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Impact of Glass Waste on the Flexural, Compressive, and Direct Tension Bonding Strengths of Masonry Bricks

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ABSTRACT

The waste material problem in today’s world has become a major topic affecting all sectors of human life. Researchers are interested in providing solutions for each kind of waste material. Waste glass is one of the waste materials whose amounts increase daily. This article deals with two types of modified cement mortar with glass granular in the masonry wall to find their effect on the wall’s property (direct tensile, flexural, and compressive bond strength). Seven different mixes were prepared according to the used glass granular ratio (three mixes contained white glass with 15, 20, and 25% while three of them contained green glass granular 5, 10, and 15%, and the last mix was a controlled mix which contains no glass granular). Based on the obtained result, the used white glass granular provides optimum compression and direct tensile bond strength when 20% of sand is replaced with white glass granular; optimum direct tensile bond value was obtained, which increased by 1.4% and increased compressive strength by 13.08% compared to control mortar. Green glass granular provides optimum compression and direct tensile bond strength when 10% of sand is replaced, direct tensile strength by 1.02%, and increased compressive strength by 3.7% compared to control mortar. The increase of the used waste glass granular in the mortar decreases flexural bond strength, and the amount of decrease depends on the chemical glass compositions.

Keywords: Compressive and Flexural bond strength, Direct tensile bond strength, Mortar, Masonry, White, and Green waste glass.

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تأثير نفايات الزجاج على قوة الترابط الانحنائي والانضغاطي والمبادر لطابوق البناء

الملخص

أصبحت مشكلة النفايات في عالمنا اليوم موضوعا رئيسيا يؤثر على جميع قطاعات الحياة البشرية. حيث يهتم الباحثون بتوفير حلول لكل نوع من أنواع النفايات. نفايات الزجاج هي واحدة من النفايات التي تزداد كمياتها يوميا. تناولت هذه الدراسة استخدام نوعين من الملاط الأسمنتاني المعجل مع الحبيبات الزجاجية بنسب معينة لدراسة تأثيرهما على الجار الطابوقي (قوة الشد المباشر ومقاومة الانضغاط). تم تحضير سبعة خلطات مختلفة اعتمادا على لون واعللم حبيبة للحفاضات الزجاجية المستخدمة (ثلاثة خلطات تحتوي على حفاضات زجاج أبيض بنسبة 15 و 20 و 25٪ بينما احتوت ثلاثة منها على حفاضات حفاظات الزجاج الأخضر بنسبة 5 و 10 و 15٪). بناء على النتيجة التي تم الحصول عليها من هذه الدراسة، فإن الزجاج الأبيض الحبيبي المستخدم أعطى مقاومة انضغاطية جيدة وقوة رابطة الشد المباشرة عند استبدال 20٪ من الرمل المستخدم بحفيصات زجاج الأبيض؛ حيث أظهرت زيادة في القيمة المطلقة لقوة الشد المباشرة بنسبة 1.4٪ بينما زادت من قوة الانضغاط بنسبة 13.08٪ مقارنة بملاء التحكم الخالي من الحبيبات. بينما في الملاط الخرساني المستخدم مع استبدال 10٪ من الرمل بحفيصات زجاج الأخضر الحبيبي حسبت من قوة الشد المباشر بنسبة 1.02٪، وأعطت زيادة لقوة الانضغاط للطابوق المستخدم بنسبة 3.7٪ مقارنة بملاء التحكم. كما بينت الدراسة زيادة التفاعلات الزجاجية الحبيبية المستخدمة في الملاط تقلل من قوة الرابطة الانحنائية، وتعتمد كمية الانخفاض على تركيبات الزجاج الكيميائي.

الكلمات الرئيسية: مقاومة الانضغاط، مقاومة الشد المباشرة، تداخل، نفايات الزجاج الأبيض والأحمض.

