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Effect of Moisture Condition and the Composition of Aggregate from Demolition Waste on Strength and Workability Properties of Recycled Concrete

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Abstract: Large quantities of construction and demolition waste are generated annually, and in many parts of the world, it is disposed of in landfills. Utilizing this waste to produce coarse aggregates for concrete production offers a potentially sustainable approach that mitigates environmental impacts. Despite the widespread encouragement of using recycled aggregates as a substitute for natural coarse aggregates, practical applications remain limited, and the concrete production industry continues to primarily rely on exploiting natural resources. The recycling of concrete waste derived from the demolition of obsolete or damaged buildings as structural concrete has been seldom realized thus far, primarily due to regulatory constraints and concerns regarding technological difficulties. This paper presents a case study to demonstrate that, with meticulous preparation, concrete waste from a demolished building can be rendered suitable for use as structural concrete. The experimental investigation examined how the proportion of recycled aggregates obtained from a demolished building and the moisture content influenced the properties of fresh and hardened concrete. The results revealed an increase in the compressive strength of the hardened recycled concrete as a higher proportion of recycled coarse aggregate was incorporated into the mixture. Moreover, pre-soaked recycled coarse aggregates were found to improve the workability of the recycled concrete mixture significantly. The results highlight the significant potential of utilizing concrete waste as a valuable resource in the production of ready-mix concrete for structural applications, provided that appropriate measures are taken to optimize its properties.

Keywords: recycled aggregates moisture condition; recycled concrete workability; recycled concrete compressive strength; construction waste recycling; sustainable concrete

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1. Introduction

Concrete, as the most widely used construction material, plays a vital role in meeting the growing demand for new buildings, infrastructure, and roads, especially as global population increases [1,2]. However, the conventional production of concrete, which relies on cement, fine aggregates, coarse aggregates, and water, is associated with significant environmental challenges [3,4]. Cement production, a key component of concrete, consumes vast amounts of energy and is a major contributor to global carbon dioxide (CO_2) emissions, accounting for approximately 5–7% of anthropogenic CO_2 emissions worldwide [5,6]. The urgent need to address climate change and achieve sustainability in the construction industry has prompted global efforts to reduce CO_2 emissions and enhance environmental protection and resource management.

Over the past few decades, governments worldwide have been actively promoting sustainable policies aimed at reducing environmental impacts and achieving economic gains [7]. These policies employ economic instruments such as taxation to discourage waste disposal in landfills while incentivizing the recovery and reintegration of construction and demolition waste (C&DW) into the production cycle. Although concrete offers numerous advantageous physical and mechanical properties, its structural lifespan is typically limited to 50–100 years, after which structures are often dismantled. In Europe, a significant number of structures constructed after World War II are approaching the end of their design life, resulting in a projected increase in C&DW volumes in the near future [8]. In fact, C&DW accounted for approximately 36% of Europe's total waste in 2016 [9].

The concept of finding beneficial applications for demolition waste is not new and applications following World War II have been documented by Gluzhge [10]. Presently, C&DW is either disposed of in landfills, as predominantly observed in developing countries, or processed in recycling plants in more developed nations. Recycled aggregates derived from C&DW are primarily employed in low-grade applications, such as raw material for the cement industry, soil stabilization, pavement bricks, road construction subbase material, and embankment fill [11]. Notably, during the reconstruction project of Puskas Stadium in Hungary, approximately 60% of the demolished waste was successfully re-used on-site or for other construction projects, while the remaining 40% was sent to landfills [12].

The properties of recycled aggregates can vary significantly, influenced by factors such as the acquisition method, particle size, attached mortar, and original concrete quality [13]. Demolished rubble from construction sites often contains various materials, including concrete, tiles, soil, bricks, and wood [14]. These additional contaminants diminish the quality of recycled aggregate, particularly when the rubble results from disasters such as wars, earthquakes, or floods. Several studies have explored various methods and treatments aimed at improving the quality of recycled aggregates. Ouyang et al. [15] concluded that the production of high-quality recycled aggregate could be achieved by either removing or strengthening the attached mortar. A comparative study by Katz [16], used silica fume impregnation to enhance the surface porosity of recycled aggregate and ultrasonic cleaning in removing loose particles from the surface of recycled aggregates. The results indicated that silica fume impregnation resulted in a greater enhancement in the compressive strength of the recycled concrete when compared to ultrasonic cleaning. In a study conducted by Junak et al. [17], geopolymer slurry was applied to coat the recycled concrete aggregates (RCA) with the aim of improving its surface characteristics. The findings revealed that this treatment led to an increase in the density of the RCA and a decrease in its water absorption capacity. According to Pandurangan et al. [18], various treatments such as mechanical, thermal, or chemical methods for removing attached mortar from recycled aggregates have shown positive effects on bond strength and increased compressive strength when compared to untreated recycled aggregate. In their study, it was observed that polymer impregnation had the most significant impact on enhancing the physical and mechanical properties of the recycled concrete aggregates (RCA), followed by the attached mortar (AM) removal method and the accelerated carbonation curing process. Although it is possible to produce high-quality recycled aggregate with properties comparable to natural aggregates, achieving such quality necessitates costly, time-consuming, and energy-intensive treatments involving the removal of contaminants, classification, washing, screening, and multiple crushing stages [19]. Recycled aggregates (R.A) generally exhibit lower density and higher water absorption than natural aggregates due to the presence of attached mortar [20]. The fine fraction of recycled aggregate tends to have a higher mortar content, making it unsuitable for use in structural concrete production [21]. Ensuring the quality of the original concrete also presents challenges in standardization. RILEM (International Union of Laboratories and Experts in Construction Materials, Systems, and Structures) guidelines recommend avoiding the use of recycled coarse aggregates with water absorption exceeding 7% in concrete production [22]. However, European standards allow for the substitution of up to 50% of natural coarse aggregates with recycled coarse aggregates under certain conditions [23]. Studies by Corinaldesi [24] and Limbachiya et al. [25] have found no significant influence on the compressive strength of recycled concrete when replacing up to 30% of natural aggregates with recycled aggregates. Moisture conditions of recycled aggregates significantly affect the workability of recycled concrete due to the higher water absorption of recycled aggregates. Several studies have investigated the effects of different moisture conditions on the properties of RA and the resulting concrete mixtures. The findings from these studies have been inconsistent and influenced by multiple variables. In 2004, Poon et al. [26] observed that high percentages of recycled aggregate, particularly in the saturated surface dried (SSD) state, resulted in less cohesive concrete mixtures and potential bleeding during casting, leading to reduced compressive strength. Also, it was noted that the optimal moisture condition was found to be the air-dried condition. Brand et al. [27] reported the highest compressive strengths were achieved using 80% SSD state, and the strength properties for recycled concrete aggregates (RCA) concrete were greatest when the RCA was at least in the partially-saturated moisture state. Other studies [28–31], reported that the presaturation of recycled aggregate negatively impacts concrete strength and durability. The duration of presoaking has been identified as a determining factor in the flowability of fresh recycled concrete. Zhang et al. [32] concluded that partially saturated RA is beneficial for the performance of recycled concrete. Given the existing technological uncertainties, further investigations are necessary to promote the use of sustainable concrete incorporating recycled aggregate.

