Production and characterization of aggregate from non metallic Automotive Shredder Residues

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Abstract

In this paper the results of an experimentation on the granulation of non metallic automotive shredder residues to produce aggregates for cementitious or asphalt mixes are presented and discussed.

In a preliminary separation step a fraction containing mainly inert and non metallic materials was sieved to obtain the required grading and analyzed for the metal content. In the following granulation step, performed in a pilot scale granulator, the sieved fraction was mixed with binding materials, fly ash and a densifier agent, to produce granules of up to 2000 kg/m^3 of specific weight. The size of the produced granules, between 2 and 40 mm, proved to be a function of water content: increasing the ratio between water and solids the diameter of the particles also increased. The diameter of the produced granules were in the range.

The granules were then used to produce artificial lightweight aggregate for concrete mixes. Concrete samples showed a specific weight up to about 2000 kg/m^3 and a compressive strength up to about 30 MPa, depending on the fluff content of the mixes, and on the nature of the binder and of the other components used.

Leaching tests performed on the concrete samples showed that a good immobilization of metals and ions was achieved.

1. Introduction

Every year, in the UE about 12 M vehicles are shredded, and 8 or 9 Mtons/year of wastes are produced: this amount will probably increase in the next future, as a consequence of the continuous expansion of the automotive industry. To minimize waste production, it is necessary to develop new strategies of management of the whole life cycle of the vehicles [1].

Right now two possible recovery pathways are outlined: the reuse of parts or components of the vehicle, and the separation and reuse of the metal fraction (iron). This second pathway generally involves the shredding of the vehicles and a ferromagnetic separation of the ferrous fraction. This treatment produces a large amount of residues, the so called fluff (ASR, Automotive Shredder Residues) that constitutes about 25% wt. of a vehicle, dealing with rubber, glass, plastics, polyurethane foams, wood, textiles, paints, adhesives and non ferrous metals [2]. This residue is generally disposed in landfill as hazardous waste. As a consequence, until today, about 25% wt. of an end-life vehicle is landfilled, and this may cause the contamination of soil and groundwater.

As a consequence of both the recent EU Directive about end life vehicles (2000/53/CE) together with the tightening of Environmental Regulation requirement for landfill disposal [3, 4], and the increasing amount of automotive shredder residues production, a new effort is necessary to find an alternative pathway for recycling and reusing the fluff fraction.

A promising solution could involve the industry of concrete production considering its increasing difficulties in finding natural aggregates as a result of the increasing use along the years of rock and mineral. Several studies have been therefore performed to evaluate the possibility to reuse wastes in the production of aggregate for the concrete industry, eventually through an intermediate treatment step [5,6,7].

Previous experimentations [8,9] have assessed that residues from end-life vehicles can be used in the production of aggregates for concrete, provided a preliminary transformation into a suitable product. This can be realized by a thermal treatment, or at room temperature.

In this paper part of the non metallic fraction of automobile shredder residues was immobilized in granules produced at room temperature in a pilot scale granulator, by mixing selected amount of fluff with a binder in the presence of other additives. The granules were characterized and used as coarse aggregate in concrete mixes.

2. Materials and methods

2.1 Materials

Experimental tests were performed on the fluff produced in the Automotive Shredding Plant “Italferro” at S. Palomba, Roma, Italy. In that plant, up to about 150 t/d of vehicles are treated and about 35 t of fluff are daily produced.

In the granulation tests CEM I 42.5 R was used as binder. In order to increase the fluidity of the mixture and to reduce water/cement /(w/c) ratio, a superplasticizer (ACE 363, Basf Construction Chemical Italia s.p.a.) was added to the mixing water (at 3% wt with respect to cement content).

To enhance mechanical properties of the granules the addition of fly ash produced in the thermoelectric plant of Brindisi was also investigated (main components of the utilized fly ash are: SiO_2 = 46.5%, Al_2O_3 = 24.4%, Fe_2O_3 = 10.1% by weight).

