Chemical and Mechanical Reliability of Sub-Grade Layer Built with Demolition Waste Materials.

Portas S.
Dipartimento di Ingegneria del Territorio, Università degli Studi di Cagliari
Email: sportas@unica.it

Synopsis

The use of recycled waste material helps to reduce non-renewable resources used to build roads, and limits the expansion of landfill sites. To recycle waste materials, Italian policy (*Decreto Legislativo n°22 5/02/1997 and integrations*) requires a detailed knowledge of their chemical, physical and mechanical characteristics.
The aim of this research is to assess the performance of C&DW aggregates from the chemical, physical and mechanical point of view and to provide useful information to develop guidelines for the proper use of construction and demolition waste (C&DW) materials for road sub-grade and foundation layers.
Previous research, conducted on an experimental road, has shown C&DW materials to possess good physical characteristics and satisfactory mechanical performance to construct both sub-grade and foundation layers of road superstructures. The research has been extended to include chemical laboratory analysis and to add more in situ tests with different C&DW streams.
Different chemical laboratory analyses were carried out to determine the potential leaching characteristics of recycling materials. Tests performed included the "16-day leaching test", "acetic acid test" and "carbon monoxide test", with all results showing negligible impact to human health.
Also, to evaluate long term mechanical behaviour, both plate and dynamic plate load tests have been performed. To date, results have shown that mechanical performance has improved with time.

Chemical and Mechanical Reliability of Sub-Grade Layer Built with Demolition Waste Materials.

INTRODUCTION

Every country is searching for new engineering methods and techniques to minimize the use of natural resources as well as to protect the environment. Road construction is one of the main fields where researchers are studying the use of alternative materials. Many different waste materials have been tested and many others are being tested. Since 1999, in view of the huge quantities of C&DW, the author has been studying the possibility of substituting primary aggregates with C&DW materials as valuable secondary or recycled resources for building sub-grade and foundation layers of road superstructures. Previous studies show that when properly sorted, graded and cleaned, C&DW can, as an alternative to dumping, be recycled as secondary aggregates which can be re-used in the road construction sector. In accordance with The Italian Waste Policy (*Decreto Legislativo n°22 5/02/1997 and integrations*), and the European law (91/156/EEC, 91/689/EEC, 94/162/EC), the use of C&DW materials instead of natural aggregates must ensure a high protection for the environment. In particular, the law specifies the need for the reuse and recycling of waste material that is non-hazardous to human health. The environmental suitability of alternative materials must be studied with chemical laboratory tests that ensure the harmlessness of their leachates. At the same time, the use of C&DW materials for road construction is strictly connected to the knowledge of their physical and mechanical performance.
The aim of this research is to evaluate the suitability of available C&DW materials from the chemical, physical and mechanical point of view. Thus, laboratory tests were conducted on different C&DW streams to evaluate both chemical and physical characteristics, and an experimental road was built in order to both study and monitor mechanical performance of recycled aggregates from C&DW in situ.

CHEMICAL CHARACTERIZATION OF C&DW

The Italian Waste Policy (*Decreto Legislativo n°22 5/02/1997 and integrations*), as well as European Commission (*199/31/EC*), requires chemical characterization of any type of waste material before being recycled or discarded to determine the nature and quantity of soluble constituents that may be washed from waste materials under natural precipitation conditions. In particular, C&DW are extremely variable in composition, (i.e. pieces of wood, plastic materials, metals, paper, concrete, bricks, tiles, bituminous materials, asbestos, excavation soil and rock, glass) and can contain harmful components.

Figure 1 Sample of construction and demolition waste

A 16-day leaching test is required by the Italian regulation (*Decreto Ministeriale 5/2/98*) to assess the presence of harmful components in waste leachates. The procedure consists of eight steps where the sample is filtered after 2, 8, 24, 48, 72, 102, 168 and 384 hours, over a total period of 16 days. This is a very strict test commonly applied for discarded wastes.
The upper limits, imposed by the law, for each possible component are reported in Table 1.

Table 1 Upper limits imposed by D.M. 5/2/98

Harmful Components			**Upper Limit** (D.M. 5/2/98)
Nitrate	NO_3	mg/l	50
Cyanides	Cn	µg/l	50
Chlorides	Cl	mg/l	200
Fluorides	F	mg/l	1.5
Sulfates	SO_4	mg/l	250
Arsenic	As	µg/l	50
Barium	Ba	mg/l	1
Beryllium	Be	µg/l	10
Cadmium	Zn	µg/l	5
Cobalt	Co	µg/l	250
Total Chromium	Cr	µg/l	50
Mercury	Hg	µg/l	1
Nickel	Ni	µg/l	10
Lead	Pb	µg/l	50
Copper	Cu	µg/l	50
Selenium	Se	µg/l	10
Zinc	Zn	mg/l	3
Vanadium	V	µg/l	250
COD		mg/l	30
Asbestos		mg/l	30
pH			5.5 -12

For this research leaching tests were carried out on samples produced from two different C&DW streams. The recycled aggregate samples were produced in two different sites, following the same procedures but crushed with different grades.

