Recycled Concrete, a Solution for fine and Coarse Raw Material for New Concrete

W. Martinez Molina, E. M. Alonso Guzman, H. L. Chavez Garcia, C. Lara Gomez, F. M. Gonzalez Valdez
Department of Materials, Faculty of Civil Engineering
University of San Nicolas de Hidalgo
Morelia, Michoacan, Mexico
wilfridomartinezmolina@gmail.com, eliamercedesalonso@gmail.com, hchavezenator@gmail.com, cindylago@hotmail.com, laboratoriomaterialesfic@gmail.com

A. A. Torres Acosta, J. T. Pérez Quiroz
Mexican Transport Research Institute
Ministry of Communications and Transports
Sanfandila, Pedro Escobedo, Queretaro, Mexico
atorres@imt.mx, jtperez@imt.mx

H. Hernandez Barrios
Department of Structures, Faculty of Civil Engineering
University of San Nicolas de Hidalgo
Morelia, Michoacan, Mexico

W. Martinez Alonso
Division of Civil and Geomatics Engineering, Faculty of Engineering
National Autonomous University of Mexico
Mexico City, Mexico

***Abstract*—Solid waste generation of Hydraulic Concrete is a new polluting of the earth. The most produced material in the world is the Portland Cement (PC), but its disadvantage lies on its requiring fossil fuels, as well as the CO_x discharge to the atmosphere. Re-use of Hydraulic Concrete waste abates simultaneously a number of problems, as dumping of solid waste and CO_x compounds into the environment; affectation of quarry sand and gravel stones, as well as endemic flora and fauna living in them; storm-water runoff by the inability of strata to filter demolished concrete contained in landfills. The use of crushed aggregates coming from Hydraulic Concrete demolition is used to generate Recycled Concrete, a material that can abate costs, diminish pollution, reduce the cost of building, and protect quarries from unnecessary exploitation. Nonetheless, development of Recycled Concrete faces the challenge of finding optimal designs to achieve the highest mechanical performance under static and dynamic stresses, the need to produce concretes less susceptible to carbonation, and therefore, to corrosion of reinforcing steel that protect with the concrete core, aside from waterproof and dense concrete.**

Keywords— recycled; concrete; aggregates

I. INTRODUCTION

Among many other areas of knowledge, preservation of the environment is a part of the civil engineering that could be solved from a Recycled Concrete perspective.

Each person, from their particular domain of knowledge, has a moral obligation to contribute, where and when possible, improving and preserving the environment for next generations; Recycled Concrete is an issue of primordial research to avoid, as far as possible, global warming. Design, manufacture, durability, performance, economy and feasibility of Recycled Concrete are now investigated.

The use of Recycled Building Materials began in the second post- world war year, in the 40's of the 20th century, as Europe had large amounts of rubble, result of the bombings, and these materials began to be used as quarries of sand and gravel to rebuild, with good results for devastated countries. Publications of the time, mostly British, German and Russian, aware of the use of rubble to build new civil structures, only that much of the debris were ceramic material (bricks, ceramic furniture of health services), natural stone material, plastics and rubbers [1, 2] and Hydraulic Concrete; subsequently slags, ashes, and silica fumes were added [3]. Hydraulic Concrete arrived at American in the late 19th century [4], and the U.S.A. began studies on recycled materials in the 20th century. The first inform of Recycled Concrete was conducted in Russia by Gluzhge in 1946, shortly after the end of the 2nd World War.

Early studies in the U.S.A. (but posterior of those developed by Gluzhge) recommend, in the first instance, the use of Recycled Hydraulic Concrete with origins in road infrastructure or rigid pavement, and, only as a second option, the one coming from buildings; as the main argument, these studies mention these materials could be contaminated with sulfur products, since plaster is used for coatings, and this could lead to sulfate attack to new concrete, which would damage the reinforcing steel embedded in the Hydraulic

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Concrete. At the beginning Recycled Hydraulic Concrete was mostly used in asphalt mixtures for pavements [5, 6].

If it is achieved that materials considered as solid waste (garbage, residues), as in the case of demolished or collapsed concrete, ceramics and mortars (binders), are re-used to elaborate new concrete mixtures.

