WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2025.156176

ARCHIVES OF CIVIL ENGINEERING

Vol. LXXI ISSUE 4 2025

 pp. 375 – 392

Research paper

Impact of using recycled fine aggregate from demolition waste on mechanical properties of cement mortar

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Abstract: The rapid expansion of the construction industry worldwide has led to a significant increase in resource use, hence depleting the existing reserves. Utilizing recycled aggregates might potentially reduce the use of natural raw materials in the production of concrete and mortar. This would further aid in reducing the quantity of waste thrown into the environment due to demolition procedures. This study investigated the feasibility of recycling recycled fine aggregate from construction and demolition waste. Limestone powder was utilized as a filler, together with waste from three different kinds of construction and demolition waste (concrete, clay bricks, and ceramics). Cement mortar mixtures of 1:3:0.5 and 1:4:0.5 were used to design 32 different mortar mixes (cement: fine aggregate: filler). Except for the control mixes, the following replacement ratios were tested: 0%, 20%, 40%, 60%, 80%, and 100% for construction and demolition waste as a partial replacement for natural fine aggregate. Cubes, prisms, and cylinders were all used to measure the physical and mechanical properties of the mortar. In this study, the physical properties (workability, dry density) were analyzed. In addition to investigating the mechanical properties (compressive, flexural, and splitting strength), The experimental results showed that the optimal percentage of natural fine aggregate replacing recycled aggregate from construction and demolition waste was 20%. Additionally, the research demonstrated that, due to its cementitious properties, recycled fine aggregate from concrete waste significantly outperformed the reference mixes in terms of all physical and mechanical properties.

Keywords: construction demolition waste, recycled fine aggregate, SEM, compressive strength, flexural strength, splitting tensile strength

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1. Introduction

Due to the depletion of resources, the rapid population growth, the rapid urbanization, and the rising worldwide demand for services and commodities, the need for construction materials is still expanding globally. Rapid housing development and expansion, as well as infrastructure growth and expansion, have become essential needs that necessitate significant consumption of building materials, particularly concrete. Concrete is the most widely used building material in the world, producing 25 billion metric tons per year. It has an aggregate content of more than 80% [1, 2]. Fine aggregate is one of the main components of concrete, and it represents 25–40% of the weight of the material. There is a high level of concern due to the potential negative impacts on the environment of the mining operations and the extraction of fine aggregates [3, 4]. The United Nations says that between 40 and 50 billion metric tons of fine aggregate are taken out of the ground every year, but only 20% of that is used to make concrete [5]. The construction industry is one of the largest producers of waste, as construction and demolition waste represent 40% of the total waste produced in the world [6]. Due to the lack of extractable quarry materials and their inability to dispose of construction and demolition waste, many countries have worked to develop recycling processes for waste produced from industrial processes, including the construction and demolition industries. Waste is converted into raw materials that can be reintegrated into the construction sector [7].

Even though construction and demolition waste recycling rates are high – 100% in certain nations, like the Netherlands – only 7% of these materials are used in the construction industry as structural elements. Depending on the environmental features of these wastes, the remainder is utilized in place of natural aggregates in road construction [8, 9]. For the aforementioned reasons, a lot of researchers have studied the possibilities of recycling construction and demolition debris in the creation of concrete or cement mortar, which may be used for various purposes depending on its characteristics. Ismail, S., et al. [10] studied the effect of replacing natural fine aggregate with recycled fine aggregate produced from waste concrete structures with replacement ratios of 0, 25, 50, 75, and 100% to produce high-strength cement mortar. The results indicated that the mortar prepared using concrete waste as fine aggregate showed poorer behavior in mechanical properties at high replacement rates, and for replacement ratios less than 25%, there was no significant effect on mechanical properties.

The effects of replacing recycled fine aggregates with 100% natural sand on the fresh characteristics, mechanical characteristics, and durability of thixotropic and self-leveling mortars were investigated by Candamano, S. et al. [11] A significant decrease was observed in the mechanical and physical properties of the produced mortar. The researchers concluded that the quality of recycled fine aggregate should be high. Calcado, G. et al. [12] investigated the behavior of Portland cement mortar with three unique combinations using recycled crushed demolition waste materials. It has undergone physical and mechanical testing. The results revealed that for some ratios of replacement, there was no decrease in mortar characteristics. As a result, its performance is determined by the function mixture and the recycled natural fine aggregate replacement content. Zhang, Y., et al. [13] evaluated the impact of replacing fine aggregate in cement mortar with two types of crushed demolition waste (concrete powder and brick powder) at rates of 0, 5, 10, 20, and 50%. It was determined that concrete powder contributed more to the development of the mechanical characteristics of cement mortar than brick powder. When the replacement proportion of concrete powder and brick powder exceeded 10%, the mechanical characteristics deteriorated by more than 20%.

