Case Study: Mechanical Reliability Of Sub-Grade Layer Built With Demolition Waste Materials.

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SYNOPSIS

This paper presents the results obtained studying the mechanical behaviour of inert materials produced from recycling construction and demolition waste (C&DW) materials. The use of recycled waste material helps to reduce non-renewable resources used to built roads, and limits the expansion of landfill sites.
To recycle waste materials, Italian policy requires a detailed knowledge of their physical and mechanical characteristics. Though waste materials are broadly studied all over the word, they are still not well known due to their intrinsically site-specific characteristics. In particular, it seems that common laboratory, as well as in situ, tests currently used for inert materials are not reliable to evaluate C&DW material behaviour. Thus, in situ tests were carried out to improve the knowledge about mechanical behaviour to enable their use as alternative inert materials.
The research has been developed in two phases. The first phase concerns the study of national and international literature about the use and behaviour of recycled materials, followed by the quantification of their production. During the second phase an experimental road was built in order to evaluate in situ mechanical behaviour. The experimental road, 1000 metres long, was built with a sub-grade made of construction and demolition waste materials for a length of 400 metres. In situ plate tests were carried out before using the road, soon after its construction, and after one working year to evaluate both short and long term mechanical behaviour.

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INTRODUCTION

This research takes into account two main issues: the construction of road superstructures and the reuse of waste materials. In fact, waste materials from constructions and demolition were studied to build sub-grade and foundation of road superstructures.
The use of waste materials instead of natural aggregates helps to reduce the use of natural aggregates and, at the same time, reduces the landfill volume required. The Italian waste policy (Decreto Legislativo del 5/02/1997 n°22), in accordance with the European law, has introduced new regulations to ensure appropriate management of waste materials and, at the same time, a high protection of the environmental. In particular, the law specifies the need for the reuse and recycling of waste material that is non-hazardous for human health. The most important strategies imposed by articles #3 and #4 are instructions about prevention and reuse of waste materials. This regulation promotes the development of new technologies that help to reduce the use of natural resources and introduces economic facilities to sustain the use of alternative materials. The law supports experiments and research that promote the use of waste materials and prevent or reduce waste production. Therefore, there is a need to study techniques and methodologies to reduce both the production of waste and the use of natural aggregates.
The two problems could have a unique common solution in the field of road construction: alternative materials, like waste materials, could be used to build or rebuild road superstructures. This type of waste management helps to reduce the use of natural aggregates and the quantity of disposed waste.
The use of the alternative materials is strictly connected with the knowledge of their physical, chemical and mechanical performance. Also, transportation and treatment costs play an important rule in the propagation of the use of wastes as alternative materials. Waste material production and characteristics vary from region to region and from country to country, and is dependent on the level of industrialization, on the type of primary materials available, and in construction techniques. Thus, it is necessary to find waste materials suitable in performance and quantity to construct road superstructures.
The suitability of alternative materials has to be studied with laboratory and in situ tests. Unfortunately, much research has already shown the absence of correlation between laboratory and in situ tests.
The goal of this case study is to evaluate the suitability of construction and demolition waste materials, produced in Sardinia, from the physical and mechanical point of view. Laboratory tests were conducted to evaluate physical characteristics and an experimental road was built to study mechanical performance in situ.

CHARACTERIZATION AND PRODUCTION OF CONSTRUCTION AND DEMOLITION WASTE

First of all, it is important to distinguish between construction and demolition wastes. Construction wastes are produced during different phases, e.g. transportation, stocking or working. Thus, their main characteristic is to be heterogeneous. Construction waste components are:

- pieces of wood;
- different kinds of plastic materials;
- different kinds of metal;
- paper, cardboard boxes, empties;
- synthetic material off-cuts, e.g. carpet, insulating materials;
- concrete pieces;
- bricks, tiles;
- bituminous materials;
- asbestos;
- polishes;
- excavation soil and rock;
- glass.

In general, demolition waste components are homogenous. Homogeneity increases the possibility to reuse or recycle this type of waste. Their main components are:

- bricks;
- cement, concrete;
- asphalt.