This paper presents the outcomes of a case study conducted in Pécs, Hungary, where recycled aggregates were obtained from a demolished reinforced concrete building constructed in the 1970s. The mechanical and physical properties of the recycled aggregates were examined, and subsequent concrete production incorporated these aggregates in two moisture conditions: dried and partially saturated. The results highlight the significant potential of utilizing concrete waste as a valuable resource in the production of ready-mix concrete for structural applications, provided that appropriate measures are taken to optimize its properties.

2. Materials and Methods

2.1. Materials

2.1.1. Cement

All concrete mixes were produced using CEM II/B-S 42.5N Portland Slag Cement as the binder material. The cement was supplied by a local supplier and complied with EN 197-1:2011 [33] without any cementitious replacement.

2.1.2. Natural Aggregates

Two types of coarse natural aggregates were used, each with different characteristics. The first type was natural round aggregate (N) extracted from riverbeds or lakes, that had a round shape and smooth surface. The second type was natural crushed stone (NC), which had an angular shape and rough surface as shown in Figure 1a.

(**a**) (**b**)

Figure 1. (**a**) Illustrates the distinction between natural (N) and recycled (R) fine and coarse aggregates, (**b**) Coarse aggregates: Natural (N), Crushed Stone (NC), and Recycled (R).

2.1.3. Recycled Aggregate

For this study, recycled aggregate (R)—see Figure 1b—was obtained from the demolition of a 25-story building in Pécs, Hungary in 2016. It is estimated that approximately 22,549 t of debris were generated from the demolition (see Figure 2a). During the demolition, the reinforced concrete elements were dismantled using a tower crane (see Figure 2b) and then broken into transportable pieces by a demolition machine equipped with a crushing head, while separating the recyclable reinforcing steel. The collected debris was transported to a landfill site where it was crushed into smaller. After primary and secondary crushing, the debris size ranged between 0/40 mm. The rubble was stored in a landfill near Pécs for several years. Although the demolished concrete rubble was considered a good-quality raw material being relatively homogeneous, its recycling as a raw material for concrete has not yet been fully realized. A significant portion of the debris remains in the landfill awaiting further use (see Figure 2c). Samples were collected from two storage locations and then graded to the required sizes for concrete mixing. Only the coarse recycled aggregate RCA with a diameter of 4/16 mm was used in the preparation of concrete mixes. On the other hand, the fine recycled portion, measuring 0/4 mm, which constitutes approximately 35% of the total weight of the collected rubble, was not included in the concrete mixture due to its composition primarily consisting of crushed mortar. (see Figure 1b). The preparation method and mixing approach were specifically designed to facilitate the implementation of recycled aggregate in ready-mix concrete production. By simplifying the processing steps and ensuring compatibility with existing concrete plant production lines, encouraging the industrial sector to adopt sustainable practices without significant modifications to their existing processes.

Figure 2. (**a**) High rise building that was the source of recycled aggregate ; (**b**) Demolition technique; (**c**) Stored debris ; (**d**) Steps for partially saturating the recycled aggregates.

2.1.4. Chemical Admixtures

Different dosages of a water-reducing admixture were used to achieve the desired workability. The superplasticizer used was Sika ViscoCrete-7710, with a recommended dosage ranging from 0.2% to 2% of the cement content (mc%).

2.2. Experimental Work

Eight concrete mixes were prepared, each varying in the content of recycled coarse aggregate and moisture conditions. Mix N served as the control mix and utilized natural round aggregates (N). Mix NC was a conventional concrete mix in which 50% of the coarse round aggregates were replaced with crushed stone (NC). The remaining six mixes incorporated different proportions of recycled coarse aggregate (15%, 30%, and 50%) and were prepared in both dried and partially saturated conditions. The recycled aggregates were submerged in water for 1 h, drained, and then left at room temperature for an additional 1 h before mixing (see Figure 2d). Table 1 provides an overview of the coarse aggregate content and moisture condition for each mix.

Table 1. Coarse aggregates content in each mix.

Mix Code	N	NC	R	RW *
Mix N	100%	-	-	-
Mix NC	50%	50%	-	-
Mix R15	85%	-	15%	-
Mix R30	70%	-	30%	-
Mix R50	50%	-	50%	-
Mix RW15	85%	-	-	15%
Mix RW30	70%	-	-	30%
Mix RW50	50%	-	-	50%

* Recycled aggregates partially saturated.

2.2.1. Mix Design

The targeted concrete class for all mixes was C30/37, with a desired workability class of F3 according to MSZ EN 12350-5 standards [34]. The water/cement ratio was fixed at 0.52, and the maximum aggregate diameter (Dmax) was set to 16 mm. The type and content of cement remained constant across all mixes. The concrete composition was determined using the absolute volume method. The specific mixture proportions for each mix are presented in Table 2.

Table 2. Concrete mix proportions.

