Preliminary exploration of recycling cementitious aggregates in the building field

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Abstract

Recycled materials give a significant contribution to environmental sustainability. Several scientific studies has been outlined the technological potential of recycled concrete. Can be obtained cementitious materials with similar properties at the mixes prepared with natural aggregates. In order to pay attention to the homogeneity aspects of the recycled aggregates and the durability of the recycled concrete, a continuous characterization of the material parameters is necessary. The use of recycled aggregates is encouraged by both the high disposal costs and the lack of landfills. This preliminary experimentation phase was carried out in order to demonstrate the limits and potential of using 100% recycled aggregates for the creation of recycled concrete from a mechanical and durability point of view. Fresh blends and hardened concrete were investigated. The results indicate that it is possible to obtain concrete with mechanical characteristics C20/25 and C25/30, respecting the environmental exposure classes XC1 and XC3 (corrosion induced by carbonation). On the other hand, the durability aspects such as the resistance to frost in the presence of antifreeze salts, the water permeability and the chloride diffusion resistance with 100% aggregate replacement cannot be achieved.

Thus, concrete containing 100 % recycled aggregates or less can be effectively used in many parts of buildings, since the mechanical properties, especially the compressive strength, reaches values up to 25 MPa. However, it is necessary a constant monitoring of the material quality to comply with the standards, and technical requirements of the construction sector.

Keywords

Demolition, recycling, concrete, durability

1. Introduction

The public construction sector is a promoter to the use of recycled aggregates of mineral origin resulting from demolition processes with the aim of preserving available landfills and saving the stocks of raw materials from natural inert quarries [1]. The *Order on Waste Prevention and Disposal* [2] requires materials from demolition such as excavation and/or clearing material to be recycled as much as possible. Nevertheless, the use of recycled aggregates does not yet have widespread recognition and among professionals in the sector [3].

The strategy of the public sector consists in creating a market where construction waste re-enters the production process [4]. The difficulty of having suitable sites available as landfills is growing. Construction activity is one of the most relevant production of waste. It has grown significantly over the years. The recycling rate fluctuates between 50% -60%, depending on the oscillations in the construction industry, the target for 2025 is to reach 70%. The objectives are reduction of waste at source with recycling (aggregates of secondary origin); export of excavated material; planning and construction of public landfills [4]. The 2019 data of the Canton Ticino relating to demolition waste, concrete and asphalt, indicate that 578 kt were produced. An amount of 282 kt went to type B landfills, 221 kt were recycled and 75 kt exported [5]. The data confirm the positive propensity to recycling.

Proceedings of FTAL 2021, October 28–29, 2021, Lugano, Switzerland
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1.1. Recycled concrete: current use and potential developments.

Mineral components from demolition waste (C&DW) can be used to produce new concrete [6]. This makes the construction sector less dependent on the scarce natural resources, thus avoiding mining and landfilling. Circular process must replace the linear ones [7].

In the road foundations the recycled aggregate are currently widely used. However, recycling of inert materials also occurs to create new concrete; in Switzerland around 1'650 buildings are made of more than 50% of recycled concrete [8]. The city of Zurich begun to promote the use of recycled concrete for new public buildings in 2007. The Zurich Art Museum, designed by David Chipperfield, is made almost entirely of recycled concrete and cement CEM III/B (conventional clinker is replaced by slag sand). The school building Leutschenbach, Zurich Oerlikon, designed by Christian Kerez, contains 95% recycled concrete [9].

A waste final layer of a flat roof replaced the natural gravel in the project pilot for the extension of K118 building at Winterthur [10].

It is essential to set up recycling processes (separation, sorting, crushing) that provide recycled mineral aggregates that can be used without reducing the quality of the building material.

The definition and implementation of selective demolition techniques to obtain increasingly homogeneous inert materials are under investigation [11, 12]; experiments with recycled aggregates demonstrate possible applications in particular the influence of recycled aggregate percentage [13, 14, 15, 16]; the definition of methods to characterize the recycled aggregates and any pre-treatments to improve their performance [17, 18, 19, 20, 21].

2. Standards for recycled concrete

Recycled aggregate is defined as *a mineral aggregate resulting from the recovery of waste of inorganic material previously used in construction* [22]. The possibility of using recycled concrete is disciplined by standards. Recycled concrete can be used as non-standardized lean, shell and backfill material and as structural concrete according to standards SN EN 206-1 [23] e SIA 262 [24]. The requirements apply to recycled concrete are described in the Merkblatt SIA 2030 [25].

Recycled concrete is *concrete whose aggregate size is > 4 mm and is made up of at least 25% by mass of recycled aggregate*. There is a substantial difference with non-recycled concrete for which a grain size of > 8 mm is expected (according to SN EN 933-11 [26]).