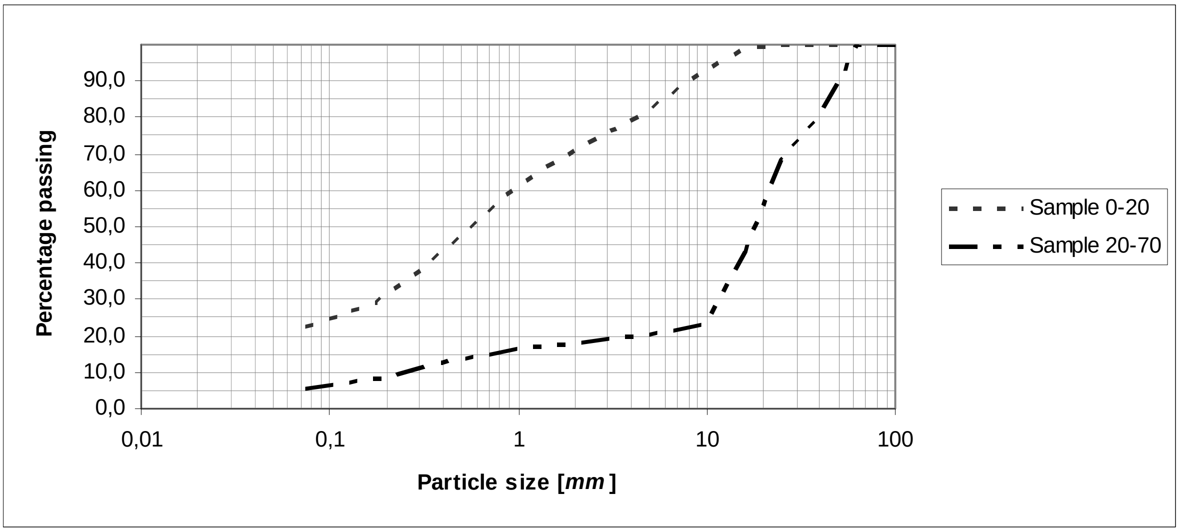

Figure 2 Grading of C&DW aggregates (Site 1)

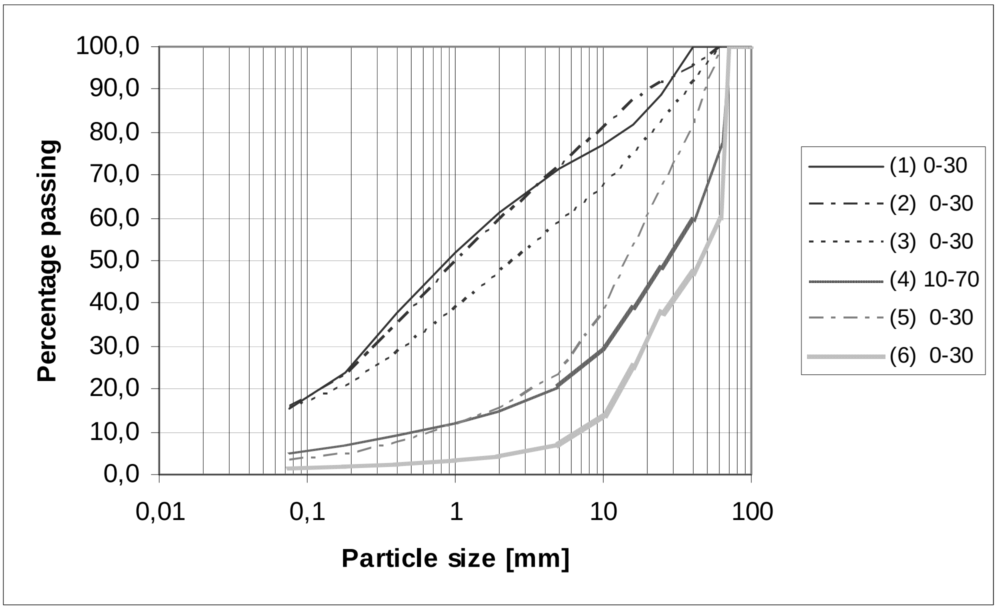

Figure 3 Grading of C&DW aggregates (Site 2)

Chemical tests were carried out on samples with a grading suitable for a road superstructure foundation layer. Grading of recycled aggregate samples is shown on the following figures.

