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An Experimental Study on Innovative Concrete Block Solutions for Reconstruction

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Abstract: In this study, an experiment was conducted to innovate a new design of interlocking concrete blocks (ICBs) containing recycled aggregates (RAs) by reducing the consumed time and cost in construction using an environmental approach. Accordingly, the designed ICBs were produced manually using RAs, and wallettes were easily built with a mortarless mechanism by stacking the blocks without any mortar layers. In the experiments, besides the individual compression tests of the two types of ICB with natural and recycled aggregates, the wallette samples that were produced using ICBs, containing either 100% natural aggregates or 100% Ras, were tested under axial compressive loading. The experimental results were assessed considering the compressive strength, displacement, and failure mode. In the obtained results, we noticed that the average compressive strengths of the wallettes that were produced with natural or recycled aggregate ICBs were large enough to meet the standards of Syrian regulations, which are considered an example reference. The resulting displacement values were acceptable and could be negligible in some wallette specimens. It was concluded that the innovative ICBs with both normal or recycled aggregates could be a good alternative to traditional blocks, especially in post-disaster or post-war areas.

Keywords: reconstruction; recycled concrete aggregate; concrete blocks; interlocking block

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1. Introduction

Within the cement sector, Türkiye, which is among the world's leading cement-producing countries, is ranked fifth in the world, and it is ranked seventh among the main cement consumer countries. In 2012, Türkiye was ranked second after Iran in the world's cement sector exports. In Europe, Türkiye's cement industry was ranked first in both production and export. While sector exports were focused in the north and west of Africa in 2012, Iraq, Libya, and Russia remained the major markets for sector exports in 2013. China leads globally within the building business. The building industry has grown to be one of the most important sectors of the national economy of China, but rising construction activity in recent years has resulted in a considerable volume of construction trash. According to data, China is the world's largest consumer of cement, and the cement consumed there accounts for 55% of global consumption [1]. Global cement consumption in 2021 grew steadily across many parts of the world and was projected to increase by 6%, excluding China. In 2022, IA cement expected a 2–4% growth in Turkish cement consumption, supported by a strong infrastructure pipeline with high-speed railways and renewable energy projects at the forefront [2]. However, compared to the previous year, cement production decreased by 6.6 percent to 73,708,000 tons. In the January–May period of 2023, there was an increase of 7.9% in cement production compared to 2022 [3].

The economic growth of many developing countries in the world is adversely affected by resource scarcity, global warming, epidemic diseases, and environmental conditions [1,4–10]. The conservation of the world's resources and the sustainability of natural habitats have emerged as the most pressing and critical issues for the survival and well-being of humans.

Due to rapid industrialization and population growth in the last two hundred years, material and natural energy resources have been consumed in large quantities, which has led to global environmental changes that human beings have never experienced before.

Besides Türkiye, EU economies are heavily dependent on the construction sector. The building industry consumes a lot of natural resources and produces a lot of waste. According to a previous European Commission declaration [11], the building industry utilizes more than half of all minerals mined from the ground and creates more than 500,000 tonnes of trash every year in the EU. In addition, the management and disposal of old buildings have become a problematic issue [12]. However, in industrialized nations, the secondary utilization of building debris is extremely common. For many years, the recycling of building debris has been carried out, particularly for recycled concrete in the United States, Japan, and certain European nations. Construction and demolition trash is recycled at a rate of around 75% in certain wealthy European nations [12]. The use of leftover concrete as aggregates in the production of recycled concrete is an important developmental trend in environmentally friendly construction materials. Concrete recycling not only allows for the effective reuse of construction materials, but it also addresses the issue of natural aggregate shortages [12].

In recent years, many studies have been conducted on recycled aggregate concrete (RAC). The authors of [13] concentrated on the material characterization and modification of recycled concrete aggregates (RCAs), as well as RAC mix designs. In general, it is considered that the larger the percentage of RCAs, the greater the decline in RAC strength. Strength fluctuation is another key obstacle limiting the broad use of RAC [14–16]. Research on RAC components, included columns, beams, and joints, demonstrated that their mechanical characteristics are essentially similar to conventional concrete [1]. Also, RAC frame construction has recently been examined for earthquake performance [17].

The study by Ferriz-Papi and Thomas (2020) [18] aimed to investigate in depth the use of recovered aggregates from building and demolition wastes in concrete mixtures in order to enhance upcycling. A review of the research and regulations on concrete block manufacturing in the United Kingdom has been created as a part of this study. The initial studies were conducted as part of a case study with a sample of a building and demolition waste recycled aggregate from a Swansea demolition and construction waste factory. Visual inspection and screening procedures were used to create a composition of the two samples, which was then compared to the original aggregates. Up to 70% of the material was earthen debris from the excavation, with the remainder being a combination of plaster, glass, and organic materials, with tiny residues of mortar, concrete, and ceramic waste. Two concrete mixes were created using 80% recycled aggregates and various water/cement ratios. Testing included compressive strength, absorption, slump, and density. When the findings were compared with the reference specimen, we discovered that the quality of both combinations declined dramatically. However, in order to successfully employ these recycled aggregates in concrete block manufacturing, they needed to be analysed, and encouraging findings were discovered.

Guo et al. (2018) [19] sought to investigate the potential application of RCAs in the production of concrete construction blocks. Concrete construction blocks containing 75% RCA were produced via laboratory research and plant trials. The durability and mechanical qualities of RAC blocks were investigated via a variety of experiments. The shear and compressive performances of wall prisms fabricated using RAC blocks were proven to be comparable to those of standard concrete walls. The authors proposed that RCAs can be used to manufacture environmentally friendly concrete construction blocks. They concluded that the usage of RAC blocks plays a significant role in the building life cycle and will benefit the long-term development of masonry structures.

There has been increasing interest in the design and manufacture of novel interlocking masonry blocks for sustainable and cost-effective structures in recent years [20–24]. One such option is to make interlocking blocks with tongue and groove portions as well as projections that exactly fit together; this has been accomplished by partially replacing fly ash for cement in the block's manufacture. This concept seeks to develop mortar-free, earthquake-resistant structures while reducing construction time and cost by up to 65%, using less labour and fewer resources [25].

