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TECHNICAL REPORT

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TR 6 .1

REPAIR AND GREEN CONCRETE

ATLANTIC AREA
Transnational Programme
investing in our common future
European Union
European Regional Development Fund

smart & green

structural and repair materials

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NOTE:

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented.

PREFACE

The main subjects concerned in this TR were discussed and a general review was made inside the working group WG A6 – Smart & green structural and repair materials. The WG was created in the DURATINET project with the aim to stimulate the creation of a new cluster on smart and green structures and to promote the use of new construction materials environmental friendly and with improved performance and/or durability.

This TR is one of a series of review documents, concerning smart & green structural and repair materials theme, which summarizes the current knowledge on the applicability of stainless steel rebars in concrete.

This TR contains two parts. The first is mainly concerned with a reflection on green materials for construction and the needs for an environmental certification. The second part of this TR makes some considerations about the use of recycled aggregates from demolition sites, their advantages for sustainable construction and as a less expensive solution.

<table>
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CONTENTS

1 Introduction

Green behaviour, in a large sense, concerns the damage made to nature. Thus, Green Materials and technologies are those that tend to minimize this damage. Nature can be damaged through extraction, deposits, emissions and, in general, any modification of the environmental equilibrium.

Modifications concern also greenhouse gas emission. In this context, green materials could be identified through:

- Materials whose fabrication, transport and use do not produce greenhouse gas emission,
- Materials whose wastes are not dangerous (their decomposition does not alter nature),
- Recycled materials, which avoid extraction or fabrication of new ones.

From this definition, recycled materials could be considered as green materials if no significant transportation is required between their production and utilisation sites. Moreover, if the re-use of waste materials needs products whose production creates greenhouse gas, the “green” characteristic disappears. Thus, the “green” label is in fact an optimisation of the three following items:

- Minimising greenhouse gas emission
- Minimising waste
- Minimising extraction of new material

For this optimisation the whole structure during its whole service life shall be considered. It is not the simple matter of material choice.

Repair materials are devised to replace old material in structures. Thus they must be able to realize the same functions as the new ones. An additional requirement is they must adhere perfectly to the old material, and must have thermal and hydric (pore network) compatibilities with the existing material. Durability shall be at least equal than expected for the old material.

Since the Kyoto agreement sustainable construction is a topic which focuses a growing consideration[1]. Sustainable construction means sustainable design, supply chain and materials. Standardization, stakeholder involvement is necessary to achieve sustainable construction. ISO 14000 standards deal with environmental management system requirements but nothing exists about certification of building materials.

In the following we detail various definitions that could be given to “green materials” and will present the European Eco Label.

2 Definition

In the case of plastic material a commission set recommendation [2] for terminology and characterization of biopolymer and bioplastic, which defines biomaterial, natural polymer, biodegradable biocomposites, green composite and sustainable biocomposite. Following this example one can define for construction: biomaterials, natural materials, green materials and sustainable materials.

2.1 Biomaterials

Two definitions coexist. The first one is link to medical application and the other one to the production mode. We will focus on the second definition which concerned also building, construction and repair. Biomaterials are materials created through biotechnology. For example wood is a biomaterial; or calcite, when it is produced by bacteria.

2.2 Natural Material

Natural materials exist as such in Nature. As a consequence they can be after use wasted in Nature without harming it.

2.3 Green Material

A green material is a material which is biodegradable or reusable or recyclable. This means that after a demolition it will be involved in a new biological or geological or building cycle. Does material made of recycled material belong to this category?. In fact it depends on the complete composition of the material.

2.4 Sustainable Material

The term ‘sustainable development’ or ‘sustainability’ was first coined by the Brundtland Commission (formally the World Commission on Environment and Development of the United Nations in 1983), and was defined as the “social and economic advance to assure human beings a healthy and productive life, but one that did not compromise the ability of future generations to meet their own needs”. Thus, a sustainable material should satisfy several requirements:

i. Renewable and/or recycled resources should be utilized for their manufacture.

ii. The extraction, synthetic, modification, and processing operations should be benign and energy and cost-effective.

iii. No hazardous environmental or toxicological effects should arise during any stage of their life cycle by emissions of degradation compounds, additives or fillers.

iv. Their waste management options (recycling, reusing, composting, and wasting) should be effectively considered and implemented to guarantee the return of the material and energetic value back to the cycles. This definition is a slight modification of that given by Vilaplana et al (2010) [3] for sustainable bio-composite.

