From building to roads. Testing road embankment with construction and demolition materials

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Highlights

Annually, transport infrastructures construction activity consume a large amount of aggregates deriving from quarries, causing considerable land, environmental and energy losses. The employment of construction and demolition waste (C&DW) as for road constructions is a valid alternative to build embankment, subgrade and granular layers. Understand how this type of materials behaves on the physical and mechanical point of view is important to encourage and develop their use. In addition, a pilot project can encourage the construction reliability and the dissemination of the results.

Abstract

The paper reports the results obtained during an experimental research conducted in real working conditions of road embankment made with C&DW. For this purpose an experimental road, 30 m long, 4 m wide and 4 m high was built, installing 12 instruments: 3 pressure cells to measure stresses and 9 Linear Variable Differential Transformers (LVDTs) to measure deformations. The data were collected under different load and traffic speed magnitude. At this point of the research data are being analysed and compared, and the results reported on this paper.

Keywords

Transport infrastructures, Construction, Demolition materials, Recycling

1. INTRODUCTION

The increasing cost of transport infrastructure, in terms of construction complexity, economic costs and environmental impact is mainly affected by aggregates supply, transport, and management.

This involves the land exploitation for the opening of new quarries to extract and the transportation of the materials from the quarries to the construction and consequent increases in energy costs and environmental.

The employment of recycling materials deriving from the construction and demolition of buildings represents a valid alternative to increase overall economic and environmental efficiency.

The C&DW use permit to limit the exploitation of natural materials and,
consequently, to reduce landfills dimension. Many road infrastructures have been built with recycled materials but this good practice is little used due to the lack of reliability of professional operators and the absence of consolidated technical knowledge.

Figure 1. Section IV of the Statal Road 597 Sassari-Olbia opening in 2017. The entire highway will be 78 km long with 320,000 m² of footprint.

Figure 2. The road embankment built in 2007 with the coal waste inside the Carbosulcis mining site.

Economic and fiscal tools have been used in some European countries (axes on landfill, defiscalization on recycling aggregates), to encourage the use of alternative materials. Despite these, the use of recycled materials in road construction is still restricted. This is due at:

1. the conception of these materials as a type of “rubbish” and hence very poor;
2. transport costs and economic reasons;
3. debatable mechanical reliability and environmental performance of the materials.

Many questions, with no satisfactory answers, are connected to the assessment...
of their actual engineering performances and their effects on the environment. Several scientific results were obtained in the last years in the understanding of alternative materials behavior but must still be used to develop construction methodologies and standard specifications.

2. STATE OF THE ART

The ISPRA Report 2018 [1] on “Land Consumption, Territorial Dynamics and Ecosystem Services,” in Italy highlights that the “artificialization” of the territory in the different forms of settlement amounts to 94.8 km² / year on 301.338 km² and 4.53 km² / year in Sardinia on 24090 km². The fundamental causes are the construction of transport networks, buildings, industrial and productive settlements and expansion of cities, quarries and landfills, densification and conversion within urban areas. About 43% of the volumes of materials and aggregates derive from the construction for transport infrastructures (roads, railways, airports, ports, etc.). The needs of the Sardinia region is estimated at over 16 million m³.

Figure 3. Land use at the municipal level (% excluding water bodies - 2017). Source: ISPRA elaborations on SNP A cartography.
In addition to C&DWs, many other types of alternative materials have been tested in road construction: glass, fly ash, plastics, oven slag, tires, etc. In Carolina (USA), a study concerned the mixing of waste sand and plastic clay creating a durable composite material [2] (FWHA, 2011). In France, the sediments dredged from the port of Dunkirk were mixed with cement creating a composite material with performances far superior to traditional materials [3] (Siham et al., 2007). In some cases, electronic equipment waste was also used for aggregates of the foundations and bituminous conglomerates [4] (Ndoke, 2011). In this context, this paper investigates the use of C&DWs, present in many sites and deriving from civil and industrial constructions.

In this research, C&DW materials were used in large quantities in the F.lli Loi plant and deriving from the demolition of buildings in the metropolitan area of Cagliari. Several laboratory tests were carried out on this material, and an experimental road embankment was built on the intersection of the new SS 554 and the SS 125. The tests conducted during construction investigated the quality of compaction and the bearing capacity of the various levels of the survey [5] [6]. A homogeneous section of the body of the embankment was subsequently selected for the installation of the instrumentation. This instrumental survey mode has been widely used in the United States. Relevant studies on instrumented roads were conducted in Pennsylvania (USA), the Bedford project, MnRoad in Minnesota, Virginia Smart Road, NCAT, and in Italy the SmartRunway at Cagliari airport [7] [8].

