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## **Aggregates from tunnel muck treatments. Properties and uses**

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**Abstract.** Tunnel muck should be considered as a valuable resource: if it is managed and treated correctly, it can be used for different purposes. This would lead not only to environmental benefits but also those of an economic nature.

This work is part of the REMUCK project and it has the purpose of evaluating the effects of different treatments on different types of excavated rock. Five case studies have been selected and, of these, two were excavated with TBM (the Torrent-La Thuile tunnel and the Brennero tunnel), one with EPB (the Turin underground railway) and two using traditional excavation methods (Turin underground railway station and the Omegna tunnel).

Tests have been carried out in the laboratory on both the muck in its natural state and on muck treated in two different plants (a mobile plant and a fixed plant) in order to characterise the aggregates from the shape and mechanical resistance points of view (according to EN 933-3 and EN 1097-2, respectively). The results of these tests have been compared with the threshold values foreseen in a muck management plan for a tunnel in Switzerland in order to verify the quality of the treatments the recycled aggregates were subjected to. This has made it possible to evaluate the suitability of the treatments, on the basis of the foreseen types of use, and to propose alternative working schemes for the nonconforming cases.

*keywords: concrete aggregates, shape, mechanical resistance, mobile plant, fixed plant*

### **1. Introduction**

Each production process is obliged to respect sustainability principles, which means complying with the economic soundness, quality of the product, safety of the workers and environmental safety requirements. This involves paying special attention to the environment and major efforts are required even by companies in the infrastructures sector.

In this context, and in particular in the “sustainable mobility” sector, REMUCK project (Innovative methods for the eco-compatible and sustainable recycling of muck from tunnel excavation, also considering the potential content of noxious minerals – Regione Piemonte – CIPE 2006 call-to-tender) has been financed with the aim of developing and turning innovative methods to face the problems posed by waste muck

disposal and of optimising the management of waste recycling, in order to take economic advantage from the reuse of excavated waste materials.

The current survey and the potential increase in underground constructions (and tunnels in particular) foreseen for the future to answer the increasing demand for infrastructures, will involve a huge amount of tunnel muck, which, if not re-used, has to be dumped, with high costs concerning both the impact on the territory and the project itself. In tunnelling excavation, two very important aspects have to be taken into account: the dumping of the excavated material and the opening of new quarries to supply raw materials.

A solution that could be proposed to minimize these relevant environmental problems is the recycling, or reusing, of the muck from tunnel excavations which can be employed as aggregates for concrete, for bituminous conglomerates, for road construction, or for raw materials for industry. Tunnel muck can be used: in its natural form, as obtained from the excavation, treated in plants, treated or in its natural form with addition of other materials or as raw material for industrial products (not very common use).

Tunnel muck is more frequently used as:

- refilling material
- material for reliefs
- road construction
- concrete
- raw material for industrial production.

The properties considered to determine the final use vary according to its final use and refer, as far as the physical aspect is concerned, to the size distribution, the maximum dimension, the shape and the density, whereas from the chemical point of view, they concern the presence of some reactive minerals.

Before muck can be used as concrete aggregates, it must have suitable properties: as far as the petrographic properties are concerned, the presence of a significant quantity of brittle minerals (clay, gypsum, talc), of very hard minerals (garnet) and of foliated and fibrous minerals (mica, graphite, asbestos), should be avoided, whereas, as far as the chemical properties are concerned, high solubility (chloride, sulphate, gypsum), low resistance to decay (anhydrite, pyrite) and alkali reactivity have a negative affect.

No notable publication concerning the reuse of tunnel muck, with treatment processes has been published since 1999. In that year the CIRIA project which was carried out in Great Britain (Kwan and Jardine, 1999), analysed 32 underground excavation cases and their related waste management systems. Some general guidelines have emerged from the CIRIA project concerning the planning, designing and building of underground construction. Moreover, the CIRIA project, took into account the different possible uses of the tunnel muck, even though in general terms. With the new large roadworks (St. Gothard, Loetschberg, Turin-Lyon, Brennero), this matter has been dealt with in different papers, on the basis of studies and investigations executed at the same time as the works are underway (Darmendrail et al., 2003; Lombardi et al., 2008;

Thalman et al., 2005). The importance of a suitable tunnel muck classification emerges from the literature pertaining to its recovery but, above all, to the necessity of correlating the kind of rock, the excavation technique, the treatment method and the possible uses; this is the aim the REMUCK project has set itself.