3. European Label

Europe has created a Ecolabel determined on a scientific basis considering the whole life cycle of products [4]. The criteria to be considered are:

a) The most significant environmental impacts, in particular the impact on climate change, the impact on Nature and biodiversity, energy and resource consumption, generation of waste, emissions to all environmental media, pollution through physical effects and use and release of hazardous substances.

b) The substitution of hazardous substances by safer substances, as such or via the use of alternative materials or designs, wherever it is technically feasible.

c) The potential to reduce environmental impacts due to durability and reusability of products.

d) The net environmental balance between the environmental benefits and burdens, including health and safety aspects, at the various life stages of the products;

e) Where appropriate, social and ethical aspects, e.g. by making reference to related international conventions and agreements such as relevant ILO standards and codes of conduct.

f) Criteria established for other environmental labels, particularly officially recognised, nationally or regionally, EN ISO 14024 type I environmental labels, where they exist for that product group so as to enhance synergies.

g) The principle of reducing animal testing should be met as far as possible.

The only construction product concerned by the Ecolabel is paint but Eco certification for construction product should be developed.

4 Recycling construction demolition waste

4.1 Why recycling

Aggregate prices increase with the rarefaction of product (extraction) and with the distance from extraction site to construction site. Some regions need more aggregates than they can produce. For example South West of France imports aggregates. A solution for less expensive materials could recycling aggregates from demolition sites not far from the construction site.

4.2 Procedure for recycling concrete

Blocks coming from demolition sites are made of various materials and are of various sizes. Some of them could be used as aggregates but others must not remain in recycled aggregates for concrete use. Thus they need to undergo a sorting operation and a crushing step also. Thus concrete breaking into aggregates is done through successive steps:

- They go through a first breaking
- Then selection is done to pick up steel
- A new breaking is done to get aggregate diameter less 50 mm
- A new selection to get rid of impurities such as wood, plaster, bricks.
- Thieves come after to select different sizes of recycled granulates
- Sometimes a new breaking is done.

Fines are eliminated from the final products.

5 Composition of recycled aggregates

In fact, in spite of a thorough selection, recycled aggregates still contain impurities. These impurities could be asphalt, plaster, wood, glass, brick and so on. Depending on recycling process and on origin, recycled aggregates contains more or less impurities and the relative amount of each of them is different (See Table 1 (EN 933-11:2009)).

Table 1. Non-floating constituents of coarse recycled aggregates

Constituent	Description
Rc	Concrete, concrete products, mortar - Concrete masonry units
Ru	Unbound aggregate, natural stone - Hydraulically bound aggregate
Rb	Clay masonry units (i.e. bricks and tiles) - Calcium silicate masonry units - Aerated non-floating concrete
Ra	Bituminous materials
Rg	Glass
X	Other: Cohesive (i.e. clay and soil) - Miscellaneous: metals (ferrous and nonferrous), non-floating wood, plastic and rubber - Gypsum plaster

The resulting concrete quality is highly dependent on the aggregate composition. The best quality is those which contain the more broken concrete and unattached aggregates.

5.1 Classification

BS8500-2 classifies recycled aggregates in RCA and RA. RCA do contain less than 5 % of brick parts, and RA could contain up to 100 %. Only RCA could be used in the fabrication of concrete of resistance class C40/50 and of durability class X0, XC1-4, DC1 and XF1. The British Research Establishment (BRE) proposes another classification based also on the brick content.

RCA(I): it is the lowest quality material. It has a low resistance and a high rate of impurity. It could contain up to 100 % of bricks or of masonry.

RCA(II): it a higher quality material made of broken concrete with up to 10% of brick material and less than 1.5 % in weight of other impurities (wood, asphalt, glass, …).

RCA(III): it lay between RCA(I) and RCA(II) regarding its bricks content. It contains less than 50 % of bricks in weight and a high rate of impurities.