1. Introduction:

Since the waste materials increased with the population and the requirement of life, continuously adding these materials to the landfill led to the impurity of the water sources and the landfill [Ogunsaro et al., 2019, Altufaily et al., 2019]. For these reasons, waste materials must be collected, reused, or recycled [Zeng et al., 2020]. Waste materials include different types and can be reused for different functions, such as eggshells as cement replacement [Abdulhameed et al., 2021], plastic waste as fibre in concrete [Abdulhameed et al., 2022], scraped tire as recycled rubber aggregate [Abdulhameed et al., 2021], waste crashed clay brick [Abaas et al., 2022]. One of these materials is waste glass; its waste increase day after day is glass since it has so many functions in human life [Papadogeorgos and Schure, 2019]. Based on the provided data in Figure1 [EPA, 2018] represent, the number of glasses produced by tones in the US between 1960 to 2018 as landfills. These subjects take interest many researchers to find a way to reuse this amount of waste glass instead of putting it on the land, including using the waste glass as partial replacement of sand in the mortar [Zeng et al., 2020] or using with other waste material inside mortar or concrete [Alshemare et al., 2022]. Mortar can be used in plastering or as bonding between masonry units since masonry is the oldest history today and is used in wall construction [Kamal et al., 2014, Lourenço., 1998]. Walls are subjected to different loadings, such as
bending, gravity, or seismic loads. Real structure size cannot be tested to find the effect of these different loads; for this reason, a small-scaled size will be used [Sathiparan et al., 2008]. These loadings supported by bonding include the shear bond strength [Sathiparan et al., 2008 – Sathiparan and Rumeshkumar., 2018] and flexural bond strength [Maheri et al., 2011, Sarangapani et al., 2008, Lourenço., 1998 – Thamboo., 2020], using [ASTM, E518., 2015], and direct tensile bond [Sathiparan et al., 2008, Maheri et al., 2011, Thamboo., 2020, Sathiparan and Rumeshkumar., 2018] using [ASTM, C321., 2012], with gravity load which controlled by compressive strength bond [Kamal et al., 2014 - Sathiparan and Rumeshkumar., 2018], using [ASTM, C1314., 2016], using modified mortar must satisfy the required amount of the bond to be stable during subjected to these loads. This article deals with applying the mortar modified with waste glass granular as a partial replacement of sand in the masonry walls and finding the effect of the used glass granular in the mortar on the flexural, compression, and direct tension bonds between masonry units and obtained mortar.

![Fig.1 Waste glass amount in the United States based on a given year](image)

2. Methodology:

Seven different mixes of mortar have been prepared, the first one without any addition of waste glass, while three of these mixes have been modified with white waste glass using 15, 20, and 25 % as a partial replacement of fine aggregate in mortar, another three mixes have modified with green waste glass using 5, 10 and 15% as a partial replacement of fine aggregate in a mortar [Ahmad, 2022]. These seven mixes have been used to prepare samples for compression, direct tension, and flexural bond strength to find the effect of
adding glass granular to the mortar on these bonds compared to control samples. The experimental workflow chart explained in Figure 2:

3. Materials:

Waste bottle glasses (Two different colors) have been used as sand replacement in mortar, confirming the standard grading of sand as shown in [ASTM, C778., 2017]. Figure 3; an SEM test has been done to show the microstructure of waste glass as in Figure 4 and Figure 5, while their physical properties and chemical composition have been described in Figure 6 and Table 1. The used cement was obtained from the Taslwja Cement Factory (35.6224746, 45.2115668) in Sulaimani City; the cement’s chemical composition and physical properties are shown in Table 2 and Table 3, respectively. These properties are observed to conform to [ASTM, C150., 2005]. The SEM image of the used cement particle size and its texture are shown in Figure 7. The sand was used according to [ASTM, C778., 2017], and sieve analysis was performed, while its physical properties are demonstrated in Table 5. Tap water was used throughout the experiments according to [ASTM, D1293., 2018], and the tap water pH was 7.3 at 25 °C. Clay bricks were used for compressive, direct tensile, and flexural bond strength tests; the dimensions of each sample have been taken as in Table 6 and compared to the required dimensions by the purchaser (75*115*235 mm) with allowable tolerance as provided in Table1 in [ASTM, C62., 2013], all dimensions were acceptable and within the allowable limits. Based on the requirement described in [ASTM C67., 2017], five samples were broken in half, according to procedures provided in [ASTM C67., 2017], physical properties were determined and recorded as in Table 6, and the obtained results were compared to the given specification in [ASTM, C62., 2013]. As a result, used bricks can be classified as grade severe weathering (SW).
**Fig.3** Granulated glass with standard sand grads (0.150 – 1.18 mm) (Scale (1:1))

