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## Residual sludge from dimension stones: characterisation for their exploitation in civil and environmental applications

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### Abstract

Residual sludge coming from dimension stones working plants represents a problem for Stone Industries (cost connected to their landfilling); sludge as such can be used for environmental restoration of derelict land or in cement plants, according to Italian regulation. However it is also possible to think about their systematic treatment for the production of Secondary Raw Materials or "New Products". To individuate possible different applications a geotechnical characterization was conducted on sludge as such and on different mixes. In detail the possibility of using them as products for dumps waterproofing and for land rehabilitation and reclamation is discussed.

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### 1. Introduction

Residual sludge coming from dimension stones working plants (diamond framesaw and ganguesaw with abrasive shots processes) represents a problem for Stone Industries. In fact the cost connected to their

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landfilling amounts to more than 3% of operating costs of dimension stone working plants. Furthermore their strict feature as waste to dump (CER code 010413) contrasts the EU principles of “resource preservation” and “waste recovery”.

The main problems related to their management are [1]:

- size distribution: the size of silt particles and the lack of pores, which means that they are virtually impermeable, with progressive compaction and consequent asphyxity [2].
- presence of heavy metals, due to the working processes and in particular Fe, Ni, Cr and lime (as antioxidant) connected to ganguesaw with abrasive shot process and Cu e Co connected to diamond framesaw process
- TPH content due to oil machines losses

Residual sludge, considered according to Italian Regulation (Dlgs152/06) [3], can be used, as waste, for environmental restoration of derelict land or in cement plants. It is also possible to think about their systematic treatment in consortium plants for the production of Secondary Raw Materials (SRM) or "New Products" (NP, eg. artificial loam, waterproofing materials, ...).

The research evidences that, on the basis of a correct sludge management, treatment and characterization, economic and environmental benefits are possible (NP or SRM in spite of waste to dump). To guarantee a real improvement of mineral waste reuse, it is important to consider their systematic treatment to obtain Secondary Raw Materials (SRM as fillers, etc..) or "New Products" (eg "artificial loam" for land rehabilitation). Such New Products or SRM have to be certified not only on the basis of their technical and physical characteristics, but also by means of appropriate chemical analysis to guarantee that products are not polluted. Magnetic or hydrogrametric treatments can be performed to reduce the heavy metals content; furthermore several biological (eg- bioremediation) or chemical treatments can decrease the presence of TPH [4] [5].

The paper outlines the results obtained during a recent research (commissioned by Camera di Commercio di Verbania) concerning residual sludge exploitation in order to obtain products (or by product) to employ for dumps waterproofing, filler material for civil works or artificial soil for land rehabilitation. The analyzed materials come from dimension stone working plants pertaining to Verbano Cusio Ossola (NE Piedmont) quarry basin. The average of the annual production of residual sludge in this area is about 70.000 t/y. Such material presents a siliceous matrix, connected to the granite and gneisses working activities.

The paper, in particular, outline the first part of the research concerning the laboratory phase, and in particular the geotechnical characterization of sludge.

## 2. Materials and methods

To individuate different applications of residual sludge in civil and environmental contexts, a geotechnical characterization was foreseen. In details grain size distribution analyses, falling head permeability tests, Atterberg limits, direct shear tests and modified Proctor compaction test were conducted.

The analyzed materials are residual sludge coming from diamond framesaw process (referred to as “CG”), ganguesaw with abrasive shots processes (referred to as “SR”) or a mixture of sludge from diamond framesaw and ganguesaw with abrasive shot process (referred to as “GG”). The geotechnical tests were carried out on sludge as such (a.s.) and also on three different mixes (Table 1) for the three different applications [6].

Table 1. Summary table of analyzed materials and their possible uses

Type of material	Type of material/mix	Sample	Hypothesized uses
Sludge a.s.	sludge coming from diamond framesaw process	CG	
	sludge coming from ganguesaw with abrasive shots processes	SR	
	mixture of sludge from diamond framesaw and ganguesaw with abrasive shot process	GG	
Sludge a.s. added to bentonite clay	CG + Bentonite Clay (95%-5%)	CG 5%	Dump waterproofing or cover
	CG + Bentonite Clay (90%-10%)	CG 10%	
	SR + Bentonite Clay (95%-5%)	SR 5%	
Sludge a.s. added to coarse materials coming from crushed dimension stones	GG + Coarse materials (90%-10%)	COA 10%	Filler material for civil works
	GG + Coarse materials (80%-20%)	COA 20%	
	GG + Coarse materials (70%-30%)	COA 30%	
Sludge a.s. mixed with sand, compost, peat	GG + Peat (50%-50% vol.)	I1	Artificial soil for quarry and civil works revegetation
	GG + Compost (50%-50% vol.)	I2	
	GG + Compost + Sand/Peat (50%-25%-25% vol.)	I3	

The results obtained from the tests (the number of tests is specified in Table 2) were fundamental to evaluate: a) the characteristics of the original materials; b) the chance to obtain new products for dumps waterproofing or cover (bentonite clay added to sludge a.s.); c) the opportunity to use them for land rehabilitation and reclamation. In details sludge a.s. added to coarse materials, coming from crushed dimension stones, could be used to fill quarry or civil works pits, while sludge a.s. mixed with sand, compost, peat could be utilised for quarry and civil works revegetation. For the last mix, phytotoxicity tests have been performed in cooperation with Agricultural Dept. – Turin University. In this case the “*cradle to grave principle*” would be applied: “waste” coming from dimension stone working plants could return to quarries.