Another study focuses on the production of interlocking masonry blocks using local materials such as Portland cement and water, without the use of mortar. Various shapes and dimensions (toe shape, bottom and top) of wall blocks were used. The compaction effort and compressive strength of these interlocking concrete blocks were found to be 3.687 (K.J./m^3) and 4.80 (MPa), respectively [26]. These values are well below the values of some specially mixed concrete specimens [27].

One study focuses on developing a new wall prospect using an interlocking concrete block model. The blocks were then exposed to compressive and axial loads. The author concluded that the new models made from the interlocking blocks may work for concrete wall construction and could be employed in typical load-bearing walls. It was shown that the new model, which is made up of interlocking blocks, may work as a concrete wall construction and be employed in typical load-bearing walls [28].

Finally, one research study explored the novel design of a hollow interlocking concrete block with a good finish that may be utilized to build steel-fibre-reinforced load-bearing walls. The blocks were examined to explore this possibility and compare their failure patterns and load capacity to those of nearby solid and hollow blocks. According to the study's findings, the load-bearing capacity of the wall was 12% and 22% greater than that of the local solid and hollow block walls, respectively. Furthermore, as compared to local blocks, the usage of steel fibre reduced the dead load by 28% and 11%, respectively [29].

Interlocking reinforced concrete blocks (IRCBs) emerged as sustainable solutions in various construction applications due to their cost and time effectiveness. This study specifically explores the potential advantages of IRCBs, particularly in disaster and war-torn countries like Syria.

The advantages of adopting IRCBs are numerous. Firstly, they are simple to install and need no specific masonry labour skills, making them appropriate for wall building. Second, IRCBs may be utilized for both structural and non-structural applications including columns, walls, and beams. They may also be used to create single or multi-story buildings, making them extremely useful in rural locations. IRCBs may be employed in both horizontal and vertical orientations, providing an architecturally pleasing perspective of the structure. Moreover, IRCBs can be dry-stacked without mortar, which significantly reduces cement usage. They also come with embedded holes for electrical and plumbing installations, making them suitable for different building requirements. IRCBs can also be sound- and heat-insulated, increasing their utility in various settings. Lastly, IRCBs are resistant to earthquakes, making them an appropriate solution for disaster-prone countries.

In summary, IRCBs offer numerous advantages, making them an innovative material in construction. Their versatility and sustainability make them suitable for various applications, especially in disaster-prone countries like Syria. With the growing need for cost-effective and sustainable construction solutions, IRCBs have the potential to be a game-changer in the construction industry.

The construction of basic structures with interlocking blocks fashioned from aggregate obtained from the transformation of concrete waste generated in war zones was seen as an efficient and cost-effective solution to the issue of shelter provision for individuals. Interlocking dry-stack bricks may require very little mortar alignment. The blocks are set with a cement slurry using an interlocking system to resist applied stresses; ICB walls may be erected at least three times faster than conventional block walls [19]. Masonry dry-stack technology based on blocks interlocking with grooves and tongues allows for proper building alignment. This wall structure is capable of withstanding a variety of external forces, due to steel rods inserted via holes. A dry-stacking wall technique would minimize shrinkage cracks on a concrete wall [30].

As can be understood from the literature, studies on interlocking blocks created using RAs are relatively limited. Moreover, examining RAs and natural aggregates simultaneously has become a very important issue. In this study, experiments are conducted to innovate a new design of interlocking concrete blocks containing recycled aggregates by reducing the consumed time and cost in construction, together with an environmental approach. According to this, the designed interlocking concrete blocks were produced manually by using recycled aggregates, and wallettes were easily built with a mortarless mechanism by stacking the blocks without any mortar layers. In the experiments, besides the individual compression tests of the two types of interlocking concrete blocks with natural and recycled aggregates, wallette specimens produced by interlocking blocks containing either 100% natural aggregates or 100% recycled aggregates were tested under axial compressive loading.

2. Experimental Study

2.1. Materials

Portland cement and tap water from the laboratory were used for the production of test elements. Coarse and fine aggregates were sourced from a factory and from construction debris from different regions.

Preparing Recycled Concrete Aggregate

Working Steps In Situ

There are several steps to produce RCAs, as shown in Figure 1:

- Collecting and selecting construction and demolition concrete waste;
- The classification of concrete aggregates;
- Crushing large and medium aggregates manually with a hammer;
- Cleaning and sieving small aggregates.

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

Figure 1. Some steps of preparing RCAs.

The recycling process in a laboratory using a single-toggle jaw crusher:

- Putting concrete waste aggregates in the hopper and crushing between fixed and swing jaws to small aggregates, and slipping down through the opening gap at the bottom, as shown in Figure 2. The size of the broken course concrete aggregate is between 4 and 12 mm;
- Screening crushed aggregates in 3.35–12.5 mm sieves to obtain the appropriate coarse aggregate;
- Separating invalid aggregates to obtain fine aggregates (sand).

2.2. Preparing Concrete Mixture

Trial Mix Design

At this stage, different mix ratios of sand, coarse aggregates, cement, and water were tried to find the appropriate mixture that would be used to produce a concrete block.

The experimental mixtures were prepared in a laboratory, and the materials were manually mixed. Therefore, water was splashed slowly with a water sprayer, as shown in Figure 3. The mixture ratio was specified as follows: for the NCA mixture, 4:1:1:1 (4 units of sand, 1 unit of coarse aggregate, 1 unit of cement, 1 unit of water = 2000 mL); for the RCA mixture, 4:1:1:1.5 (4 units of sand, 1 unit of coarse aggregate, 1 unit of cement, 1.5 units of water = 3000 mL).

Mould Design

Figure 2. Recycling concrete process (**1**) collecting waste concrete, (**2**) and (**3**) reducing the size of concrete pieces in the crusher, (**4**) obtaining RA.