Concrete Mix	Cement (kg)	Water (kg)	W/C	Sand (kg)	Coarse Aggregate (kg)				Plasticizer (mc% *)	Density kg/m^3
					Natural		Recycled			
					N	NC	R	RW		
N	350	182	0.52	732	1098	-	-	-	0.18	2363
NC	350	182	0.52	732	549	549	-	-	0.13	2372
R15	350	182	0.52	732	933	-	165	-	0.31	2356
R30	350	182	0.52	732	769	-	329	-	0.51	2361
R50	350	182	0.52	732	549	-	549	-	0.50	2315
RW15	350	182	0.52	732	933	-	-	165	0.23	2326
RW30	350	182	0.52	732	769	-	-	329	0.31	2322
RW50	350	182	0.52	732	549	-	-	549	0.10	2312

* The percentage of superplasticizer to the weight of cement.

The same mixing method and sequence were followed for all mixes. The natural coarse aggregates (N&NC) and fine aggregates were in an oven-dried condition by drying them at 105 °C for 24 h and then were cooled at room temperature before mixing. While the recycled aggregate (R) was used in two states: oven-dried (as in mixes R15, R30, and R50) and partially saturated (RW) (as in mixes RW15, RW30, and RW50). Tests were conducted on the aggregates to determine their characteristics. The grading curves for recycled and natural aggregates exhibited similar trends, as depicted in Figure 3. These curves were generated in accordance with the EN 933-1 standard [35].

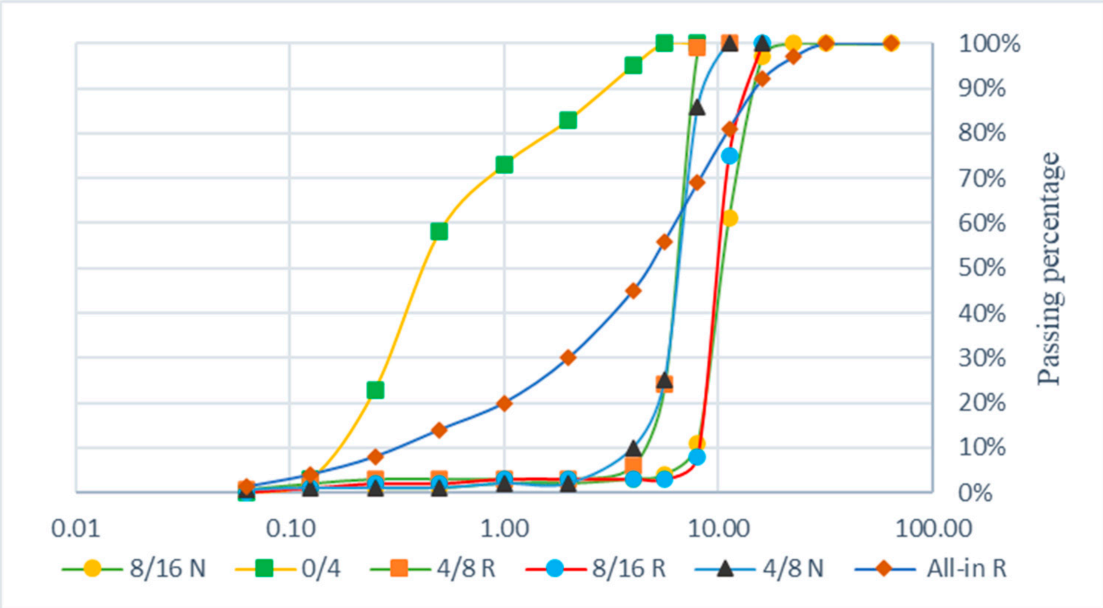

Figure 3. Grading curves of the fine and coarse aggregates.

The physical properties of the aggregates, such as particle density and water absorption, were tested in compliance with the requirements of EN standards [36]. The quality of the recycled aggregate was further assessed by evaluating its mechanical properties, including resistance to fragmentation, as determined by the Los Angeles and Micro-Deval aggregate impact tests. These tests were carried out in accordance with standard EN-1097-2 [37,38] procedures. In addition, shape index and bulk density tests were carried out to gain an overall understanding of the aggregate properties [39,40]. Contaminants, including wood, paper, tiles, bricks, and metal debris, were present in the recycled aggregates (R) and were removed during the separation process to obtain the required fractions. The total mass of these contaminants was less than 10% (Rc 90 and Rcu 95), classifying the recycled aggregate as type A according to EN 206 standards [23]. The coarse aggregate with sizes ranging from 4–16 mm was divided into two standard fractions: 4/8 mm and 8/16 mm using vibrating mechanical sieves, constituting 44% and 56% respectively of the coarse aggregate volume. The volume of the different aggregate fractions was the same in each mixture: 0/4 fraction accounted for 40%, 4/8 fraction accounted for 26%, and 8/16 fraction accounted for 34%.

2.2.2. Concrete Batching Procedure

The concrete batching procedure involved using a pan-type mixer with a 50-L capacity for preparing all the concrete mixtures. To simplify the process and make it more practical, the conventional mixing sequence was followed. The coarse aggregate was added first, followed by cement, and then the sand was added to cover the cement and prevent it from dusting. Dry mixing was performed for approximately 60 s. Water was then gradually added during mixing to ensure a uniform mixture. The wet mixture was then mixed for an additional 1–3 min, during which the superplasticizer was gradually added to achieve the desired workability. If needed, this final step was repeated. Following the mixing process, the fresh properties of the concrete were tested to assess the quality of the mixture.

After that, the concrete mixtures were cast in standard size moulds with dimensions of (150 × 150 × 150) mm and compacted using a mechanical vibrating table. After casting the specimens were stored at room temperature of (20 ± 2) °C and 95% relative humidity (RH) for 24 h, and then cured in water until the designated testing time after 28 days (according to the Hungarian standard, MSZ 4798:2016) [41].

2.2.3. Concrete Testing Methods

Tests were conducted to evaluate various properties of the concrete mixes. Regarding the fresh concrete properties, the consistency class was determined by performing the flow table test in accordance with the EN 12350-5:2009 standard [34]. The fresh density of the concrete was measured and calculated following the guidelines provided in the EN 12350-6:2009 standard [42]. Additionally, the air content was determined using the pressure gauge method specified in the EN 12350-7:2009 standard [43].

Moving on to the hardened concrete properties, the compressive strength of the concrete mixes was assessed at 28 days using three standard-sized (150 mm) cubical specimens per mix following the EN 12390-3:2009 standard [44]. The hardened density of each concrete mix was calculated in accordance with the EN 12390-7:2009 standard [45].

