ZERO-IMPACT RECYCLING OF RETURNED CONCRETE

GIORGIO FERRARI AND ALBERTO BROCCHI

Abstract

Returned concrete is a heavy burden for the ready-mix plant and it sums to the other wastes produced at the plant, like wastewater from the washing of drums of truck mixers. According to the European Directive 2008/98/CE on wastes, returned concrete should be removed from the waste stream and transformed into reusable materials. In the present paper, a new method to recycle returned concrete is presented. Specific not dangerous additives are added directly into the drum of the truck mixer and, in few minutes, transform the returned concrete into granular materials that can be reused as aggregates for new concrete. The new method does not produce wastes and substantially reduces the amount of wastewater at the plant. With the new method, quarries exploiting is reduced and protection of natural resources and economical benefit is accomplished. Furthermore, the easiness of the process and the use of not dangerous substances make this new method acceptable from the social point of view. Environmental, social and economical benefits achievable by the new method represent an important example of concrete sustainability.

Keywords

Aggregates, natural resource protection, recycling, returned concrete, sustainability.

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1. INTRODUCTION

The production of construction and demolition waste (C&DW) is concurrent with the concrete production, which is the second most consumed material, after water. It is estimated that roughly 25 billion tonnes of concrete are manufactured globally every year (over 3.8 tonnes per person in the world) and 510 million tonnes of C&DW are consequently generated in Europe (40% of the overall waste production). The US produces about 325 million tonnes of C&DW and Japan about 77 million tonnes every year. Given that China and India are now producing and using over 50% of the world's concrete, their waste generation will also be significant as development continues.

One of the most important issue of the recent international environmental legislation is the reduction of waste production and the reduction of disposal to landfill. European Directive 2008/98/EC gives clear indication that European Community should move to a "recycling society" seeking to avoid waste generation and to use waste as a resource[1]. Many countries have recycling schemes for C&DW and very high levels of recovery are achieved in countries such as Netherlands, Japan, Belgium and Germany, but in many other countries C&DW is still disposed in landfill[2]. Recycling or recovering concrete has two main advantages: 1) it reduces the use of virgin aggregate and the associated environmental costs of exploitation and transportation and 2) it reduces unnecessary landfill of valuable materials that can be recovered and redeployed. Therefore, recycling of concrete is one of the most important issue for concrete sustainability.

Returned concrete is the unused ready-mixed concrete that comes back to the plant in the concrete truck as excess material. This can be small amounts of concrete leftover at the bottom of the drum in the truck, or more significant quantities not used by the customer on the construction site. Typically, the amount of waste concrete generated by ready-mixed deliveries can be as low as 0.4% to 0.5% of total production. However, during peak periods, when pressure for supply is greatest, the waste can increase to 5% to 9%. Globally, it can be estimated that over 125 million tonnes of returned concrete are generated every year[2]. These data confirm that returned concrete is a heavy burden for the ready-mixed plants and sums to the other C&DW produced at the ready-mixed plant. In a study conducted in the UK, it has been estimated that a typical ready-mixed plant may generate from 20 to 80 tonnes of waste each month, with consequent high costs for their disposal and high impact on the environment[3].

Current methods of processing returned concrete include:

1. Discharging returned concrete at a location in the ready-mixed plant. The hardened discharged concrete is then removed and stored before the disposal to landfill. Alternatively, it can be crushed for reuse as base for pavements or fill for other construction.
2. Site paving at the ready-mixed production plant and production of concrete elements, such as blocks for breakwaters and counterweights. This possibility is limited by several factors, including the limited area in the plant that can be paved and the local market conditions and opportunities for the blocks production.
3. Reclamation systems to reuse or dispose the separated ingredients, including the process water with hydration stabilizing admixtures, as needed. The fines and cement materials are washed out of the mix and held as a slurry in suspension tanks. Sand and aggregates are also extracted and stockpiled. The recovered sand and aggregates, together with the slurry water, can be used in the manufacture of new concrete. Nevertheless, this method is generally limited to large volume plants in metropolitan areas and require significant capital investments, followed by careful attention to proper practice[4].
4. Reuse of returned concrete by using extended set retarding admixtures. These admixtures suspend the hydration reaction of cement compounds and allow the holding of returned concrete or truck-mixer wash water for several hours. Treated concrete or wash water can then be incorporated in the next load of concrete. Some of the commercial admixtures are available as a two component system: a "stabilizer", that slows or stops the hydration of cement grains, and an "activator", which may be used as an antidote to counteract the

effect of the stabilizer and allows cement hydration to continue and it is used prior to batching fresh material with treated wash water of returned concrete. Anyway, the use of these chemicals requires several preliminary tests and adequate training of plant personnel to obtain reliable performance[5].

