Concrete production with recycled materials in the sustainable development context

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Abstract. The waste coming from demolition and construction can provide a source of recyclable materials, useable in the construction industry. In terms of environmental impact, the waste recycling and reuse from construction and demolition activities, reduce the occupied authorized landfills area. Also, by recycling and reuse, it is achieved an economy of non-renewable natural resources. From the economic point of view, the use of recycled materials in place of the natural resources, that reach extremely high costs, it becomes, from one year to another, a solution increasingly more advantageous. This paper presents some opportunities to recycling various waste (glass, polypropylene, filler, ceramic blocks) by using them in the concrete production. The experimental researches have revealed the opportunity to reconsider the four waste studied types, by introducing them as raw materials in the concrete preparation. Moreover, there is the possibility to obtain some types of concrete with special characteristics. Therefore, we can say that the waste recycling and reusing, and their revaluation as raw materials for the concrete production, is a technology which meets the sustainable development criteria.
Key Words: concrete, glass, polypropylene, filler, ceramic block, sustainability.

Introduction. A significant part of construction and demolition waste are coming from various activities, such as demolition of whole or part of buildings and infrastructure works, construction and roads maintenance. The construction and demolition waste can be a raw material resource in the construction industry. Reuse of construction and demolition waste reduces the space for authorized landfills and allows the saving of natural resources. From economical point of view, the use of recycled materials in place of natural resources gets, from one year to another, an increasingly more advantageous solution, reducing the energy, extraction and sintering costs (Rao et al 2007; Terec & Szilagyi 2011; Gheorghe et al 2011).

Thus, the EU Member States are obliged till to 2020, to make the preparation for reusing, recycling and other material recovery operations of non-hazardous waste material from construction and demolition activities. The minimum level required by the Directive 98/2008 is 70% from the total mass of non-hazardous waste from construction and demolition activities. This Directive promotes:

- the sustainable use of natural resources and classification in "waste hierarchy";
- the minimizing of adverse impacts on population health and on the environment;
- measures to ensure the decoupling of (broken) link between economic growth and waste generation;
- the introduction of measures to streamline the penalties system, commensurate with the effect, the ultimate goal being to discourage those who violate the provisions of the imposed rules;
- the introducing of measures which ensure the sorting at source, the collection and the recycling of priority waste streams.

Currently, the waste is deposited on landfill, recycled or incinerated. Some countries (Germany, Netherlands, Denmark and Belgium) achieved recycling rates of up to 80% (Puskas et al 2015).

Waste types from construction and demolition. The amount of generated waste from construction and demolition represents approximately 25% of all EU generated waste and they are (Huang et al 2007; Bhanbhro et al 2014; Meyer 2009; European Comission, EUROSTAT 2012):

- materials resulting from construction and buildings demolition. They may be based on cement, bricks, tiles, ceramics, stone, plaster, plastic, metal, iron, wood, glass, scrap carpentry, expired construction materials;

- materials resulting from the construction and maintenance of access roads and associated structures. In this category are pitch, sand, gravel, asphalt, stone construction, pitch substances, substances with hydraulic or bituminous binders;
- excavated material during construction activities, decommissioning, dredging, remediation etc. Eg soil, gravel, clay, sand, rocks, vegetables scraps.
- construction and demolition waste which contain polychlorinated biphenyls compounds and similar (generically called PCB): glues containing PCBs, flooring based on resin containing PCBs, electrical equipment (ex. capacitors) which contain oil with PCBs, fireproof substances, used substances for dust control (eg. in asphalt mixtures), special adhesives, plasticizers (concrete joints filling material, rubber elements used for woodwork sealing), dyes etc. (Huang et al 2007).

Figure 1 shows the distribution of different types of waste in the total mass.