Furthermore, the splitting tensile strength of the concrete mixes was evaluated at 28 days using three standard-sized (150 mm) cubical specimens per mix following the EN 12390-6:2009 standard [46].

3. Results and Discussion

3.1. Recycled Aggregates

Table 3 presents the mechanical and physical properties of the recycled aggregate.

Table 3. Recycled aggregates properties.

Type of Test	Recycled Aggregate Size (mm)		Standard
	4/8	8/16	
Water absorption (24 h)	7.9%	6.1%	EN 1097-6 [36]
Density	2.32 g/cm^3	2.37 g/cm^3	EN 1097-6 [36]
Los Angeles (L.A%)	34.8%		EN 1097-2 [37]
Micro-Deval MDE	25%		EN 1097-1 [38]
Bulk density	1.11 g/cm^3	1.13 g/cm^3	EN 1097-3 [39]
Shape index SI	18.3	22.1	EN 933-4 [40]

3.2. Aggregate Moisture Content and Fresh Concrete Properties

3.2.1. Workability

To assess the influence of the moisture condition and recycled aggregate content on the workability of the concrete mixes, the flow table test was conducted directly after mixing according to MSZ EN 12350-5:2009 Testing fresh concrete—Part 5 [34]. The results are shown in Figure 4.

As the substitution ratio of dried recycled aggregate increased, it was anticipated that the workability would decrease due to its higher water absorption. To ensure the desired flowability comparable to the control mix, a higher dosage of superplasticizer was required.

When recycled aggregates or crushed stone were used in the mixes (Mix R15, R30, R50, and Mix NC), the angular shape and rough surface texture of the aggregate affected the flowability of the fresh concrete. Angular shapes have a larger surface area compared to rounded shapes, and the rough surface texture requires more cement paste, leading to higher water absorption and lower concrete consistency which is in line with the findings from other studies [29,47,48].

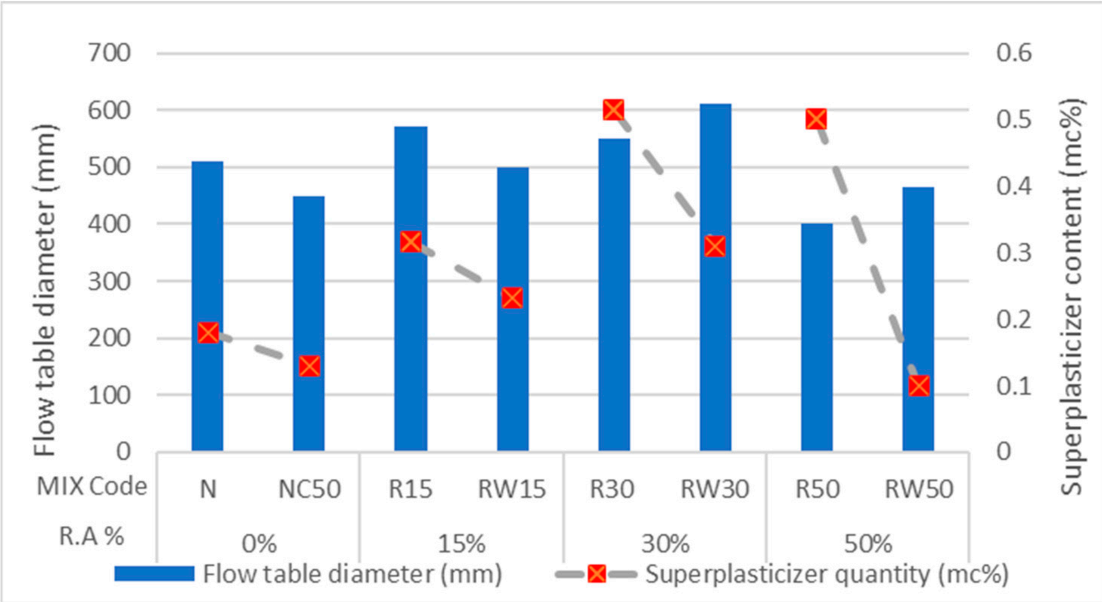

Figure 4. Flow table results and superplasticizer content for both the dried and partially saturated conditions of recycled aggregates.

In contrast to fully saturated wet aggregate or saturated surface dried (SSD) conditions, where excessive free water leads to aggregate segregation and decreased compressive strength as concluded in previous studies [26,48], partially saturating the recycled aggregate improved the workability of recycled concrete and reduced the need for superplasticizer, without any significant effects on the hardened concrete properties.

Through a process of pre-soaking the recycled aggregate for 1 h and subsequently exposing it to air at room temperature for 1 h, the moisture condition of the aggregate was partially saturated, as shown in Figure 5.