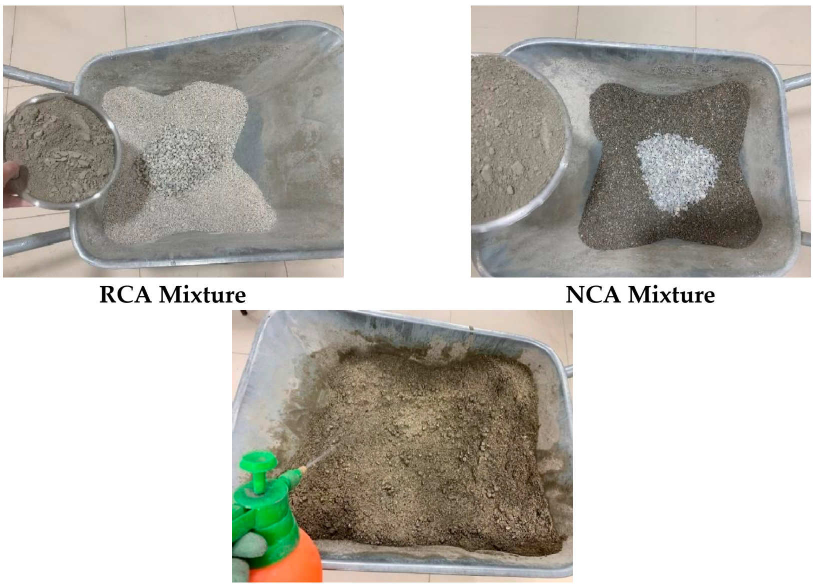


Figure 3. Mixture prepared in the laboratory.

When designing the ICB, a concrete block that is used in construction, the size and shape of the block were carefully considered to ensure its structural integrity and ease of use. The wooden mould used to create the block was inspired by Portuguese design [31], specifically the traditional use of wooden moulds in their construction industry.

It has two hinges at the backside and two hasps at the front to remove it easily and flexibly after turning the mould over without collapsing the block wall. To produce a standard block that would be portable for construction workers and bear more pressure with a long top protrusion (24 cm), the following was designed:

- The back piece, to obtain the block's groove; bottom and half-bottom blocks can be made by turning the front part over;
- The front piece, to obtain the block's protrusion; top and half-top blocks can be made by turning the back piece over;
- The bottom base, to fix the mould and prevent the block from sliding while compacting the mixture, which helps us to hold the mould when we want to turn the mould over;
- A wooden hand, to compact the levels manually 3 or 4 times in the mixture, especially the last one.

This block wall system includes a standard block (24 × 12 × 18 cm), a bottom block, a top block, a half-bottom block, and a half-top block, as shown in Figures 4–6.

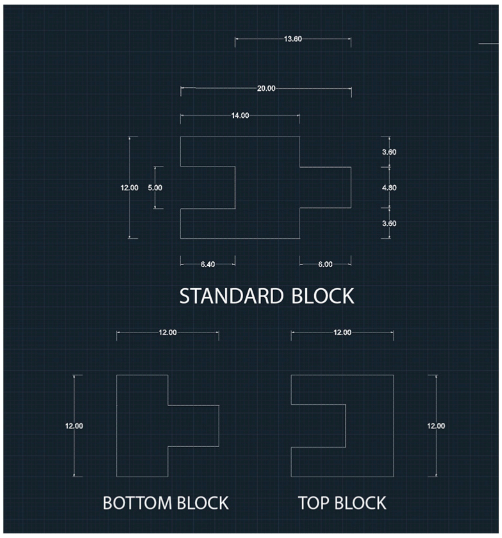


Figure 4. Interlocking block system design (**standard**, **bottom**, and **top**).

Figure 5. Main plywood mould, back piece, front piece, and wooden hand.

The height of the protrusion measured 6 cm, while its width measured 4.8 cm. On the other hand, the height of the groove was augmented to 6.4 cm, and the width to 5 cm. Such an increase in both the height and width of the backside piece facilitates the placement of mortar between the blocks when interlocking them to form a wall. Additionally, it enables the removal of the wooden back piece easily, without causing any collapse in the protrusion.

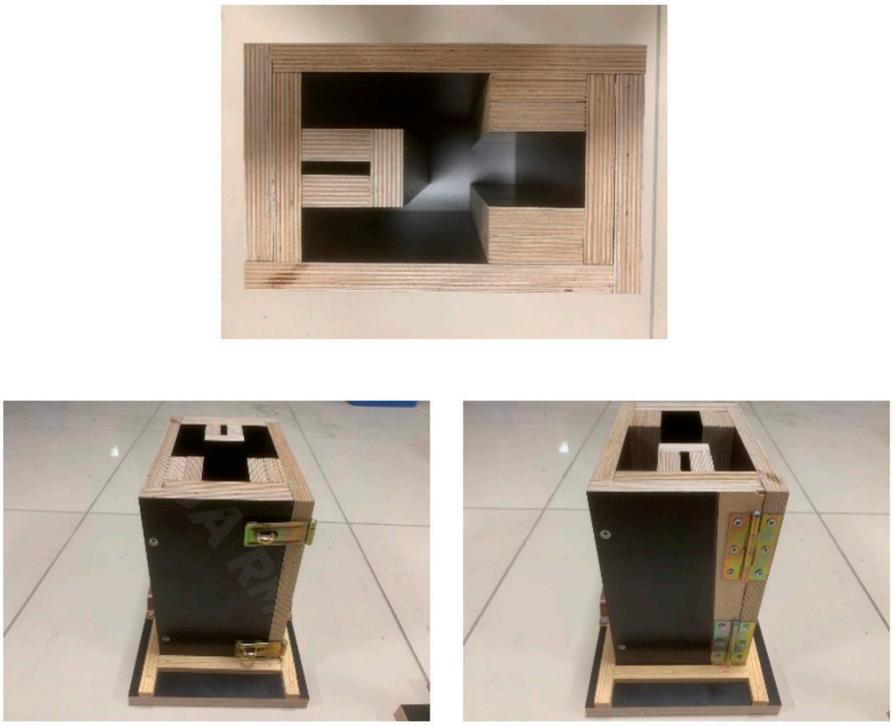


Figure 6. Plywood mould in three views.