Particular interest has the European cooperative research programs ALTMAT, POLMIT, and SAMARIS:

- **ALT-MAT “Alternative materials in road construction.”** The objective of ALT-MAT is to improve methods to assess the suitability of non-standard unbound materials for transport infrastructure application (sub-base, subgrade, and embankment). ALMAT, completed in 1999, founded by “Fourth RTD Framework Program” of the European Commission, involving 7 European countries coordinated by the TRL (UK), with a wide

![Figure 4. C&DW re-use process of buildings in a road.](image)
variety of climatic conditions, unconventional and natural materials and methods of road construction.

• SAMARIS “Sustainable and advanced materials for road infrastructure.” SAMARIS is a research project from the Growth program of the 5th Framework Programme, financed by the EU Commission and other public partners. The principal aim of the project is to encourage better use of recycled components in pavement materials. The second main objective is to prepare for the harmonization of European procedures and specification within the next generation of EN standards. This indicates moving from a recipe approach, which puts much importance on the intrinsic characteristics of the constituents, to a performance-based approach in-situ.

• POLMIT “Pollution of Groundwater and Soil by Road and Traffic Sources: Dispersal Mechanism, Pathways, and Mitigation Measures”: The project objectives are to provide and understand the absolute and relative importance of potential sources of pollution in and around roads, including the spreading of pollutants in soil and groundwater. The project is carried out under EU - DG XII “Transport Program” with the “Danish Road Institute” and other 6 European organizations.

However, despite extensive studies [11] [12] [11] and research, there are no studies in the literature concerning real-scale road sections made with C&DW materials while numerous experimental experiences involve laboratory tests, which have a lower significance than traditional materials due to the different origin of the materials (concrete parts, plaster, plaster, bricks, ceramics, etc.) and dimensional heterogeneity. It is important to note that in many cases the C&DW materials tested in the laboratory do not give satisfactory results, but once implemented they provide progressively increasing values up to the high performance. This is to be found in the presence of hydraulic binders and the crushed materials due to rolling with the release of fines that have binding power. In this situation, the presence of humidity activates hydration processes with the result of a monolithic behavior of the whole detected [14] [15] [16].

3. METHODOLOGY

The main objective of the research is to understand the behavior of the C&DW material in road construction, measuring the response of road layers under the loading of a heavy vehicle in different environmental conditions.

The paper describes the methods, tests, and analyses conducted and the needs for further research. In the preliminary phase, granulometric, abrasion (LA), water sensitivity (Atterberg limits) and CBR lift tests were conducted in the
During the construction of the embankment, the compaction was evaluated with the in situ density test, with the sand cone method and the load-bearing capacity by plate tests, both dynamic and static. The C&DW survey, built in January 2010, is part of the road works of the new SS 554, it is about 30 m long, 4 m wide and 3 m high. The instrumented area covers about 5 m² positioned on the right side of the embankment (Figure 5) and can measure the effect transmitted by the tires on both axles of the heavy vehicle in all directions.

The experimental road section was instrumented with 12 instruments: 9 LVDTs and three pressure cells. The sensors were installed in 3 different levels to monitor the entire structure. In each layer 2 standards, LVDTs were installed in longitudinal and transverse positions to measure deformations, 1 LVTD to detect vertical deformations and 1 pressure cell to measure vertical pressure. The sensors were installed after construction by a data acquisition system connected to a notebook. To simulate the effect of traffic a 4-axle heavy vehicle (42 t) was used at different speeds: 1.5 km / h, 2.5 km / h and 4 km / h, with different offsets over the entire surface. First, the weight of the axes was determined by electronic axle weighing for each axis of the vehicle in order to know the tension level imposed on the surface of the embankment.

The embankment response was measured in different periods of the year: January 2010, immediately after construction, autumn 2010 and summer...

Figure 5. The site and the instrumented embankment.
2011. This allowed us to highlight the performance of the material and their evolution under real traffic and environmental conditions.

The laboratory tests, conducted on the samples taken from the C&DW recycling plant, concerned: the flattening index of the aggregate, the shape of the coarse aggregate, the percentage of crushed, the Atterberg limits and the density. These methods have been the same used to evaluate the performance of natural aggregates.