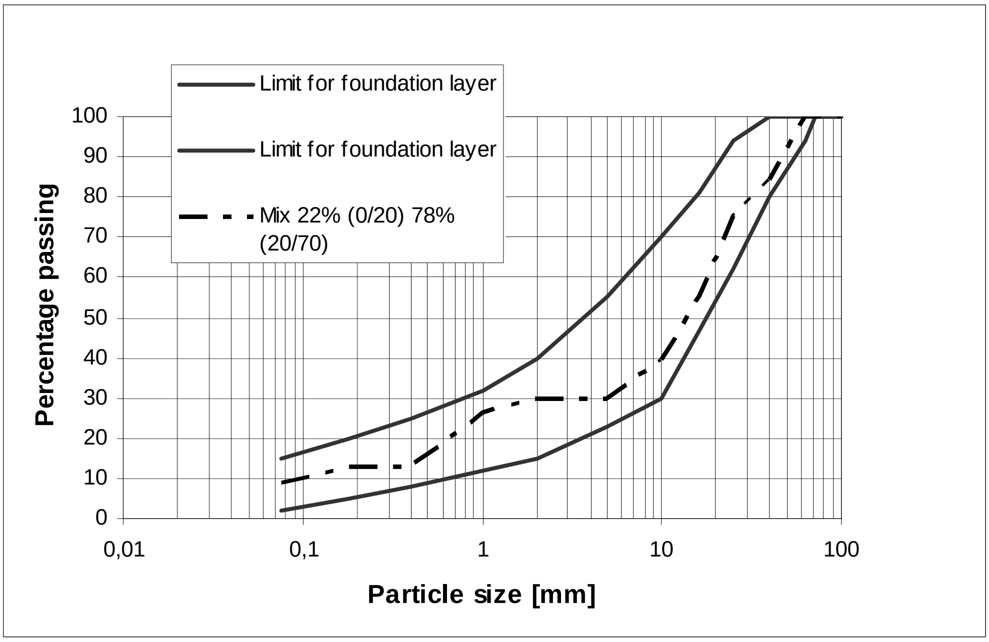

Figure 4 Sample for chemical test from Site 1

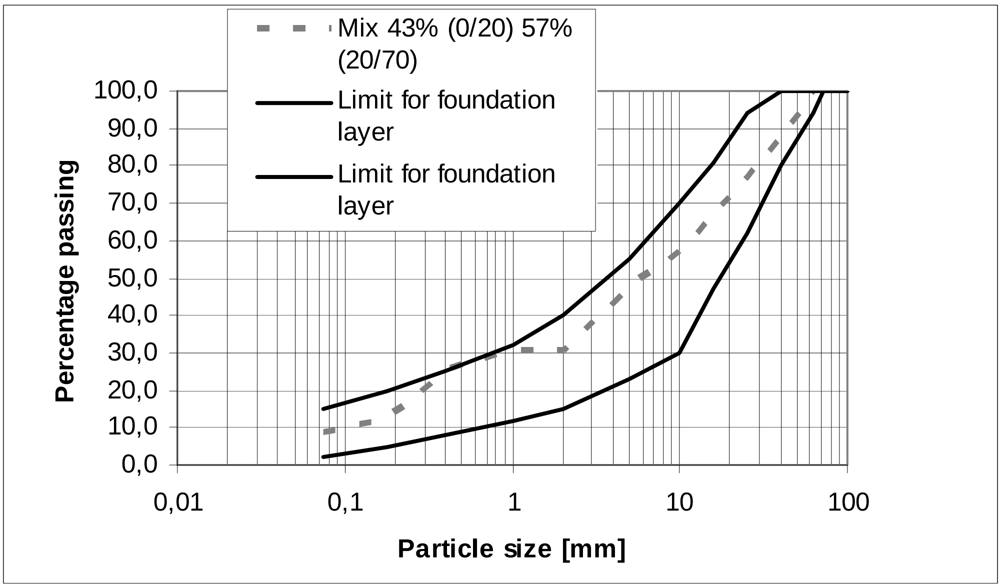

Figure 5 Sample for chemical test from Site 2

Results of 16-day leaching test on C&DW samples from Site 1

Leaching tests were carried out following the Italian law protocol. In Table 2 and Table 3 both the total and partial quantities of each component are listed.

Table 2 16-day leaching test on sample from Site 1

			2 h	8 h	24 h	48 h	72 h	102 h	168 h	384 h	Total
Chlorides	*Cl*	*mg/l*	85,9	32,2	30,8	14,85	9,25	7,95	6,7	10,2	197,85
Fluorides	*F*	*µg/l*	414	351	384	368	390	393	379	764	**3433,0**
Nitrate	*NO_3*	*mg/l*	8,32	4,24	6,78	6,11	4,02	2,29	1,51	1,62	34,89
Sulfates	*SO_4*	*mg/l*	136	43	66	65	55	66	53	158	642,0
Arsenic	*As*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Barium	*Ba*	*mg/l*	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	0,03	0,05	0,08
Beryllium	*Be*	*µg/l*	<3	<3	<3	<3	<3	<3	<3	<3	<3
Cadmium	*Cd*	*µg/l*	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
Cobalt	*Co*	*µg/l*	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total Chromium	*Cr*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Copper	*Cu*	*µg/l*	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Mercury	*Hg*	*µg/l*	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2
Nickel	*Ni*	*µg/l*	<2	<2	<2	<2	<2	<2	<2	<2	<2
Lead	*Pb*	*µg/l*	<2	<2	<2	<2	<2	<2	<2	<2	<2
Selenium	*Se*	*µg/l*	<3	<3	<3	<3	<3	<3	<3	<3	<3
Vanadium	*V*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	*Zn*	*mg/l*	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Asbestos		*mg/l*	-	-	-	-	-	-	-	-	-
pH			9,3	7,9	8,7	7,8	8,6	8,5	8,1	8	-