Hadavand, and Imaninasab [14], studied the effect of utilization of demolition waste materials on properties of concrete. Using different concentrations of waste (0%, 10%, 20%, 30%, and 50%) as a partial replacement of aggregate. They investigated the physical and mechanical characteristics of concrete using statistical analysis. The findings shown that construction and demolition waste does not have a substantial influence on compressive strength, but it noticeably impairs workability. Regarding tensile and flexural strength, a mere 50% of construction and demolition waste resulted in a significant decrease.

The significance of this work is in addressing the issue of millions of metric tons of building and demolition waste. The battle that erupted in Mosul, the second biggest city in Iraq, led to the accumulation of millions of tons. This research seeks to alleviate the significant quantities of waste produced by demolished buildings in our city. The War on Terror has resulted in significant amounts of building demolishing waste, mostly consisting of concrete, brick, ceramic, limestone, hydraulic gypsum waste, and several other sorts of waste. This research used three kinds of destroyed building waste (concrete, brick, and ceramic powder) as a viable alternative to natural fine aggregate. Furthermore, limestone powder was used as a filler. Figure 1 depicts the occurrence of crushed building waste.

Fig. 1. Illustrates a regrettable part of the damage in Mosul, Iraq [15]

2. Materials

2.1. Cement

In this study, ordinary Portland cement grade 32.5, conforming to ASTM C150 [16] requirements, from Badoosh Cement Factory in Mosul, Iraq, was used. Table 1 shows the chemical and physical parameters of the cement utilized in this study. Cement tests were carried out in accordance with ASTM C191 [17], ASTM C204 [18], ASTM C151 [19], and ASTM C109 [20].

Table 1. Chemical and physical characteristics of the used cement

Characteristics	**Value**
CaO	63.31%
SiO_2	21.44%
Al_2O_3	5.74%
Fe_2O_3	2.99%
MgO	2.19%
SO_3	2.24%
L.O.I	0.97%
Free lime	0.79%
Physical and mechanical characteristics	
Initial setting time	117 minutes
Final setting time	285 minutes
Blain	3788 m^2/kg
Autoclave	0.083%
Specific gravity	3.12
3 Days compressive strength	26.5 MPa
7 Days compressive strength	33.8 MPa

2.2. Fine aggregates and filler

Natural river sand conforming to ASTM C33 [21] was used for the control mix. Specific gravity and water absorption were 2.63 and 1.21%, respectively. From the crushed demolition waste of buildings in the ancient city of Mosul came recycled aggregate and filler. Approximately 5 m^3 were sorted, mainly consisting of concrete, bricks, ceramic, and limestone. By dry grinding and sieving, high-quality fine aggregate and filler were then produced. The limestone filler was created by crushing limestone through Sieve No. 200. Figure 2 represents the grain size distribution curves of natural and recycled aggregate.

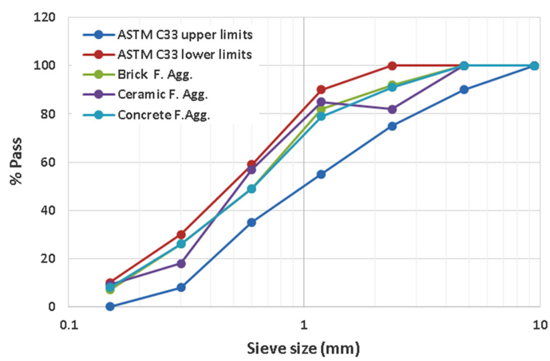


Fig. 2. The natural and recycled aggregate grain size distribution curves

3. Method

In this research, three types of recycled fine aggregate from construction and demolition waste were utilized (concrete, clay brick, and ceramic), in addition to limestone powder, which was incorporated as a filler in the cement mortar. To evaluate the mechanical properties of the produced cement mortar, 31 mixes were produced. The standards for the two mixing ratios of 1:3:0.5 and 1:4:0.5 were the ratio of replacing natural sand and the type of replaced fine aggregate (concrete, clay brick, ceramic). Ninety-three cubes of 50 × 50 mm for compressive strength, ninety-three prisms of 40 × 40 × 160 mm for flexural strength, sixty-two cylinders of 100 × 200 mm for splitting tensile strength, and ninety-three cubes of 70 × 70 mm for dry density and water absorption capacity were cast and tested to determine the compressive, flexural, splitting tensile, and dry density of the produced cement mortar.