Manufacture of PC produces approximately the same weight in Carbon compounds emissions to the atmosphere as the PC, making recycling concrete is also a good option to reduce the carbon footprint of carbon in the atmosphere.

Concrete is one of the most widely used materials in the world, maybe the most used after water, in the construction of civil and military structures, but is also a generator of large volumes of solid waste associated with the demolition, seismic damages, and waste processes as restoration, conservation, renovation [7]. Since signing of the Kyoto Protocol, negotiated in 1997, which sought to compromise 37 developed countries reduced their emissions of greenhouse gases (GHG) by 5 per cent in 2012, compared to the emission levels in 1990 (Mexico, not being considered a developed country, did not sign), climate change and environmental pollution have become topics of capital interest, incentivizing the countries which initiate policies whose focus is the reduction of these volumes of air and solid waste dumped into the atmosphere, which is World Heritage, the atmosphere does not have limits or boundaries as the countries, it is not possible to avoid the polluted air to move from one place to other [8]; through its re-use or searching out for other alternatives [9-11]. Studies conducted in the European Union [12-14] have been able to establish that the production of construction waste amounts to about 900 million Tons/year, as showed in Table I. Similarly, Spain, Germany, France and the United Kingdom have determined the feasibility of reusing hydraulic concrete proceeding from construction as granular material, maximum if there is a lack of natural stone aggregates.

TABLE I. RECYCLED CONCRETE GENERAL SUMMARY.

Country	Recycled Concrete *(millions of Tons)*
Australia	550
Europe: United Kingdom, Sweden, Switzerland, Spain, Portugal, Netherlands, Luxembourg, Italy, Ireland, Germany, France, Finland, Denmark, Czech Republic, Belgium, Austria	354
America: United States, Colombia, Mexico	368
Asia: Japan, Taiwan, Thailand	154

It can be noted that, with respect to the amount of recycling concrete, Australia is distinguished. Many countries still lack reliable registrations. Devastating earthquakes affecting countries like Afghanistan and Turkey have been noticed but there are no records in the literature of the quantities used for recycling, not to mention these countries continue the tradition to build ceramic and/or adobe walls.

World Hydraulic Concrete Production is estimated at 25 billion Tons annually, so the recycled concrete is a very, very small amount. As a consequence of the environmental pollution and climate change, initiating the creation of collective consciousness in underdeveloped countries to reduce the extraction of stone materials from natural environments gains importance, hence reducing an accelerated depletion of sands, gravel, and stones from both riverbeds and quarries [15, 16]. The demand for natural resources and a shortage of raw materials is important; therefore, the need to preserve and protect the environment from an ecological crisis makes the technique of Recycled Concrete [17], an activity of great boom in construction [18]. Previous research has shown that the physical and mechanical properties of Recycled Hydraulic Concrete, conformed by recycled aggregate additions in its core, can ensure its strength and mechanical performance [19-21]. Studies derived from specific applications in civil engineering constructions show that, often, concrete residues are not efficiently used.

For successful recycling, several variables must be considered in the design of new concrete mixtures: percentage of recycled material, percentage of recycled coarse material and fine material, water-cement ratio, density of the recycled material, use of fluidifiers, slump (workability), mechanical resistance, homogeneity, density, porosity [22]; the study of the microstructure of Recycled Concrete presents new challenges because the interfacial transition zone (ITZ) has 2 zones [23, 24], old and modern concrete settings, with different compositions, porosities, densities, age, moisturizing and hardness.

The decreased size of Hydraulic Concrete hardened method to obtain gravels can produce spray losses, sizes almost as those of sands ($\leq$ ¼ in or 6.4 mm), porous areas with the corresponding shapes, sizes and distribution if the pores in the cores, which increases the surface area, and thus augmenting demand for PC in the new mixture [25, 26], undesirable morphology of crushed particles where $X \neq Y \neq Z$ (the sizes in tridimensional axis), producing elongated or semi-acicular shapes [27]. To prevent Recycled Concrete sands from presenting problems as the described above, the product of fine and coarse crushing must be characterized for optimal concrete designs; some countries already have a code for recycled stone material [28]. Another parameter to take into account is the percentage of natural stone that can be replaced by recycled material [12], because the consumption of cement per cubic meter of Hydraulic Concrete and the mechanical resistance is a function of this percentage [29]; some mixtures only replace the coarse aggregates for recycled material, and some others only replace fine aggregates for recycled material [30, 31]. The quality and properties of the recycled aggregates depend on the bedrock or concrete where they come from, and the greater the resistance of the primary concrete, the greater the resistance of the recycled aggregates coming from the original concrete [32]; other designs mix both types of recycled aggregate, with some authors working with specific percentages of each aggregate [33], and variations are designed and manufactured based in the design properties sought in the Recycled Concrete [34, 35].