Table 3 16 -Day Leaching Test on sample from Site 2

			2 h	8 h	24 h	48 h	72 h	102 h	168 h	384 h	Total
Chlorides	*Cl*	*mg/l*	81,8	25,5	26,1	13,6	9,35	8,6	6,8	10,9	182,7
Fluorides	*F*	*µg/l*	422	209,6	754,4	556,4	582,4	524,65	473,6	571,8	**4094,85**
Nitrate	*NO_3*	*mg/l*	85,9	32,2	30,8	14,85	9,25	7,95	6,7	10,2	197,85
Sulfates	*SO_4*	*mg/l*	470	426	632,8	540	621,2	818,1	682,3	882,3	**5073,1**
Arsenic	*As*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Barium	*Ba*	*mg/l*	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	0,03	0,05	0,08
Beryllium	*Be*	*µg/l*	<3	<3	<3	<3	<3	<3	<3	<3	<3
Cadmium	*Cd*	*µg/l*	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
Cobalt	*Co*	*µg/l*	<10	<5	<5	<5	<5	<5	<5	<5	<5
Total Chromium	*Cr*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Copper	*Cu*	*µg/l*	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Mercury	*Hg*	*µg/l*	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2
Nickel	*Ni*	*µg/l*	<2	<2	<2	<2	<2	<2	<2	<2	<2
Lead	*Pb*	*µg/l*	<2	<2	<2	<2	<2	<2	<2	<2	<2
Selenium	*Se*	*µg/l*	<3	<3	<3	<3	<3	<3	<3	<3	<3
Vanadium	*V*	*µg/l*	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc	*Zn*	*mg/l*	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
Asbestos		*mg/l*	-	-	-	-	-	-	-	-	-
pH			10,3	9,6	9,07	8,7	10,6	10,1	9,8	8,15	-

Table 4 shows the total amount of components obtained in 16 days for both samples and upper limits imposed by the Italian law (*Decreto Ministeriale 5/2/98-Allegato III)*. The results obtained for the tested samples are almost the same. In general, concentration of harmful components is much lower than the limit values imposed by the law, except for fluorides and sulfates which have a concentration much higher than the upper limits.

Table 4 Results comparison

			Site 1	Site 2	Upper Limits
Chlorides	*Cl*	*mg/l*	197,85	182,7	200
Fluorides	*F*	*µg/l*	**3433,0**	**4094,85**	1500
Nitrate	*NO_3*	*mg/l*	34,89	197,85	50
Sulfates	*SO_4*	*mg/l*	642,0	**5073,1**	250
Arsenic	*As*	*µg/l*	<5	<5	50
Barium	*Ba*	*mg/l*	0,08	0,08	1
Beryllium	*Be*	*µg/l*	<3	<3	10
Cadmium	*Cd*	*µg/l*	<0,5	<0,5	5
Cobalt	*Co*	*µg/l*	<10	<5	250
Total Chromium	*Cr*	*µg/l*	<5	<5	50
Copper	*Cu*	*µg/l*	<0,01	<0,01	50
Mercury	*Hg*	*µg/l*	<0,2	<0,2	1
Nickel	*Ni*	*µg/l*	<2	<2	10
Lead	*Pb*	*µg/l*	<2	<2	50
Selenium	*Se*	*µg/l*	<3	<3	10
Vanadium	*V*	*µg/l*	<5	<5	250
Zinc	*Zn*	*mg/l*	<0,01	<0,01	3
Asbestos		*mg/l*	-	-	30

It is important to notice that the concentration of most of the components remain constant with time, as shown in Figure 6.