2.2 Experimental procedure and analysis

The aim of the experimentation was to set up a process to produce aggregate for concrete from the non metallic fraction of the automotive shredder residues.

The proposed process deals with three steps: the selection of the product, the lab-scale granulation, the semi-pilot scale granulation.

In the first step plastics and foam materials were separated by grinding the fluff produced in the plant and passing a 4 mm diameter mesh, while iron residues were separated with a magnetic system. Table 1 shows the characteristics of the selected product.

Pilot scale granulation tests were performed on the granulator device shown in figure 1 and designed to the purpose, basing on the results obtained in the previous tests performed in the lab scale granulator [10]. Granulation tests were performed using in each test a total amount of mixture of 3-5 kg. The influence of the water content, fluff/binder ratio on the range of granulation and on granules diameter was evaluated.

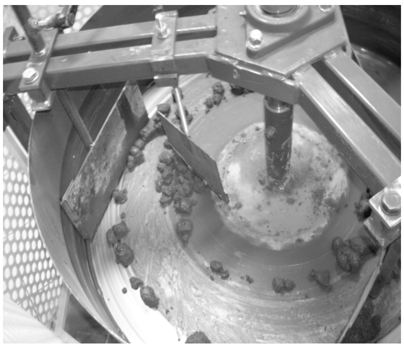

Figure 1- Granulation tank

Parameter	Unit	Value
Residue at 105°C	%	91.1
Residue at 600°C	%	39.4
Copper	mg/kg	3727
Lead	mg/kg	7420
Chromium	mg/kg	<2
Cadmium	mg/kg	11
Zinc	mg/kg	450

Table 1 – Product characterization

The ratio between binder (C) and the sum of fly ash (FA) and fluff (F) in each test was 0.2. The weight ratio between fly ashes and fluff (FA/F) was selected at 0.83, 1 and 1.2, according to the results obtained in a previous work [10]. Water dosage was varied to individuate a range from a minimum necessary to obtain the granules, to a maximum preventing the formation of a semifluid sludge in the granulator (water content granulation range). This value was considered as the optimal value for the granulation process.
After a 28 days period of curing, at room temperature, in moisture saturated chamber, the granules were subjected to compressive strength tests, according to the UNI EN 13055 Part 1 [11], and to a leaching tests, according to the UNI EN 12457-4 [12, 13]. Specific weight of the granules was measured by hydrostatic weighing.
The pH of the leached solutions was measured with a Crison 421 pH meter; a ionic chromatograph Dionex DX-120 was used to determine ionic species; a Philips PU 9200 atomic absorption spectrophotometer was used to determine the metal content.
The granules produced were then used as coarse aggregate in concrete samples, prepared according to the UNI 11013 [14].
All the tests were performed in triplicate.

3. Results and discussion

3.1 Granules production
Pilot scale tests results confirmed the granulation process effectiveness. The experimental conditions of the tests, based on the experience of a previous work [10], are summarized in table 2 together with the amount of granules produced in each test (distributed in four granulometric fractions: 20/40 mm, 12.5/20 mm, 4/12.5 mm nd the fraction passing to the 4 mm sieve).
The average diameter distribution obtained in the tests performed in the pilot scale granulator was strongly dependent upon the experimental conditions in each test, as shown in table 3. The size of the produced granules was a function of water content: increasing the ratio between water and solids, the diameter of the particles also increased. The tests when the average diameter values was higher where in fact the tests when the higher amount of water was used (series D). In addition, a narrow diameter distribution interval was observed in the tests when a low water content was associated to the lower fly ash content.