PC consumption depends on the design method, safety factor, types of material, additives, additions and seismic coefficient; there are no universally recognized design methods to design mortar or concrete with sands coming from Recycled Concrete successfully [36]. Concrete mixtures design began in the late 19th and early 20th century with Dr. Duffus Abrams [37]. Until the late 20th century, Hydraulic Concrete was designed primarily based in the compressive strength, which is the index concrete property; however, since the beginning of the 21st century the approach changed, and now, due to the concrete performance, its lifespan and the necessity for maintenance reduction, concrete mixtures design takes into account mainly durability criteria [38].

Concrete mixtures with recycled material are evaluated from the mechanical performance, physical performance, durability [39], failure modes [40], fluidity, slump [41], age and hydration of cement [42] perspectives; ~~e~~ the accommodation of the recycled admixtures can be achieved with vibratory methods or special self-compacting types of cement [43] or the use of additives, all these variables are also taken into account.

The mechanical performance of concrete is evaluated with destructive breaking stress to simple compression tests [44], simple tension and indirect tension, and bending or rupture modulus. This characterization is essential for the case of rigid pavements design, and the evaluation is also made with the use of non-destructive tests that do not require material preparation, can be repeated and do not cause damage; electrical resistivity tests and ultrasonic pulse velocity are the most commonly used techniques [45]. To improve the performance of the Hydraulic Concrete mixtures, safety factors, decreased W/C ratio, concrete curing through immersion or prolonged spaying are employed [46]; additives, and additions or substitutions of the PC are frequently used for the same purpose.

II. RESULTS

The manufacturing performance of concrete using fine and coarse aggregates product of Recycled Concrete has been generally sufficient to produce new material whose mechanical performance and durability meet the international standards, solving the solid waste contamination. Perhaps, its main drawback could be the porosity of coarse and fine aggregates produced by crushing hydraulic concrete; nonetheless, this problem can be solved considering, for the design of new mixtures:

1. Decreased W/C ratio that will favor durability and obtaining of high mechanical resistance; this resolution is made employing fluidifiers, ~~or~~ super-fluidifiers, high range water reduction, high-slump (flowing), water reducers (additives listed as in ASTM C-494);

2. Using wet crushed recycled concrete to avoid water loss of the Portland cement matrix;

3. Use of agro-industrial wastes presenting pozzolan activity to "fill" holes/pores in the hardened paste (recrystallize and densifying pores of the core) or the pores in the recycling crushed aggregates; the addition of pozzolan wastes solves the use of other solid waste products that pollute. The use of pozzolan additions increases the mechanical performance of the new mixtures, mixtures that increase the protection of the reinforced steel embedded in them, diminishing carbonization attack on concrete and thus steel corrosion.

4. Adding artificial pozzolan or chemicals pozzolan of industrial purity that can be activated at low temperatures, such as geopolymer materials [47-49] or alkali-activated cement types.

III. CONCLUSIONS

Recycled Concrete solve the scarcity of stone aggregates as well as addressing the problem of aggregates not complying with current legislation, such as the case of volcanic foams; the use of Recycled Concrete aggregates also allows statured materials in the mixtures, starting thus internal curing of the new Recycled Concrete mixtures.

Use of recycled material allows as well no accumulations of collapsed or demolished concrete needing to be removed or transported to solid waste landfills; additionally, the number of polluting emissions to the environment is decreased.

Recycled material employment enables the unnecessary over-exploitation of quarries, retaining, when possible, the landscape architecture and promoting specialized geological tourism which involves the preservation of endemic biota, reducing the environmental impact of extractions and the failure modes by sliding of bank materials near population centers.

Serious efforts to initialize the use of stone materials product of recycling, for different edifications in Mexico, confirm the above.

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