The control mixes with proportions of 1:3 and 1:4 (cement:aggregate) were used in the manufacture of natural aggregate mortars. The recycled aggregate mortars had a (cement:aggregate:filler) ratio of 1:3:0.5 as shown in Table 2 and 1:4:0.5 as shown in Table 3. For this investigation, the replacement ratios of fine aggregates were 0% (control mix), 20%, 40%, 60%, 80%, and 100% by weight. The workability for the different mixes shown in Tables 2 and 3 was experimentally fixed from 193 to 205 mm. The cement mortar microstructure was investigated using a scanning electron microscope (SEM). Mortar specimens were collected after 28 days of curing to serve as indicative samples. Finally, the samples were submerged in anhydrous alcohol for 72 hours to prevent further hydration. Before microscopic evaluation, the materials were dried in a vacuum desiccator at 50°C for 72 hours.

Table 2. Mix proportion of recycled aggregate mortars 1:3:0.5

Mix	Cement kg/m^3	Natural fine aggregate kg/m^3	Recycled fine aggregate			Limestone filler kg/m^3	w/c	Flow mm
			Concrete kg/m^3	Brick kg/m^3	Ceramic kg/m^3			
M0	450	1350	–	–	–	225	0.49	200
MRC20	450	1080	270	–	–	225	0.49	194
MRC40	450	810	540	–	–	225	0.49	190
MRC60	450	540	810	–	–	225	0.49	184
MRC80	450	270	1080	–	–	225	0.49	178
MRC100	450	0	1350	–	–	225	0.49	162
MRB20	450	1080	–	270	–	225	0.49	178
MRB40	450	810	–	540	–	225	0.49	172
MRB60	450	540	–	810	–	225	0.49	158
MRB80	450	270	–	1080	–	225	0.49	142

Continued on next page

Table 2 – *Continued from previous page*

Mix	Cement kg/m^3	Natural fine aggregate kg/m^3	Recycled fine aggregate			Limestone filler kg/m^3	w/c	Flow mm
			Concrete kg/m^3	Brick kg/m^3	Ceramic kg/m^3			
MRB100	450	0	–	1350	–	225	0.49	131
MRCE20	450	1080	–	–	270	225	0.49	190
MRCE40	450	810	–	–	540	225	0.49	185
MRCE60	450	540	–	–	810	225	0.49	163
MRCE80	450	270	–	–	1080	225	0.49	152
MRCE100	450	0	–	–	1350	225	0.49	139

Table 3. Mix proportion of recycled aggregate mortars 1:4:0.5

Mix	Cement kg/m^3	Natural fine aggregate kg/m^3	Recycled fine aggregate			Limestone filler kg/m^3	w/c	Flow mm
			Concrete kg/m^3	Brick kg/m^3	Ceramic kg/m^3			
N01	337.5	1350	–	–	–	225	0.49	203
NRC20	337.5	1080	270	–	–	225	0.49	195
NRC40	337.5	810	540	–	–	225	0.49	188
NRC60	337.5	540	810	–	–	225	0.49	174
NRC80	337.5	270	1080	–	–	225	0.49	161
NRC100	337.5	0	1350	–	–	225	0.49	153
NRB20	337.5	1080	–	270	–	225	0.49	192
NRB40	337.5	810	–	540	–	225	0.49	188
NRB60	337.5	540	–	810	–	225	0.49	168
NRB80	337.5	270	–	1080	–	225	0.49	156
NRB100	337.5	0	–	1350	–	225	0.49	131
NRCE20	337.5	1080	–	–	270	225	0.49	196
NRCE40	337.5	810	–	–	540	225	0.49	181
NRCE60	337.5	540	–	–	810	225	0.49	174
NRCE80	337.5	270	–	–	1080	225	0.49	154
NRCE100	337.5	0	–	–	1350	225	0.49	138

4. Results and discussion

This section presents the experimental findings of the hardened mortar specimens' compressive strength, tensile strength, dry density, and water absorption tests. After 28 days of moist curing, all tests were performed. Table 4 displays the results of the cube compressive strength, prism flexural strength, and cylinder split tensile strength tests for the recycled aggregate mortars, which had a cement: aggregate: filler ratio of 1:3:0.5. Table 5 shows the results of the cube compressive strength, prism flexural strength, and cylinder split tensile strength tests for the recycled aggregate mortars with a (cement:aggregate:filler) ratio of 1:4:0.5. The results are analyzed and discussed in the following sections.

