Sustainable Concentrate Mixture with Recycled Aggregate

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Abstract

The use of recycled aggregate in concrete mixtures represents a significant step toward sustainability in the construction industry. This study focuses on the characteristics and mechanical properties of concrete mixtures in which natural aggregate is replaced with recycled material obtained from construction debris. The main advantages of this approach include the conservation of non-renewable natural resources, the reduction of construction waste, contribution to the circular economy, and the reduction of the carbon footprint. The research analyzes two variations of concrete mixtures with recycled aggregate—the first replacing only the coarse fraction up to 50%, and the second with a full 100% replacement of both coarse and fine fractions. The study compares compressive strength, bulk density, and modulus of elasticity, with results indicating that a higher proportion of recycled aggregate leads to lower strength and elasticity values. Laboratory tests demonstrated a gradual increase in strength over time, with the maximum achievable strength classes being C30/37 for a 50% replacement and C20/25 for a 100% replacement. Concrete mixtures with recycled aggregate are particularly suitable for sub-base layers, foundations, and infill structures. However, their application is limited in heavily loaded or chemically aggressive environments. The findings of this study suggest that recycled aggregate has the potential to become a viable alternative to natural materials in specific applications. To further expand its usability, additional testing is required, particularly regarding freeze-thaw resistance and chemical durability. The research supports the role of recycled aggregates in sustainable construction while highlighting areas for further development.

Keywords: *Recycled aggregate, sustainable concrete, mechanical properties, circular economy.*

1. Introduction

A concrete mixture with recycled aggregate, replacing natural aggregate by up to 100% with recycled material, is an innovative approach in the construction industry that contributes to environmental sustainability. This type of concrete utilizes construction debris generated from building demolitions, promoting recycling and minimizing the need for natural stone extraction. Recycled aggregate, obtained from processed old concrete, bricks, and other materials, is incorporated into the mixture while maintaining high quality, provided that strict standards and control tests are followed. In addition to environmental benefits such as conserving natural resources and reducing carbon footprints, this technology also supports the circular economy, lowers concrete production costs, and offers an alternative to traditional building materials. This approach has the potential to be applied in various construction projects and contribute to reducing the environmental impact of the construction industry.

2. Objectives

- Enhance Sustainability in the Construction Industry – Promote the use of recycled aggregate in concrete mixtures to reduce the consumption of natural resources and contribute to environmental protection.
- Optimize Concrete Mix Quality – Ensure regular testing and quality control of concrete mixtures to guarantee long-term stability and performance across various applications.
- Support the Circular Economy – Reduce construction waste and encourage its reuse in building materials, minimizing environmental impact.
- Expand Application Possibilities – Extend the use of recycled aggregate concrete to additional construction types after completing necessary tests.
- Utilize Innovative Products like PENETRON* – Improve the durability of concrete structures with advanced technologies such as crystalline waterproofing and waterproof membranes for protection against water and aggressive chemicals.

3. Characteristics of Concrete Mixture with Recycled Aggregate

A concrete mixture utilizing up to 100% replacement of natural aggregate with recycled aggregate represents an innovation that contributes to the sustainability of the construction industry. Recycled aggregate is obtained by processing construction debris generated from the demolition of structures at the end of their service life.

Construction debris typically consists of a mixture of crushed old concrete, bricks, natural aggregate, and other materials. To ensure consistent quality of the concrete composite, regular quality control tests of this material must be conducted, along with an evaluation of the recycled aggregate in compliance with applicable standards. It is crucial to carefully assess and select the source of construction debris.

Maintaining communication with demolition companies is also essential to ensure the maximum separation of materials such as wood, aerated concrete, bricks, concrete, plastics, and asphalt-based materials.

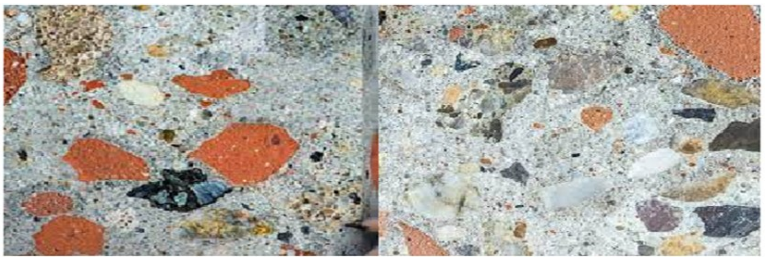

Fig. 1. Structure of Concrete Mixture with Recycled Aggregate

Main Advantages of Using Concrete Mixture with Recycled Aggregate

- Conservation of non-renewable natural resources
- Reduction of construction debris storage needs
- Contribution to the circular economy by utilizing recycled and secondary materials
- Lower carbon footprint in material production
- Cost-effective concrete production