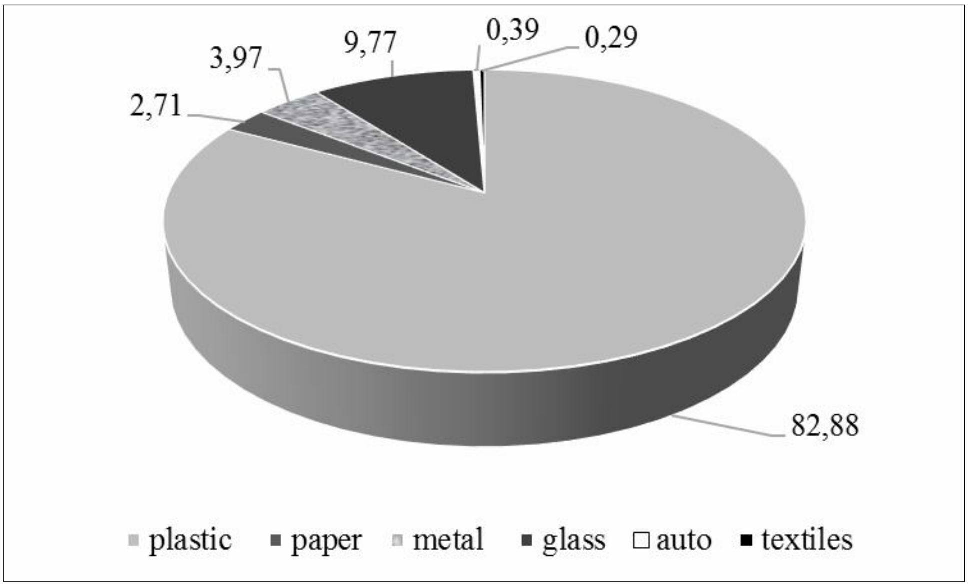

Figure 1. Collected waste composition (Puskas et al 2015).

Construction and demolition waste is classified to the 17th category, according to the Waste European Catalogue and in Romania, are regulated by Government Decision no. 856/2002 concerning the waste management records and for waste list approving, including the hazardous wastes. Of the 44 types of construction and demolition waste, 16 are classified as hazardous waste (Puskas et al 2015; Huang et al 2007; Bhanbhro et al 2014; Meyer 2009; European Comission, EUROSTAT 2012).

Waste valorisation. The waste valorisation operation is based on the criterion of end-of-waste statute, because, it becomes a new material. An important step for waste quality establishing or that of new material, is the assessment of its quality. If the material meets the quality standards, it will be considered a new product. The compliance with such standards must be guaranteed by controlling the whole recovery process from the used waste management, through production process and applied technologies to the needs of the product. It can provide a qualitative evaluation map, which analyzes the final product from both technical point of view as well as environmental impact. The obtained new product shall fulfill requirements under specific harmonized European Norms (Puskas et al 2015).

The waste energy valorisation, the composting, the recycling of metals, paper, glass and plastics, and other waste streams, including their transforming into secondary raw materials through which can be substituted the natural resources, should be encouraged as a priority, in the near future. Through these recycling and reusing operations of construction and demolition waste, it contributes significantly to the reduction of greenhouse gas (GHG emissions). For illustration it was selected from literature the following data, listed in Table 1.

Table 1

Main Sources of Greenhouse Gases Emissions (European Comission 2010)

Efficient use measures for resources	*GES associated emissions*
Hazardous waste treatment	875 kg CO_2 – eq. per tonne of waste
Saved GES emissions as a result of the use of	waste storage alternative methods
Valorisation with energy recovery of organic waste	90 kg CO_2 – eq. per tonne of waste
Valorisation with energy recovery of of paper and cardboard	700 kg CO_2 – eq. per tonne of waste
Valorisation with energy recovery of plastic	1290 kg CO_2 – eq. per tonne of waste
Paper and cardboard recycling	680 kg CO_2 – eq. per tonne of waste
Glass recycling	1720 kg CO_2 – eq. per tonne of waste
Metal recycling	4110 kg CO_2 – eq. per tonne of waste
Biowaste composting	80 kg CO_2 – eq. per tonne of waste
Anaerobic digestion of biowaste	180 kg CO_2 – eq. per tonne of waste

The recycling rate of construction and demolition (R) is expressed as a percentage and represents the ratio between the amount of construction and demolition waste recovered as materials and the waste amount from construction and generated demolition.