Table 4. Mechanical properties of recycled aggregate mortars 1:3:0.5

Mixes	**Compressive strength N/mm^2**	**Flexural strength N/mm^2**	**Splitting strength N/mm^2**
M0	40.5	5.704	4.98
MRC20	43.2	5.806	5.31
MRC40	37.8	5.602	4.65
MRC60	32.4	5.399	3.99
MRC80	29.2	5.278	3.59
MRC100	26.1	5.162	3.21
MRB20	34.5	4.635	3.90
MRB40	30.1	4.495	3.40
MRB60	26.5	4.380	2.99
MRB80	19.3	4.151	2.18
MRB100	17.6	4.097	1.99
MRCE20	40.3	5.258	4.55
MRCE40	35.7	5.098	4.03
MRCE60	30.2	4.907	3.41
MRCE80	26.6	4.782	3.01
MRCE100	23.5	4.674	2.66

Table 5. Mechanical properties of recycled aggregate mortars 1:4:0.5

Mixes	**Compressive strength N/mm^2**	**Flexural strength N/mm^2**	**Splitting strength N/mm^2**
N01	28.6	4.79	3.32
NRC20	31.2	4.88	3.63

Continued on next page

Table 5 – *Continued from previous page*

Mixes	Compressive strength N/mm^2	Flexural strength N/mm^2	Splitting strength N/mm^2
NRC40	27.4	4.74	3.17
NRC60	23.8	4.70	2.83
NRC80	22.2	4.55	2.71
NRC100	20.1	4.41	2.44
NRB20	27.8	4.84	3.01
NRB40	24.5	4.75	2.64
NRB60	20.2	4.42	2.11
NRB80	14.3	3.88	1.54
NRB100	11.2	3.64	1.17
NRCE20	32.4	4.89	3.83
NRCE40	27.6	4.77	3.25
NRCE60	24.2	4.71	2.88
NRCE80	20.3	4.55	2.53
NRCE100	13.4	3.67	1.64

4.1. Dry density

ASTM C642-13 [22] was followed to conduct density testing of 70×70 mm cube specimens. At 28 days, the specimens were weighed in SSD condition (W_s). The specimens were weighed both while immersed in boiling water for 5 hours (W_a) and after being evacuated from the water, which was cooled to 25°C (W_b). The density of the specimens was determined using the formula (4.1) below.

$$Density\left(\frac{\text{kg}}{\text{m}^3}\right) = \left[\frac{W_s}{W_b - W_a}\right] \cdot 1000 \tag{4.1}$$

Figure 3 presents the average density of three mortar specimens at 28 days. All specimens containing recycled fine aggregate had a lower density than the control mixes. In addition, the density of specimens containing recycled fine aggregate from construction and demolition waste decreased with the increase in the replacement ratio. These findings are consistent with those obtained by [20] and [23, 24]. As shown in Fig. 3, mixed specimens (1:3:0.5) have higher density values than their counterparts (1:4:0.5) with the same replacement ratio. Also, mixes containing recycled concrete fine aggregate from construction and demolition waste provided higher density values than those containing recycled ceramic fine aggregate and recycled brick fine aggregate. These findings are consistent with those obtained by [6, 25, 27].

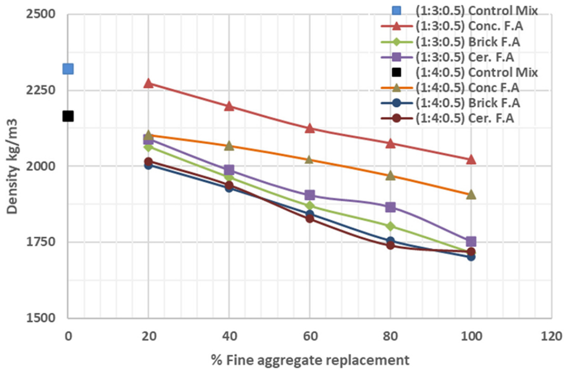


Fig. 3. Relationship between density for mortars (1:3:0.5) & (1:4:0.5) with % F.A replacement

4.2. Workability

It is typical practice in the preparation of recycled mortars to increase the amount of water included in the mixes in order to produce acceptable workability and acquire a consistency comparable to that of the reference mortar. Presoaking the recovered aggregates in water or adding more water while mixing are also viable options [23]. Mortars' workability and flowability are mostly determined by the amount of water required for mixing. The quantity of water needed for the mix is determined by the weight of cement and the percentage of water needed to produce a flowability of 110 ± 5% according to ASTM C1437 [28]. In Fig. 4, it is noticed that an increase in the replacement of fine aggregate from building and demolition waste resulted in a decrease in flowability.