2.3. Casting Process of Interlocking Concrete Block Specimens

After preparing the mixture using a 4:1:1:1 ratio and obtaining the necessary tools, such as a metal rod, hammer, and wooden hand, the production process for interlocking concrete blocks (ICBs) is shown in Figure 7. The process includes the following steps:

- Painting all mould faces with oil;
- Placing the mould base on the ground;
- Placing the wooden mould on the base and closing the hasps with a thin wooden rod;
- Filling the mould with the concrete mixture;
- Consolidating and compacting the mixture three times for three levels by hammering the wooden hand;
- Shaking the mixture three times manually by using a metal rod for each level;
- Turning the mould over and knocking the base with a plastic hammer;
- Extracting the concrete block by opening the hasps and carefully removing one side of the front wooden piece.

Figure 7. Production process of interlocking concrete blocks (**1**) preparing the mixture, (**2**) placing it in the mold, (**3**) and (**4**) compressing the mixture, (**5**), (**6**), (**7**) and (**8**) dismantling the mold.

2.4. Curing Blocks

After removing the mould, we sprayed water on each block periodically, morning and evening, for seven days.

2.5. Fabrication of ICB Wallette

The wallette panels were constructed using the interlocking block system, which consists of five blocks: the standard block, top block, bottom block, half-bottom block, and half-top block. The standard blocks serve as the primary unit in wallette construction, while the bottom blocks provide structural support for the wall. The top blocks are used to seamlessly terminate the wallette without interlocking keys, whereas the half-bottom and half-top blocks are used to achieve accurate completion of the wall course.

Each wall specimen is composed of one bottom block, two half-bottom blocks, two standard blocks, one top block, and two half-top blocks. These blocks interlock easily with each other using their protrusion key. The wallette's construction entails stacking each dry block one by one, without mortar between them, resulting in a mortarless or dry-stack wall system. The wallette panel specimen's dimensions are L = 480 mm × H = 30 mm.

In this study, the authors constructed five wallette panel specimens using interlocking block systems containing 100% normal aggregates, and five other specimens containing 100% recycled aggregates.

2.6. Specimens and Instrumentation Setup

Axial Compression Tests on Blocks

The compressive strength test is a crucial property used to determine the load-bearing capacity of blocks. This is provided by utilizing the Automatic Compression Testing Machine (ASTM), as shown in Figure 8, to measure blocks' ability to withstand loads before failure. The compressive strength test is particularly significant when using the blocks to construct load-bearing walls. The test involves placing a block between two steel plates, ensuring that it is centred on the loading axis. The load is then gradually increased (0.2 kN/s) until the block fails, and the compressive strength of the block is measured. To prepare for the compression test, multiple tests were conducted using standard blocks with varying mix ratios and ages. Subsequently, five standard natural blocks (NBs) made entirely of natural aggregates and five recycled blocks (RBs) made entirely of recycled aggregates were casted. After curing for seven days, both sets of blocks were subjected to a compression test after 28 days of age, as listed in Table 1.

Axial Compression Tests on ICB Wallettes

Figure 8. Standard interlocking concrete block in the compression test machine.

Table 1. Standard blocks with 100% NCAs and 100% RCAs.

%	Block ID	Age (Day)	Water Treatment Time (Day)	Mix Ratio (Sand:C.Agg:C:W)
100% NA	NB1	28	7	4:1:1:1
	NB2			
	NB3			
	NB4			
	NB5			
100% RA	RB1	28	7	4:1:1:1$\frac{1}{2}$
	RB2			
	RB3			
	RB4			
	RB5			

During the compression test, the panel specimen was positioned between a metal beam at the bottom and a hydraulic vertical load jack. Additionally, two rectangular metal plates were placed over the top end of the panel to ensure that the load was evenly distributed. The load was then gradually increased (0.2 kN/s) until the wallette failed. To measure the vertical displacement accurately, linear variable differential transformer (LVDT) instruments are attached to each wall specimen on the wallette's side in the vertical direction, as illustrated in Figure 9.

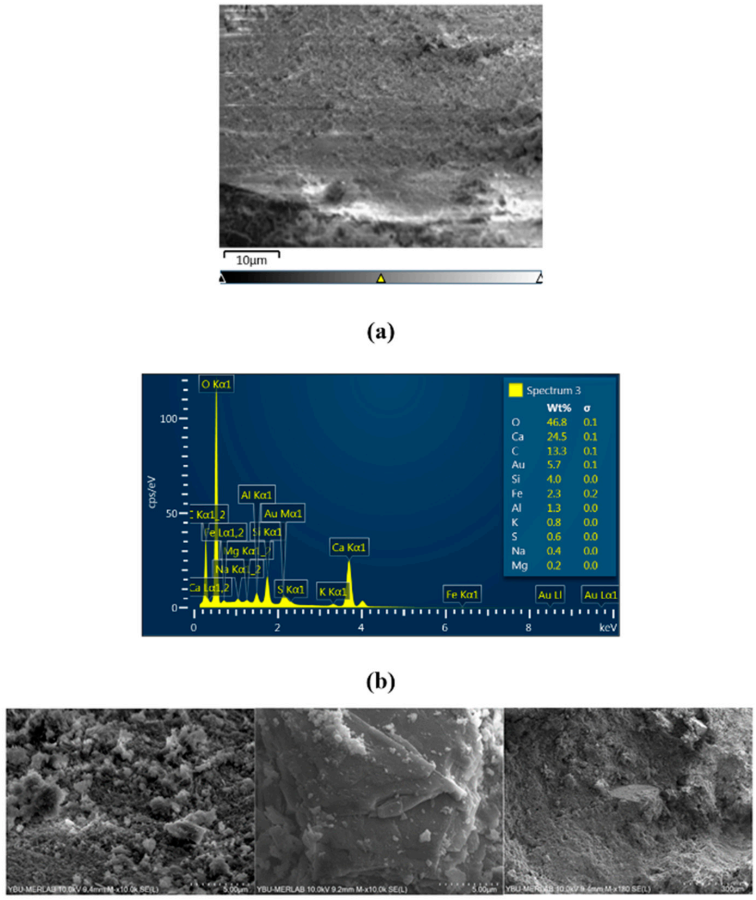
Figure 9. ICB wallette specimen test setup.