However, analyzing the developments for the past four years 2007-2010, it notes, that beginning with 2009, a decrease of the generated waste amount, both as average in the UE as well as for the most Member States. But this development is estimated that is due to, mainly, economic crisis and less to prevention measures. Regarding the municipal waste generation indicators, according to Eurostat data (European Comission 2010; MECC 2014), in the year 2010, for Romania, the amount was 365 kg / resident / year, with 27% lower than the European average (502 kg / resident / year) (Figure 2). The evolution of these indicators, in the range 1995-2008, is similar in both cases of evolution of generated municipal waste quantities.

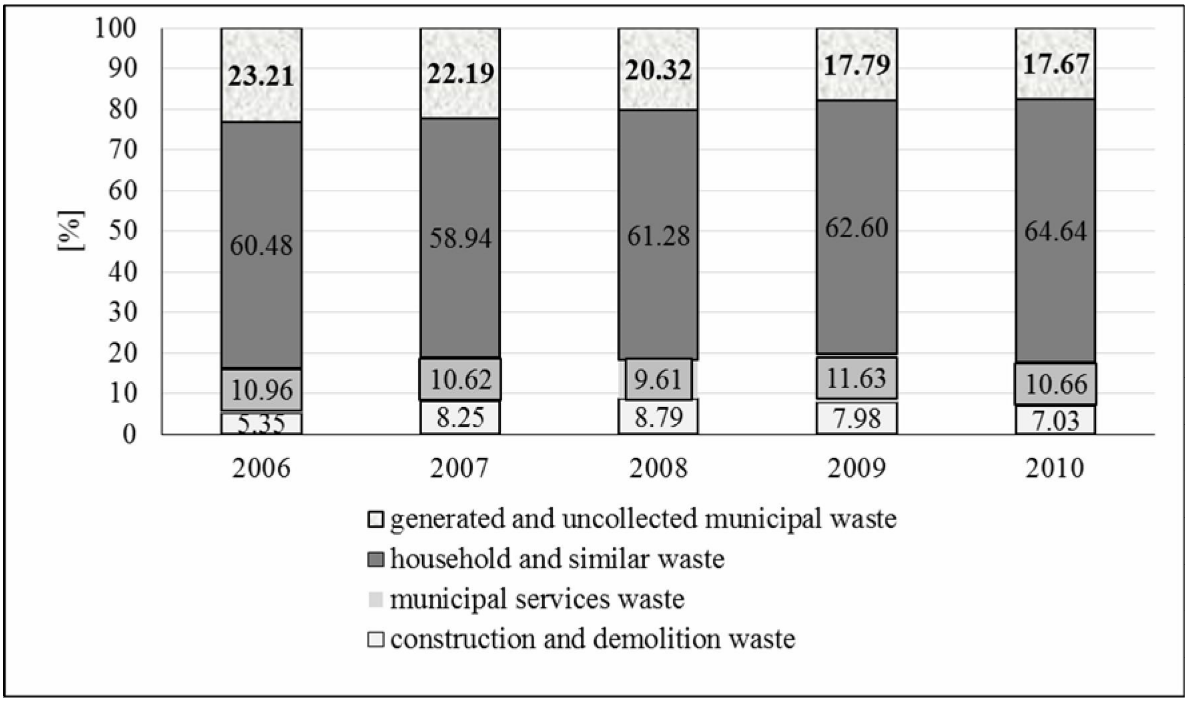

Figure 2. Generated municipal waste structure in the period 2006-2010 (European Comission 2010).

Glass. The glass is considered a waste, one of the most difficult to use. In the process of storing, this material is not affected by water, air, sunlight or frost. In addition, the glass is resistant to corrosion so that the material does not disintegrate under the influence of organic compounds, mineral, bio, salts, such as fungi and bacteria. Therefore, compared with organic waste (paper, food waste, etc.) which are completely decomposed after 1-3 years, the glass could be maintained, without destroying, decades or even hundreds of years (Huang et al 2007).