**Fig.4** Particle structure of white glass using SEM test
Fig. 5 Particle structure of green glass using SEM test
**Fig. 6** Chemical composition of white and green glass

### Table 1 Physical properties of white and green glass

| Properties                  | Green Glass | White glass | Standards        |
|-----------------------------|-------------|-------------|------------------|
| Oven dry specific gravity   | 2.52        | 2.56        | ASTM C128., 2015 |
| Water absorption            | 0.16%       | 0.16 %      | ASTM C128., 2015 |
| Fineness modulus            | 3.154       | 3.15        | ASTM C136., 2019 |
| Dry density                 | 1284 kg/m³  | 1403 kg/m³  | ASTM C29., 2017  |

**Table 2** Chemical composition of cement

| Composition name               | Composition percentage (%) | Allowable limit (%) |
|--------------------------------|----------------------------|---------------------|
| SiO₂ (Silicon dioxide)         | 19.12                      | -                   |
| Al₂O₃ (Aluminum oxide)         | 4.53                       | 6 (max)             |
| Fe₂O₃ (Iron(III) oxide)        | 4.55                       | 6 (max)             |
| CaO (Calcium oxide)            | 62.52                      | -                   |
| MgO (Magnesium oxide)          | 3.75                       | 6 (max)             |
| SO₃ (Sulfur trioxide)          | 2.42                       | 3 (max)             |
| K₂O (Potassium oxide)          | 0.47                       | -                   |
| Element                                | Value  | Unit     |
|----------------------------------------|--------|----------|
| Na₂O (Sodium oxide)                    | 0.12   |          |
| CO₂ (Carbon dioxide)                   | 2.53   |          |
| LSF (Lime Saturation Factor)           | 101.12 |          |
| Silica Ratio                           | 2.1    |          |
| Aluminum Ratio                         | 0.995  |          |
| C₃S                                    | 65.39  |          |
| C₂S                                    | 5.45   |          |
| C₃A                                    | 4.31   | 8 (max)  |
| C₄AF                                   | 13.86  |          |

Table 3: Physical properties of cement

| Tests name                        | Tests result | Allowable limit | Units   |
|-----------------------------------|--------------|-----------------|---------|
| Fineness [ASTM C115., 2010]       | 3535         | 2600-4300       | cm²/gr  |
| Normal consistency [ASTM C187., 2016] | 26.9        | -               | %       |
| Initial setting time [ASTM C191., 2019] | 140         | 45 (minimum)    | Minute  |
| Final setting time [ASTM C191., 2019] | 190         | 375 (maximum)   | Minute  |
| Specific Gravity [ASTM C188., 2017]    | 3.14        | -               |         |
| Density [ASTM C188., 2017]           | 1.44         | -               | gr/cm³  |
Fig. 7 SEM, Microstructure of cement particles

Fig. 8 Sieve analysis of used sand
**Table 4** Physical properties of standard sand

| Properties                     | Green Glass | Standards        |
|-------------------------------|-------------|------------------|
| Fineness modulus              | 2.42 %      | ASTM C136., 2019 |
| Oven dry specific gravity     | 2.63        | ASTM C128., 2015 |
| Dry compacted density         | 1574 kg/m³  | ASTM C29., 2017  |
| Water absorption              | 1%          | ASTM C128., 2015 |
| Particles finer than 75μm     | 0.94%       | [ASTM C33., 2013, ASTM C117., 2017] |

**Table 5** Bricks dimension as described in the sketch

| Sample | L1 (mm) | L2 (mm) | L3 (mm) | L4 (mm) | W1 (mm) | W2 (mm) | W3 (mm) | W4 (mm) | H1 (mm) | H2 (mm) | H3 (mm) | H4 (mm) |
|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| S1     | 235     | 236     | 235.5   | 236     | 114     | 114     | 114     | 114     | 73      | 73      | 73      | 73      |
| S2     | 235     | 236     | 237     | 236     | 114     | 114     | 114     | 114     | 73      | 73.5    | 73      | 73.5    |
| S3     | 236     | 236     | 236     | 236     | 114     | 114     | 114     | 114     | 73      | 73      | 73      | 73      |
| S4     | 236     | 235.5   | 236     | 236     | 113     | 113     | 114     | 114     | 73      | 73      | 74      | 74      |
| S5     | 235     | 235     | 236     | 236     | 114     | 114     | 114     | 114     | 73      | 74      | 73      | 73      |