Previous studies on C&DW aggregates shows that they do not always meet all the specifications required for tests on traditional materials and that in many cases there is no correlation between these tests and the results in situ [5] (Portas, 2004). Vice versa, in situ tests, on full-scale models, highlight satisfactory and increasing performance over time. For this reason, it is essential to compare the data obtained in the laboratory test and those obtained under real conditions of use.

The sensors were positioned at three different depths 0.5 m, 1.0 m, 1.5 m. The material was laid in 25 cm layers, and each layer 4 instruments were installed: 3 LVDT and 1 pressure cell, for a total of 12 instruments (Figure 6). The horizontal distance between the instruments of 0.6 m reduces the possibility of mutual influence of the sensors.

![Figure 6. Experimental surveyed cross section and position of the sensors.](image)

The 3 pressure cells were set according to the maximum expected pressure: 0.068 MPa at 1.5 m, 0.136 at 1.0 m and 0.344 MPa at 0.5 m. The installation techniques used have followed the protocols already verified in the Virginia Smart Road and Italian Smart Runway projects.

A thin layer of sand was added around the sensors to ensure complete contact between the pressure cell and C&DW materials, placing a geotextile and sand sheet at the top as protection from the rollers during compaction (Figure 7).
The LVDTs installed are of 2 types, 25.4 mm and 50.8 mm, modified to improve the duration and coupling between sensor displacements and granular mass. They consist of 2 65 mm diameter aluminum plates connected with a sleeve (Figure 8). During installation, the two disks were kept with a predefined opening, controlling their vertical alignment. Modifications have been introduced to protect the LVDTs from water infiltration, with adhesive thermo-shrinking sheaths, and with a 25 mm diameter molded neoprene sleeve.

The IOtech data acquisition system used allows the contextual reading of the signal from the 12 instruments installed. The 2001 DaqBook portable system is a portable data acquisition device capable of simultaneously receiving analog, frequency and digital inputs in a frequency range up to 200 kHz and manageable from a laptop or PC via Ethernet. The unit is able to amplify and condition the signal by using two DBK65 units that have been connected to the 12 instruments. Each unit can accommodate 8 sensors where the voltage can be set; the pressure cell channels have been set to 10 V and LVDT to 24 V. The test program saw the application of a moving load, applied with a heavy state set in base alla pressione massima prevista: 0.068 MPa a 1.5 m, 0.136 a 1.0 m e 0.344 MPa a 0.5 m. Le tecniche di installazione utilizzate hanno seguito i protocolli già verificati nell’ambito dei progetti Virginia Smart Road e Italian Smart Runway. Un sottile strato di sabbia è stato aggiunto intorno ai sensori per assicurare un perfetto contatto tra cella di pressione e i materiali C&DW, disponendo in sommità un tela di geotessuto e sabbia come protezione dai rulli durante la compattazione (Figura 7).

Gli LVDT installati sono di 2 tipologie, da 25.4 mm e 50.8 mm, modificati per migliorare la durata e l’accoppiamento tra spostamenti del sensore e ammasso granulare. Esistono di 2 piastre di alluminio da 65 mm di diametro connesse con un manicotto (Figura 8). Durante l’installazione, i due dischi sono stati mantenuti con un’apertura predefinita, controllandone l’allineamento verticale. Modifiche sono state introdotte per proteggere gli LVDT dall’infiltrazione di acqua, con guaine termo-restringenti adesivi e con un manicotto di neoprene modellato di diametro 25 mm. Il sistema di acquisizione dati IOtech utilizzato permette la lettura contestuale del segnale proveniente dai 12 strumenti installati. Il
construction vehicle, both empty and fully loaded, with 4 axles and an empty weight of 11500 kg (Figure 9) in transit at different speeds.

Each axle of the truck (Figure 10) and the tire pressure were measured before allowing the truck to maneuver on the embankment.

After the embankment construction, standard tests were carried out to determine the dry density and the bearing capacity by load plate tests. The sand cone method was used to measure dry density, according to the CNR UNI protocol valid for natural aggregates.
4. RESULTS

The C&DW material used highlighted a granulometric distribution resulting as coarse gravel sand A1a (HRB-AASHTO), with plasticity index Ip = 0. The bearing capacity (CBR) measured on the 25 mm ASTM sieve were carried out with different moisture contents. The results are shown in Table 1.

The mean value of the Los Angeles coefficient is 36.9%, highlighting a high aptitude for the fragmentation of the C&DW aggregates. Table 2 summarizes the values obtained.