The grain size distribution were measured with sieve analysis according to ASTM standards (ASTM D421-85(1998) [7]; D422-63(1998) [8]; D1140-00 [9]; D2217-85(1998) [10]).

The Atterberg limits are a basic measure of the nature of a fine-grained soil. In this research, plastic limit and liquid limit were assessed. The plastic limit was determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. The procedure is defined in ASTM Standard D 4318-10 [11]. For the liquid limit, the water content at which a soil changes from plastic to liquid behaviour was

evaluated with Casagrande standardized apparatus, according to ASTM standard test method D 4318 -10 [11].

The hydraulic conductivity was evaluated with the falling head permeability tests (ASTM D 5084 [12]); in the falling-head method, the soil sample is first saturated under a specific head condition, then the water is allowed to flow through the soil without maintaining a constant pressure head. For two sample, the hydraulic conductivity was also measured with in a modified triaxial cell.

The modified Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. The followed procedures and equipment details for the modified Proctor compaction test are designated by ASTM D1557 [13] and AASHTO T180 [14].

Finally direct shear tests were conducted in order to evaluate the stability of the material put on a slope. The tests were performed according the U.S. standards ASTM D 3080-72 [15].

Table 2. Summary table of performed geotechnical tests on sludge a.s. and mixture of sludge a.s. and other materials (/ = test not performed).

Type of material	Sample	Size distribution analyses	Atterberg limits	Falling head permeability tests	Modified Proctor compaction tests	Direct shear tests
Sludge as such	SR	2	2	1	1	2
	CG	2	2	1	1	2
	GG	2	2	1	1	2
Coarse materials coming from crushed dimension stones	COA	2	/	/	/	/
Sludge a.s. added to bentonite clay	SR 5%	4	2	2	1	2
	CG 5%	2	2	1	1	2
	CG 10%	4	2	2	1	2
Sludge a.s. added to coarse materials coming from crushed dimension stones	COA 10%	1	2	/	1	1
	COA 20%	1	2	/	1	1
	COA 30%	1	2	/	1	1
Sludge a.s. mixed with sand, compost, peat	I1	1	2	1	/	1
	I2	1	2	1	/	1
	I3	1	2	1	/	1

### 3. Results

Sludge as such (SR, CG and GG), according to grain size distribution analyses, are clayey silt weakly sandy; only one sample CG presents a size distribution as silt weakly sandy and clayey.

The Atterberg limits describes the materials, characterized by sand fraction, as not plastic. The hydraulic conductivity  $k$  is very low (table 3): falling head permeability tests highlight a  $k$  equal to  $2.3 \cdot 10^{-8}$  m/s for CG,  $2.9 \cdot 10^{-8}$  m/s for SR and  $9.2 \cdot 10^{-9}$  m/s for GG. The modified Proctor compaction tests indicate an optimal water content of 15% for CG and 14% for SR and GG (table 3). Sludge as such are not natural material and are characterised by sharp-cornered grains; as a consequence the peak shear

strength is expected to be higher than the one find for natural materials, characterised by the same size distribution. Moreover, the presence of metallic elements (related to abrasive shot) also contributes to the same phenomenon. Indeed the peak shear strength, according the direct shear tests, ranges between 34.2° and 34.4° for CG, 36.7° and 37.3° for SR, 31.9° and 33.0° for GG (table 3).

Table 3. summary table of the results of the geotechnical tests for sludge a.s.

Sample	Hydraulic conductivity k (m/s) (falling head permeability test)	Optimal water content (%) (modified Proctor compaction test)	Peak shear strength (direct shear tests)
CG	2.3*10 <sup>-8</sup>	15 %	34.2° - 34.4°
SR	2.9*10 <sup>-8</sup>	14 %	36.7° - 37.3°
GG	9.2*10 <sup>-9</sup>	14 %	31.9° - 33.0°

The results of geotechnical tests on mixture are described on the basis of the uses hypothesized, as shown below.

### 3.1. Dumps waterproofing or cover

The mixture of sludge a.s. and bentonite clay, useful for dumps waterproofing or cover, presents nearly the same size distribution of sludge a.s. (clayey silt weakly sandy); only SR 5% presents a particle size distributions as sandy-clayey silt. Adding a small percentage of bentonite clay to sludge a.s., the new mixes show plastic attitude (Table 4).

Table 4. Liquid and plastic limits for the mixture of sludge a.s. and bentonite clay.