Tolerance |
7.9       | 4.8      | 2.4      |
Table 6 Physical properties of brick

| Sample Name | W.s (gr) | W.d (gr) | W.b (gr) | Load (N) | Water absorption (%) | Coefficient of saturation | Compressive strength (MPa) |
|-------------|----------|----------|----------|----------|----------------------|--------------------------|---------------------------|
| S1          | 1319.5   | 1184     | 1387     | 323600   | 17                   | 0.66                     | 23.94                     |
| S2          | 1327.2   | 1187     | 1377     | 296000   | 16                   | 0.73                     | 21.90                     |
| S3          | 1325     | 1191     | 1369.5   | 358500   | 15                   | 0.75                     | 26.53                     |
| S4          | 1333.2   | 1191     | 1394     | 303500   | 17                   | 0.7                      | 22.46                     |
| S5          | 1320     | 1187     | 1377.5   | 341400   | 16                   | 0.69                     | 25.26                     |

Where:

w.s: saturated weight of brick after 24 hours of immersion in water
w.d: dry weight of brick after 24 hours in the oven
w.b: brick weight after 5 hours of boiling

4. Mix proportions:

Based on the provided condition in [ASTM C1329., 2016], a mix composition of 1:2.5 has been chosen as cement to the sand ratio for the required mortar type (M). Used mortar must pass flow condition 110±5 as in [ASTM C109., 2021] and obtain by using a w/c ratio of 0.67. Used replacement ratios of glass were as follows for each type of glass (white and green bottle glass). Mortar compositions have mixed as described in the [ASTM C305., 2020].

Table 7 Mix proportions for each type of glass

| Mix Name | Replacement percent | Mix Ratio | w/c  | Water (kg/m³) | Cement (kg/m³) | Sand Content (kg/m³) | Glass Content (kg/m³) |
|----------|----------------------|-----------|------|---------------|----------------|----------------------|-----------------------|
| Control Mix | 0                  | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1507.3               | 0                     |
| M1       | 5                    | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1431.9               | 75.36                 |
| M2       | 10                   | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1356.6               | 150.73                |
| M3       | 15                   | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1281.2               | 226.1                 |
| M4       | 20                   | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1205.85              | 301.5                 |
| M5       | 25                   | 1:2.5:0.67 | 0.67 | 404.3         | 602.9          | 1130.475             | 376.82                |
5. Experimental Works and Results:

This section aims to determine the effect of the added waste glass granular to mortar on the compressive, flexural, and direct tensile bond strength between mortar and brick masonry:

5.1 Direct tensile bond strength:

This test was used to find the amount of the bond strength between mortar and masonry brick when subjected to the direct tensile load based on the [ASTM, C321., 2012]. Six samples have been prepared for each mix. Six samples have been prepared for each mix, equal to forty-two-sample as in Figure 9, and subjected to the load rate as in Figure 10, which creates movement of 6 mm/min. The maximum applied load has been recorded, and a direct tensile bond has been found by dividing the failure load by the bond area. Obtained results are summarized in Figure 11:

![Fig.9 Prepared samples for direct tensile bond in masonry for different mixes](image-url)
Based on the obtained Result, Direct tensile bond strength increases when the mortar contains 10% of green glass granular as a sand replacement and provides tensile bond strength higher than the control mortar by 1%, while this percent becomes 1.84% when the mortar modified with 20% of white glass.