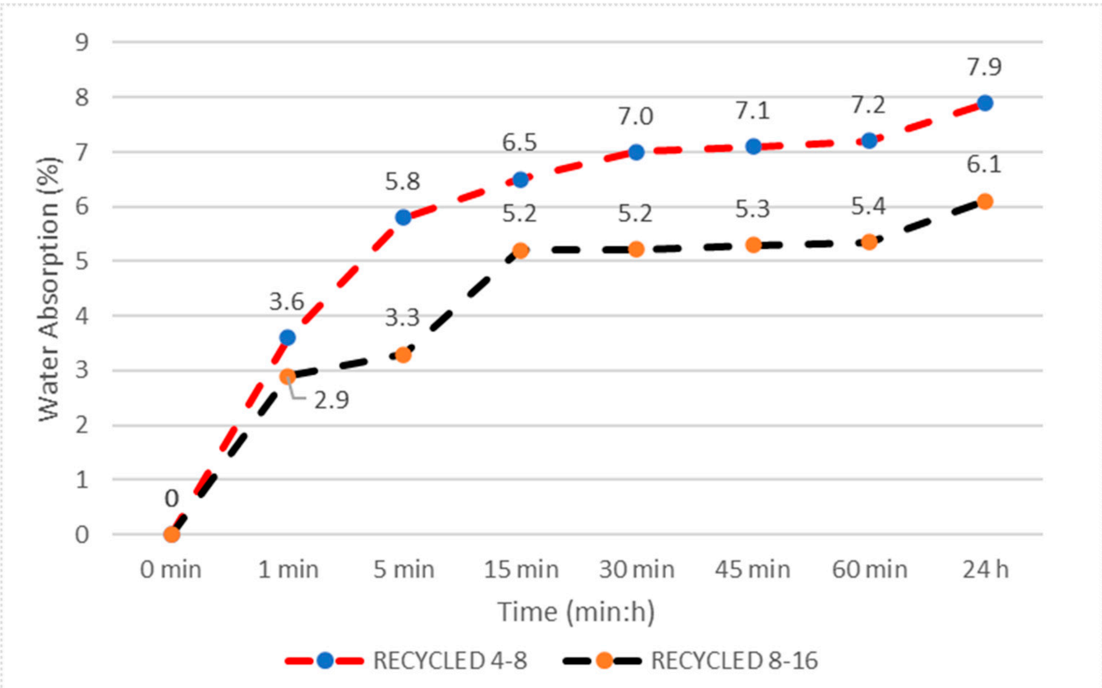

Figure 5. Water absorption of recycled aggregate over 24 h period.

This approach provided improved control over the water content in the mixture and enhanced the overall workability of the concrete mixture. Additionally, reducing the dosage of superplasticizer is more cost effective.

3.2.2. Density and Air Content

The density of recycled aggregate is approximately 5–8% lower than that of natural aggregates due to the presence of attached mortar, which is more porous compared to natural round aggregates. However, the density of recycled concrete did not exhibit significant differences compared to conventional concrete. This can be attributed to the cubical shape of the recycled aggregate, which facilitates better packing. There was an observed increase in the air content of the recycled concrete, likely caused by factors such as the higher porosity of the recycled aggregate, resulting in an elevated entrained air content see Figure 6.

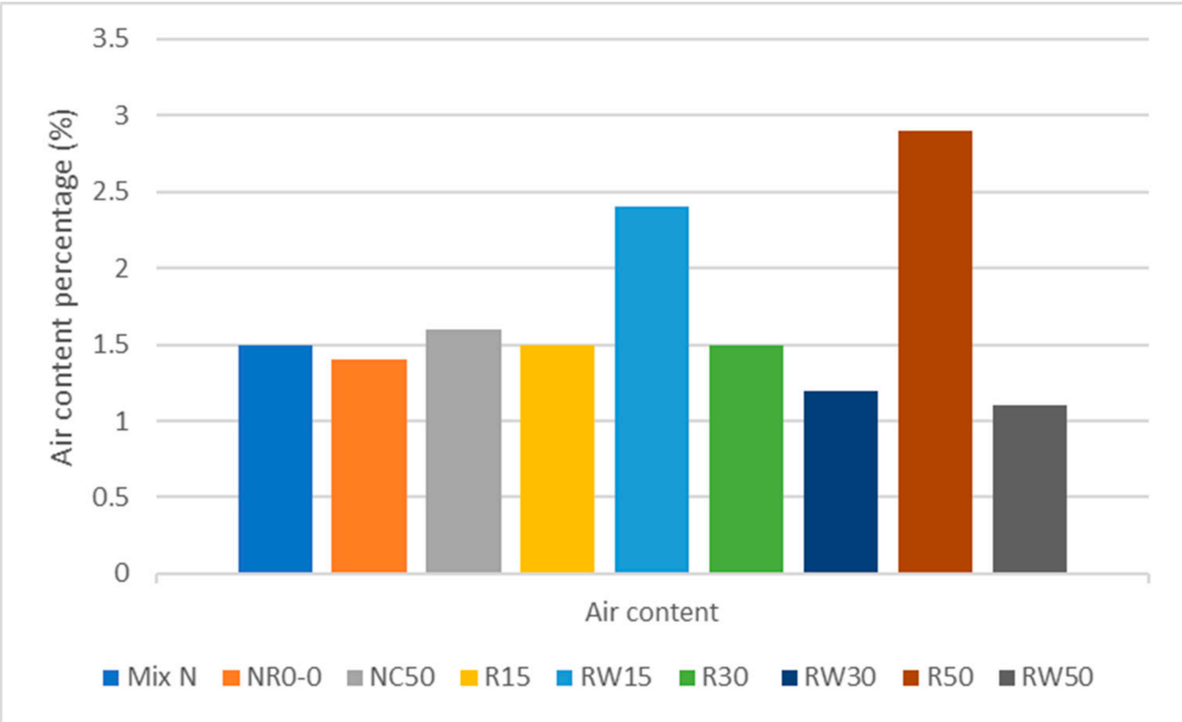

Figure 6. Air content results of fresh concrete.

3.3. Hardened Concrete Properties

3.3.1. Compressive Strength and Hardened Density

The incorporation of dried recycled aggregate demonstrated a slight increase in the compressive strength with a higher percentage of replacement, as depicted in Figure 6. This indicates that the dried recycled aggregate can contribute to the overall strength of the concrete, even at higher replacement percentages.

In contrast, when presoaked recycled aggregate was utilized, the compressive strength remained comparable to that of the control mix. This suggests that the partial saturation of the recycled aggregate aided in preserving its strength properties and preventing any substantial decrease in compressive strength, see Figure 7.