Sample	Liquid Limit WL %	Plastic Limit WP%
CG 5%	39.7	29.2 - 31.0
CG 10%	36.3 - 37.2	24.9 - 25.8
SR 5%	39.7 - 40.5	26.3

The hydraulic conductivity k decreases, passing from sludge a.s. to the mixture sludge a.s. + bentonite clay; In particular, the addition of 10% of bentonite clay highly reduces the k, also of two order of magnitude (Table 5).

As for the modified Proctor compaction tests, adding bentonite clay (from 100% sludge to 95-90% sludge + 5-10% bentonite clay) it is possible to underline that the optimal water content increases (Table 5).

For the mixture of sludge a.s. and bentonite clay, the peak shear strength decreases slightly or remains constant with respect to sludge a.s. (Table 5).

Table 5. Results of the geotechnical tests for the mixture of sludge a.s. and bentonite clay; (\*) = test performed with a constant flow in a modified triaxial cell (as comparison).

Sample	Hydraulic conductivity k (m/s) (falling head permeability test)	Optimal water content (%) (modified Proctor compaction test)	Peak shear strength (direct shear tests)
SR 5%	$5.2 \cdot 10^{-9}$ - $5.6 \cdot 10^{-9}$ (*)	18%	36.8°
CG 5%	$1.9 \cdot 10^{-9}$	17%	28.9° - 29.3°
CG 10%	$2.3 \cdot 10^{-9}$ - $4.2 \cdot 10^{-11}$ (*)	16%	33.7° - 35.2°

### 3.2. Filler material for civil works

Sludge a.s. added to coarse materials, coming from crushed dimension stones, could be used to fill quarry or civil works pits. Coarse materials, according to size distribution analyses, show a sandy gravels weakly silty attitude. The mixtures of sludge a.s. and coarse material present a particle size distributions as sandy silt weakly clayey and gravely for COA 10%, and silt weakly gravely-clayey-sandy for COA 20% and COA 30%.

Sludge mixed with coarse material are characterized by sandy fraction and are not plastic.

As for the modified Proctor compaction tests, adding coarse heterogeneous material (from 100% sludge to 90-80% sludge + 10-20% coarse materials) it has to be underlined that the optimal water content increases if compared to sludge a.s. GG (Table 6).

For the mixture of sludge a.s. and coarse materials, the peak shear strength further increases compared to of sludge a.s. (sample GG) (Table 6).

Table 6. Results of the geotechnical tests for the mixture of sludge a.s. and coarse materials.

Sample	Optimal water content (%) (modified Proctor compaction test)	Peak shear strength (direct shear tests)
COA 10%	17 %	37.6°
COA 20%	18 %	38.1°
COA 30%	17 %	38.8°

### 3.3. Artificial soil for quarry and civil works revegetation

The mixture of sludge a.s. (GG) with sand, compost and peat, that could be utilized for quarry and civil works revegetation, according to grain size distribution analyses are silt weakly clayey with sand (I1), silt weakly gravely-clayey with sand (I2) and sand with silt weakly clayey (I3).

As well as for sludge a.s. added to coarse materials and for sludge a.s., sludge mixed with other materials (sand, peat and compost) are characterized by high sand fraction, so that they are not plastic.

The hydraulic conductivity is higher than sample GG, because of the addition of sand, peat and compost that increase the conductivity (Table 7).

For the mixture of sludge a.s. and sand, compost and peat, the peak shear strength increases compared to of sludge a.s. (sample GG) (Table 7).

Table 7. Results of the geotechnical tests for the mixture of sludge a.s. and sand, compost and peat.

Sample	Hydraulic conductivity k (m/s) (falling head permeability test)	Peak shear strength (direct shear tests)
I1	$6.8 \cdot 10^{-8}$	38.3°
I2	$6.9 \cdot 10^{-8}$	36.1°
I3	$5.2 \cdot 10^{-8}$	36.9°

#### 4. Conclusion

The described tests showed that the geotechnical parameters could be suitable to exploit sludge as such and sludge a.s. mixed with other materials (bentonite clay, coarse crushed material and compost/sands/peat) to obtain new products to use for environmental recovery or civil works.

In details, the hydraulic permeability of analyzed samples show that sludge a.s. and mixtures with bentonite clay have the requested features for dumps cover (GG, SR 5%, CG 5%, CG 10%) and dumps waterproofing (CG 10%). Indeed, according to Italian Law (DLgs 36/2003 [16]), the permeability k has to be  $\leq 10^{-9}$  m/s for dump bed and  $k \leq 10^{-8}$  for dump cover.

As regards the use as filler and for quarry and civil works rehabilitation, the results coming from geotechnical tests are promising. However, to exploit sludge mixtures in civil and environmental applications, it is necessary to guarantee, by means of appropriate chemical analysis, that there are no problems connected to soil, water and air pollution (connected to heavy metals and TPH contents). Magnetic or hydrogravimetric separation can be performed to reduce heavy metal content; TPH decrement can be reached by mean of specific agronomic treatments (eg. bioremediation).

Finally an in situ application is fundamental to sustain these data and to compare the laboratory results to the “pre-industrial” ones: the obtained data will be potentially useful to propose some integration to the present Italian legislation.

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