a need of possible strategies for limiting the consumption of natural aggregates, as well as the use of recycled aggregates [6]. Possible correlation of the main planning tools regarding extractive activities for geo-resources planning sector, and the urban master plan, to identify environmental indicators, useful for monitoring and for decision support systems [7].

Fig. 2. Granite scraps in the district of Calangianus

Since the commercialization of Sardinia granite has become an organized trade in 1870, there are four leading ornamental quarrying districts: Arzachena-Luogosanto, Tempio-Calangianus, Buddusò-Ala dei Sardi, and Ovodda, such districts are located for the majority on the northeast of Sardinia as shown in Fig. 3.

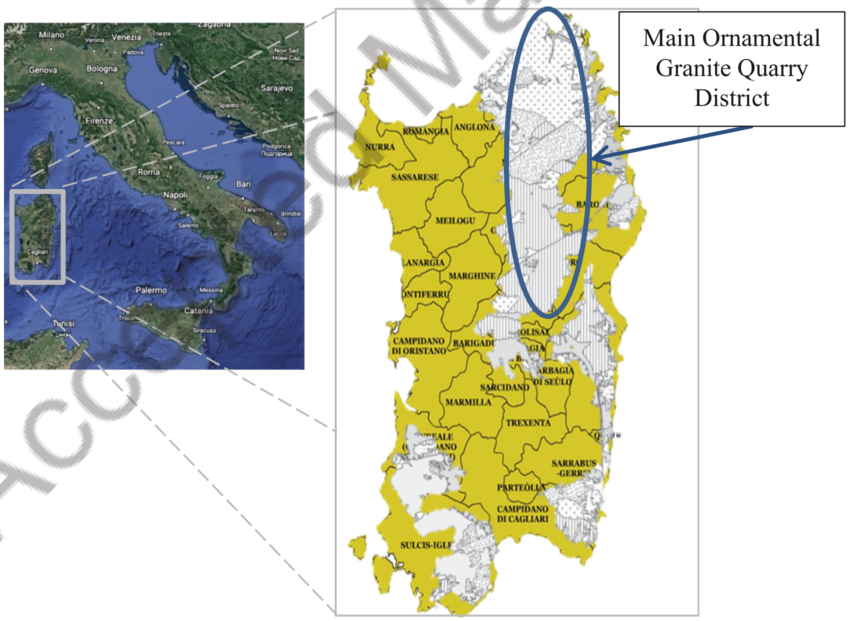

Fig. 3. Geological sketch map of late-hercynian granitoids of Sardinia, in which is highlighted the ornamental quarry district (source Secchi and Lorrai, 2001)

Almost more than 89% of the international quarrying activity is concentrated in nine Countries, each of them producing more than 2 million tons of natural ornamental stones per annum: China, Italy, India, Iran, Spain, Turkey, Brazil, Greece, and Portugal [8].

In this scenario Italy is one of the leading countries for the commercialization of granite, making Sardinian granite account for 75% of Italy's total granite output, although this tendency is drastically decreasing. Some of the major producing countries are researching the possible use of what remains from the many processes to which granite and other ornamental stones are subjected before reaching commercialization.

Mainly the attention is being focused on the use of the fine particles that due to their dimensions can become threatening to human and animal health. The use of such material is being studied to be used as filler in the construction industry.

In Brazil, the possibility of using granite and marble dust deriving from the cutting of the larger blocks has been evaluated. The main objective of the research evaluated the incorporation of these fines as a mineral aggregate in asphalt formation and analyze the performance and compare it with that of basalt rocks [9]. In Turkey studies on how to be able to recycle granite and marble wastes deriving from ornamental quarrying activities are being developed considering both coarse and fine aggregates. The durability of concrete using granite and marble wastes with a maximum nominal size of 19 mm was studied. The results of this study showed that ornamental quarrying wastes deriving from marble and granite can be used to improve the mechanical properties, workability, and chemical resistance of conventional concrete mixtures [10].

The potential use of marble and granite quarrying scraps rocks as a replacement for natural aggregates in civil engineering projects is being studied in many fields [11–13].

There is a high scientific interest to evaluate the possible applications of this type of scrap in many parts of the world because it would be capable of solving many environmental issues resulting from the exhaustion of the natural resources of aggregates.