Main Application Areas of Concrete Mixture with Recycled Aggregate

- Subbase concrete
- Foundation structures (strips, footings)
- Infill structures
- Interior wall structures
- Temporary structures

Structures Unsuitable for Concrete Mixture with Recycled Aggregate

- Horizontal flexural structures (slabs, beams)
- Foundation slabs and walls for white tank structures
- Structures exposed to aggressive environments

In the future, the usability of the mixture is expected to expand to additional structures after the completion of necessary tests. [1]

Parameters of Concrete Mixture with Recycled Aggregate

- *Recycled aggregate* - obtained from construction debris generally has inferior properties compared to natural aggregate. Since aggregate properties significantly influence the final cement composite, some parameters of this mixture are technically limited.
- *Compressive Strength* - Due to the lower strength of recycled aggregate compared to natural aggregate, the maximum achievable strength class is limited. The maximum strength class depends on the proportion of recycled aggregate in the composite.
- *Tensile Strength* - The tensile strength values of concrete mixtures with recycled aggregate are comparable to those of concrete with natural aggregate. For calculating the bond strength between concrete and reinforcement, the mean compressive strength values (fcm) can be considered according to STN EN 1992-1-1 (Eurocode 2).
- *Bulk Density* - Concrete mixtures with recycled aggregate have a lower bulk density than conventional concrete due to the lower density of recycled aggregate. The bulk density in the hardened state depends on the proportion of recycled aggregate in the mix. [1]
- *Modulus of Elasticity* - Recycled aggregate is more porous than natural aggregate. This porosity affects both the strength of the recycled aggregate and the static modulus of elasticity. The modulus of elasticity of the final composite is proportionally influenced by the percentage of recycled aggregate. Lower values of the modulus of elasticity in concrete mixtures with recycled aggregate limit their application to lightly loaded structures. This mixture is not recommended for flexural elements such as slabs or beams, where excessive deflections may occur. It is also unsuitable for heavily loaded columns or piers, as it could lead to excessive creep and shortening of structural elements. [1]
- Environmental Exposure Class - The mixture can be used for the following environmental exposure classes:

X0 – No risk of corrosion or degradation

XC1-2 – Corrosion due to carbonation

Given current technological knowledge, concrete mixtures with recycled aggregate are not suitable for environments with alternating freeze-thaw cycles (XF1-4) or for highly chemically aggressive environments (XA1-3). This also includes applications for **white tank structures** and other impermeable structures, where there is a risk of exposure to aggressive substances in water or soil. It is expected that, in the future, the use of recycled aggregate concrete for these types of structures may expand after the necessary tests are completed. [1]

- Consistency - All variants of concrete mixtures with recycled aggregate are produced in consistencies S1, S2, S3, and S4, determined by the slump test using the Ambrós cone according to STN EN 12350-2.
- Maximum Aggregate Size - The maximum aggregate size in the mixture depends on the supplied fraction of recycled

aggregate from the recycling facility. However, the mixture is typically produced with a maximum aggregate size of Dmax 16mm and Dmax 22mm. [1]

4. Evaluation and Documentation of Laboratory Tests

This section provides a detailed description of the process for evaluating the cube and cylinder compressive strength of the concrete mixture **C20/25 X0 S4**, as well as determining the bulk density of the individual samples. The process also includes an analysis of strength progression at various time intervals. The goal is to obtain relevant data on the development of concrete strength over time, which is essential for assessing its applicability and stability in real-world constructions.

For the evaluation, concrete samples from the **C20/25 X0 S4** mixture were used. Cube samples were made from fresh concrete using molds designed for cube compressive strength testing. Cylinder samples were prepared using core drilling with a diameter of 150 mm and a length of 300 mm for testing cylinder compressive strength. A sufficient number of samples is required for each test.

The cube compressive strength values of the concrete samples were provided by the accredited laboratory **Betotech Ostrava**. The compressive strength tests on cylinder samples were conducted by **Ing. Jozef Prokop, PhD.**, at the testing laboratory **SvF – ŽU**.