3. Experimental Results

3.1. Chemical Properties of Recycled Concrete Aggregates

The recycled fine and coarse aggregates were analysed using a scanning electron microscope (SEM). The elemental mapping of our sample surface layer was obtained through X-ray diffraction (XRD) and energy dispersive spectroscopy (EDX). Additionally, SEM can capture high-resolution and three-dimensional images, which provide information on the topography, morphology, and composition.

The SEM-EDS measurements indicated the presence of such constituent elements as O, Ca, C, Au, Si, Al, Fe, S, Mg, K, and Na. The shape and size of the recycled aggregates were irregular because of crushed concrete debris. The RCA particles had irregular shapes, and the surface was acute. Small particles were adhered to the RCA particles, as shown in Figures 10 and 11. The presence of oxygen, carbon, and calcium was determined with high percentages, and they were classified as prominent elements. In Figure 10b, the micro-analysis data of the coarse aggregate show the concentrations of several chemical elements in weight percentages It was indicated that the coarse aggregate particles contained mostly 46.8% oxygen, 24.5% calcium, and 13% carbon. However, the micro-analysis data of the fine aggregates in Figure 11b show that their particles had mostly 43.5% oxygen, 30% calcium, and 12% carbon. Figure 11c shows the scanning electron microscopy (SEM) images of the recycled fine aggregate used.



(a)

(b)

(c)

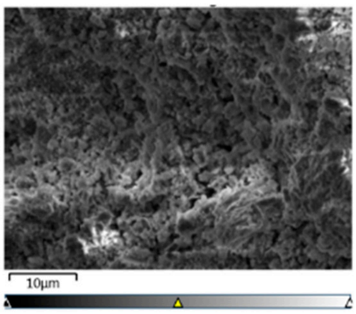
Figure 10. SEM-EDS results of recycled coarse aggregate sample: (**a**) general SEM pattern, (**b**) overall EDS analysis, and (**c**) local SEM images.

3.2. Compressive Strength Results of Block Specimens

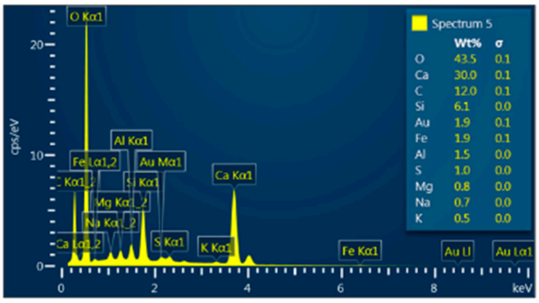
The compressive strength results of the experimental standard block specimens are reported in Table 2. Figures 12 and 13 show the comparison between the NB and RB block groups.

Table 2. Compressive strength results of standard block specimens.

%	Block ID	Surface Area (cm^2)	Maximum Load (KN)	Maximum Stress (MPa)	Average Stress (MPa)
100% NA	NB-1	4.8 × 24	101.1	8.7	9.22 (with a standard deviation of 0.43)
	NB-2		112.3	9.7	
	NB-3		106.2	9.2	
	NB-4		111.9	9.7	
	NB-5		101.7	8.8	
100% RA	RB-1	4.8 × 24	56.8	4.9	4.9 (with a standard deviation of 0.99)
	RB-2		49.1	4.2	
	RB-3		73.3	6.3	
	RB-4		64.8	5.6	
	RB-5		40.9	3.5	



(a)



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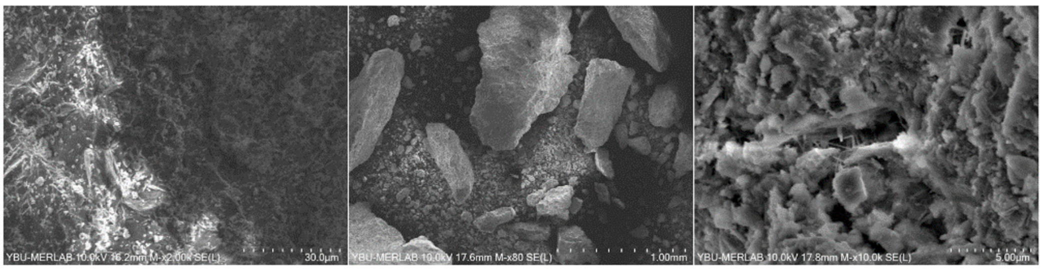


(**c**)

Figure 11. SEM-EDS results of recycled fine aggregate sample: (**a**) general SEM view, (**b**) overall EDS analysis, and (**c**) local SEM images.

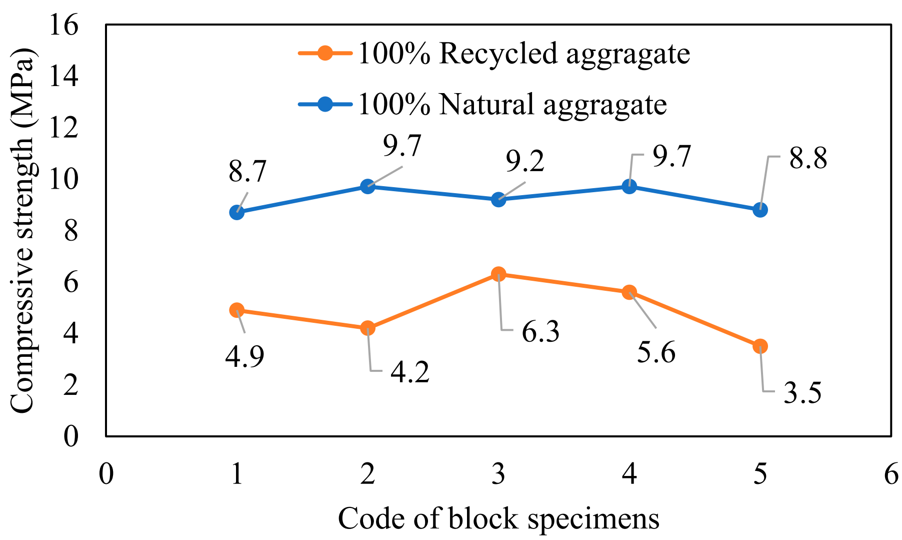


Figure 12. Compressive strength results of standard block specimens.