So far, working complexity and capital investments of the current most advanced methods of processing returned concrete, have limited the possibility of achieving high level of recycling. In the present paper, a new method for recycling returned concrete, which fully complies with requisites of sustainability, is presented.

2. The new method of recycling returned concrete

The new method transforms, in few minutes and without the need of any specific apparatus, returned concrete in granular materials which can be reused as aggregates for the production of new concrete. The new technology permits the complete recycling of returned concrete without the generation of wastes and also contributes to reduce the overall production of C&DW at the ready-mixed plant.

2.1 Description of the new method

The new method consists of 4 steps:
Step 1 - Addition of a superabsorbant polymer SAP (Part A) into the drum of the truck mixer containing the returned concrete. Just after the addition, the polymer begins to absorb water, to swell and slowly dissolves. Most of the free mixing water is absorbed by the polymer and the concrete becomes more and more stiff. After about four minutes of mixing inside the truck mixer, returned concrete is transformed into a granular material and most of the grains display a layered structure which include a core formed by the original aggregates covered by a layered of a composite material made from the hydrating cement paste, sand and a network of swollen/dissolved SAP, as shown in Figure 1.

Figure 1 Typical aspect of a fresh granular material after the addition of SAP

The dosage of Part A is in the range 0.2 to 0.6 kg of polymer per cubic meter of returned concrete, depending on its consistency. It is important that returned concrete is not too washed with excess of water when it comes back to the plant and has a consistency class not higher than S4 (slump value of 160 – 210 mm), according to EN 206-1:2000. In the case returned concrete is too washed, it is advisable to add an extra amount of virgin aggregates to the returned concrete (from 50 to 150 per cent by weight of returned concrete) before adding Part A.

Step 2 - Addition of a set accelerator SET ACC (Part B) to the granular material already formed in the drum of the truck mixer after Step 1 and mixing for additional four minutes. Part B is an inorganic compound which instantaneously forms Ettringite crystals when it comes in contact with hydrating cement and it is added at dosage from 4 to 8 kg per cubic meter of returned concrete. The newly formed Ettringite precipitates over the granular material and chemically binds many water molecules in the crystal lattice. Therefore, its formation has the double effect to produce a further drying of the granular material due to the chemical consumption of water and to consolidate, through a sort of “chemical sintering”, the surface of the fresh granular material, giving it enough strength to be further processed.

Step 3 – Discharge. After Step 2, the granular material is discharged from the truck mixer and stored in the bulk. Due to the addition of Part B, the discharged granular material has enough strength to resist to compaction and re-agglomeration. Nevertheless, it is advisable to avoid to accumulate the granular material in high piles in order to prevent excessive loading over the bottom layers. A convenient way is to distribute the granular material over a wider surface by rotating the hopper of the truck mixer during the discharge.

Step 4 – Curing. Like any cementitious material, the discharged granular material needs to be cured; anyway, curing can be made in the bulk without special protection. The only precaution is to move the piles with a grab once within the first 24 hours, in order to break the weak bonds of hydrated cement paste among the grains and detach them each other. If the granular material is left for longer times before moving, the bonds among the different grains become stronger and difficult to break, leaving lumps which can be more difficult to separate. Once the granular materials have been moved, there is not further risk of agglomeration and can be stored like a normal aggregate.

After the discharge of the granular material, the interior of the drum of the truck mixer remain quite clean, as shown in Figure 2. The reason for this outstanding result is due to the fact that all the fines (cement, filler and sand) and water are kept by the SAP and wrapped onto the aggregates.