Table 2. Classification of recycled aggregates according to British standards

Contaminant (% of mass)	BS 8500 (RCA)	BRE Digest 433 RCA (II)
Masonry (brick)	< 5 %	< 10 %
Light materials (< 1000 kg/m^3)	< 0.5 %	Included in the other materials
Asphalt	< 5 %	Included in the other materials
Other impurities (glass, plastic, letals)	< 1 %	Included in the other materials
Other materials	Included in the other impurities	< 1 %
Wood	No specific information but must be < 0.1 % as for EN 12620	<0.5 %
Total	< 11.5 %	<11.5 %

The aggregate classification allows the resulting concrete to encounter some repeatability concerning it physical properties.

5.2 Recycled aggregate physical characteristics

A recycled aggregate is composed of a natural aggregate, and cement paste attached around. As this paste is porous, and has a limited mechanical resistance, the quality of the aggregate depends on the rate of cement paste attached to it. It depends also on the quality of the origin concrete, on the recycling process and of the origin of the initial concrete: prefabrication concrete or demolition materials. In the first case the aggregates are cleaned. In the second case the aggregates are contaminated by dust, soil, metals.

5.2.1 Physical properties

<u>Density</u>

Recycled aggregate density is lower than that of natural aggregate because of porous cement which is attached to it. It depends on the origin concrete resistance [20]. It is higher for concrete which has a higher resistance. It depends on the size of the aggregate (the lower the higher the density). It depends on the method and crushing energy [12] [15] [5]. The density determination of aggregates plays an important in the composition of the concrete [27].

<u>Water absorption</u>

Water absorption capacity is indicative of recycled aggregates (Rec Ag) performances [27]. It varies a lot and is higher than that of natural aggregates (Nat Ag). It is a problem for the determination of water quantity for good workability.

Brick water absorption is around 22 to 25% in mass [13]. Crushed Brick Aggregates (CBA) capacity varies between 8% and 28% [34].

Crushed concrete is very porous and can reach a capacity lying between 5 and 10 % in mass [9]. RCA reach an absorption capacity of around 2.7 % within 60mn (RA 2.2%)[11]. Globally it lies between 4.8 and 5.5%, which is 4 times that of Nat Ag [34].

<u>Drying shrinkage</u>

BS 8500-2 standard demands that the combined aggregates have a drying shrinkage lower than 0.075 % with BS EN 1367-4. According to Wrap [34] it is realised in the case of RCA and RA. CBA results varies depending on the source and can be lower than that of natural aggregates.

<u>MDE and impact resistance</u>

LA coefficient RA or RCA value depends on initial concrete resistance, on attached cement rate and on initial aggregate quality. It depends also on the crushing method. LA coefficient decreases as initial concrete resistance increases, which is link to the amelioration of the initial cement paste [18]. Resistance to fragmentation test leads to values given on table 3.

Standard limit LA to 50 % (ASTM C-33), 45 % (British code 882, 1201, report 2, 1973) and 40 % (EHE-98 and XP P 18-545). Micro Deval coefficient is evaluated to 16 % for natural aggregates, between 29 and 38 % for RA and RCA and can reach 42 % in the case of CBA[34].

Table 3. Resistance to fragmentation

Recycled aggregate type	Composition	LA value	Bibliographical source
RA	80 % RC and 12%RB	29	
		29 to 40	[4]
RCA		22	[30]
		29 to 40	[4]
RA	Asphalt	32	[4]
	Natural aggregates	22	[30]
CBA		60	[30]

5.2.2 Chemical properties

<u>Sulphate content</u>

Sulphate can cause rupture through expansion of concrete due to their oxidation. Before October 2003 BS5800-2: 2002 limited mass content of RA and RCA to 1.0 %. Sulphate content which are acid (soluble) measured with BS EN 1744-1 is 0.1 % (mass) for natural aggregates and lies between 0.4 and 0.5 % for RCA[34].

<u>Chloride content</u>

Concrete standards limit chloride content to 0.2 to 1.0 % of the mass of final concrete. Chloride content water (soluble) measured with BS EN 1744-1 is lower than 0.01 % of aggregate mass for RCA (0;03 to 0.08 %), RA (0.07 to 0.08 %), CBA (< 0.01 %)[34], and about 0.01 % for natural aggregates.