In this context, the paper focuses the attention on verifying potential applications of granite scraps for road construction purposes and evaluating if different excavation techniques could modify the physical and mechanical behaviour when used in road pavement layers. The research focused its attention on a construction site located on the southeast coast of Sardinia (Sarrabus-Gerrei) in which five natural tunnels were being excavated, in compacted and homogenous granite rocks. The project consisted in the realization of the new road S.S.125 involving three main tunnels plus two service tunnels. The excavated granite was derived from the same mother rock but was subjected to different excavation methodologies and treatment processes, leading to three types of materials to be analyzed. The tunnels were being excavated using a Tunnel Boring Machine (TBM) for the service tunnels while Drilling and Blasting (D&B) technique was adopted for the realization of the three main tunnels. The estimated excavated material resulted in 800000 m^3.

2 Case Study

Three types of granite scraps were tested, in Table 1 are reported the three different types of material. Granite aggregate named by code AG-1 derived from the excavation of the two service tunnels using an open shield TBM machine. The AG-2 material came from the excavation of the main tunnels using D&B technique, such material was subjected to screening and passing a 60 mm sieve.

Also, AG-3 came from the D&B excavation technique, in this case, the larger blocks were reduced in size using a mobile jaw crusher with a feed size ranging from 600–900 mm obtaining a material passing a 50 mm sieve.

Table 1. Granite aggregate scrap samples

Code	Tunnel type	Excavation method	Treatments
AG-1	Service tunnels	TBM	No further treatment
AG-2	Main tunnels	D&B	Screening
AG-3	Main tunnels	D&B	Crushing screening

The samples were collected according to UNI EN 932-1 [14] (Italian national standards institute) specifications for stockpiles. Once in the laboratory, they were reduced according to UNI EN 932-2 [15] specifications to perform further tests. Preliminary tests were conducted to evaluate if the scraps could be environmentally suitable. For this reason, leaching tests were performed to evaluate the permissible concentrations of elemental species according to Italian legislation. To evaluate the uniformity of the geological body, chemical and mineralogical composition was analyzed. A petrographic examination can give general indications of the potential performance of the aggregates. After this preliminary characterization, specific tests were performed to analyze the use of such materials in road pavement layers. Unbound granular layers were analyzed first, gradation of the aggregates was analyzed as one of the factors that most companies use in the selection of the aggregates. Also, Atterberg limits tests were performed to classify the aggregates. To measure aggregates toughness Los Angeles abrasion test was performed. Moisture and density relationship was obtained by performing laboratory compaction using the modified proctor method. Finally, Cement Bound Granular Material (CBGM) layers were studied, and tests conducted to evaluate the performance following the specifications imposed by the Italian National Center of Research (CNR) 29/72 [16]. Specimens were molded using five different percentages of Portland cement contents ranging from 0.5%, 1.5%, 2%, 3% and 3.5%. According to the specifications, it is possible to use cement content of up to 5%. The potential use of coarse granite and marble scraps as replacement soil under foundations has been investigated with good results in Egypt [17]. In this paper granite scraps will be characterized to evaluate potential applications not only in unbound granular layers but also in CBGM layers and the entire mix will be composed of granite scraps. Also, alternative hydraulic binders are being studied in order to partially replace ordinary Portland cement in CBGM layers. The main materials are Fly Ash (FA) and Silica Fume (SF) but also Anhydrous Calcium Solfate (ACS) [18] is being studied. In this research ordinary Portland cement type CEM IV/B 32.5 R was used.

3 Experimental Results

The results obtained from the leaching tests, to evaluate the environmental compatibility of the scraps, were conducted following the Italian legislation and regulation LG.D. n.152/2006 [19] and the D.M. n. 161/2012 [20]. Such regulations give the guidelines on which procedure to use to perform the tests and the list of elements that must be tested with the maximum permissible concentration. The range values of pH, must be between 5.5–12. In Table 2 are reported the obtained average values for pH and conductivity, pH values are inside the imposed range.

Table 2. pH and conductivity values

Code	pH	Cond. (μS/cm)
AG-1	9.95	119.22
AG-2	11.85	755.5
AG-3	9.65	138.00
Blanck	8.95	29.65

Of all the twenty tested elements only Fluoride (F) was over the maximum concentration limit. This value was obtained for samples AG-2 and AG-3. Such values can be attributed to the type and amount of explosives used during the D&B excavation method. Samples collected from AG-1 stockpiles, in which the TBM was used, didn't show any contamination from Fluoride and the other remaining tested elements.