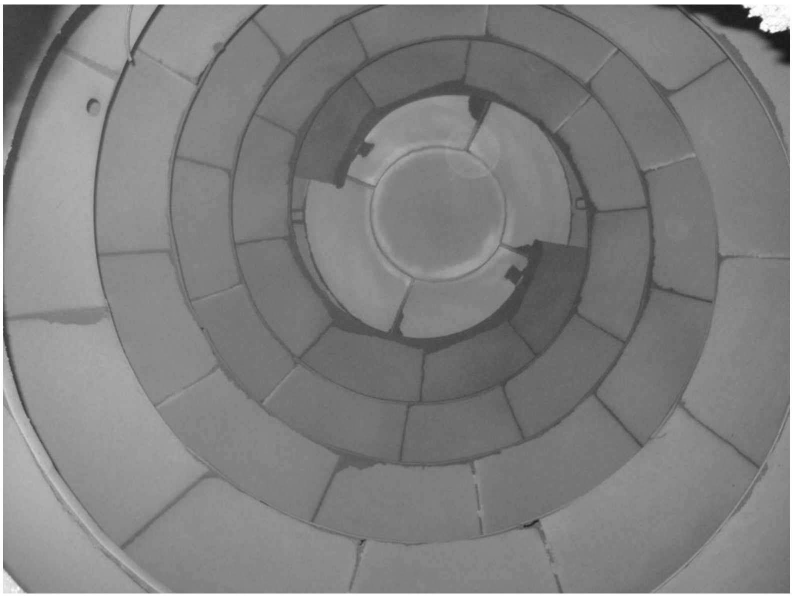

Figure 2 View of the inside of the drum of the truck mixer after the discharge of the returned concrete treated by the new method.

The sketch of operations is shown in Figure 3. In the first step, SAP (Part A) in water soluble bag is added to the returned concrete directly in the truck mixer and the drum is mixed for 4 minutes. After this period of mixing, SET ACC (Part B) in water soluble bags is added and the drum is mixed for other four minutes. At the end of this period, the granular material is discharged in bulk.