The amount of unused glass shards, in accordance with the Institute of Secondary Resources, represented in 2000 years, more than 2.5 million tons. Among the variety of urban waste, the broken glass occupies one of the leading positions, more than 20% of the total. Many world's research centers have developed in recent years top programs for recycling broken glass. For example, in the US, there were conducted studies, by experts from the Faculty of Engineering and Applied Science at Columbia University (New York), on aggregates replacement with glass (Terec & Szilagyi 2011).

These studies have shown that the broken pieces of glass of poor quality together with different colored glass, which have high contamination levels, can be used in the concrete production and in the asphalt achieving, as filler in construction, replacing the natural aggregates. The asphalt with crushed glass (Figure 3), a mixture of 10-20% glass shards with asphalt, is suitable only for roads with speed limits under 60 km / h, because it offers a poor adherence of the tires, at high speeds. As an aggregate material, the broken glass has many of the gravel properties, so that the demand is largely dependent on the gravel prices and the broken glass prices.

Figure 3. Asphalt-containing waste glass (Huang et al 2007).

Industrial applications include the use of some glass pieces or of some very small fragments, as blasting medium. Many glass beads manufacturers, glass art objects manufacturers and decorative plates manufacturer use, as raw material, the recycled glass shards. The reflective beads, used on the roads to improve the drivers safety, are made from recycled glass, too.

The concrete with recycled glass has a comparable strength, to that of conventional concrete, and fiberglass has the same bonding results as cement. Under optimum conditions, this material can be perfectly integrated into the environment, but only in areas without large fluctuations in the weather. It is well known that glass is sensitive to alcalo-silica reactions. When this silicon reacts with the cement hydroxide ions, it formes silica gel which causes cracks in the cement and creates the possibility for absorbing the water. Also, the residual material on glass, as organic particles, may adversely affect the concrete strength. Yet, the concrete with glass waste produced by well-controlled process technology is successfully used in the construction of polished floors or countertops tables (Huang et al 2007).

Polypropylene. Through his studies in the 40s, the romanian engineer Gogu Constantinescu introduces and details the concept of polypropylene fiber reinforced concrete, being among the promoters of this new material. The reinforcing fibers are made from pure polypropylene by a conventional extrusion process (cooling with water). These, through various transformation processes reach to outstanding physical and mechanical characteristics (tensile strength, tenacity and elongation) (Meyer 2009).

The process continues by cutting the fibers to various sizes from 5 mm to 70 mm, and packing in water-soluble paper bags. While cutting, the fibers are coated with a superplasticizing thin film that gives them a upper slip and the freedom to disperse tridimensional throughout the mixture, without to be necessary to add in concrete or in mortars other additives.

The polypropylene is absolutely inert and stable, it does not corrode, it is resistant to alkali, it is antistatic and anti-magnetic, with a virtually unlimited durability. At room temperature it is resistant to all organic solvents, and not dangerous. Polypropylene reinforcing fibers improve the properties of concrete. The dispersed reinforcing with polypropylene fibers is advantageous in the case of the necessity of using a small percentage of reinforcement or in the case of the constructive reinforcement to common reinforced concrete.

Polypropylene reinforcing fibers increase the plasticity and workability of concretes and mortars, eliminating segregation and concrete and mortars compaction. The using possibilities of reinforced concrete with dispersed polypropylene reinforcing fibers are increasing due to improved cracking behavior, to shrinkage decreasing in the drying process, to shear strength increasing, to wear resistance increasing, impact and freeze-thaw cycles, reducing permeability to water and water vapors. An important area are the construction elements subjected to dynamic loading, to which it can increase the energy takeover ability at this effort. In the case of some works with large cargoes or joining an increased gauge, it appears necessary the fiber reinforcement (ACI 2002).

Fiber reinforced concrete is used for: industrial floors; exterior platforms, parking lots, concrete runways; airport runways; foundations tram lines; consolidation with injected concrete and reinforced concrete for tunnels and slopes; prefabricated elements for any destinations; foundations with high dynamic loading; concrete pipe; retaining walls; thin facade elements; foundations of machine tools.

Limestone filler. Limestone filler is a product obtained through dry crushing of the limestone with a high content of calcium carbonate ($CaCO_3$ > 95%) and gravity sorting. The resulted product is stored in big capacity silos under controlled temperature and humidity, to not be altered its physico-chemical properties.