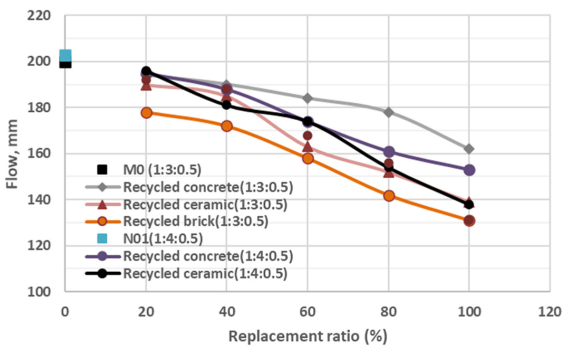


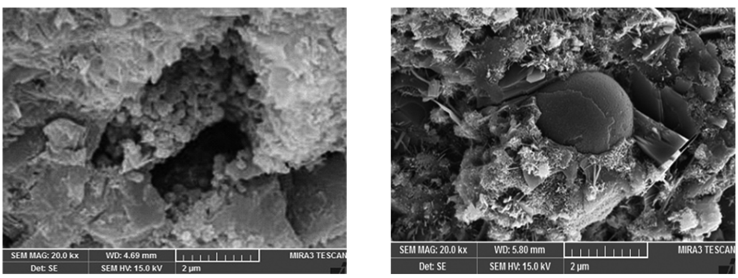
Fig. 4. Relationship between flow and replacement ratio of fine aggregate for mortars (1:3:0.5) & (1:4:0.5)

In Fig. 4, it was noticed that an increase in the replacement of fine aggregate from building and demolition waste resulted in an increase in water demand. The rise in water demand because of the following factors (1) presence of voids/pores [29], (2) more homogenous, rough, and angular texture of recycled fine aggregate tends to entangle and decrease the moment between the particles [30], (3) presence of a high amount of fine limestone particles (Tables 2 and Table 3) required for the hydration process when compared to the control mortar, (4) more amount of water is necessary to encompass the surface recycled fine aggregate to provide the mixture with higher plasticity [31, 32]. Previous research [33, 34] implies that the requirement for water rises as the recycled fine aggregate content increases to attain the same workability.

4.3. Microstructure

The optimal replacement ratio was chosen to be 20%, and Fig. 5(a), (b), (c), and (d) SEM images were compared. Figure 5 shows SEM images of specimens cured for 28 days with a) normal, b) recycled concrete, c) ceramic, and d) brick fine aggregate at a 20% replacement ratio for mortar (1:3:0.5). When compared to the control specimen, the interior microscopic morphology of the mortar specimens containing recycled fine aggregate from construction and demolition waste is comparably dense at a replacement ratio of 20%. The use of recycled fine aggregate and limestone as fillers affects the shape and amount of hydration products in cement mortar [35]. It can be observed from Fig. 5(a) that the interior microscopic morphology of the control specimen seems to be loose, and there are numerous holes. The hydration products are principally needle ettringite and flaky Ca $(OH)_2$, and the quantity of C–S–H is minimal. Figure 5(b) shows that the microstructure of cement mortar is much enhanced when recycled concrete is used as a fine aggregate. Because the aggregate's surface has become rougher, the hydration products "bite" each other to produce a greater mass of hydration products, and the interior structure is more compact, which is reflected in the remainder of the cement mortar's physical and mechanical characteristics.

Figure 5(c) shows a SEM image of cement mortar produced from a 20% replacement of natural sand by crushed ceramic waste. It demonstrates that the matrix is less crowded and evenly filled with hydration products. The number of voids in the matrix has dramatically decreased compared to the control mix. This finally lowers the porosity, causing a slight increase in physical and mechanical characteristics [36]. Figure 5(d) depicts the microstructure of the cement mortar that includes the brick waste as a fine aggregate. It is easy to notice the presence of interfacial disintegration in the internal structure of the cement mortar. The reason may be due to poor adhesion between the brick particles and the cement matrix. Also, the need to increase the w/c, which weakens the bonding area, in general, the physical and mechanical properties of cement mortar decreased with the increase in the percentage of replacing fine aggregate with brick waste [37].