It is possible to find other materials, but the percent is very low compared with the three main components named above.
In general, it is not easy to evaluate C&DW material composition. It varies greatly with location, level of industrialization, and construction techniques. Table 1 shows the production of C&DW materials of some European countries and the USA; showing differences in both produced quantities and types of material.

Table 1: C&DW materials production in Europe and USA [1993]

Country / Material	Denmark	Germany	Italy	USA
Cement concrete	83,3%		10%	77%
Cement concrete with steel		40%	20%	
Bricks		47%	50%	4,5%
Asphalt			5%	
Excavation soil and rock			6%-10%	
Wood	12,5%	7%		11%
Paper, cardboard boxes	0,2%		0,6%-4%	
Plastic	0,4%	4%		0,3%
Metal	2,5%		3%	3,2%
Gypsum				4%
Inert aggregates		2%		
Mix	0,6%		1%-4%	

It is of fundamental importance to exactly know the components of waste material to establish both treatment methods and design techniques, e.g. to remove hazardous materials and to obtain a satisfactory mechanical behaviour.

A CASE STUDY: MECHANICAL BEHAVIOUR OF C&DW MATERIALS USED IN THE SUB-GRADE AND FOUNDATION OF ROAD S.P. N°1.

Each material used to build road superstructure layers has to be tasted to verify physical, chemical and mechanical performance. In Italy, fixed criteria based on laboratory and in situ tests exist to evaluate the performance of natural aggregates. Rules or methods defined for natural inert aggregates are not completely applicable to test alternative materials. Furthermore, many the tests conducted on alternative materials have not shown a correspondence between laboratory and in situ tests (see report ALT-MAT: Alternative Materials in Road Construction). More specifically, alternative materials have shown a good mechanical performance in situ, however laboratory tests do not support these results.
Thus, based on the results obtained from other research, it has been decided to construct an experimental road with C&DW materials to evaluate mechanical performance with in situ tests.
The experimental road has been constructed with the collaboration of the Provincial Administration of Cagliari. Also, laboratory and in situ tests were conducted in collaboration with the Geotechnical Laboratory of the Provincial Administration of Cagliari.
The experimental road was built in September 2002 and is a part of the provincial road network called “s.p. n°1”. It connects an industrial zone, named Macchiareddu, with a locality named Santa Lucia. Santa Lucia is a mountain protected zone, so to reduce visual impacts part of the road was built with asphalt.
The experimental road was built starting where the asphalt ends, as it is shown in Figure 1. It is almost 100 m long and 6 m wide, and was built partially on a small concrete bridge with the remainder on an embankment.

Figure 1: Experimental road

The experimental road was built instead of rebuilding an existing road (due to structural failure of the embankment) in September 2002. Thus, part of the new sub-grade and foundation layers were built with C&DW materials (100 m of roadway), with the remaining length of road being rebuilt with natural aggregates. The waste material was taken from a site located close to the experimental site.
A sample of the alternative material used is shown in Figure 2. The material is heterogeneous; in fact, it is possible to distinguish between components of different nature, like stones, pieces of concrete, rubble, asphalt, metals, tails, bricks, glass and other calcareous materials.

Figure 2: Construction and Demolition Waste

Before being posed, the alternative material was tested in laboratory. In particular, granulometric analysis and Limits of Atterberg were carried out and protocol of natural aggregates was followed. Mechanical performance was studied only with in situ bearing capacity tests.
Typical laboratory mechanical tests for natural aggregates were intentionally avoided for two main reasons: it is not possible to follow the same protocol of natural aggregates and, mostly, previous research has not shown reliable results.
Short and long term analysis of both physical characteristics and mechanical performances were studied. Granulometric analysis was carried out on samples of the alternative materials before building the experimental road, soon after the compaction of the sub-grade and foundation layers, and after a working year.
To determine sub-grade and foundation layer bearing capacities, plate tests were carried out soon after layer's compaction and after a working year.

Short Term Behaviour

First, laboratory tests were carried out on a sample taken from the site. The sample was analyzed following the same protocols of natural aggregates to determine its granulometric distribution and water sensitivity.