## 2. Materials and methods

Five case studies have been selected in the REMUCK project: two cases of the Torino underground railway and the Omegna tunnel –regional road 229 in Piedmont (Italy), the Torrent – La Thuile tunnel for a hydroelectric power station in Aosta Valley (Italy) and the Brennero tunnel which connects Innsbruck (Austria) to Fortezza (Trentino Alto Adige – Italy). The studied cases, the kind of muck analysed and the excavation techniques are reported in Table 1.

Table 1. The studied cases in the REMUCK project with the analyzed muck and the excavation methods

tunnel	Torino - Corso Dante	Torino - Largo Marconi	Omegna	Torrent - La Thuille	Brennero (Aica)
muck	alluvial rocks: quartz, green rocks, cemented rocks	alluvial rock: quartz, green rocks, cemented rocks	granite	calcareous schist	granite
excavation method	cut&cover	earth pressure balance	drilling&blasting	tunnel boring machine	tunnel boring machine

A sample of muck has been taken from each tunnel and analysed in the Politecnico di Torino laboratories, in order to verify the suitability of the muck for re-use either in its natural state or after treatment. As far as the treatments concerned, the tunnel muck taken from the excavation yards has been treated in two different plants of two companies involved in the REMUCK project: one mobile and the other fixed.

The mobile plant (Figure 1) has an output of 280 t/h and a maximum input dimension of 600 mm. It is essentially made up of a vibrating screen above a primary jaw crusher and a magnetic separator above a conveyor belt, before the point where the treated material exits. The procedure produces only one kind of output.

The fixed plant (Figure 2) has an output of 250 t/h and a maximum input dimension of 300 mm. It is made up of two compartments: the one of the aggregates in their natural state with only a screen and washing process and that of the crushed aggregates. Water is used in the treatment plant. Two hammer crushers and a jaw crusher (secondary crushing) are placed in sequence in the crushing compartments and these are followed by vibrating screens.

From an accurate analysis of the EN standards concerning the different test methods foreseen for the different aggregate uses (which are the same Standards for

the EC marking of aggregates), the following characterization tests have been selected and carried on the tunnel muck materials:

- petrographic description (see Table 1);
- grain size distribution;
- shape of coarse aggregates (flakiness index and shape index );
- resistance to fragmentation of the coarse aggregates.

The evaluation of the finest content has been performed on the Torino underground railway muck, because of its high content of fine grained material.



Fig. 1. The mobile plant



Fig. 2. The fixed plant

### 3. Comparison with the requirements foreseen for the aggregate control plan of a Swiss tunnel

In the planning of an underground construction, the management of the excavation materials should be an integral part of the project which should also

contain a control plan. This plan should include tests that have to be executed on tunnel muck to verify the suitability for different uses.

The control plan of a Swiss tunnel has been taken into account due to the extensive experience of this country in the reuse of tunnel muck. This plan foresees five different uses, according to the quality of muck: concrete with high – medium compression resistance, second quality aggregates, third quality aggregates for relief and refilling, non compactable and silty, polluted materials. It should be pointed out that all the tunnel muck that has been analysed shows good petrographic properties, according to UNI 8981-8, EN 12620 and EN 932-3. The following tests are included in the control plan for the first three kinds of use: the flakiness index (according to EN 933-3: 2003) and resistance to fragmentation (according to EN 1097-2: 2008 - Los Angeles test).

The threshold values required by the Swiss control plan are reported in Table 2, together with the laboratory test results.

Table 2. The studied cases in the REMUCK project: variation of shape and flakiness index and mechanical resistance after the two different treatment plant  
(N: not treated; M: mobile plant; F: fixed plant)

		Torino-Corso Dante	Torino - Largo Marconi	Omegna	Torrent - La Thuile	Brennero (Aica)	Threshold values from Swiss control plan		
		Concrete	Aggregates 2 <sup>nd</sup> quality	Aggregates 3 <sup>rd</sup> quality					
Shape/Flakiness index	N	21/36	14/13	14/15	53/44	36/22	flakiness 20	flakiness 35	flakiness 50
	M	19/16	4/10	7/10	29/40	-			
	F	-	-	7/2	17/21	6/10			
Mechanical resistance (Los Angeles /Micro Deval)	N	28/19	22/11	-	-	24/9	30	40	not required
	M	29/18	24/12	31/23	27/-	-			
	F	-	-	38/11,5	22/-	23/-			

#### 4. Results and discussion

The two different treatment technologies have led to different effects on the size distribution of the studied tunnel muck. Fundamentally, the treatment in the mobile plant does not furnish a suitable size distribution for the treated tunnel muck to be used as concrete aggregates. An example of this is the granulometric distribution of the Omegna tunnel muck after the treatment in the mobile plant, that has been compared, in figure 3 with Fuller and Bolomey curves referring to ideal concrete aggregate distributions (Colleparidi, 1991). The fixed plant offers a suitable product for concrete, if the different size fractions obtained in the plant are mixed appropriately.