(a) (b)

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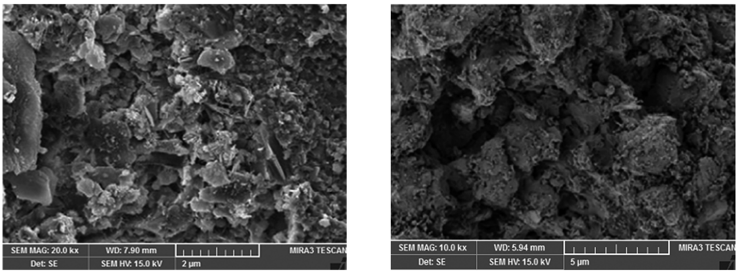

(c) (d)

Fig. 5. Relationship between density for mortars (1:3:0.5) & (1:4:0.5) with % F.A replacement

4.4. Compressive strength

One of the most essential properties of cement mortar is its compressive strength. It is influenced by the quantity of mix, aggregate type, curing time, quality, and water-cement ratio [38]. According to past experience, compressive strength has a considerable impact on the performance characteristics of the mixture as well as the overall quality of the completed product. The compressive strength of natural and recycled fine aggregate mortar is shown in this section for the two tested mortar mixtures (1:3:0.5) and (1:4:0.5). The compressive strengths of the control mix and the three types of crushed demolition waste fine aggregate mortar are shown in Figs. 6 and 7.

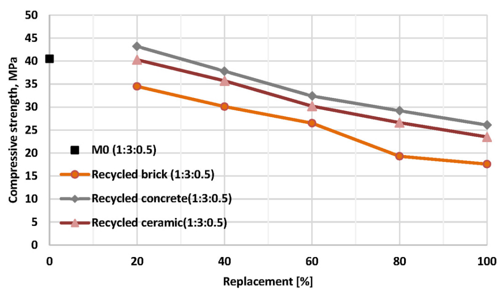

Fig. 6. Relationship between mortar compressive strength and replacement ratio for mixtures (1:3:0.5)

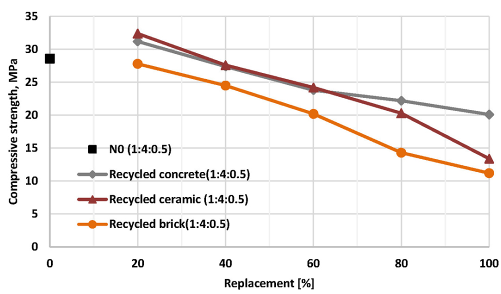

Fig. 7. Relationship between mortar compressive strength and replacement ratio for mixtures (1:4:0.5)

The results showed that substituting natural fine aggregate with 20% recycled construction and demolition waste (fine concrete aggregate, fine brick aggregate, or fine ceramic aggregate) resulted in cement mortar with slightly greater compressive strength than the control mix. As the amount of construction and demolition waste used as a substitute for fine aggregate increased, compressive strength decreased gradually. This behavior is consistent with prior research [39]. As shown in Figs. 6 and 7, when utilizing 20% recycled fine aggregate concrete waste, the compressive strength of the cement mortar increased by roughly 8%. Following that, there was a considerable drop and deterioration in the compressive strength of the cement mortar whenever the natural fine aggregate was replaced by recycled fine aggregate concrete. In comparison to the control mix, the cement mortar containing 100% recycled fine aggregate lost roughly 30% to 36% of its strength. This might be owing to the high percentage of fine components in recycled concrete aggregate. The behavior was virtually the same in the case of employing brick and ceramic waste as fine aggregate in cement mortar, except that there was no gain in compressive strength compared to the control mix.

In the case of fines, ceramics and brick aggregate from construction and demolition waste may have some pozzolanic reactivity, but fine aggregates of ceramics and bricks larger than 0.150 mm are also possible. It is also possible that other chemicals besides pozzolanicity and physical properties such as absorption, shape, and rough interactions between materials may contribute to this increase or slight decrease in strength at lower replacement ratios (20 and 40%).