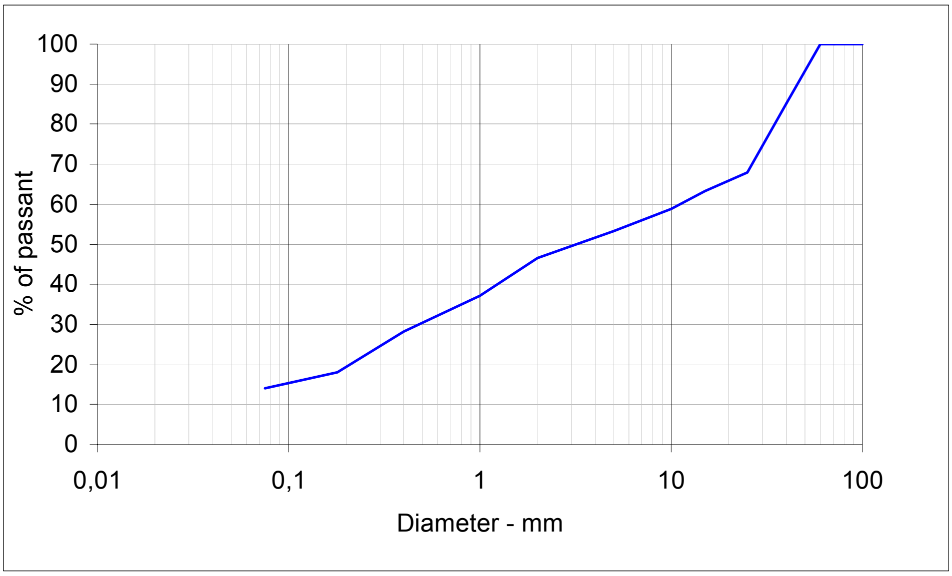

Figure 3: Granulometric curve before compaction

The granulometric curve is homogeneous and element size varies in a range between 0.06 *mm* and 60 *mm,* as it is shown in Figure 3. Carrying out Atterberg's Limits in laboratory, a non-plastic behaviour was found.
After compaction, see Figure 4, plate tests were carried out to determine in situ bearing capacity of both sub-grade and foundation layers built with C&DW materials. To determine the Deformation Modulus (Md) a circular plate with a diameter of 300 *mm* was used. The protocol of CNR-B.U. n° 146 for natural aggregated was followed.
To determine Md for sub-grade layer settlements were measured at pressures of 0,05 N/mm^2 and 1,5 N/mm^2, and for foundation layer settlements were measured at a pressure of 0,15 N/mm^2 and 0,25 kg/cm^2.

Figure 4: Foundation layer after compaction

Values of applied pressures and measured settlements were reported in **Errore. L'origine riferimento non è stata trovata.**2. For the sub-grade a Deformation Modulus of 77,7 N/mm^2 was obtained. It is a satisfactory value; in fact it is much higher than the required value, which has to be not less than 50 N/mm^2.

Table 2: Determination of Modulus of Deformation

Layer	Pressure (P)	Settlement (s)			Average (s)	Modulus of deformation (Md)
Sub-grade	N/mm^2	Pos. 1	Pos. 2	Pos. 3	mm	N/mm^2
	0,05	0,17	0,17	0,16	0,16	
	0,1	0,38	0,39	0,39	0,39	
	0,15	0,55	0,55	0,55	0,55	**77,7**
Foundation	2,00	0,75	0,75	0,76	0,75	
	2,50	0,92	0,92	0,92	0,92	**805,03**

In the same position where plate tests were carried out, a sample was taken, see Figure 5, to measure moisture conditions, compaction level, and most importantly, to control if there was any production of fine elements after compaction.

Figure 5: Taking samples after compaction

In the Figure 6, the blue curve shows the granulometric distribution before compaction and the pink curve shows the distribution after compaction. The two curves are fairly identical; in particular the production of fine grains is imperceptible.