The SN 670 071 [27] framework standard for recycling indicates as demolition material *a construction site waste produced by the construction or demolition of works containing at least 95% by volume of stones or similar materials.* Additionally, four categories of waste are distinguished: bituminous conglomerate (tar demolition), demolition concrete, non-separated demolition material, gravel material. The use, in varying proportions of these types of mineral waste, can give rise to two types of recycled concrete:

- RC-C, obtained from concrete granulates C, with or without the addition of natural granulates, and contains at least 25% of the weight of demolition concrete and a percentage of less than 5% of unseparated demolition material.
- RC-M, obtained from mixed granulates M, with or without the addition of demolition concrete and natural granulates, and contains at least 5% of the weight of non-separated demolition material and at least 25% of the weight of demolition concrete and unseparated demolition material.

This article presents the preliminary experimentation carried out in order to demonstrate the limits and potential of recycled aggregates for the creation of recycled concrete from a mechanical and durability point of view. Therefore, considering the provisions of standard SN EN 206 [23], concretes with resistance classes C25/30 and C30/37 can be prepared, generally usable for exposure classes XC1-4 and XF1. To encourage the use of recycled concrete it is necessary to demonstrate the durability of the concrete: porosity and water permeability, resistance to freeze-thaw in the presence of antifreeze salts, diffusion of chlorides [28].

3. Experimental Test

Identification of funding sources and other support, and thanks to individuals and groups that assisted in the research and the preparation of the work should be included in an acknowledgment section, which is placed just before the reference section in your document.

3.1. Characterization of the recycled aggregates

The quality and durability of the final product is influenced by the aggregates. Therefore, recycled aggregates must meet the requirements of standard SN EN 12620 [22]. Company G. Ecorecycling SA has supplied the aggregates used in the experimental investigation. The aggregates was obtained crushing from the concrete artefacts demolition waste (Figure 1). For the crushing of the aggregates a jaw crusher was used. The aggregate used were provided with the indication of the absence of unwanted or harmful substances.

Figure 1: Recycling aggregates (0/32)

The demolished concrete was separated, grinded in single fractions. The recycled aggregates were characterized by granulometric analysis [29] and water absorption [30].

The single fractions are comparable to a natural material. In fact, by comparing the granulometric distribution of the recycled aggregate (Figure 2) with the natural fluvial-type aggregate (Figure 3), the curves are similar. The mixture limits in the graphs refer to the standard SIA 162-1:1989 which set particularly restrictive limits.

Water absorption of the recycled aggregates was found to be 4.5% at saturation and 3.6% after 30 minutes. The values are higher than those obtained with natural aggregates with a value of approximately < 1%. Determining this parameter is fundamental in order to optimize the mix design with the right amount of water.

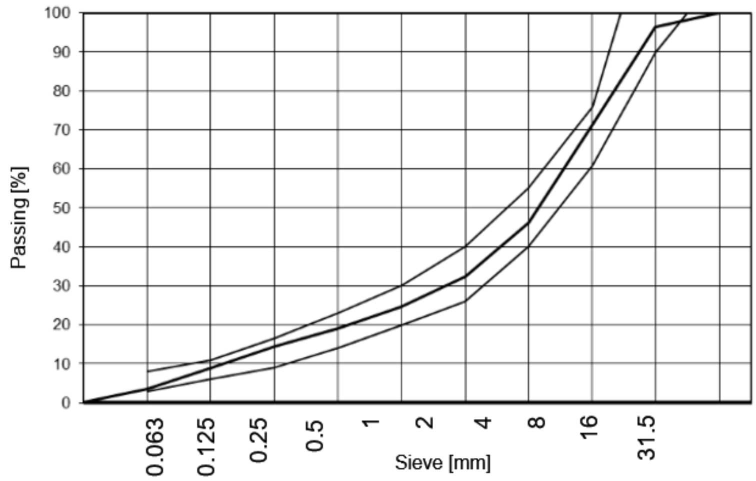

Figure 2: Grain size distribution curves of RC-C, single fraction.

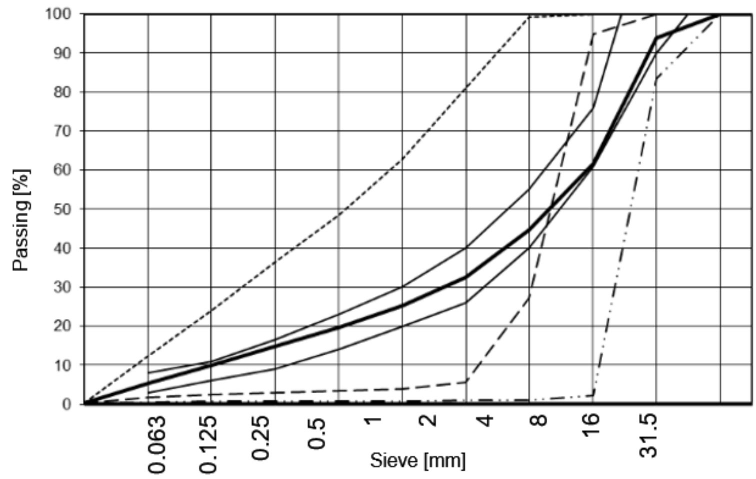

Figure 3: Grain size distribution curves of natural aggregates (fraction 0/4, 10/16, 16/32).