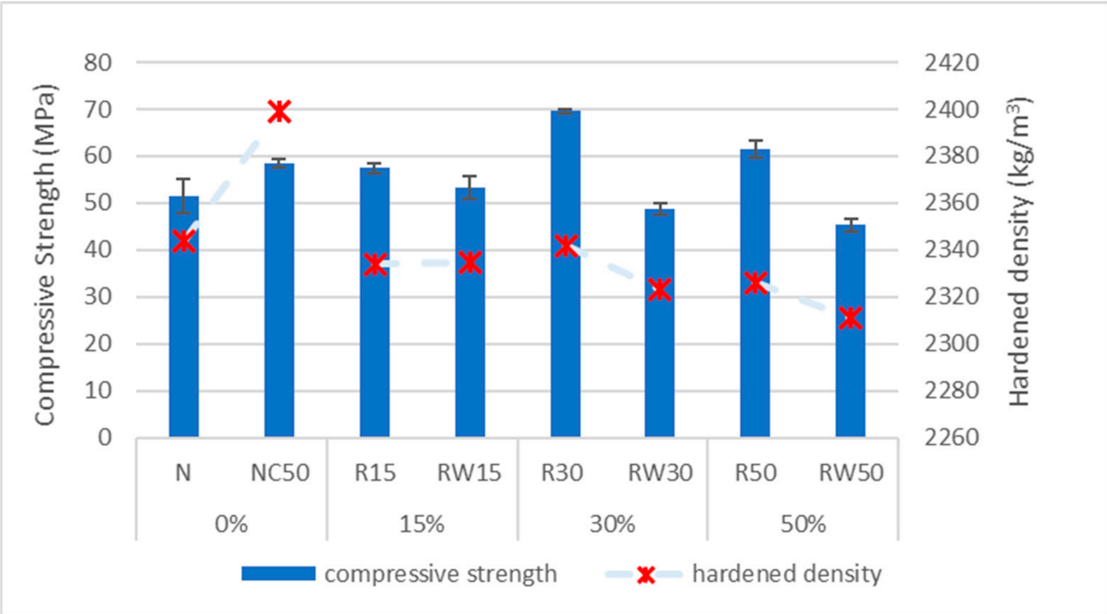

Figure 7. The compressive strength and the hardened density results (average values and ranges).

3.3.2. Splitting Tensile Strength

With 15% and 30% substitution with recycled coarse aggregate, the splitting tensile increased by 10% and 20% respectively while partially saturating the recycled aggregates had a slight impact. However, using 50% recycled aggregates dried or partially saturated aggregates led to lower splitting tensile strength as shown in Figure 8.

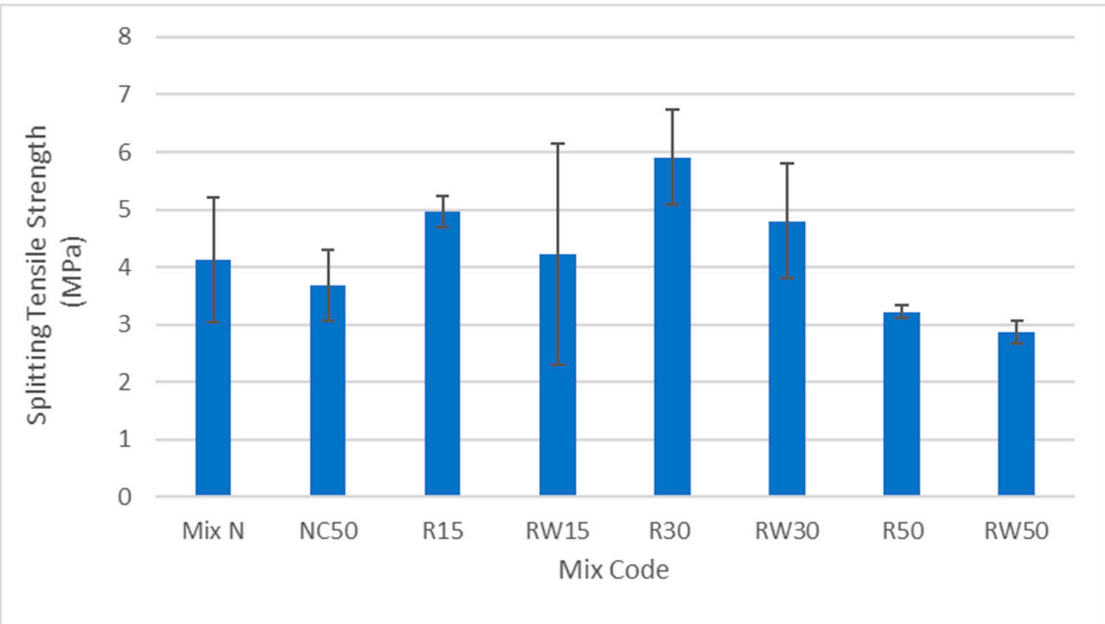

Figure 8. Splitting tensile strength results (average values and ranges).

4. Conclusions

The results of the research demonstrate that recycled coarse aggregate (RCA) can serve as a viable alternative to natural coarse aggregates in various concrete applications. It has been demonstrated through a case study that the appropriate use of RCA in the concrete production process not only reduces the reliance on natural resources in the construction industry, but also provides the opportunity to achieve concrete properties required for structural applications.

The use of recycled aggregate, whether in dried or partially saturated condition, can yield recycled concrete with comparable properties to conventional concrete mixes, even for structural applications. However, the optimal saturation level of the recycled aggregate to mitigate workability loss without compromising compressive strength can vary depending on factors such as the source, quality, composition of the recycled material, and other environmental conditions.

Conducting comprehensive testing and evaluation of the specific recycled aggregate being employed is essential to determine the ideal saturation level for achieving the desired workability while maintaining the compressive strength of the concrete. Partial saturation, where the recycled aggregate is soaked in water for a limited duration without reaching full saturation, has shown promise in enhancing the properties of recycled concrete compared to using fully saturated recycled aggregate or adding excess water directly to the mix. This approach improves workability without introducing excessive water content, which can lead to aggregate segregation and reduced compressive strength. By finding the right balance between moisture content and aggregate proportions, it is feasible to optimize the fresh and hardened properties of recycled concrete while minimizing potential adverse effects. Although the attained compressive strength of recycled concrete proves its suitability for structural applications, additional research is needed to evaluate its durability and performance under various exposure conditions.

This highlights the importance of understanding the specific characteristics of the recycled aggregate and tailoring the concrete mixture accordingly to achieve the desired concrete performance while considering environmental conditions and sustainability goals.

5. Recommendations and Future Research Directions

In addition to the findings of this study, there are several areas that warrant further research and could provide valuable opportunities for future work. Firstly, investigating the long-term durability of concrete utilizing recycled aggregates in various exposure conditions, such as freeze-thaw cycles or when exposed to chemicals, would provide insights into the performance and resilience of recycled concrete over time. Additionally, exploring the potential of incorporating additives or admixtures to enhance the properties and performance of recycled concrete could allow the optimization of its characteristics for different applications. Conducting life cycle assessment studies to assess the environmental impact and sustainability aspects of using recycled aggregates would provide a comprehensive understanding of its benefits and contribute to informed decision-making in construction projects. Moreover, assessing the feasibility of utilizing recycled aggregates in specialized concrete applications, including high-strength concrete or self-compacting concrete, would further expand the potential applications of recycled materials.