6 Recycled concrete properties

They depends on aggregates properties high replacement rate. If the rate is lower than 20 %, concrete properties are not modified. For higher replacement rate it is important to modify w/c ratio. Two interfacial zone exist: the first one between initial granulate and old cement paste, the second one between recycled aggregate and the new cement paste. This transition zone play influence badly concrete characteristics. Moreover cement paste linked to aggregate influences recycled concrete performances, for instance resistance and permeability [23] [21].

6.1 Fresh concrete properties

6.1.1 Workability

It is an key property of concrete due to concrete placement. Because of recycled aggregate high porosity, recycled concrete is less workable. Khalaf [16] find a low workability for CBA concrete due probably to angularity of aggregate surface. The slump obtained with recycled aggregate (not wetted before use) far from the slump class of classic concrete. Slump for water saturated before use aggregate is near the normal concrete class[8].

6.1.2 Finishing

Recycled aggregate (rate over 30 %) have the same than ordinary concrete. Recycled concrete finish is facilitated by a high RC content[8].

6.2 Technical properties

6.2.1 Compression strength

A replacement rate lower than 30 % does not modify compression strength[7]. To obtain the same resistance as normal concrete it is necessary to change concrete formulation. Using water saturated recycled aggregates ameliorates compression resistance [7]. The compression resistance of origin concrete has no effect on the performance of recycled aggregate concrete [34]. Resistance to compression decreases with replacement rate. In the case of RCA, a 20-30 % replacement rate leads to resistance which is significantly not different from that of ordinary concrete. The same rate leads to a higher decrease in the case of RCA. Ra rate has little influence on compression resistance when replacement rate is low but when it reaches 100 %, compression resistance decrease with Ra rate. To get the same resistance the ratio w/c must be decreased proportionally to the replacement rate. A diminution of this ration means an augmentation of cement content or/and an increase in the (adjuvant) content which is not compatible with recycling policy. Thus the correction factor must be limited to 0.9. Table 4 gives the limiting compression resistances to be taken into account as function of replacement rate and recommendations.

Table4. Limits to compression strength[30]

Country	Strength category (N/mm²) 100% recycled large aggregate	Strength category (N/mm²) 20% recycled large aggregate
Rilem	50	No limit
Hong Kong	20	25-30
Belgium	30	
Holland	45 (cubic)	No limit
United Kingdom	40	No limit
Japan(civil works)	24	-
Australia (non structural application)	40	-

6.2.2 Bending strength

According to Wrap et al[34], a replacement rate up to 40% of the mass of aggregates (replacement with Rec Ag) has little influence on bending resistance. When the rate reaches 100 % with Rec Ag aggregates, bending resistance is function of Rb rate: W/C = 0.61 leads to a high decrease of resistance with increase of Rb rate, but with W/C = 0.84 Rb has little influence on bending resistance. For a 20% Rec Ag replacement rate, an Rb rate up to 30 % has no effect on bending resistance. The relative performance decrease with Rb rate but it is still higher than 0.95 for Rb rate lower than 50 %. Xiao et al[31], propose the following relation based on 24 RCA :

$$f_{bend} = 0.75\sqrt{f_{cu}}$$

According to Hansen [14] and Khaloo [17], a better adhesion of cement paste to brick aggregates leads recycled concrete based on CBA to a higher bending and tensile resistance.

6.2.3 Tensile strength

According to Vasquez[30] this property is not affected even if replacement rate is 100%. The relation between characteristic compression strength f_{ck} and tensile strength is then the same as for concrete with natural aggregates:

$$f_{tens} = 0.30\sqrt[3]{f_{ck}^{2}}$$

6.2.4 Young modulus

According to Wrap [34] recycled concrete Young modulus is generally lower than that of ordinary concrete. Young modulus reduction is not significant for replacement rate lower than 20-30 %. Moreover the relative performance (compared with recycled concrete with 20 % RCA) decrease with the increase of Rb rate. If Rb rate is lower than 50 % then the relative performance is higher than 0.92. Young modulus decreases with the increase of compression strength and for identical compression strength; if Rb rate is high then Young modulus is lower than RCA or Nat Ag concrete.