Series	Fraction	Weight (g)	W/C	FA/F	W/(C+FA)
1A	20/40	2505,64	1,08	1	0,41
1A	12.5/20	567,87			
1A	4/12.5	82,89			
1A	<4	*0,00*			
1B	20/40	1013,46	1	1	0,375
1B	12.5/20	1887,56			
1B	4/12.5	339,50			
1B	<4	127,96			
1C	20/40	731,11	0,92	1	0,34
1C	12.5/20	579,98			
1C	4/12.5	904,73			
1C	<4	671,68			
1D	20/40	3307,93	1,17	1	0,44
1D	12.5/20	*0,00*			
1D	4/12.5	*0,00*			
1D	<4	*0,00*			
2A	20/40	1600,92	1,08	1,2	0,36
2A	12.5/20	1289,31			
2A	4/12.5	133,14			
2A	<4	*0,00*			
2B	20/40	1120,16	1	0,83	0,375
2B	12.5/20	851,93			
2B	4/12.5	1312,46			
2B	<4	161,57			
2C	20/40	422,72	0,92	0,83	0,31
2C	12.5/20	474,74			
2C	4/12.5	1950,37			
2C	<4	190,42			
2D	20/40	2054,46	1,17	0,83	0,39
2D	12.5/20	1134,46			
2D	4/12.5	70,61			
2D	<4	*0,00*			
3A	20/40	1058,73	1,08	0,83	0,36
3A	12.5/20	469,87			
3A	4/12.5	1463,75			
3A	<4	351,34			
3B	12.5/20	654,86	1	0,83	0,36
3B	4/12.5	1880,47			
3B	<4	270,23			
3C	20/40	485,07	0,92	1,2	0,34
3C	12.5/20	677,64			
3C	4/12.5	897,70			
3C	<4	992,81			
3D	20/40	2939,59	1,17	1,2	0,39
3D	12.5/20	402,15			
3D	4/12.5	30,27			
3D	<4	*0,00*			

Table 2 – Summary of the experimental conditions and granules production

	Granules diameter (mm)											
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D
Min	8	2	2	22	6	2	2	15	2	2	2	10
Max	35	30	30	40	30	25	25	40	25	18	25	40

Table 3 – Granules average diameter measured in the pilot scale tests

Depending upon the composition of the paste, the specific weight of the granules varies between 1400 and 2000 kg/m^3, originating a family of lightweight aggregates.
Mechanical properties of these aggregates depend both on water content and fluff content: compressive strength values of the produced granules varied in the range between 0.8 and 1.5 MPa. As it would be expected, higher compressive strengths and densities were achieved in the tests performed using the lower water/cement ratio. An increase in mechanical properties of the granules produced was observed using the superplasticizer.
The results of leaching tests performed directly on the granules, are shown in Table 4, when the limit for inert and not hazardous wastes in the EU Directive 2003/33/CE are also reported. Comparing these results with the raw material (Table 1) it can be assessed that a first strong immobilizing action with respect to heavy metals and organics, was associated to the formation of the granules with the only exception of a high COD content measured in some tests. This exception could be due to both the presence of plastic residues in the sieved fraction, and to a slight oil contamination of the fluff, due to the fluids contained in vehicles tanks. This does not allow the use of the granules alone, but only as aggregate in a concrete mixture.

Test	**pH**	**COD**	**Pb (mg/l)**	**Zn (mg/l)**	**Cd (mg/l)**	**Cu (mg/l)**
2A	10.86	40	0	0.35	0.05	0.22
2B	10.53	<20	0	0.04	0.05	0.22
1C	10.65	197	0.21	0.53	0.05	0.22
2C	10.79	473	0.06	0.04	0.05	0.23
3C	10.86	<20	0.05	2.62	0.05	0.16
2003/33/CE inert	-	50	0.05	0.4	0.004	0.2
2003/33/CE not hazardous	-	80	1	5	0.1	5

Table 4 – Results of leaching tests performed on selected granules (UNI EN 12457)

3.2 Concrete mixes characterization

The composition of selected concrete mixes and concrete samples characterization in term of specific weight and compressive strength are reported in Table 5. Sand (Specific Weight=2690 kg/m^3) was used as fine aggregate.