The results of the standard tests show an average dry density of 89% of the maximum AASHTO mod. The values are low if referred to a non-bound and compacted layer in a standard way. The degree of compaction has been deliberately limited to make the progressive setting phenomenon evident. This occurs because C & DW materials have a high percentage of hydraulic binders (cement, lime, gypsum, etc.)

![Graph.png](attachment:Graph.png)

Table 1. CBR as a function of water content.

<table>
<thead>
<tr>
<th>Water content</th>
<th>CBR</th>
</tr>
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<tbody>
<tr>
<td>4%</td>
<td>13.1%</td>
</tr>
<tr>
<td>8%</td>
<td>97.0%</td>
</tr>
<tr>
<td>11%</td>
<td>23.4%</td>
</tr>
<tr>
<td>13%</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

Table 2. Summary of laboratory tests.

<table>
<thead>
<tr>
<th>C&amp;DW test</th>
<th>Classification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRB</td>
<td>HRB [A1-a]</td>
<td>coarse sand</td>
</tr>
<tr>
<td>Atterberg limit</td>
<td>Ip = 0</td>
<td>not plastic</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>[%]</td>
<td>36.9</td>
</tr>
</tbody>
</table>

Table 3. Summary of in situ tests.

<table>
<thead>
<tr>
<th></th>
<th>Section 3</th>
<th>Section 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural density</td>
<td>[kN/m³]</td>
<td>17.9</td>
</tr>
<tr>
<td>Dry density</td>
<td>[kN/m³]</td>
<td>16.7</td>
</tr>
<tr>
<td>Water content</td>
<td>[%]</td>
<td>6.8</td>
</tr>
<tr>
<td>Max density AASHTO mod</td>
<td>[kN/m³]</td>
<td>18.9</td>
</tr>
<tr>
<td>% compaction</td>
<td>[%]</td>
<td>88.4</td>
</tr>
</tbody>
</table>
Static plate tests were integrated with LWDT (Leight Weight Drop Test) dynamic tests for a quick estimation of the dynamic Evd module. Measurements were performed every 1.50 m, along the left and right median edge, along the entire length of the embankment with a total of 66 measurements. The adequate measures were performed in autumn 2010 and during the summer of 2011, highlighting the good behavior of the material after a post-consolidation period (Figure 6).

The highest value is recorded along the central axis and is due to the compaction action of the means which is higher in the middle of the embankment. In fact, in this area, the machines work better than the edges have a higher bearing capacity. Another reason is due to the reduced width of the road, which meant that the area near the central axis was subjected to several passages of the compacting means double than the edge.

Figure 12 shows the response of the pressure cells due to the passage of the axis. The highest value was measured with the passage of the most massive quarter. The maximum pressure measured in tests during truck maneuvers was around 94 kPa (Figure 13). The vertical pressure decreases rapidly, almost linearly, within the first meter. A similar trend was achieved for the three different speeds.

The displacements (Figure 14) in the first layer (0.5 m) have been found between 5 and 7 mm, while at 1.5 m of depth between 0.5 and 1.8 mm.

In the other directions, longitudinal and transversal, the displacements have a lower absolute value, and they also become near to zero rapidly already in the first meter of depth.

Regarding the effect of transit speed the acquired data do not show a defined trend. This is due to the geometric configuration of the experimental road which did not allow an exact repetition of the tests on the same track covered by the tires.
Figure 12. The response of the pressure cells during the transit of the 4 axes.

Figure 13. Response of pressure cells to different depths.

Figure 14. The response of displacement LVDTs to different depths and direction.
5. CONCLUSIONS

The research aimed to verify the behavior in real working conditions of C&DW materials using displacement and pressure sensors in an experimental survey. The value of the dynamic module was on average equal to 61.3 MPa higher than the generally accepted minimum values of 50 MPa. The repetition of the tests after one year shows how the value grows further, reaching 80.2 MPa with an increase of 26.7%. The field of stress and displacements is rapidly extinguished already in the first meter of the C&DW embankment, highlighting the excellent behavior of the materials.

The possibility of reusing demolition debris deriving from civil and industrial buildings is, therefore, a correct technique to guarantee the mechanical performance of road bodies and at the same time reduce the impact of waste in the environment.

6. REFERENCES

[7] Imad L. Al-Qadi, Silvia Portas, Mauro Coni, Samer Lahouar Runway Instrumentation and Response Measurements