From the geological maps of the region, the granite had to be a Granodiorite. Chemical and mineralogical composition tests were conducted, on the material deriving from the main and the service tunnels to evaluate the uniformity of the geological body. To perform the measurements the granite aggregates were reduced to a granular size of 0.063 mm. In Table 3 is reported the average chemical composition of granite aggregate samples collected from stockpiles.

After this preliminary characterization, physical tests were performed. Particle size distribution was conducted according to UNI-EN 933-1 [21] specification. In Fig. 4 are reported the average particle size distribution of the three materials obtained from the samples collected from different stockpiles. If compared with the grading imposed by the Italian Ministry of infrastructure and transport for unbound granular layers in foundation and base layers, these materials must need further screening to have the correct percentage of aggregate fractions.

Other conducted tests were: density according to UNI EN 1097-6 [22] specification, Atterberg limit according to CNR UNI 10014 [23], abrasion and sand equivalent value according to UNI EN 1097-2 [24].

Table 4 reports the obtained average results from all the collected samples on freshly excavated material and crushed granite scraps.

The values reported in Table 4 show for sample AG-1 values slightly over the limit for Los Angeles Abrasion test that must be 30% or lower. While sample AG-2 and AG-3 didn't reach the minimum value of 40% for the sand equivalent test. To determine

Table 3. Chemical composition of granite

Component	AG-1 (%)	AG-2 (%)
SiO_2	69.69	66.64
TiO_2	0.39	0.52
Al_2O_3	14.43	14.58
Fe_2O_3	3.53	4.46
MnO	0.07	0.08
MgO	1.20	2.07
CaO	2.84	5.09
Na_2O	3.00	2.82
K_2O	3.75	3.50
P_2O_5	0.12	0.15
LOI	1.55	1.09
Total	100.59	101.04

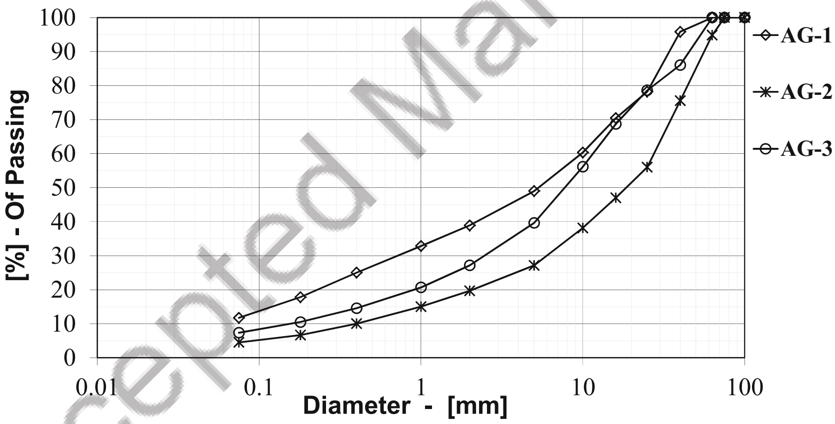

Fig. 4. Particle size distribution of the three types of granite scraps

Table 4. Physical and mechanical properties of granite aggregates

Sample	Particle density (g/cm^3)	Los angeles abrasion (%)	Sand equivalent (%)	Atteberg limit
AG-1	2.65	31.01	40.81	Non-plastic
AG-2	2.66	25.79	39.92	Non-plastic
AG-3	2.66	28.02	37.02	Non-plastic

the bearing capacity of the three granite aggregates tests were performed on unbound granular samples. The preliminary moisture and density relationship was measured by performing a modified Proctor test using specifications UNI-EN 13286-2 [25]. In the tests conducted samples were prepared using each of the three granite scraps and mixing each of the aggregates with six selected water content values: 2%, 4%, 5%, 6%, 8%, and 10%. The average optimum water content and corresponding dry density are reported in Table 5.

Table 5. Optimum water content and dry density mean values

Sample	Dry density (kN/m^3)	Optimum water content (%)
AG-1	21.55	6.50
AG-2	21.30	5.40
AG-3	21.65	6.00

In the next phase, mechanical characteristics were measured on CBGM mix design. A total of n°60 samples were prepared to evaluate the performance following the specifications imposed by the C.N.R. 29/72 protocol. Tests were performed on two types of materials AG-1 n°30 samples and AG-2 n°30 samples. The specimens were molded using five different percentages of Portland cement (CEM IV/B 32.5 R) contents ranging from 0.5%, 1.5%, 2%, 3% and 3.5%. For each chosen percentage of cement, preliminary tests were performed to obtain optimum moisture content and maximum density. The initial water content used was the one obtained from the modified proctor tests. Then the water content was gradually increased when increasing the percentage of cement in the mixtures. Before performing the tests the right grading was obtained.