4.5. Flexural strength

This test was carried out in accordance with ASTM C348 [40] by applying an increasing force in the middle band of a 40 × 40 × 160 mm slurry prism. Three specimens were used from each type of mortar that had previously undergone a 28-day curing period. The results are shown in Figs. 8 and 9. Their variation is normal for mortars and shows no visible trend in terms of the addition of recycled aggregate. The flexural strength increased relative to the proportions of sand replacement with recycled fine aggregate waste, reaching about 20 to 40%, respectively. To obtain higher replacement ratios, the flexural strength decreased in all mixes containing fine aggregate from the used construction and demolition waste. However, a greater decrease in flexural strength was observed when rubble brick waste was used.

According to Silva et al. [41], who showed that the inclusion of fine aggregate recovered from construction and demolition debris might have a detrimental impact on compressive and flexural strength, this drop is consistent with the literature that is currently accessible. However, the initial gradual fall may have been caused by a combination of the pozzolanic impact [42, 43] of these ceramic, brick-demolished waste fine aggregates and the influence of limestone powder as a filler [44, 45]. However, the result showed the same flexural strength behavior for the two tested mortar mixtures (1:3:0.5) and (1:4:0.5). However, the error bars in Figs. 8 and 9 showed that there are no significant different in individual data points vary around the mean value of flexural strength of mortar mixtures (1:3:0.5) and (1:4:0.5). In Fig. 9, the error bars of flexural strength in mixture (1:4:0.5) were lower, which indicates that the results of flexural strength were very close to the average flexural strength of these mixture.

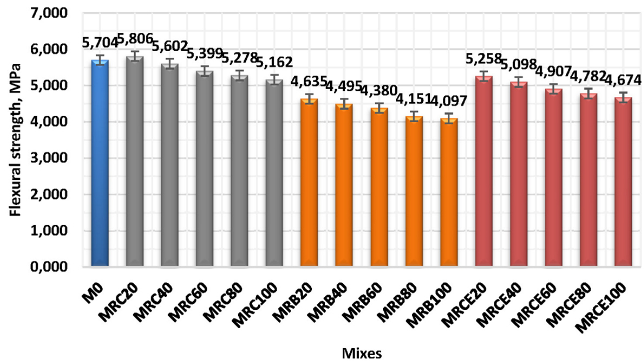

Fig. 8. Distribution of mortar flexural strength for mixtures (1:3:0.5)

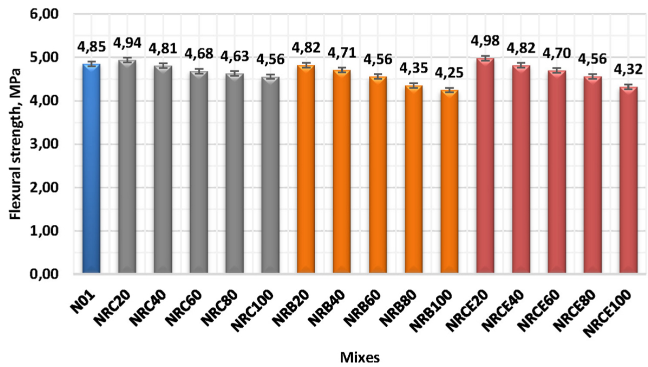

Fig. 9. Distribution of mortar flexural strength for mixtures (1:4:0.5)

For flexural strength, the impact of nailing cement paste to recycled aggregates due to their greater porosity and angle is a feasible explanation [46, 47]. Similar results were got when replacing natural sand with recycled fine concrete aggregates to produce cement mortar, i.e., a positive trend for lower replacement ratios and a negative trend for higher replacement ratios. This analysis did not account for another potential source, which is the cement hydration process from collected recycled concrete particles that were previously dissolved in water when producing the original concrete [48–50].

4.6. Splitting tensile strength

In this investigation, tensile strength is evaluated using a tensile test method in line with ASTM C496 [51]. In this test, the sides of the mortar cylinder are subjected to the application of diametrically opposed compressive stresses. The cylinders used in this investigation were 100 mm by 200 mm in size. Figs. 10 and 11 depict the results of tensile strength tests conducted on mixes (1:3:0.5 and 1:4:0.5, respectively), including several types of recycled fine aggregates made from construction and demolition waste.

The tensile strength testing results for the 1:30.5 mix show that the cement mortar prepared with recycled fine aggregate from concrete waste at a replacement ratio of 20% is slightly more tensile than the same mortar manufactured with natural fine aggregate. However, when the percentage of fine aggregate replacement rises in the recycled concrete aggregates and cement mortar, a progressive decline of 11–16% in tensile strength is shown. The error bars in Figs. 10 and 11 showed that there are no significant different in individual data points vary around the mean value of splitting strength of mortar mixtures (1:3:0.5) and (1:4:0.5). In Fig. 11, the error bars of splitting tensile strength in mixture (1:4:0.5) were lower, which indicates that the results of splitting tensile strength were very close to the average splitting tensile strength of these mixture.