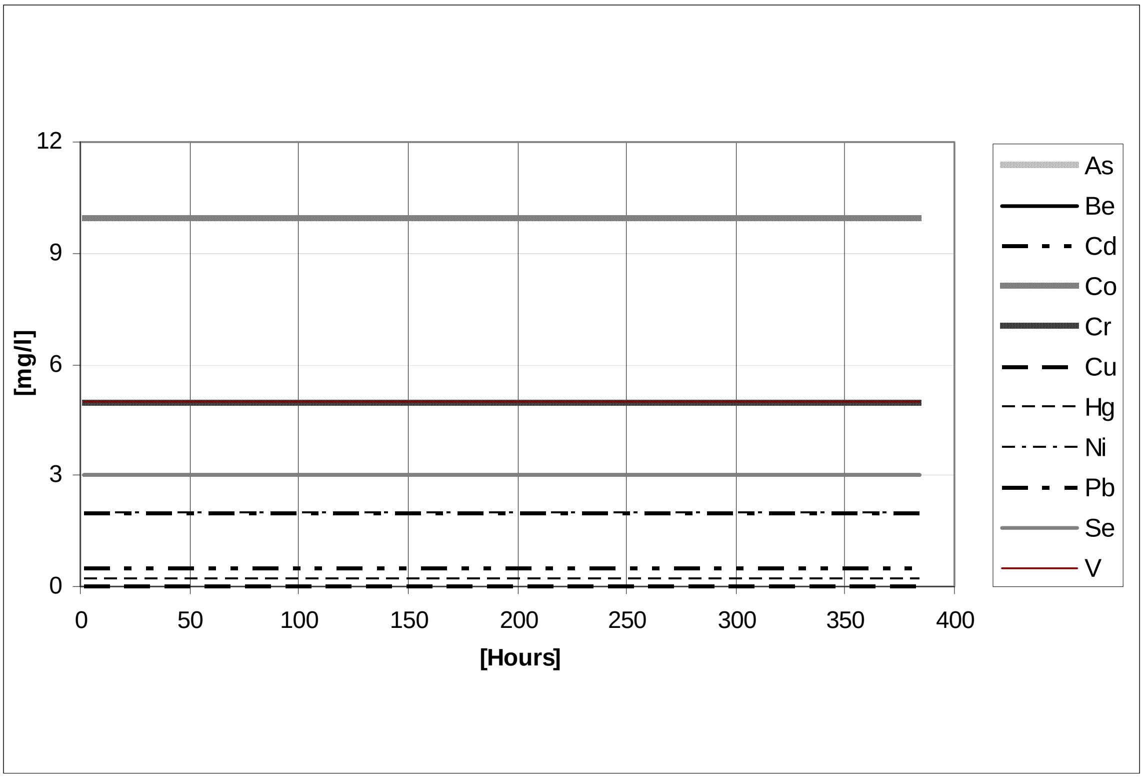

Figure 6 Results of 16-day leaching test (sample from Site 1)

In Figure 7, sulfate concentration is evidently changing at both the beginning and end of the test, beryllium increases with time and, meanwhile nitrate decreases with time.

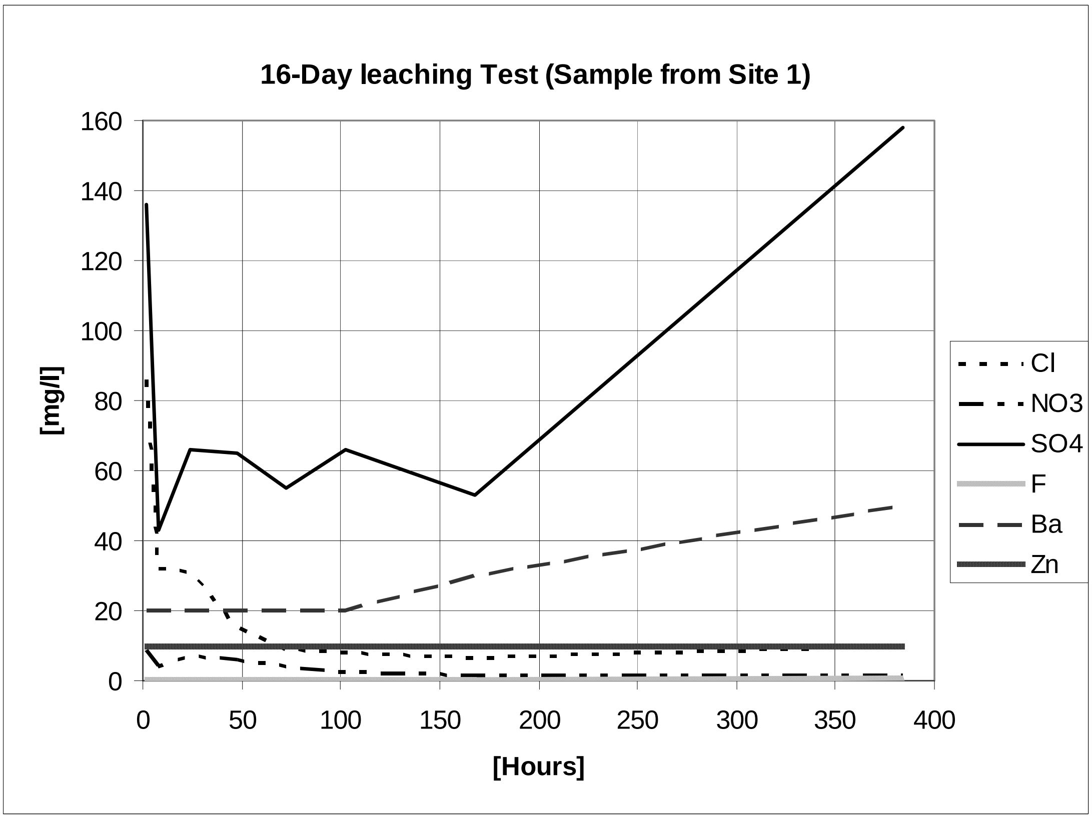

Figure 7 Results of 16-day leaching test

Only three component concentrations out of 18 are changing with time. It seems that their leachate are not needed to be monitored for a long time. Also, the time scale required to run this chemical test is too long to be accepted in a road construction program.

Even though it is not required by the Italian regulation, Acetic Acid and Carbon Monoxide leaching tests were carried out in order to assess C&DW leachate over a shorter period of time.

Acetic acid leaching test

The Italian regulation requires an Acetic Acid leaching test to evaluate the need to clean up a land *(Decreto Ministeriale N° 471, 25/10/99*). It requires cleaning up the land to different concentration limits, depending on land use. The lower limits are applied for industrial uses and upper limits are imposed for private use. It was developed specifically for special wastes and the leaching solution is acetic acid. The liquid/solid ratio is determined over an extraction time of 24 hour.