4.1 Determination of Bulk Density of Concrete Mixture

The bulk density of the concrete mixture is determined based on individual samples, which are weighed after curing. This process is carried out according to the following steps:

- Weighing the samples: Each sample (cube or cylinder) is weighed on an analytical balance.
- Calculation of bulk density: The bulk density is calculated using the following formula:

$$\rho = \frac{\mathrm{m}}{V} \qquad (1)$$

Where:

- ρ = Bulk density (kg/m³)
- m = Mass of the sample (kg)
- V = Volume of the sample (m³)

4.2 Expression of Percentual Strength Increase of Concrete Samples at Various Time Intervals (7-14 days, 14-21 days, 21-28 days, 28-90 days)

The percentual increase in strength between two consecutive periods is calculated using the following formula:

$$\text{Percentual Increase} = \left(\frac{\text{Strength at later period} - \text{Strength at earlier period}}{\text{Strength at earlier period}}\right) x\ 100 \qquad (2)$$

Where:

- Strength at later period: The compressive strength of the concrete sample at the later time interval.
- Strength at earlier period: The compressive strength of the concrete sample at the earlier time interval.

Tab. 1. Evaluation and Documentation of Compressive Strength Laboratory Tests on Cylindrical Samples of Cement Composite C20/25 X0

Compressive Strength Tests on Cube Samples of Cement Composite C20/25 X0

Sample No.	Age (days)	Bulk Density (kg/m³)	Compressive Strength (MPa)	Strength Increase (%)
K1	7	2150.00	22.70	
K2	28	2180.00	32.40	29.94 (increase from 7/28 days)
K3	90	2190.00	49.70	34.81 (increase from 28/90 days)

Tab. 2. Evaluation and Documentation of Compressive Strength

Laboratory Tests on Cylindrical Samples of Cement Composite C20/25 X0 S4

Sample No.	Age (days)	Bulk Density (kg/m³)	Compressive Strength (MPa)	Strength Increase (%)
V1	7	2160.83	17.58	
V2	7	2193.99	20.11	
V3	14	2156.00	21.89	13.89 (increase from 7/14 days)
V4	14	2155.00	21.88	
V5	21	2192.00	26.00	16.57 (increase from 14/21 days)
V6	21	2181.00	26.46	
V7	28	2144.00	28.90	8.69 (increase from 21/28 days)
V8	28	2118.00	28.55	

The following bar chart shows the increase in cube and cylinder compressive strength over different time periods.

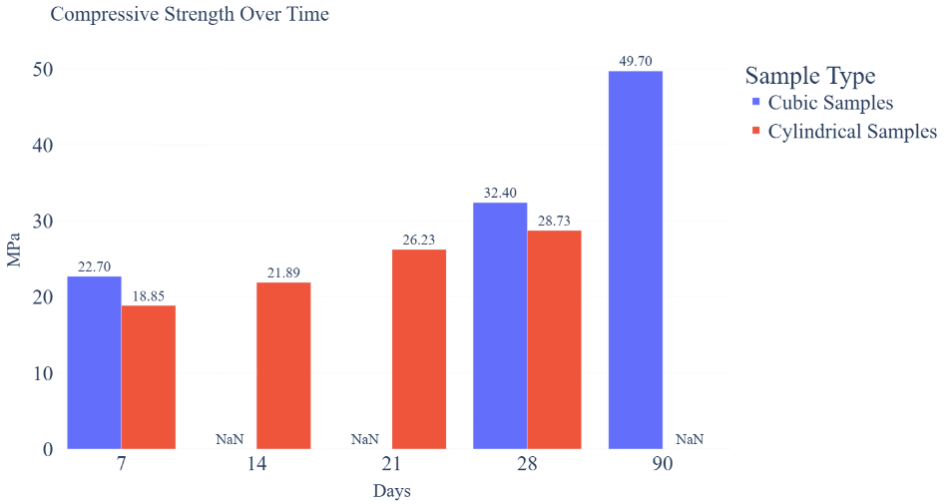

Fig. 2. Graphical representation of the increase in the strength of the cement composite.

5. Use of Concrete Mix with Recycled Aggregates in Products

An example of the use of this mix in products would be concrete blocks (commonly known as LEGO blocks), which have a shape and locking system similar to traditional LEGO bricks.

These blocks are designed to be easily assembled and combined, allowing for the quick and efficient construction of various structures such as walls, fences, storage spaces, or even temporary buildings.