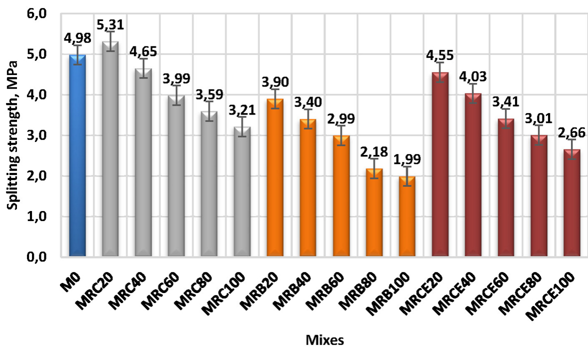

Fig. 10. Splitting strength for mixtures (1:3:0.5)

As shown in Fig. 11, the results of the 1:4:0.5 mixtures showed a trend almost similar to that of the 1:3:0.5 mixtures, except an increase in splitting strength in the mixtures containing ceramic waste as a fine recycled aggregate with a replacement ratio of 20%. When the percentage of recycled ceramic fine aggregates was increased, the splitting strength gradually decreased. Generally, mixtures that contained brick waste used as a replacement for fine aggregate showed a significant decrease in splitting strength compared to the reference mixture or the rest of the other mixtures tested.

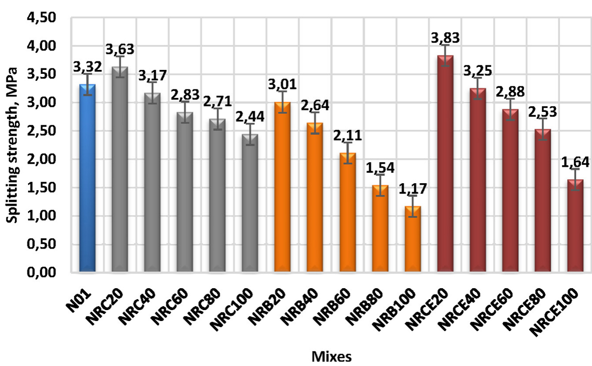

Fig. 11. Splitting strength for mixtures (1:4:0.5)

5. Conclusions

In this research, three types of construction and demolition waste as a fine aggregate in cement mortar were investigated for the production of recycled mortars, their characteristics were then studied, and the following results may be drawn:

1. The flowability of the recycled mortar decreased with the increase in the proportion of recycled aggregate from construction and demolition waste. This decrease in flowability was mainly due to the higher absorption rates, rougher surfaces, and particles of completely irregular shape than the recycled aggregates.
2. According to experimental results, the optimal replacement ratio of recycled fine aggregate from construction and demolition waste as a partial replacement for natural fine aggregate was 20% for the three kinds utilized. The physical and mechanical properties significantly improved. The use of recycled aggregates from construction and demolition waste in the manufacture of new eco-friendly mortar can be useful for both environmental and economic aspects in the construction industry.
3. An increase in the replacement ratio decreased the density, compressive, flexural, and splitting strengths of all mortars using recycled fine aggregate from construction and demolition waste. This is conclusive proof that the replacement ratio is a significant factor influencing the physical and mechanical characteristics of the produced mortar.
4. Recycled concrete fine aggregate mortar had lower water consumption, higher density, and higher compressive, flexural, and rupture strengths than clay brick powder aggregate and fine aggregate for ceramic powder at the same replacement ratio. This shows the effect of using recycled concrete fine aggregate and limestone as fillers on the form and amount of hydration products in cement mortar.
5. According to the search results SEM scanning and testing of mortar incorporating recycled concrete fine aggregate reveals the recycled fine aggregate retains traces of cement and has some binding characteristics. The strength of the result is related to the fact that the addition of water to the recycled sand activates some of the binding characteristics provided by the traces of cementitious material that had not been hydrated previously.
6. The statistical analysis of the experimental data revealed no significant variations in the error bars. This suggests that the test results were well controlled and of very good quality.
7. The utilizing of recycled fine aggregate from demolition waste might prove to be advantageous in the process of rehabilitating devastated regions, reconstructing cities, or recycling existing materials.

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Received: 2024-06-17, Revised: 2024-07-18