3.2. Characterization of the recycled concrete mixes

The experimental activities consisted in the packaging of mixtures with the same type and dosage of cement and the complete replacement of natural aggregates with recycled aggregates.

In this exploratory phase of the research, two mixtures were selected with the same type and dosage of cement and 100% replacement of natural aggregates with recycled aggregates using two different fractions (single: 0/32 and compound: 0/4, 10/16, 16/32 mm).

To improve the workability of the mixtures A plasticizer was added (1%), while an air-entraining additive (0.2%) was added to improve frost resistance. Table 1 shows the mixtures prepared in the laboratory.

Table 1

Composition of the different mixes

Properties	Mixture M1	Mixture M2
Cement CEM I 42 N [kg/m^3]	340	340
$w_{eff/c}$	0.53	0.53
Fluidizing additives [%]	1	1
Aerating additives [%]	0.2	0.2
Recycled aggregates [100%]	100	100
Aggregate fraction RC-C [mm]	0/32	0/4, 10/16, 16/32

Each blend was prepared in order to verify its durability in accordance with the Swiss standard SIA 262 [24] e SIA 262/1 [31]. Were testing performed for the apparent density, the effective water/cement ratio [32], the occluded air content [33] and the compaction index [34].

Mechanical compressive tests and specific tests required by Swiss Standard were performed: compressive strength on three concrete cubes at 28 days [35]; modulus of elasticity on three prisms [36]; porosity and water permeability on series of five cores [31]; behavior to freeze-thaw cycles in the presence of antifreeze salts on three cubes [31]; penetration of chlorides on series of five cores [31].

The SN EN 206-1 standard [23] sets out the limits allowed for each parameter in relation to the durability and class of exposure.

4. Results

4.1. Properties of the fresh concrete

The consistency measurements indicate an optimal workability. The property of fresh concrete prepared with recycling aggregate are comparable to the requirements of concrete with natural aggregates (workability C3 Walz 1.10-1.04, $w_{eff/c} < 0.65$).

In accordance with SN EN 206, the mixtures belong to the C3 consistency class. After 30 minutes the mixtures losed workability. This aspect is relevant during the execution phase and depends on the absorption properties of the recycled aggregates (3.6% after 30 minutes).

The mixtures with 100% recycled aggregate required a greater quantity of water to achieve the necessary workability. This data is consistent with the results on hardened concrete.

Table 2 shows the results on fresh concrete for the two mixtures, compared with concrete with natural aggregates.

Table 2
Results fresh concrete tests

Properties	Mixture M1	Mixture M2
Unit weight [kg/m^3]	2202	2225
Occluded air [%]	4.5	3.5
Walz coefficient [-]	1.04	1.06
Walz coefficient after 30’ [-]	1.13	1.31
$w_{eff/c}$	0.35	0.35

4.2. Properties of the hardened concrete

Mixture M1 corresponds to the C20/25 strength class, whilst the M2 (100% recycled aggregate with composite fraction) mixture falls under strength class C25/30. The mechanical properties of the hardened concrete shows the mixture M2 to have major compressive strength and elasticity modulus as compared to mixture M1. Compared to the elasticity modulus of a traditional concrete, the values tend to be low.

Table 3 shows the results on hardened concrete for each mixture.

Table 3
Results hardened concrete tests

Properties	Mixture M1	Mixture M2
Compressive strength 28 days [N/mm^2]	30.1	34.2
Elastic Modulus [N/mm^2]	19450	22100
Water permeability [g/m^2*h]	11.3	9.7
Penetration of chlorides [10^{-12} m^2/s]	19.6	17.6
Freezing and thawing in the presence of de-icing salts [g/m^2]	2500	2400

About the water permeability, penetration of chlorides and freezing and thawing in the presence of de-icing salts, the values measured for both mixtures are high. Only mixture M2 exhibits a water permeability in the exposition class XC3.

5. Conclusions

The use of recycled aggregates encourages the effective recycling of waste materials that are difficult to place and dispose.

Without any optimization of the mixtures, it is possible obtained concrete with mechanical characteristics C20/25 and C25/30 and conforming to exposure classes XC1 and XC3. Concrete containing 100% recycled aggregates can be effectively used in many parts of buildings, since the mechanical properties are still satisfactory, especially the compressive strength.

Following this initial exploration, the experimental activities have progressed by using recycled material of excellent quality to produce recycled concretes with resistance class C30/37 and excellent durability [37].

The structural use of recycled concrete is feasible but requires specifications that cannot be limited only to quantitative maximum limits of recycled aggregates and the strength of the concrete.

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