In terms of recommendations for practice, it is crucial to promote the adoption of guidelines and standards for the production, quality control, and use of recycled aggregates in concrete. Establishing clear criteria and regulations ensures consistent and reliable performance and fosters confidence in utilizing recycled materials. Increasing awareness and educating industry professionals about the potential benefits of recycled aggregates is also vital to encourage their widespread use. Collaboration with regulatory bodies and stakeholders to develop policies and incentives that support the use of recycled aggregates will further drive the adoption of sustainable practices in the construction industry. Lastly, establishing partnerships between researchers, manufacturers, and contractors can facilitate the transfer of knowledge and best practices, promoting the effective implementation of recycled aggregates in construction projects. By addressing these future research directions and implementing the recommended practices, the utilization of recycled aggregates can be maximized, contributing to a more sustainable and environmentally friendly construction industry.

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References

1. Naik, T.R. Sustainability of Concrete Construction. *Pract. Period. Struct. Des. Constr.* **2008**, *13*, 98–103. [CrossRef]
2. Zhong, X.; Hu, M.; Deetman, S.; Steubing, B.; Lin, H.X.; Hernandez, G.A.; Harpprecht, C.; Zhang, C.; Tukker, A.; Behrens, P. Global Greenhouse Gas Emissions from Residential and Commercial Building Materials and Mitigation Strategies to 2060. *Nat. Commun.* **2021**, *12*, 6126. [CrossRef]
3. Serres, N.; Braymand, S.; Feugeas, F. Environmental Evaluation of Concrete Made from Recycled Concrete Aggregate Implementing Life Cycle Assessment. *J. Build. Eng.* **2016**, *5*, 24–33. [CrossRef]
4. Bravo, M.; De Brito, J.; Pontes, J.; Evangelista, L. Mechanical Performance of Concrete Made with Aggregates from Construction and Demolition Waste Recycling Plants. *J. Clean. Prod.* **2015**, *99*, 59–74. [CrossRef]
5. Worrell, E.; Price, L.; Martin, N.; Hendriks, C.; Meida, L.O. Carbon Dioxide Emissions from the Global Cement Industry. *Annu. Rev. Energy Environ.* **2001**, *26*, 303–329. [CrossRef]
6. Prakash, R.; Raman, S.N.; Subramanian, C.; Divyah, N. Eco-Friendly Fiber-Reinforced Concretes. In *Handbook of Sustainable Concrete and Industrial Waste Management: Recycled and Artificial Aggregate, Innovative Eco-Friendly Binders, and Life Cycle Assessment*; Woodhead Publishing: Thorston, UK, 2022; pp. 109–145. [CrossRef]
7. Piccinali, A.; Diotti, A.; Plizzari, G.; Sorlini, S. Impact of Recycled Aggregate on the Mechanical and Environmental Properties of Concrete: A Review. *Materials* **2022**, *15*, 1818. [CrossRef]
8. Lotfi, S.; Eggimann, M.; Wagner, E.; Mróz, R.; Deja, J. Performance of Recycled Aggregate Concrete Based on a New Concrete Recycling Technology. *Constr. Build. Mater.* **2015**, *95*, 243–256. [CrossRef]
9. European Statistics-Eurostat. *Energy, Transport and Environment Statistics*, 2020 Ed. ed; European Commission: Luxembourg, 2020; ISBN 9789276207375.
10. World Business Council for Sustainable Development. *The Cement Sustainability Initiative: Executive Brief*; World Business Council for Sustainable Development: Geneva, Switzerland, 2012; p. 42.
11. Kox, S.; Vanroelen, G.; Van Herck, J.; de Krem, H.; Vandoren, B. Experimental Evaluation of the High-Grade Properties of Recycled Concrete Aggregates and Their Application in Concrete Road Pavement Construction. *Case Stud. Constr. Mater.* **2019**, *11*, e00282. [CrossRef]
12. The Demolition of the Puskás Ferenc Stadium Will Last for 8 Months-Daily News Hungary. Available online: https://dailynewshungary.com/the-demolition-of-the-puskas-ferenc-stadium-will-last-for-8-months/ (accessed on 23 July 2022).
13. Sim, G.; Quattrone, M.; Monteiro, W.; Cazacliu, B.G. Current Applications of Recycled Aggregates from Construction and Demolition: A Review. *Materials* **2021**, *14*, 1700.
14. Tam, V.W.Y.; Soomro, M.; Evangelista, A.C.J. A Review of Recycled Aggregate in Concrete Applications (2000–2017). *Constr. Build. Mater.* **2018**, *172*, 272–292. [CrossRef]
15. Ouyang, K.; Shi, C.; Chu, H.; Guo, H.; Song, B.; Ding, Y.; Guan, X.; Zhu, J.; Zhang, H.; Wang, Y.; et al. An Overview on the Efficiency of Different Pretreatment Techniques for Recycled Concrete Aggregate. *J. Clean. Prod.* **2020**, *263*, 121264. [CrossRef]
16. Katz, A. Treatments for the Improvement of Recycled Aggregate. *J. Mater. Civ. Eng.* **2004**, *16*, 597–603. [CrossRef]
17. Junak, J.; Sicakova, A. Effect of Surface Modifications of Recycled Concrete Aggregate on Concrete Properties. *Buildings* **2017**, *8*, 2. [CrossRef]
18. Pandurangan, K.; Dayanithy, A.; Om Prakash, S. Influence of Treatment Methods on the Bond Strength of Recycled Aggregate Concrete. *Constr. Build. Mater.* **2016**, *120*, 212–221. [CrossRef]
19. Quattrone, M.; Angulo, S.C.; John, V.M. Energy and CO_2 from High Performance Recycled Aggregate Production. *Resour. Conserv. Recycl.* **2014**, *90*, 21–33. [CrossRef]
20. Wang, B.; Yan, L.; Fu, Q.; Kasal, B. A Comprehensive Review on Recycled Aggregate and Recycled Aggregate Concrete. *Resour. Conserv. Recycl.* **2021**, *171*, 105565. [CrossRef]
21. Chen, X.; Li, Y.; Kang, X.; Fan, Y. Study on Recycled Concrete Powders as Mineral Admixture in Recycled Concrete Study on Recycled Concrete Powders as Mineral Admixture in Recycled Concrete. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *330*, 022113. [CrossRef]
22. Silva, R.V.; De Brito, J.; Dhir, R.K. Properties and Composition of Recycled Aggregates from Construction and Demolition Waste Suitable for Concrete Production. *Constr. Build. Mater.* **2014**, *65*, 201–217. [CrossRef]