Table 5 Result of Acetic Acid Test on C&DW from Sites 1 and 2

			Site 1	Site 2	Lower Limit	Upper Limit
Arsenic	*As*	*mg/kg*	<1	<1	20	50
Barium	*Ba*	*mg/kg*	2,11	92	-	-
Beryllium	*Be*	*mg/kg*	1,18	1,12	2	10
Cadmium	*Cd*	*mg/kg*	<0,5	<0,1	2	15
Cobalt	*Co*	*mg/kg*	<2	<2	20	250
Total Chromium	*Cr*	*mg/kg*	16,9	13,5	150	800
Copper	*Cu*	*mg/kg*	27,1	21,7	120	600
Mercury	*Hg*	*mg/kg*	<0,1	<0,1	1	5
Nickel	*Ni*	*mg/kg*	<0.4	<0.4	120	500
Lead	*Pb*	*mg/kg*	59,8	65,7	100	1000
Selenium	*Se*	*mg/kg*	<0,6	<0,6	3	15
Vanadium	*V*	*mg/kg*	<1	<1	90	250
Zinc	*Zn*	*mg/kg*	81,5	53,2	150	1500

In this case, concentration of harmful components for both samples are much lower than the required limits. It confirms the harmlessness of C&DW aggregates.

Carbon monoxide leaching test

The Italian regulation requires a Carbon Monoxide leaching test to evaluate the leachate of industrial waste. (*Decreto Ministeriale N° 471, 25/10/99, ex-legge Merli/D.Lgs 152/99*). The test is carried out on an agitated solution saturated with carbon monoxide over an extraction time of 6 hour.

Table 6 Carbon Monoxide Test on C&DW Site 1 & 2

			Site 1	**Site 2**	**Limits**
Arsenic	*As*	*µg/l*	<5	<5	10
Barium	*Ba*	*mg/l*	0,04	27	-
Beryllium	*Be*	*µg/l*	5	5	-
Cadmium	*Cd*	*µg/l*	<0,5	<0,5	5
Cobalt	*Co*	*µg/l*	<10	<5	-
Total Chromium	*Cr*	*µg/l*	<1	<1	50
Copper	*Cu*	*mg/l*	<0,01	<0,01	10
Mercury	*Hg*	*µg/l*	<0,2	<0,2	1
Nickel	*Ni*	*µg/l*	<2	<2	20
Lead	*Pb*	*µg/l*	<2	9	10
Selenium	*Se*	*µg/l*	<3	<3	10
Vanadium	*V*	*µg/l*	<5	<5	50
Zinc	*Zn*	*mg/l*	<0,01	<0,01	-

As well as for the case above, concentration of harmful components for both samples are much lower than the required limits. All these results are confirming the harmlessness of the tested C&DW aggregates.

PHYSICAL AND MECHANICAL CHARACTERIZATION OF C&DW AGGREGATES

During preview studies, these alternative materials were tested in laboratory and in situ to assess their performance as aggregates for road constructions. In particular, granulometric analysis (see Figure 2 and Figure 3) and Limits of Atterberg, CBR test and Los Angeles test were carried out following protocols of natural aggregates.

Table 7 Results from laboratory tests carried on samples of C&DW aggregates

Tests	**Samples from Site 1**				**Samples from Site 2**						
	1		2								
Plasticity index	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.	n.p.
Group index	0	0	0	0	0	0	0	0	0	0	0
Classification	A1b.	A1a.	A1b.	A1a.	A1b.	A1a.	A1a.	A1a.	A1a.	A1b.	A1b.
A.A.S.H.O. m. test											
Maximum density [*g/cm³*]	1,885		1,818		1,818						
Optimum humidity *(%)*	10,0		11,0		11,0						
Indice CBR											
@ 2,5 [*mm*]	44,1		24,8		24,8						
@ 5 [*mm*]	54,9		20,3		20,3						
desità secca *g/cm³*	1,9		1,8		1,8						
Humidity	9,99	19,75	11,18	11,71	11,18	11,71					
Swelling *(%)*	0,030		0,090		0,090						
LOS ANGELES test *(%)*	40,36		41,14		46,38						

The values obtained in laboratory are acceptable, in particular the plasticity and group index were very good. Also, granulometric analysis were carried out on CBR samples to evaluate possible modification of particles size. As shown on Figure 8 and Figure 9, grading curves after compaction present a higher percentage passing, meaning that compaction has modified particle size.