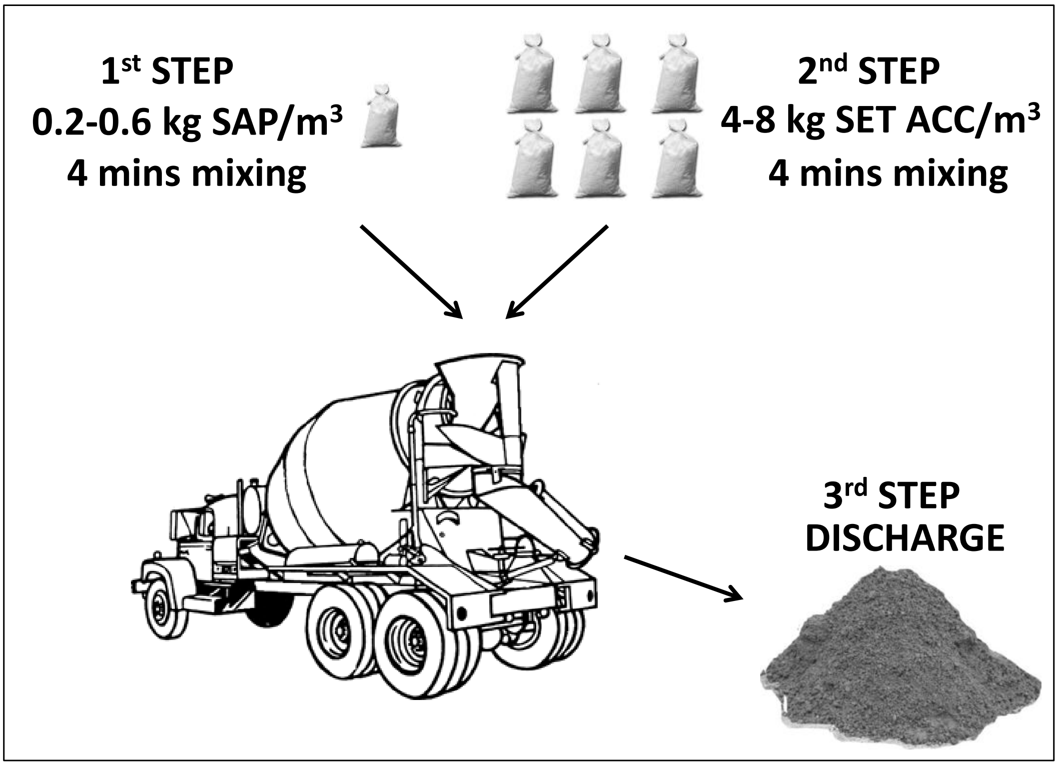

Figure 3 Scheme of operation of the new proposed technology.

2.2 Characteristics of the aggregates obtained by the new method of recycling returned concrete

The properties of the aggregates produced by the new process relates to those of the original aggregates of returned concrete. Nevertheless, the composite layer that surrounds them influences their characteristics, both in terms of size and other physical/chemical properties. The comparison between the original cumulative aggregate distribution and that of the recycled aggregates obtained after the treatment of the returned concrete is shown in Figure 4. This figure shows that the average size of the aggregates produced by the new process is larger than that of the original aggregates of the returned concrete, as indicated by the fineness module, which increases from 5.225 for the original aggregates to 5.906 for the recycled aggregates. The most pronounced variation occurs for the fraction lower than 4 mm, while the fraction larger than 10 mm is less affected. This is the result of the action of SAP, which agglomerates the finer particles (cement, fillers and sand) in a composite material wrapping onto the aggregates and increasing their size.

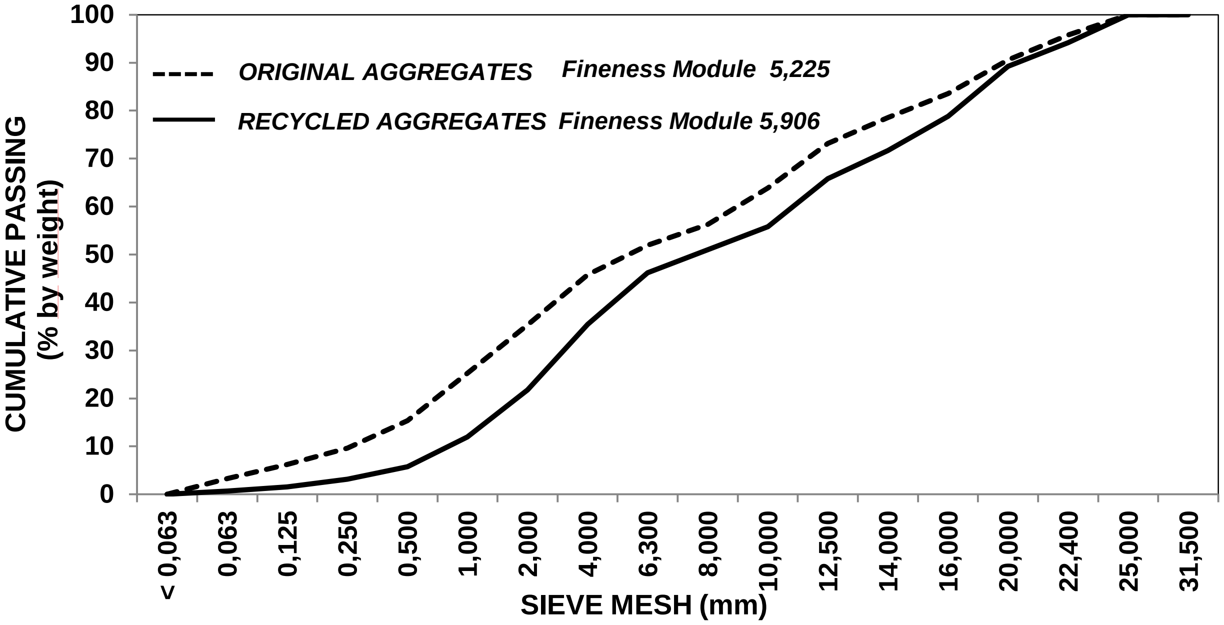

Figure 4 Cumulative size distribution of recycled aggregates from the new process of recycling returned concrete (solid line) compared with that of the original aggregates (dotted line).