23. *MSZ EN 206:2013*; Concrete-Specification, Performance, Production and Conformity. Hungarian Standards Institution: Budapest, Hungary, 2017.
24. Corinaldesi, V. Structural Concrete Prepared with Coarse Recycled Concrete Aggregate: From Investigation to Design. *Adv. Civ. Eng.* **2011**, *2011*, 283984. [CrossRef]
25. Limbachiya, M.C.; Leelawat, T.; Dhir, R.K. Use of Recycled Concrete Aggregate in High-Strength Concrete. *Mater. Struct. Mater. Constr.* **2000**, *33*, 574–580. [CrossRef]
26. Poon, C.S.; Shui, Z.H.; Lam, L.; Fok, H.; Kou, S.C. Influence of Moisture States of Natural and Recycled Aggregates on the Slump and Compressive Strength of Concrete. *Cem. Concr. Res.* **2004**, *34*, 31–36. [CrossRef]
27. Brand, A.S.; Roesler, J.R.; Salas, A. Initial Moisture and Mixing Effects on Higher Quality Recycled Coarse Aggregate Concrete. *Constr. Build. Mater.* **2015**, *79*, 83–89. [CrossRef]
28. Ferreira, L.; De Brito, J.; Barra, M. Influence of the Pre-Saturation of Recycled Coarse Concrete Aggregates on Concrete Properties. *Mag. Concr. Res.* **2011**, *63*, 617–627. [CrossRef]
29. Kebaili, O.; Layachi, B.; Nourredine, A. Influence of Moisture Conditioning of Recycled Aggregates on the Properties of Fresh and Hardened Concrete. *J. Clean. Prod.* **2013**, *54*, 282–288. [CrossRef]
30. Guerzou, T.; Mebrouki, A.; Castro-Gomes, J. Influence of Pre-Saturation of Recycled Aggregates on Concrete Workability and Strength. *Int. J. Eng. Res. Afr.* **2019**, *42*, 76–85. [CrossRef]
31. García-González, J.; Rodríguez-Robles, D.; Juan-Valdés, A.; del Pozo, J.M.M.; Guerra-Romero, M.I. Pre-Saturation Technique of the Recycled Aggregates: Solution to the Water Absorption Drawback in the Recycled Concrete Manufacture. *Materials* **2014**, *7*, 6224–6236. [CrossRef]
32. Zhang, H.; Xu, X.; Liu, W.; Zhao, B.; Wang, Q. Influence of the Moisture States of Aggregate Recycled from Waste Concrete on the Performance of the Prepared Recycled Aggregate Concrete (RAC)—A Review. *Constr. Build. Mater.* **2022**, *326*, 126891. [CrossRef]
33. *MSZ EN 197-1:2011*; Cement—Part 1: Composition, Specifications, and Conformity Criteria for Common Cements. Hungarian Standards Institution: Budapest, Hungary, 2011.
34. *MSZ EN 12350-5:2009*; Testing Fresh Concrete—Part 5: Flow Table Test. Hungarian Standards Institution: Budapest, Hungary, 2009.
35. *MSZ EN 933-1:1998*; Tests for Geometrical Properties of Aggregates—Part 1: Determination of Particle Size Distribution—Sieving Method. Hungarian Standards Institution: Budapest, Hungary, 1998.
36. *MSZ EN 1097-6:2006*; Tests for Mechanical and Physical Properties of Aggregates—Part 6: Determination of Particle Density and Water Absorption. Hungarian Standards Institution: Budapest, Hungary, 2006.
37. *MSZ EN 1097-2:2006*; Tests for Mechanical and Physical Properties of Aggregates—Part 2: Methods for Determination of Resistance to Fragmentation (Los Angeles Test). Hungarian Standards Institution: Budapest, Hungary, 2006.
38. *MSZ EN 933-5:1998*; Tests for Geometrical Properties of Aggregates—Part 5 Determination of Percentage of Crushed and Broken Surfaces in Coarse Aggregate Particles Essais. Hungarian Standards Institution: Budapest, Hungary, 2005.
39. *MSZ EN 1097-3:2006*; Tests for Mechanical and Physical Properties of Aggregates—Part 3: Determination of Loose Bulk Density and Voids. Hungarian Standards Institution: Budapest, Hungary, 2006.
40. *MSZ EN 933-4:2008*; Tests for Geometrical Properties of Aggregates—Part 4: Determination of Particle Shape—Shape Index. Hungarian Standards Institution: Budapest, Hungary, 2008.
41. *MSZ 4798:2016*; Aggregates for Concrete. Hungarian Standards Institution: Budapest, Hungary, 2016.
42. *EN 12350-6:2009*; Testing Fresh Concrete—Part 6: Density. European Committee for Standardization: Luxembourg, 2009.
43. *EN 12350-7:2009*; Testing Fresh Concrete—Part 7: Air Content—Pressure Methods. European Committee for Standardization: Luxembourg, 2009.
44. *EN 12390-3:2009*; Testing Hardened Concrete—Part 3: Compressive Strength of Test Specimens. European Committee for Standardization: Luxembourg, 2009.
45. *EN 12390-7:2009*; Testing Hardened Concrete—Part 7: Density of Hardened Concrete. European Committee for Standardization: Luxembourg, 2009.
46. *EN 12390-6:2009*; Testing Hardened Concrete—Part 6: Tensile Splitting Strength of Test Specimens. European Committee for Standardization: Luxembourg, 2009.
47. Sagoe-Crentsil, K.K.; Brown, T.; Taylor, A.H. Performance of Concrete Made with Commercially Produced Coarse Recycled Concrete Aggregate. *Cem. Concr. Res.* **2001**, *31*, 707–712. [CrossRef]
48. de Andrade Salgado, F.; de Andrade Silva, F. Recycled Aggregates from Construction and Demolition Waste towards an Application on Structural Concrete: A Review. *J. Build. Eng.* **2022**, *52*, 104452. [CrossRef]