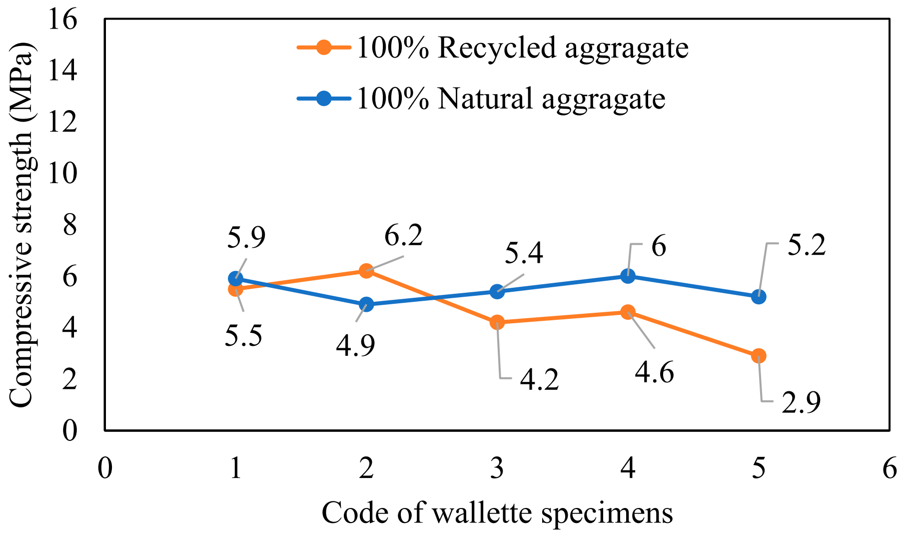


Figure 13. Compressive strength results of wallette specimens.

3.3. Compressive Strength Results of Wallette Panel Specimens

Table 3 summarizes the compressive strength results of the wallettes. The average compressive strength of the NW wallette specimens is 5.48 MPa, while the average compressive strength of the RW wallette specimens is 4.68 MPa.

Table 3. Compressive strength results of wallette specimens.

%	Code of Wall	Surface Area (cm^2)	Max. Load (KN)	Max. Stress (MPa)	Average Stress (MPa)	Δ (mm)	Average Δ (mm)
100% NA	NW1	48 × 7	199.7	5.9	5.48 (with a standard deviation of 0.43)	3.16	2.12 (with a standard deviation of 1.05)
	NW2		165.6	4.9		1.61	
	NW3		181.3	5.4		3.57	
	NW4		200.7	6		0.86	
	NW5		173.3	5.2		1.44	
100% RA	RW1	48 × 7	183.9	5.5	4.68 (with a standard deviation of 1.13)	1.97	1.67 (with a standard deviation of 1.05)
	RW2		208.8	6.2		0.9	
	RW3		140.8	4.2		2.12	
	RW4		155.1	4.6		1.85	
	RW5		95.8	2.9		1.53	

The curves in Figures 14 and 15 show that the displacement values of both the NWs and RWs range between 0.86 and 3.57 mm for the NWs, and range between 0.9 and 2.12 mm for the RWs.

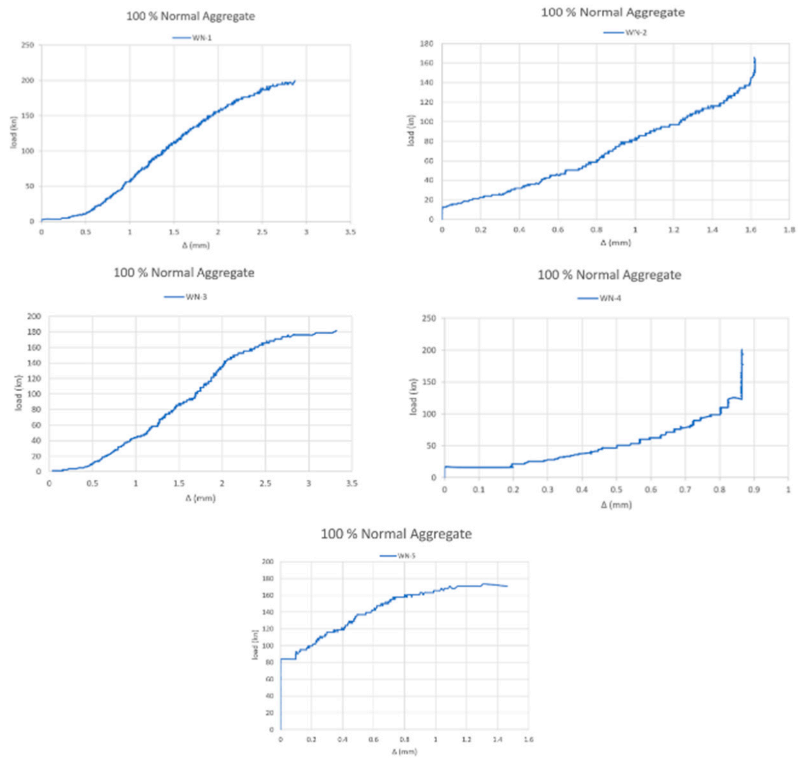


Figure 14. Load–displacement curves of the NW wallette panels.