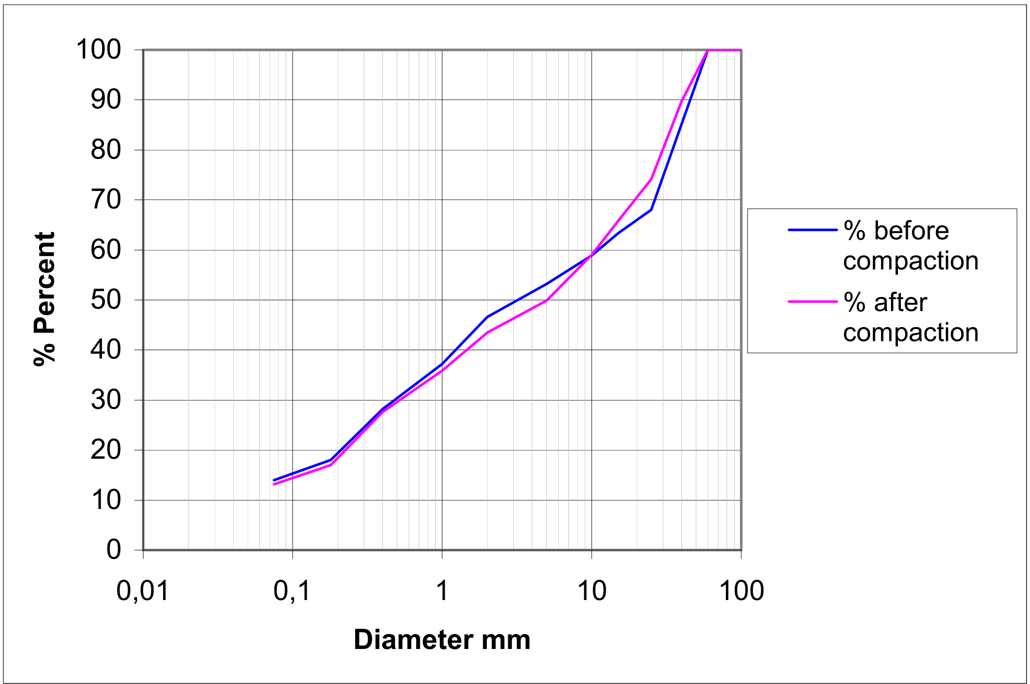

Figure 6: Comparison of granulometric curves

Long term behaviour

After a working year on the experimental road, granulometric analysis and bearing capacity tests were carried out to evaluate long term performance of alternative materials. To better evaluate their behaviour, laboratory and in situ tests were carried out on both waste materials and natural aggregates layers.

Three samples were taken. One sample was taken from the middle of the line and the other two from the sides. The results obtained from the granulometric analysis are shown in the Figure 7.