After seven days of curing time, compressive strength tests were performed. The obtained results are shown in Table 6, in which is reported the compressive strength resistance value and the amount of cement, and water that has been used for each mix. The C.N.R. 29/72 specification imposes that the compressive strength value must be between 2.50 and 4.50 MPa. These values are reached for booth aggregates with a low percentage of cement 2.0%.

4 Data Analysis

Evaluating the environmental compatibility of such aggregates, the tests have shown that in some cases the processes to which these materials are subjected can contaminate them. The results obtained from the leaching tests have proven that aggregates AG-2 and AG-3 have a concentration of Fluoride (F) over the concentration limit (1.5 mg/l). This can be attributed to the type and amount of explosive that was used during the D&B excavation phase, which it has contaminated the aggregates during the explosion. For this reason, the washing of the aggregates could be considered in order to reduce such contamination inside the imposed limits. The pH values that were measured showed that all the three materials were always in the imposed limit range. Values of pH like the one

Table 6. Compressive strength tests mean values

Sample	Cement content (%)	Water content (%)	Compressive strength (MPa)
AG-1	0.50	6.60	1.05
	1.50	6.70	1.62
	2.00	6.80	3.28
	3.00	7.10	4.19
	3.50	7.30	5.16
AG-2	0.50	5.60	1.03
	1.50	5.70	2.46
	2.00	5.90	2.79
	3.00	6.30	3.73
	3.50	6.50	5.34

obtained for AG-2 aggregate have been measured when performing leaching tests on granite fines deriving from gang saw [26]. Test conducted on the three types of granite by-products to evaluate the possible application for unbound layers has shown that first of all the process to which they are subjected can influence the grading but also the shape. Following the results from the particle size distribution, it is possible to establish that aggregates deriving from TBM have a content in fines that is in the range of 10% more if compared with the other two types of aggregates. Analyzing the values obtained from the modified Proctor test it is possible to see that these values can be related to the particle size distribution of the three aggregates. In AG-1, the optimum water content values has an average value of 6.5% while dry density is 21.55 kN/m^3. This can be related to the presence of more fines, which not only absorb more water they tend to fill the voids in the coarse aggregate acting as workability agents and improving dry density values. Also, the slightly higher values obtained performing the Los Angeles abrasion tests on AG-1 aggregates can be explained by the shape. They have a flat and elongated form, that tends to disaggregate more easily. Following the results from the Atterberg limit test, the three types of aggregates resulted non plastic. The sand equivalent value for AG-2 and AG-3 didn't achieve the minimum value of 40% for foundation layers.

The tests conducted on CBGM specimen have shown, according to the specifications, that the two types of granite scrap tested, AG-1 and AG-2, achieved excellent compressive strength values with low cement content only 2%.

5 Conclusions

It is possible to state that granite scraps can be considered a valid alternative to natural aggregates currently used in Sardinia for road construction purposes. More specifically, the potential use in both unbound and hydraulically bound pavement layers has highlighted in some cases issues that can be easily solved. First of all, despite the pavement layer we want to introduce the scraps, washing the aggregates must be performed to reduce Fluoride contamination when it appears. Following the results from the tests conducted, it is possible to establish that the three granite scraps if they are to be used in foundation and base layers they need to be crushed and screened in order to have the correct fractions to achieve the specified blend. Also, the crushing will be useful especially for aggregate AG-1 in order to modify the shape of the aggregates to achieve better values when performing the Los Angeles abrasion test. In CBGM layers the results obtained showed how this type of aggregate can achieve good values of compressive strength with low percentages of Portland cement only 2%. Usually, the minimal amount introduced in the mix using natural aggregates is 3%. Overall, there are no specific limitations to not use such materials, there is a need to encourage their use towards a circular economy model.

Author Contributions. Concept and methodology, J.R., M.C., and F.M.; experimental campaign and validation, J.R.; analysis, J.R., M.C., and F.M.; writing, review and editing, J.R. and F.M.; project administration, M.C.. All authors have read and agreed to the published version of the manuscript.