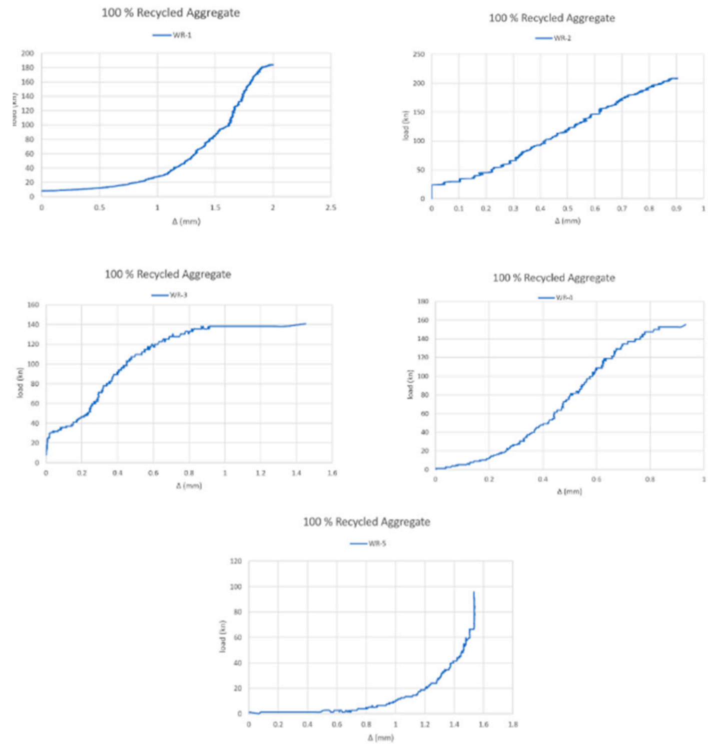


Figure 15. Load–displacement curves of the RW wallette panels.

4. Discussion

This study involved testing specimens using a compression test machine to measure the compressive strength of individual standard blocks (NB, RB) and wallette panels (NW, RW). Prior to the experiment, the optimal mixture for the interlocking concrete blocks was determined through several attempts. Various standard blocks with different mixture ratios were constructed and tested to determine their strengths. The Syrian Arab Code for unreinforced load-bearing walls on buildings [6] was used to define the permissible value of compressive strength. The current study aimed to investigate the use of 100% recycled concrete aggregates (RCAs) in mortarless interlocking concrete blocks, which could provide economic and environmental benefits. Two groups, each containing five blocks, were produced: the first group contained 100% RCAs, and the second group contained 100% natural concrete aggregates (NCAs). The experimental results indicated that the average compressive strength of the standard ICB containing 100% NCAs was 9.22 MPa, while that of the standard ICB containing 100% RCAs was 4.9 MPa. Figure 12 shows a comparison between the NB and RB block groups, indicating that the average compressive strength of the NCA blocks was almost twice that of the RCA ones. The low strength of the RCA blocks could be attributed to the inadequate homogenization of the RCA particles in both the fine and coarse aggregates, as well as the highly porous adhered mortar structure in the RCA mixture, which led to a weak concrete. Manual compaction and vibration mechanisms during preparation may also reduce concrete strength. After loading the axial force, a failure occurred along the protrusion, as indicated with the long line crack that extended to the bottom of the blocks, as shown in Figure 16.

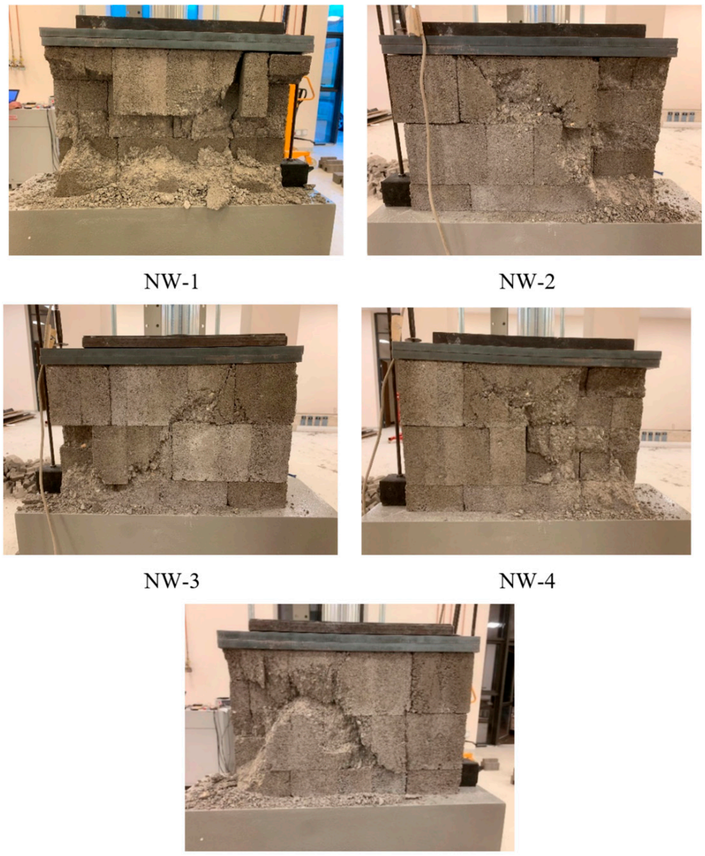
Figure 16. Vertical lines of cracks after loading axial force.

Two sets of tests were carried out on the wallette panels to investigate their compressive strength. Ten wallette samples were constructed using an interlocking block system: five with 100% natural coarse aggregates (NCAs) and five with 100% recycled coarse aggregates (RCAs). A load was applied along the surface face of the wallette (480 mm $\times$ 120 mm) to ensure uniform distribution. The results of the compressive strength tests are summarized in Table 3. The average compressive strength of the NCA wallette specimens was 5.48 MPa, with a maximum of 5.9 MPa and a minimum of 4.9 MPa. The average compressive strength of the RCA wallette specimens was 4.68 MPa, with a maximum of 6.2 MPa and a minimum of 2.9 MPa. The compressive strength results of both types of wallette specimens, were similar and met the Syrian load-bearing wall code, with the average compressive strength of the RCAs being nearly six times higher than 0.8 MPa and that of the NCAs being nearly seven times higher than 0.8 MPa.