The shape and flakiness of the tunnel muck condition the suitability of use as concrete aggregates to a great extent. Very flat particles are not suitable for use as concrete aggregates. The jaw crusher in the mobile plant causes a slight decrease in the shape and flakiness index but, the jaw crusher is not suitable for schistose rocks, like that of Torrent-La Thuile tunnel (excavated by means of TBM). As far as the

Torrent – La Thuile muck is concerned, after the crushing in the mobile plant, the flakiness index decreased from 44 to 40 (and the shape index from 53 to 29); this value is however still too high. The results pertaining to the muck shape, after the treatment in the fixed plant, are undoubtedly better: this treatment causes a decrease in the flakiness index of 50%. The mechanical resistance values, instead, are not affected by the different treatment processes (Table 2).

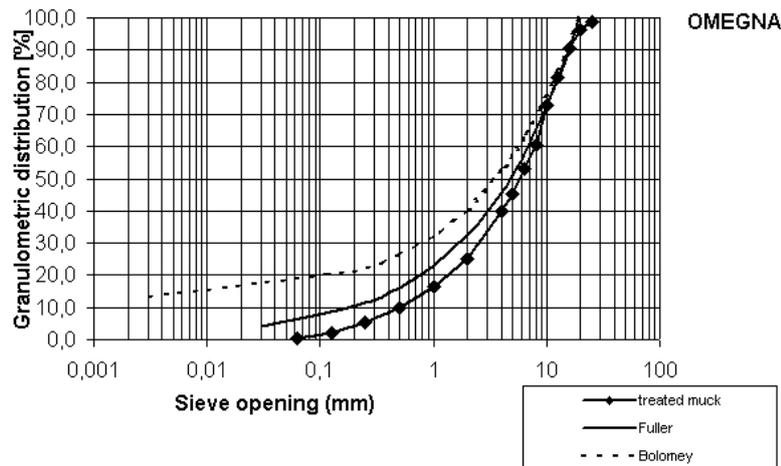


Fig. 3: Granulometric distribution of the Omega muck after treatment in the mobile plant, compared with the Fuller and Bolomey curves for concrete

If a comparison is made of the test results, on the different tunnel mucks, with the threshold values of the Swiss tunnel control plan (Table 2), it is possible to note that among the studied tunnels, the Torino underground railway (Largo Marconi) muck is the only one that is suitable for use as it is for concrete (taking into account only the shape and mechanical resistance). The Omega tunnel muck complies with the shape requirements but, being a weakly jointed rock, does not have a satisfactory mechanical resistance. The rocks excavated by TBMs (Torrent and Brennero) are suitable for use as concrete aggregates but only after treatment in the fixed plant.

## 5. Conclusions

The flaky shaped particles of tunnel muck excavated by TBMs have proved to be unsuitable for reuse as concrete aggregates since, during the concrete mixture, the particles tend to deposit according to horizontal levels, trapping water in the mixture which consequently causes a decay in the structure. The surface roughness and the presence of sharp corners make the bond between the aggregates and cement better, but at the same time reduce the workability, as the muck requires a higher amounts of water and cement which, therefore, leads to an increase in costs. Only the treatment in the fixed plant (with two hammer crusher and a secondary jaw crusher) makes the

aggregates rounder and isodiametrical and reduces the flakiness index therefore making it comply with the requirement for concrete.

As the outputs of the two treatment plants are different, especially concerning the shape of the treated muck, it is possible to assert that the action of the hammer crusher is important. A mobile plant with a primary “hammer” or “impact” crusher could result in products that are more suitable for use in concrete and which could answer to versatility requirement that is often required in this kind of yards

The use of tunnel muck in concrete, roads, refilling and relief is not the only possible final utilization. Some kinds of rocks such as the granite (found in the Omegna and Brennero tunnels) can also be further valorised and some of their minerals such as quartz and feldspars can be recuperated and employed in the glass or ceramic sector.

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