Table 5.Young Modulus for various compositions

Density	RB rate	W/C	Young Modulus	Replacement rate	Source
>2455 kg/m^3		0.61	> 19 kN/mm^2	< 90 %	[30]
>2455 kg/m^3		0.84	>16 kN/mm^2	< 90 %	[30]
			50 to 60 % of that of ordinary concrete	100 %	[10]

Vasquez [30] suggests to use a correction coefficient if the replacement rate is higher than 20% for the equation giving Young modulus in the Structural Concrete Instruction.

$$E_c = r\alpha 8500 \sqrt[3]{f_{cm}}$$

r is a correction coefficient depending on the percentage of recycled aggregates used, α is the correction coefficient depending on the nature of the conventional aggregate (Structural Concrete Instruction).

Table 6. Correction coefficient for Young Modulus (Vasquez [VAS, 2004])

	Correction coefficient	
Country	100% recycled large aggregates	20% recycled large aggregates
Belgium	0.80	-
RILEM	0.80	1.00

6.2.5 Drying shrinkage

According to Dhir[8], for a compression strength of 30 N/mm^2, and a replacing rate up to 30 %,drying shrinkage is not modified, but it increases if the replacing rate increases. Fraaj [11] RA concrete has a drying shrinkage lower than RCA concrete and ordinary concrete. Wrap [34] shows that Rb rate (mass rate) must be limited to 40 % to obtain drying shrinkage lower than 0.075%. Table 7 shows corrective coefficient to apply to shrinkage as function of recommendation and replacement rate.

Table 7 – Correction coefficient for shrinkage [30]

	Correction coeficiente	
Country	100% Recycled large aggregates	20% Recycled large aggregates
Belgium	1.50	1.00
RILEM	1.50	1.00
Holland	1.35 to 1.55	1.00

6.2.6 Creep

According to Fraaji et al [11] RA concrete flows more than ordinary concrete. Table 8 shows correction coefficients.

Table 8 – Correction coefficient for shrinkage [30]

	Correction coefficient	
Country	100 % recycled large aggregates	20 % recycled large aggregates
Belgium	1.25	1.00
RILEM	1.25	1.00
Holland	1.25 to 1.45	1.00

6.2.7 Bonding

For replacing rate greater than 20% adhesion of concrete and steel is altered but for lower replacing rate there will be no difference between recycled and ordinary concrete[30].

6.3 Permeability

6.3.1 Surface absorption

Recycled concrete water absorption process is the same as ordinary concrete, and follows the same laws[14]. Surface absorption tests [4] [15] show that for replacing rates up to 30 %, no surface concrete property is affected but the initial surface absorption increase for higher replacement rates. If the replacement rate is lower than 50 %, surface absorption after 10 min is about 50 $ml/m^2/s$. RA concrete have absorption greater than RCA concrete. (1 % more for 20 % replacement rate, 3 % for 100 % replacement rate). Wrap[34] shows that surface absorption is very high for CBA concrete and that RCA has the same as ordinary concrete. Price [22] assumes that 1 $ml/m^2/s$ is the upper performance limit of ordinary concrete. Thus a 20 % limit of Rb in the mix is required for 100 % replacement rate. For a 20 % replacement rate all the values are lower than 1 $ml/m^2/s$.

6.3.2 Carbonation

The degree of Carbonation decreases with the replacement rate with a better behaviour of 100 % Rb rate RA than RCA for an identical compression resistance. In fact recycled concrete must have more cement in the mix to get the same compression resistance than ordinary concrete. Moreover recycled aggregates contain cement attached to old aggregates. This constitutes an alkaline reserve which protects recycled concrete from carbonation.

7 Conclusion

Eco certification is necessary for construction materials if Europe wants really to meet the objectives of SDS for the next years. This eco-certification has to define requirements for sustainable construction products for each type of product existing in building economy.

The requirements for repair materials are:

1. Durability (how many years?)
2. Protection against water, moisture and carbon dioxide
3. Protection against chlorides
4. Protection against flaking off
5. Resistance to cracking
6. Resistance to cleaning (high pressure water)

As seen above Rec Ag concrete have a high porosity and a low resistance to crushing. Thus points 2, 3 and 6 are not fulfilled.

A development of repair with recycled aggregate concrete will be then possible if a particular attention is given to these points when creating the repair zone.

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