Series	Cement (g)	Aggregate (g)	Sand (g)	W/C ratio	Rc_{28} (MPa)	SW (kg/m^3)
2A (<20)	392	581	855	0.26	18.06	1882.37
2B (4-12.5)	390.6	883.68	474.6	0.32	16.67	1800.64
2C (4-12.5)	390.6	797.27	619.8	0.30	27.27	1892.63
1B (4-12.5)	390.6	747	611.6	0.34	23.00	1911.87
3A	390.6	858.88	409.6	0.38	25.77	1900.09
3C	390.6	859.59	408.3	0.37	21.00	1819.53
1C	390.6	868.52	392.2	0.38	24.21	1896.89
3B	390.6	622.75	835.90	0.46	30.30	2013.88

Table 5 – Concrete mix design and characterization

The results show that concrete samples prepared using as coarse aggregates the produced granules showed a specific weight up to 2000 kg/m^3 and a compressive strength up to about 30 MPa, depending on the fluff content of the mixes, and on the nature of the binder and of the other components used.

4. Conclusions

In this paper the non metallic residue of an automotive shredder plant was granulated to produce aggregates for cementitious admixtures.
In a preliminary separation step a fraction constituted mainly by inert non metallic materials, in the form of a sand, with diameter less than 4 mm, was separated and characterised to investigate metal content.
In the following granulation step, performed in a pilot scale granulator tank, granules were produced by mixing this fraction with binding materials, fly ash and a superplasticizer, at room temperature.
Results show that the granulation technique can be successfully used to immobilize fluff from ASR and to regulate the size of the granules. The obtained granules had 2-40 mm of diameter and up to 2000 kg/m^3 of specific weight, while leaching tests showed that a good immobilization of metals and ions was achieved, except for organics. Preliminary results on concrete samples prepared using as coarse aggregates the produced granules showed a specific weight up to 2000 kg/m^3 and a compressive strength up to about 30 MPa.

5. References

[1] Levizzari A., Il fine vita dell'automobile, prospettive tecnologiche e ambientali, Area, 2001 http://www.area.trieste.it /html/pubblicazioni/volumi/download/ autodemolizione.pdf.

[2] ARPA Emilia Romagna, Il Decreto Discariche, www.arpa.emr.it/arparivista/legislazione1_03.htm
[3] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.
[4] Directive 1999/31/EC of the European Parliament and of the Council of 26 April 1999 on landfill of wastes.
[5] K.K. Sagoe-Crentsil, T. Brown, A.H. Taylor, Performance of concrete made with commercially produced coarse recycled concrete aggregate, Cem. Concr. Res. 31 (2001) 707-712.
[6] D. Sani, G. Moriconi, G. Fava, V. Corinaldesi, Leaching and mechanical behaviour of concrete manufactured with recycled aggregates, Waste Manag. 25 (2005) 177-182.
[7] I. B. Topcu, S. Sengel, Properties of concretes produced with waste concrete aggregate, Cem. Concr. Res. 34(8) (2004) 1307-1312.
[8] J. Péra, J. Ambroise, M. Chabannet, Valorization of automotive shredder residue in building materials, Cem. Concr. Res. 34 (2004) 557 – 562.
[9] G.J. Xu, D.F. Watt, P.P. Hudec, Recycling automotive related wastes in concrete, J. Mater. Process. Techn. 48 (1995) 385-390.
[10] V. Alunno Rossetti, L. Di Palma, F. Medici, Production of aggregate from non-metallic automotive shredder residues, J. Hazardous Materials, B137 (2006) 1089-1095.
[11] UNI EN 13055, Lightweight Aggregates – Part 1: Lightweight aggregates for concrete, mortar, grout.
[12] UNI EN 12457, Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges.
[13] Italian Environmental Regulation (D.L. 5 febbraio 1998), Individuazione dei rifiuti non pericolosi sottoposti alle procedure semplificate di recupero ai sensi degli articoli 31 e 33 del Decreto Legislativo 5 febbraio 1997, n. 22.
[14] UNI EN 11013, Lightweight Aggregates – Expanded clay and slate – assessment of the properties by standard lab concrete tests.