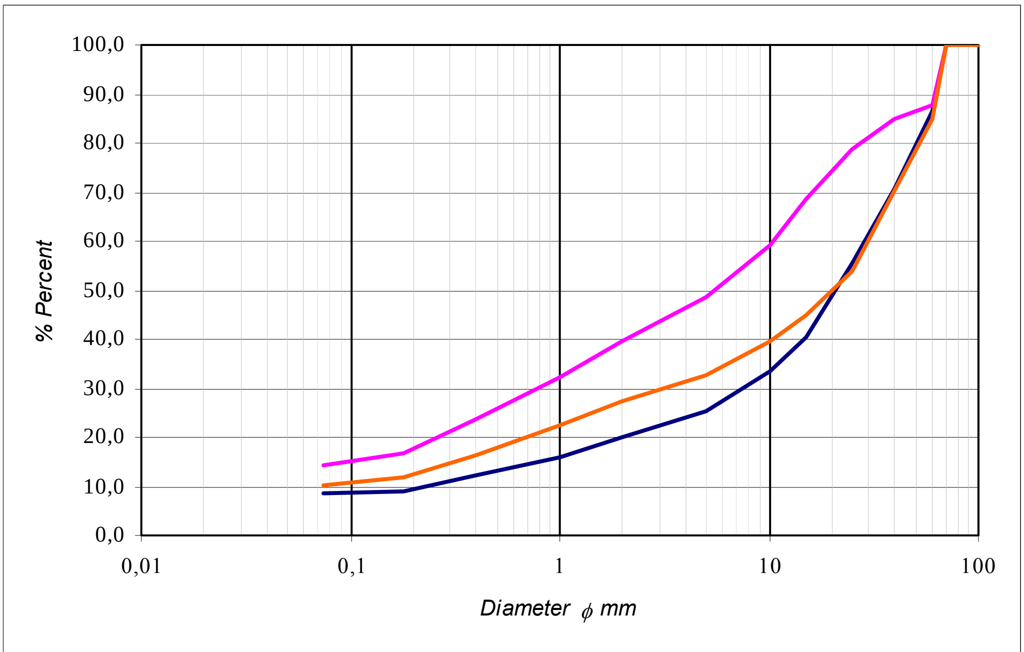

Figure 7: C&D granulometric curves after a working year

Figure 8 reports the granulometric curves of C&DW materials and natural aggregates. C&DW materials were represented with a continuous line and natural aggregates were represented with a dash line. It is evident all three samples of alternative material possess a higher percent of fine, whereas the percent of particles vary for each type of sample.

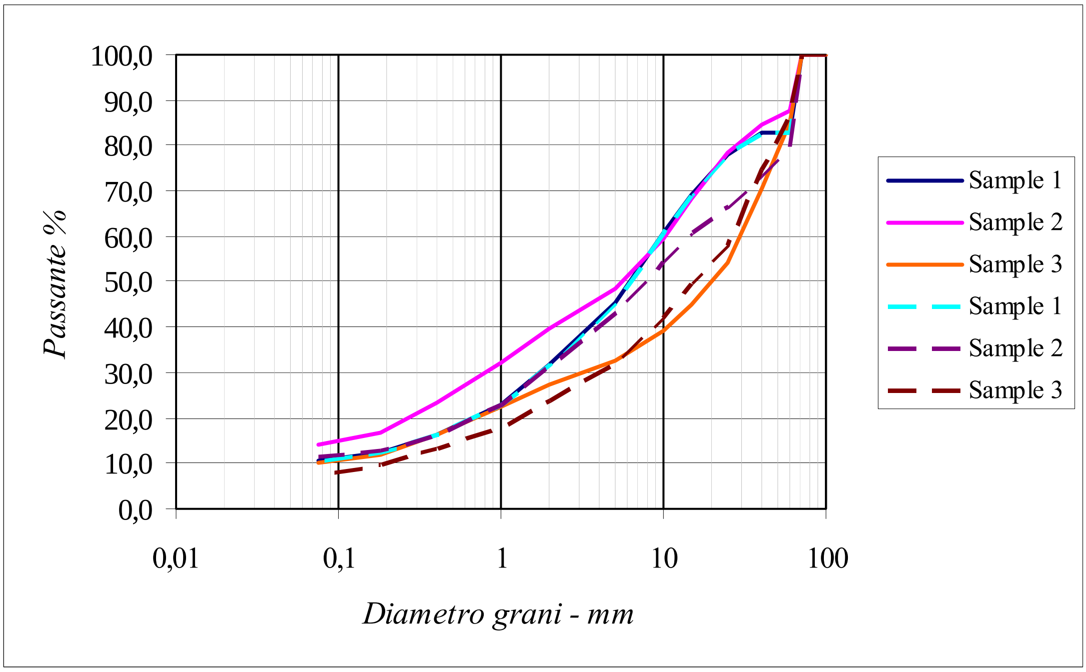

Figure 8: Comparison between natural aggregates and C&D waste materials

To assess the granulometric assortment, the granulometric curves obtained for the sub-grade layer were compared with a common granulometry range imposed for a layer built with natural aggregate. As it is shown in Figure 9, there is a slight deviation of sample (2), C&DW material, which has a higher percent of fine particles.