Fig. 3. Production and Use of Concrete Blocks

The blocks are manufactured in the following dimensions:
- Height: 50 cm
- Thicknesses: 25 cm and 50 cm
- Lengths: 25 cm, 50 cm, 100 cm, 150 cm, 200 cm

The main advantages of concrete LEGO blocks include:
- Ease of Assembly: Thanks to their shape and locking mechanism, they can be easily assembled without the need for special tools.
- Resistance to Various Weather Conditions and Mechanical Damage.**
- Flexibility: Suitable for various purposes and can be easily moved or disassembled, which is beneficial for temporary or mobile structures.
- Environmental Availability: In many cases, they are made from recycled materials or with minimal environmental impact, as well as from residual materials.
- Lower Bulk Density: The use of recycled aggregates leads to lower bulk density, which contributes to the economic advantage of transportation.

6. PENETRON® – Intelligent protection of concrete and LEGO blocks

6.1 What is PENETRON®?

PENETRON® is an innovative crystalline waterproofing system that provides permanent protection for concrete structures. This material penetrates the concrete and forms insoluble crystals that close pores and microcracks, thus ensuring the waterproofness and durability of the concrete. Thanks to this unique process, the concrete becomes resistant to water and other external influences, which guarantees its long-term durability and reliability.

6.2 How does PENETRON® work?

1. After application or addition to the concrete mix, the active chemicals are activated upon contact with water.

2. A chemical reaction with the cement creates insoluble crystals that spread deep into the concrete.
3. These crystals close capillaries and microcracks, thus ensuring the waterproofness of the concrete.
4. The process is repeated every time it comes into contact with water, which allows the concrete to close small cracks on its own, thus extending its life.

6.3 Areas of application for PENETRON®

PENETRON® is ideal for all concrete structures exposed to moisture, water or chemicals, such as [3]:
• Foundations, basements, underground garages
• Water tanks, swimming pools, wells
• Wastewater treatment plants, chemical tanks
• Tunnels, underground railways and metro systems
• Bridges, dams, retaining walls
• Industrial floors and warehouses

6.4 Advantages of the PENETRON® system

• Permanent waterproofing: Penetrates to a depth of up to 30 cm and provides long-term protection against water and moisture.
• Self-healing of cracks up to 0.4 mm: When in contact with water, the crystallization process is restored, allowing the concrete to "heal" smaller cracks.
• Resistance to aggressive chemicals: Protects against sulfates, chlorides, seawater, acids and other chemicals.
• Easy to apply: Can be applied to both fresh and existing concrete in a variety of conditions, including high humidity.
• Eco-friendly: Non-toxic and certified for use in contact with drinking water.
• Cost savings: Reduces the need for additional waterproofing layers and service interventions.

4.5 Using PENETRON® products in combination with LEGO blocks

PENETRON® products can also be effectively used in construction projects using LEGO blocks, specifically to protect these blocks from water and moisture, especially in cases where they are located below ground level. Applying PENETRON® to LEGO blocks will ensure that these structures are protected from water and moisture ingress, thereby increasing their durability and reliability.

1. Waterproofing LEGO blocks below ground level: PENETRON® can be applied to the surfaces of LEGO blocks that are located below ground level, thus preventing water from penetrating from the surrounding soil. This is particularly useful in constructions such as underground garages or building foundations.

2. Using PENEBAR® in construction joints: PENEBAR waterproofing strips can be used in joints between foundation structures and LEGO blocks. These strips prevent groundwater ingress, thus providing protection against high hydrostatic pressure.

3. Protecting joints between LEGO blocks: PENETRON® can also be used to seal joints between individual LEGO blocks placed below ground, reducing the risk of moisture and ensuring the long-term durability of the structure. [2]

7. Conclusion

Concrete Mix with Recycled Aggregates represents a significant step towards a more eco-friendly and sustainable construction industry. By utilizing recycled aggregates, which are obtained through processing construction debris, not only is the strain on natural resources reduced, but it also contributes to the circular economy. By saving non-renewable resources, reducing waste, and lowering the carbon footprint, this material is particularly promising for use in sub-base concretes and temporary structures.

Although recycled aggregates may have technical limitations, such as lower compressive strength or a limited modulus of elasticity, their advantages in ecological sustainability and economic efficiency are undeniable. Further research and technological innovations could expand the use of this material in additional constructions, thus further extending its potential.

Therefore, concrete mix with recycled aggregates presents not only a practical but also an environmentally beneficial solution that can contribute to the future development of the construction sector.

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