Based on these results, interlocking recycled concrete block walls (IRCBWs) can be considered as load-bearing walls for single- and multi-story buildings, using a mortarless interlocking block wall system. This system increases construction productivity and reduces labour and construction duration in war/disaster-affected areas. However, as seen in Figure 17, the grooves are not sufficiently connected to the tongue key, which may adversely affect the wall strength. This is because the dry bed joints between interlocking block layers play a significant role in the performance of the mortarless masonry wall system. Moreover, some design imperfections were evident during the casting stage when producing half of the top and bottom blocks. The length of the mould was 24 cm, but the half-block was only 12 cm, resulting in the inadequate compaction of the last layer of the block. As a result, some half-blocks did not complete the wall entirely, leaving part of the tongue or groove outside the wallette.

Figure 17. Interlocking three types of blocks.

Vertical cracks were observed as starting from the top of the wallette and extending through the three compaction layers of the block. This occurrence can be attributed to inadequate contact between the groove's lower surface and the protrusion's upper surface for each type of block. As a result, the crack propagates from one block to another until the entire wallette fails. The failure mode is presented in Figures 18 and 19.

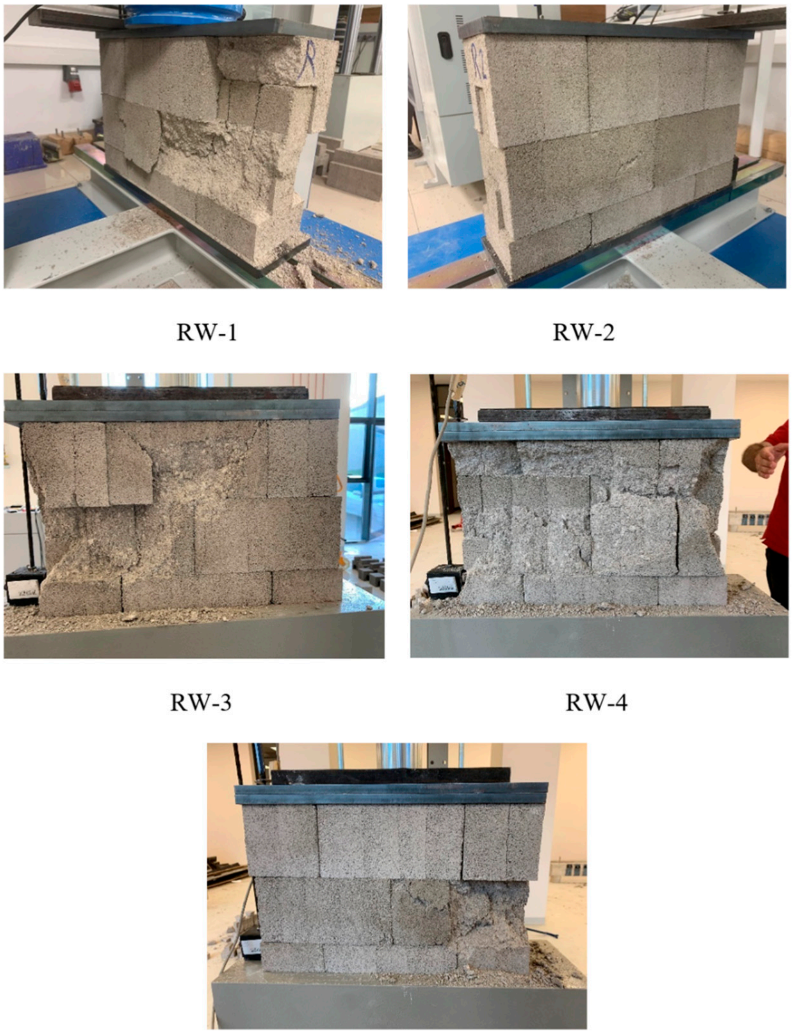


NW-1 NW-2

NW-3 NW-4

NW-5

Figure 18. Failure pattern of the NW wallette panels.



RW-1 RW-2

RW-3 RW-4

RW-5

Figure 19. Failure pattern of the RW wallette panels.

Figures 14 and 15 illustrate the displacement values of both the NWs and RWs. The NW displacement ranges between 0.86 and 3.57 mm, while the RW displacement ranges between 0.9 and 2.12 mm. Notably, the average displacement value of the NWs (2.12 mm) is higher than that of the RWs (1.67 mm). Overall, the wallette structure does not exhibit significant displacement.

As a general evaluation with the mechanical results obtained, it was understood that the natural and recycled aggregates that were used in the production of interlocking blocks gave close results in the concrete compressive strength of the walls. In other words, the use of recycled aggregates, which is a very environmentally friendly approach, has proven to be quite suitable for the production of interlocking blocks. However, it is obvious that more successful results will be obtained when the production defects shown in Figure 17 are eliminated. The simple and fast construction of walls with the three types of blocks proposed in this study was demonstrated during the production of the test elements. That is, when these blocks are available for sale on the market, people will build their houses and other basic structures in a simple way, since no skilled labour is required. Finally, the fact that the material used is recycled and that the production of the blocks is simple will reduce the cost considerably and provide cheap access to the market.

5. Conclusions

In the present study, the potential and feasibility of using recycled concrete aggregates (RCAs) obtained from construction and demolition (C&D) waste were evaluated. This study explored the possibility of constructing a load-bearing wall using interlocking concrete blocks (ICBs) through a dry-stack mechanism. The system comprised five types of inter-locking concrete blocks, namely standard, bottom, top, half-top and half-bottom, designed to be placed and stacked easily without mortar. This study further examined the compressive strength, displacement, and failure mode of wallette panel specimens using ICBs containing 100% NCAs and 100% RCAs. As a result, the following conclusions were made:

- The average compressive strength of the NCA wallette specimens was 5.48 MPa, with a maximum of 5.9 MPa and a minimum of 4.9 MPa;
- The average compressive strength of the RCA wallette specimens was 4.68 MPa, with a maximum of 6.2 MPa and a minimum of 2.9 MPa;
- The compressive strength results of both types of wallette specimens were similar and met the Syrian load-bearing wall code, with the average compressive strength of the RCAs being nearly six times higher than 0.8 MPa, and that of the NCAs being nearly seven times higher than 0.8 MPa.

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