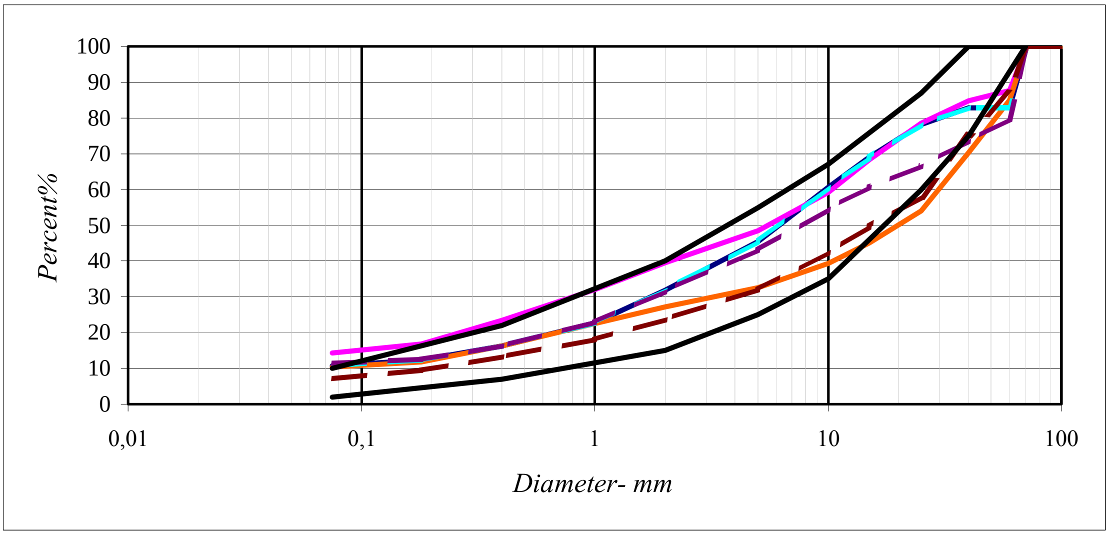

Figure 9: Comparison with granulometry for foundation layer

As reported in **Errore. L'origine riferimento non è stata trovata.**3, the values obtained in laboratory for Plasticity Index were acceptable and for Group Index were very good. Thus, C&DW material and natural aggregate were classified as A1 and A2-4.

Table 3: Limits of Atterberg and Classification of C&DW and natural aggregates

Samples	Limits of Atterberg			Group Index	Classification
	Liquid Limit	Plastic Limit	Plastic Index		
Sample C&D 1	30	22	**8**	0	**A2-4**
Sample C&D 2	28	21	**7**	0	**A2-4**
Sample C&D 3	27	23	**4**	0	**A1-a**
Sample 1	28	17	**11**	0	**A2-6**
Sample 2	24	17	**7**	0	**A2-4**
Sample 3	20	17	**3**	0	**A1-a**

The results obtained from plate tests have shown that the bearing capacity of both the sub-grade layer has increased. After a working year, the followings values of bearing capacity were obtained. The comparison between short and long term bearing capacity of sub-grade layer shows that bearing capacity increases with time. In a working year it has increased of the 12%.

Table 4: Comparison between Modulus of Deformation

Md [*N/mm²*]	**Sample C&D 1**	**Sample C&D 2**	**Sample C&D 3**	**Sample 1**	**Sample 2**	**Sample 3**
Sub-grade *(after one year)*	111,1	81,1	140,6	118,4	111,1	89,1
Sub-grade *(after construction)*	77,7					

CONCLUSIONS

The study of environmental policy has highlighted the need of using alternative materials instead of natural aggregates. To ensure both reuse and recycling processes of waste materials to build road superstructures, new laws and research are needed.
The goal of this case study was to evaluate the physical and mechanical performance of inert wastes, available in Sardinia, used as sub-grade and foundation base of road superstructures. Laboratory tests and in situ mechanical tests have shown good physical characteristics and satisfactory mechanical performances. Also, mechanical performances have improved with time, thus long term mechanical performances are better than short term.
Further studies and research need to be carried out to better understand and to better predict their physical, chemical, and mechanical behaviour. Upon improving the knowledge in this field, roads may be built and rebuilt with alternative materials.

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