The limestone filler is used in various fields such as: road construction (it is a basic component for the preparation of asphalt mixtures) or in construction elements exposed to corrosive environments (Bhanbhro et al 2014). This material is also used for the floors achievement, for insulation works in construction, as a raw material in the glass industry, in the production of adhesives, sealants, fine plasters for finishing works, in the chemical industry for the detergents production, in energy industry in the wastewater treatment process, in the ceramics industry and in agriculture as soil fertilizer or as mineral supplement for animals.

Research has shown that certain changes made to self-compacting concrete, by viscosity increasing, has been achieved by adding fine part, in this case was limestone filler, with high density. Thus, the self-compacting concrete (BAC) is considered a new concrete, which successfully replaces the classic, that imposes vibration to put into place (Gheorghe et al 2011). Thus, the self-compacting concrete advantages are that it allows the realization of high quality concrete elements, saving time, labor and energy. Self-compacting concrete (BAC) can be classified as "green concrete" due to energy savings and noise reduction (Terec & Szilagyi 2011).

Concrete and ceramic masonry bodies. Of the total rubble amount (concrete and ceramic masonry bodies) resulting from the recycling, about 80% comes from civil engineering (buildings) and the rest from urbanistic buildings, roads and bridges (Bhanbhro et al 2014). The rubble that comes from civil engineering demolition work is expressed as m^3rubble /m^2 of built area. The construction activity rubble represents about 3% of the used materials. The resulted rubble of renovation / modernization / restoration activities is about 2% of the originally used material.

The rubble recycling involves a complex process of manually collecting of wood, stone, metals, plastics or glass impurities, followed by loosening of the resulting material on conveyor belts at different speeds, the manual separation (performed on the bands, too), separating of fine material from rubble through different sieves (depending on the desired particle size), followed by temporary storage till to sail respectively to valorisation of "recycled aggregates."

The recycled aggregates can be used for the roads foundation layers and mounds, as unbound mixtures with homogeneous granulation or for mixtures preparation for low resistance concretes. These, like the natural aggregates, do not have all the same features, so that, depending on their specific performances, they are more or less suitable for certain applications. It is therefore, of great importance, to know their properties and their behavior regarding various factors (strength, exposure to freeze-thaw cycles or water, etc.), rather than knowing their origin (Sabau 2013).

The recycled aggregates can be used as aggregates for lightweight concrete with good insulation properties. The concretes with recycled aggregates have the bulk density between 1350 kg/m^3 and 1700 kg/m^3 and the compressive strength of 30-250 daN/cm^2. Because, through drying, it happens large shrinkages, they can not be used in monolithic construction of large dimensions, being indicated only for foundations (Huang et al 2007).

Conclusions. Construction and demolition waste provides a substantial source of raw material for construction works and others. Research conducted so far show that waste can be capitalized on construction sites, demolition of refurbishments and there are more important their characteristics than their origin source. Construction waste must be collected separately, taking into account the cleanliness and contamination by harmful substances. Avoiding contamination, which can cause future problems, it is essential to ensure the resistance degree and exploitation safety, providing a satisfactory sustainability, pollution reduction on long term and it is vital to the health of users.

Construction and demolition waste recycling reduces the need for land for stockpiling. Research conducted so far shows that a proper waste management reduces the production costs of new construction materials. The biggest problem regarding the waste management, is not related to its quality, but regarding the quantity generated. Waste production in Europe reaches 850 million tons/year of which, in many countries, a large proportion is stockpiled. Thus, it must mandatory introduce the pre-sorting at source, in homogeneous groups, which reduces the recycling or disposal cost and ensures a better quality of recycled products.

The onsite waste valorisation is advantageous due to the null cost of transport, regarding both waste and aggregates.

Because of their origin, the recycled aggregates are hardly marketed. Therefore, the price of recycled aggregates should be kept at least 20% lower than that of natural aggregates.

To permanently remove the prejudices of all users, it is necessary to define as soon as possible, the criteria for determining when waste ceases to be regarded as such and becomes material (end of waste).

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