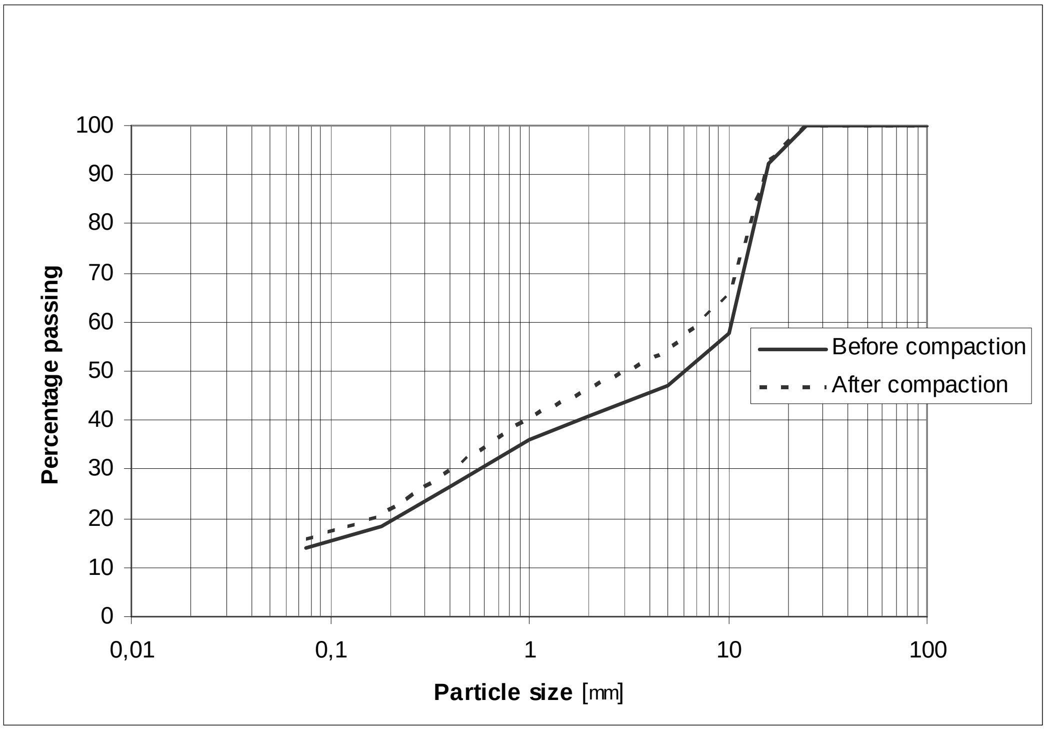

Figure 8 Grading of C&DW aggregate sample for CBR test (Site 1)

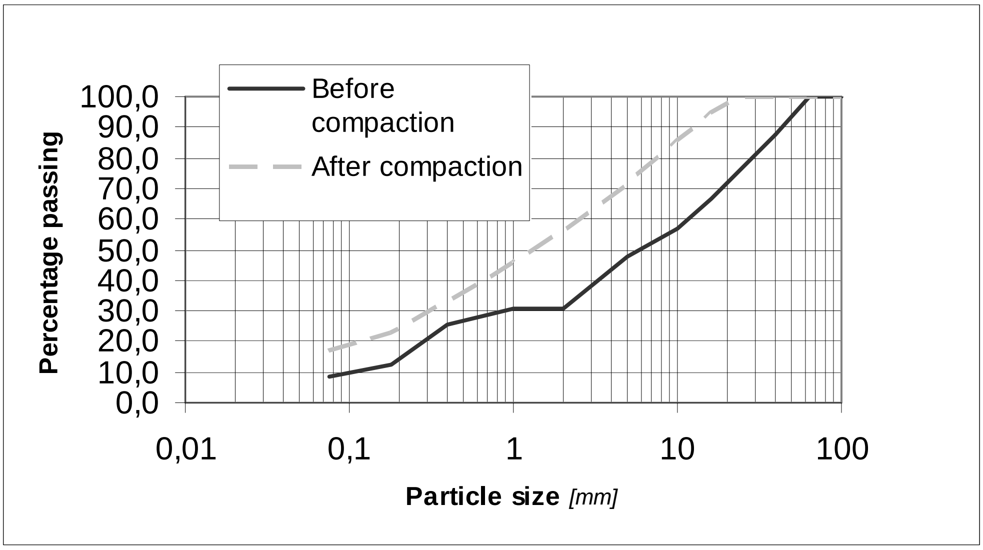

Figure 9 Grading of C&DW aggregate sample for CBR test (Site 2)

An experimental road was constructed with C&DW materials to evaluate mechanical performance with in situ tests. It has been built with the collaboration of the local administration. Previously, mechanical performance was studied only with in situ bearing capacity tests. Satisfactory values were obtained, in fact they were all comprised in a range between 70 N/mm^2 and 100 N/mm^2 which was much higher than the required value for a sub-grade layer.

Currently, Light Weight Drop and Dynamic Plate tests are being used to continuously monitor mechanical performance in situ.