References

1. Karasahin, M., Terzi, S.: Evaluation of marble waste dust mixture of asphaltic concrete construct. Constr. Build. Mater. **21**(3), 616–620 (2007)
2. Contu, A., et al.: Applications of super compaction technique using granite by-products. sustainability, eco-efficiency and conservation in transportation infrastructure asset management. In: 2014 Proceedings of the 3rd International Conference on Tranportation Infrastructure, Pisa, Italy, pp. 255–261 (2014)
3. Rombi, J.: The use of Sardinian granite by-products from the Sarrabus-Gerrei region to be used in road pavement layers. Ph.D. thesis University of Cagliari, Sardinia, Italy (2014)
4. Natural Stone from Sardinia, Technical Handbook, 229 p. (2002)
5. ISTAT Homepage. http://dati.istat.it/Index.aspx?QueryId=8909
6. Balletto, G., Mei, G., Garau, C.: Relationship between quarry activity and municipal spatial planning: a possible mediation for the case of Sardinia, Italy. Sustainability **7**(12), 16148–16163 (2015)
7. Balletto, G., Garau, C.: Smart city governance in the geo-resources planning paradigm in the metropolitan city of Cagliari (Italy). In: Gervasi, O., et al. (eds.) ICCSA 2017. LNCS, vol. 10406, pp. 368–379. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62398-6_26
8. Founti, A.M., et al.: Environmental management aspects for energy saving in natural stone quarries. In: Proceedings Global Stone Congress 2010, Alicante, Spain (2010)
9. Ribeiro, R.C.C., et al.: Uses of aggregates produced from marble and granite quarry waste in asphalt pavements: a form of clean technology. In: Proceedings of the 2008 Global Symposium on Recycling, Waste Treatment and Clean Technology, Cancun, Mexico (2008)
10. Binici, H., et al.: Durability of concrete made with granite and marble as recycle aggregates. J. Mater. Process. Technol. **208**(1–3), 299–308 (2008)
11. Aliabdo, A., et al.: Re-use of waste marble dust in the production of cement and concrete. Constr. Build. Mater. **50**, 28–41 (2014)
12. Tunc, E.T.: Recycling of marble waste: a review based on strength of concrete containing marble waste. J. Environ. Manag. **231**, 86–97 (2019)
13. Hebhoub, H., et al.: Use of waste marble aggregates in concrete. Constr. Build. Mater. **25**(3), 1167–1171 (2011)

14. UNI EN 932-1. Tests for general properties of aggregates - Methods for sampling. Italian Organization for Standardization (U.N.I.)
15. UNI EN 932-2. Tests for general properties of aggregates - Methods for reducing laboratory samples. Italian Organization for Standardization (U.N.I.)
16. CNR 29/72, Italian National research council, specification for Cement Bound Granular Material
17. Ahmed, H. M., Abdelhaffez, G. S., Ahmed, A. A.: Potential use of marble and granite solid wastes as environmentally friendly coarse particulate in civil constructions. Int. J. Environ. Sci. Technol. **19**(2), 889–896 (2020). https://doi.org/10.1007/s13762-020-03014-2
18. Rombi, J., Coni, M., Olianas, M., Salis, M., Portas, S., Scanu, A.: Application of anhydrous calcium sulphate in cement bound granular pavement layers: towards a circular economy approach. In: Gervasi, O., et al. (eds.) ICCSA 2021. LNCS, vol. 12958, pp. 91–99. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-87016-4_7
19. Legislative Decree No. 152/2006 Italian Legal Framework, approving the Code on the Environment, which sets out the legislative framework applicable to all matters concerning environmental protection
20. D.M. n. 161/2012: regulates terms and conditions at which excavated materials may be reused as by-products and thus managed as non-waste
21. UNI EN 933-1. Tests for geometrical properties of aggregates - Determination of particle size distribution - Sieving method. Italian Organization for Standardization (U.N.I.)
22. UNI EN 1097-6. Tests for mechanical and physical properties of aggregates, determination of particle density and water absorption
23. CNR-UNI 10014. Determination of the Consistency (Atterberg) of a Soil. Italian National Research Council (C.N.R.) and Italian Organization for Standardization (U.N.I.)
24. UNI EN 1097 2, 2010. Tests for mechanical and physical properties of aggregates. Methods for the determination of resistance to fragmentation
25. UNI EN 13286-2. Unbound and hydraulically bound mixtures – Test methods for laboratory dry density and water content – Proctor compaction. Italian Organization for Standardization (U.N.I.)
26. Delgado, J., et al.: Geochemical assessment of the contaminant potential of granite fines produced during sawing and related processes associated to the dimension stone industry. J. Geochem. Explor. **8**, 24–27 (2005)