The other physical/chemical characteristics of recycled aggregates cured for 28 days are reported in Table 1. From this table, it can be seen that the density of the aggregates decreases and water absorption increases with the reduction in the size of recycled aggregates. These results can be explained by considering that the hardened composite layer which is attached to the recycled aggregates is made by cement, water, sand and the additives, a matrix is more porous and less dense than the core of natural aggregate. Furthermore, due to the higher relative proportion of cover of the fine aggregates in comparison with the coarse ones, the variation of the density and the water absorption are higher for the recycled aggregates of smaller size. Nevertheless, coarser aggregates (size > 4 mm) comply with European EN 12620: 2008 and Italian UNI 8520-2:2005 norms for physical, chemical, durability and mechanical properties and can therefore be used for concrete production. Furthermore, since the mass losses values of the freezing and thawing tests result quite low, one can expect these aggregates are suitable for the production of the freeze/thaw resistant concrete.

Table 1 – Characteristics of recycled aggregates

Test	**u.m.**	**Size of recycled aggregates (mm)**			
		0/4	**4/10**	**10/20**	**20/30**
Density	Mg/m^3	2.41	2.48	2.53	2.55
Water absorption	%	3.5	2.8	1.8	1.8
Los Angeles	%	n.m.	24	26	n.m.
Micro Deval	%	n.m	31	21	n.m.
Soluble sulphate	%	n.m.	0.35	n.m.	n.m.
Total sulphur	%	n.m.	n.m.	0.16	n.m.
Soluble chlorides	%	n.m.	0.0008	n.m.	n.m.
Organic substances	%	n.m.	clearer than ref. soln.	n.m.	n.m.
F/T (mass loss)	%	n.m.	0.1	0.2	n.m.

n.m. = not measured

2.3 Characteristics of concrete with recycled aggregates

Thirty per cent by weight of recycled aggregates were used in substitution of natural aggregates for the production of new concrete. This concrete was compared with a reference mixture prepared with natural aggregates; both mixes were characterized by the same dosage of cement (CEM 32.5R II/A-LL, 320 kg/m^3), water to cement ratio (W/C = 0.55) and consistency class (S4 according to EN 206-1). In order to obtain the same gradating curves for both the concrete with the recycled and natural aggregates, it was necessary to combine recycled aggregates with a supplementary amount natural sand. The characteristics of hardened concrete made with recycled aggregates and those of a reference concrete using natural aggregates are compared in Table 2. These results indicate that the unit weight of both, the fresh and the hardened concrete, is from about 3 to 5 per cent lower for the concrete produced with the recycled aggregates in comparison with the corresponding values of the concrete made with natural aggregates. This effect is not due to a higher content of entrained air but, rather, is the result of a lower density of the recycled aggregates in comparison with the natural ones. Nevertheless, this slight reduction in the unit weight does not substantially affect the mechanical strength. Furthermore, the higher water absorption of the aggregates produced by the new proposed technology can reduce the effective water to cement ratio of the concrete produced with the recycled aggregates, in comparison with the concrete produced with the natural ones. This aspect can account for the comparable strength to the control concrete.

Table 2 – Comparison between a concrete mixture with recycled aggregates and reference concrete with natural aggregates

Time of curing	**Control concrete**				**Recycled aggregates concrete**			
	Density		**Compressive strength***		**Density**		**Compressive strength***	
Days	kg/m^3		N/mm^2		kg/m^3		N/mm^2	
1	2470	2455	5.8	5.8	2330	2330	4.6	4.8
	2440		5.7		2330		4.9	
2	2410	2420	12.5	12.5	2330	2320	11.1	11.1
	2430		12.5		2310		11	
7	2420	2425	24.4	24.5	2350	2360	24.4	24.4
	2430		24.6		2370		24.3	
28	2360	2365	36	36	2290	2280	35.7	36.1
	2370		36		2270		36.4	
56	2380	2375	39.9	39.5	2290	2290	39.8	40.1
	2370		39		2290		40.3	

*Measured on 15x15x15 prismatic specimens after curing in normal conditions (23 °C, 95% r.h.)