### 5.2 Compression bond strength:

This test was used to find the bond strength between mortar and masonry brick when subjected to the Compressive load based on the [ASTM, C1314, 2016]. For each mortar,
three samples have been prepared, a total of twenty-one samples prepared as in Figure 12, and subjected to the load rate as in Figure 13, causing the failure of the sample between 1 to 2 minutes, and the maximum applied load has been recorded. A compression bond has been found by dividing the failure load into the bond area. Obtained results are summarized in Table 8 and Figure 14 below:

![Prepared samples of compressive bond in masonry with modified mortar](image1)

**Fig.12** Prepared samples of compressive bond in masonry with modified mortar

![Compression bond test sample that its mortar contains 5% of green waste glass under load machine](image2)

**Fig.13** Compression bond test sample that its mortar contains 5% of green waste glass under load machine

Since the ratio of hp/tp is equal to 1.39, for this reason, based on the ATSM, C1314, the correction factor will be 0.7995
Based on the obtained result, compressive strength bond strength increase when the mortar contains 10% of green glass granular as a sand replacement and provides compressive bond strength higher than the control mortar by 3%, while this percent becomes 13.8% when the mortar is modified with 20% of white glass, and in the most cases the failure mode faced shell separations as in Figure 15 below:

**Table 8** Compression bond strength results:

| Mortar modified with Green Glass | Compressive strength bond (MPa) | Compressive strength bond (%) | Mortar modified with White Glass | Compressive strength bond (MPa) | Compressive strength bond (%) |
|----------------------------------|----------------------------------|-----------------------------|----------------------------------|----------------------------------|-----------------------------|
| 0                                | 19.5                             | -                           | 0                                | 19.5                             | -                           |
| 5                                | 16.3                             | -16.4                       | 15                               | 18.7                             | -4.1                        |
| 10                               | 20.1                             | +3.07                       | 20                               | 22.2                             | +13.8                       |
| 15                               | 18.3                             | -6.1                        | 25                               | 17.9                             | -8.2                        |

**Fig.14** Compression bond for all mixes
5.3 **Flexural bond strength:**

This test was used to find flexural bond strength in masonry, using [ASTM, E518, 2015]. Five samples have been prepared for each type of mortar, a total of thirty-five samples as in **Figure 16**. The weight of all samples, has been taken and recorded after the prepared samples have loaded at a rate that provides the failure of the sample in the time between (one to three) minutes, as shown in **Figure 17**. After loading, the maximum load, which provides the failure of the sample, has recorded as the maximum applied load, and the flexural strength founded using the equation below:

\[
R = \frac{(P + 0.75*Ps)*l}{b*d^2}
\]  \hspace{1cm} (1)

Where:

P: Maximum applied load recorded as failure load (N)

Ps: Weight of samples (N)

l: Span (mm)

b: Average width of samples (mm)

d: Average depth of samples (mm)
Fig. 16 Prepared samples for Flexural bond in masonry with modified mortar

Fig. 17 Flexural bond test sample under load machine

Fig. 18 Flexural bond for all mixes
Table 9 Flexural bond strength results:

| Mortar modified with Green Glass | Flexural strength bond (MPa) | Flexural strength bond (%) | Mortar modified with White Glass | Flexural strength bond (MPa) | Flexural strength bond (%) |
|----------------------------------|-----------------------------|-----------------------------|---------------------------------|-----------------------------|-----------------------------|
| 0                                | 1.53                        | -                           | 0                               | 1.53                        | -                           |
| 5                                | 1.41                        | -7.8                        | 15                              | 1.46                        | -4.57                       |
| 10                               | 1.34                        | -12.41                      | 20                              | 1.18                        | -22.9                       |
| 15                               | 1.33                        | -13                         | 25                              | 1.11                        | -27.4                       |

Based on the obtained results as in figure 18 and Table 9, the increase of the waste glass percent in mortar as replacement of sand decreases the flexural strength, and the amount of the decrease depends on the chemical composition of the glass granular.

Conclusions:

Based on the reviewed work and the obtained experimental data, the following points are obtained:

1- The effect of Waste glass granular in the mortar depends on its chemical compositions

2- When 20% of the sand was replaced with white glass granular, the optimum direct tensile bond value was obtained by 1.4% compared to the control mortar.

3- When 10% of the sand was replaced with green glass granular, the optimum direct tensile bond value was obtained, which increased by 1.02% compared to the control mortar.

4- When 20% of the sand was replaced with white glass granular, the optimum compressive strength value was obtained, which increased by 13.08% compared to the control mortar.

5- When 10% of the sand was replaced with green glass granular, the optimum compressive strength value was obtained, which increased by 3.7% compared to the control mortar.

6- Different percentages of waste glass (green and white colour) negatively affect flexural strength in a mortar, and the decrease depends on the chemical glass compositions.

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