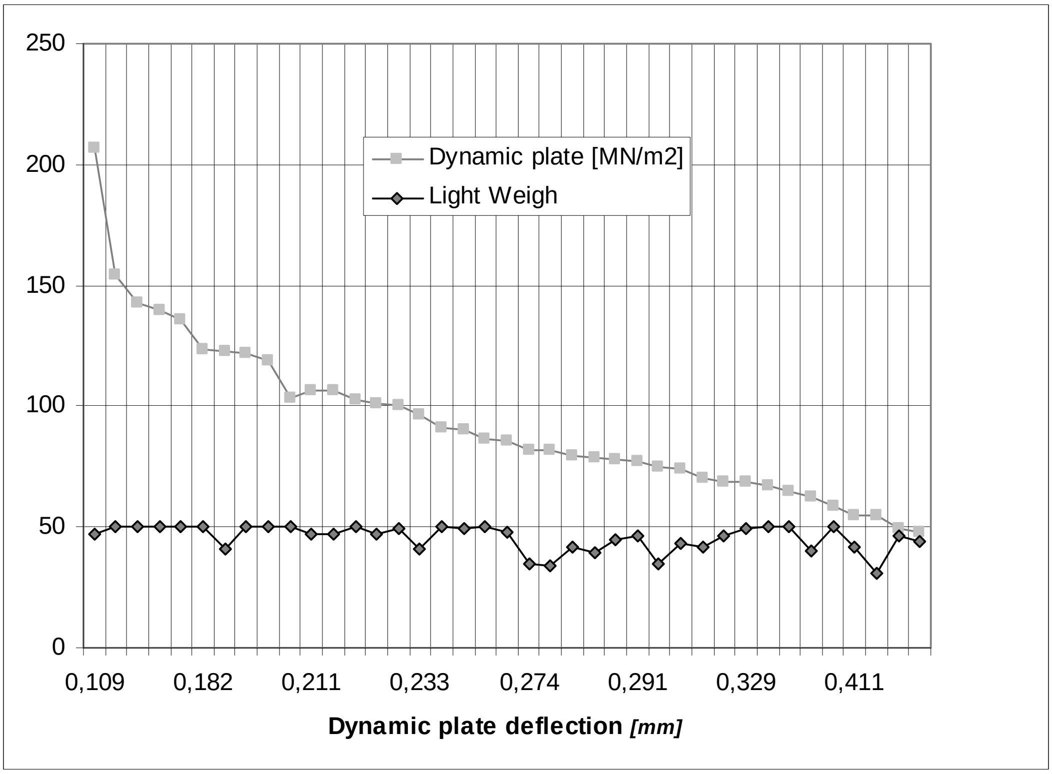

Figure 10 Light Weight Drop and Dynamic Plate tests on experimental road

Results from Dynamic Plate are very variable, but all are good values for both sub-grade and foundation layers. Light Weight Drop test has not shown reliable results.

CONCLUSION

The assessment of C&DW aggregates as alternative material for primary aggregates has obtained positive results from the chemical physical and mechanical point of view. Laboratory tests and in situ mechanical

tests have shown good physical characteristics and satisfactory mechanical performances. Also, in situ mechanical performances have improved with time.
The 16-day, acetic acid and carbon monoxide leaching test have shown that concentration of harmful components on C&DW aggregates leachate are not dangerous for the environmental, even if the composition of tested sample was variable. In fact, their chemical characteristic could be improved by sorting the material into appropriate waste streams at the source, thereby reducing the amount of impurities. On the other hand, the time scale to process the 16-day leaching test is, in general, longer than can be accommodated in a road construction program. This implies that potential recyclable materials are sent to landfill and, thus, primary aggregates used instead. This makes the use of recycled aggregates less attractive than primary aggregates and works against the principle of sustainable construction. Therefore in this case, for environmental protection, the Italian law is more of an obstacle to using recycled aggregates instead of primary aggregates.
So far, it seems that the main obstacle to their use is the lack of specification to evaluate a real potential pollution of the environment.
To sustain their use, chemical tests will be conducted directly at the experimental road.

REFERENCES

American Society for Testing and Materials (1992), 'ASTM Designation: D 3987-85, Standard Test Method for Shake Extraction of Solid Waste with Water', ASTM, West Conshohocken, PA, 4p;

Page, A.L., Miller,R.H. and Keeney, D.R. (1982), 'Methods of Soil Analysis: Part 2 - Chemical and Microbiological Properties', 2nd Edn., American Society of Agronomy Inc., Soil Science Society of America Inc., p199-209;

Price, W.A. (1997), 'DRAFT Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia', British Columbia Ministry of Employment and Investment, Energy and Minerals Division, Smithers, BC, (April), 143p.

Price, W.A., Morin, K. and Hutt, N. (1997), 'Guidelines for the Prediction of Acid Rock Drainage and Metal Leaching for Mines in British Columbia: Part II - Recommended Procedures for Static and Kinetic Testing', Proc. 4th International Conference on Acid Rock Drainage, Vancouver, BC, p15-30;

Province of British Columbia (1992),'Waste Management Act: Special Waste Regulation Schedule 4, Parts 1 and 2', Queen's Printer, Victoria, BC, p72-79;

U.S. Environmental Protection Agency (1996), 'Test Methods for Evaluating Solid Waste - Physical/Chemical Methods (SW-846)', USEPA, Washington, DC;

Direttiva 1999/31/CE del Consiglio, (1999),'DIRETTIVA 1999/31/CE DEL CONSIGLIO del 26 aprile 1999 relativa alle discariche di rifiuti', Gazzetta ufficiale n. L 182 del 16/07/1999,Italy

Decreto Legislativo n. 372 del 4 agosto 1999, (1999), 'Attuazione della direttiva 96/61/CE relativa alla prevenzione e riduzione integrate dell'inquinamento', Gazzetta Ufficiale n. 252 del 26 ottobre 1999, Italy

EPA, (1999), ' Leaching Meeting Proceedings, Proceedings of the Environmental Protection Agency', PUBLIC MEETING ON WASTE LEACHING, Session IV - Leaching Policy and Applications;

Decreto Legislativo N. 471 del *25/10/99*, (1999), '*Valori di concentrazione limite accettabili nel suolo e nel sottosuolo riferiti alla specifica destinazione d'uso dei siti da bonificare*', Gazzetta Ufficiale, Italy.

ACKNOWLEDGMENTS

I would like to thank the Provincial Administration of Cagliari and the Provincial Geotechnical Laboratory of Cagliari for their contribution for the construction of the experimental road.