Durability tests, including freeze-thawing, scaling resistance and permeability to water have been undertaken to assess the behaviour of concrete made with recycled aggregates in severe environment.

3. Benefits of the new technology for recycling returned concrete

The definition of sustainable development, given by the World Commission on Environment and Development in 1987, includes three critical components that must be considered to address sustainability[6]. These three pillars are environment, economy and society and are often referred as the “triple bottom line of sustainability”[7]. A product or a project are supposed to encompass these three features in order to be sustainable. The environmental dimension is very important in the sustainability of any project because any economic activity utilizes the environment and hence depleting the natural resources. Therefore, any economic development must have consideration for the environment in order for their products to be sustainable. Another feature that is important in ensuring sustainability is the social issues, such as workers safety, healthy living environments and fair business practices toward labor and the community. The social dimensions are very important since the society must benefit from the project in the long term. Economic features are very important in sustaining a product due to the fact that the goal should not be all about reaping maximum benefits from the environment, but also sustaining the environment in a manner that the project will be able to reap benefits for a longer period of time and this can be undertaken through efficient use of natural resources. A way to looking at the “triple bottom line of sustainability” is shown by the Venn diagram of Figure 5. The portion where all three areas overlap represents sustainability. A product can be green or wonderful for the society, but that alone would not make it sustainable.

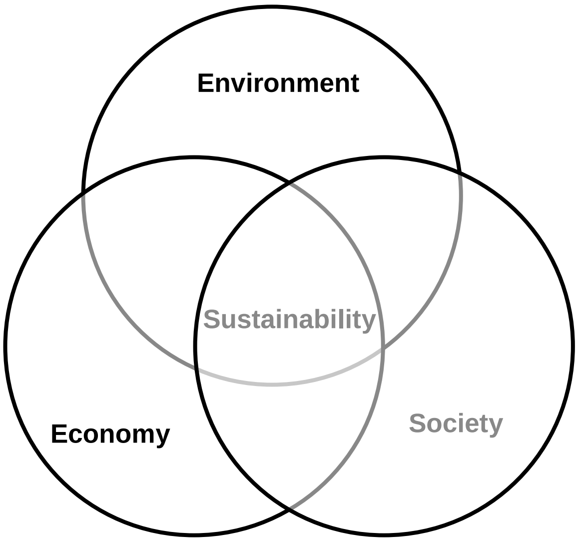

Figure 5 Venn diagram representation of the three pillars of sustainability.

3.1 Issues of sustainability of the new technology for recycling returned concrete

The new proposed method allows to recycle returned concrete, producing granular materials which can be fully reused as aggregates for the production of new concrete. This process is accomplished by using not dangerous, easy to use additives, which act in very short time, without the need of special equipments and without generation of wastes. Furthermore, the reduced amount of washing water of the truck mixers can be fully recycled as mixing water at the concrete mixing plant.

The following main environmental benefits result from the complete recycling of returned concrete with the new proposed method: a) saving of natural resources, b) reduction of the generation of wastes and c) reduced impact of road material transportation with consequent reduction of emissions and saving of fuel. The easiness of application of this method and the use of not dangerous additives represent important issues of sustainability from the social

point of view. Finally, the proposed new method is attractive from an economical point of view because it does not need capital investments, permits to reduce the costs of disposal of C&DW at the ready-mixed plant and allows to produce valuable material from returned concrete (1 cubic meter of returned concrete gives 2.4 tonnes of recycled aggregates).
The new method of recycling returned concrete contributes to LEED certification at item "material and resources" MR2 (Construction waste management), MR4 (Recycled content) and MR5 (Regional materials) and therefore gives an important contribution to LEED certification of buildings[8].

CONCLUSIONS

The proposed technology transforms returned concrete into recycled aggregates which, after curing, can be reused for production of new concrete. The new technology is based on the combined effect of a superabsorbant polymer and a setting accelerator, which easily transform the returned concrete into a valuable, reusable granular material. The proposed technology offer many advantages from environmental, social and economical point of view and represents an interesting example in the field of concrete sustainability.

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