University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 28 Number 11 November 2022

Civil and Architectural Engineering

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

Serwan Kh. Rafiq*
Asst. Prof. Dr.
College of Engineering
University of Sulaimani
Sulaimani, Iraq
serwan.rafiq@univsul.edu.iq

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.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.11.07

Article received: 10/8/2022
Article accepted: 10/10/2022
Article published: 1/11/2022

تأثير نفايات الزجاج على قوة الترابط الانحنائي والانضغاطي والمباشر لطابوق البناء

ا.م.د. سيروان خورشيد رفيق
استاذ مساعد
جامعة السليمانية كلية الهندسة

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 الاسمنتي المعدل مع الحبيبات الزجاجية بنسب معينة لدراسة تأثيرهما على الجار الطابوقي من حيث (قوة الشد المباشر وقوة الانثناء ومقاومة الانضغاط). تم تحضير سبعة خلطات مختلفة اعتمادا على لون و النسبة الحبيبية للمخلفات الزجاجية المستخدمة (ثلاثة خلطات تحتوي على مخلفات زجاج أبيض بنسبة 15 و 20 و 25٪ بينما احتوت ثلاثة منها على حبيبات مخلفات الزجاج الأخضر 5 و 10 و 15٪ ، وكانت الخلطة الاخيرة عبارة عن ملاط خرساني خالي من الحبيبات الزجاجية). بناء على النتيجة التي تم الحصول عليها من هذه الدراسة ، فان الزجاج الأبيض الحبيبي المستخدم اعطت مقاومة انضغاطية جيدة وقوة رابطة الشد المباشرة عند استبدال 20٪ من الرمل المستخدم بحبيبات مخلفات الزجاج الأبيض ؛ حيث اعطت زيادة في القيمة المثلى لقوة الشد المباشرة بنسبة 1.4٪ بينما زادت من قوة الانضغاط بنسبة 13.08٪ مقارنة بملاط التحكم الخالي من الحبيبات . بينما في الملاط الخرساني المستخدم مع استبدال 10٪ من الرمل بمخلفات الزجاج الأخضر الحبيبي حسنت من قوة الشد المباشر بنسبة 1.02٪ ، واعطت زيادة لقوة الانضغاط للطابوق المستخدم بنسبة 3.7٪ مقارنة بملاط التحكم. كما بينت الدراسة زيادة النفايات الزجاجية الحبيبية المستخدمة في الملاط تقلل من قوة الرابطة الانحنائية ، وتعتمد كمية الانخفاض على تركيبات الزجاج الكيميائي.

الكلمات الرئيسية: مقاومة الانضغاط، مقاومة الشد المباشرة، مقاومة الانثناء،الطابوق،نفايات الزجاج الابيض والاخضر.

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 [**Ogundairo 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 [**Al shemaree et al., 2022**]. Mortar can be used in plastering or as bonding between masonry units since masonry has 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.

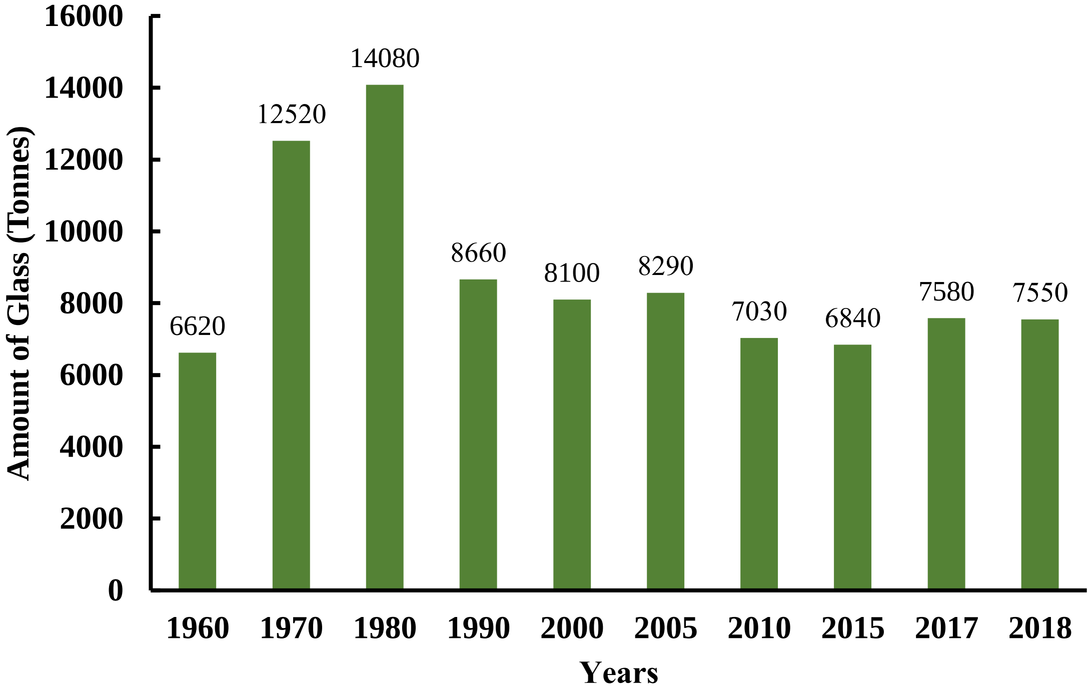


Fig.1 Waste glass amount in the United States based on a given year

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 char explained in **Figure 2**:

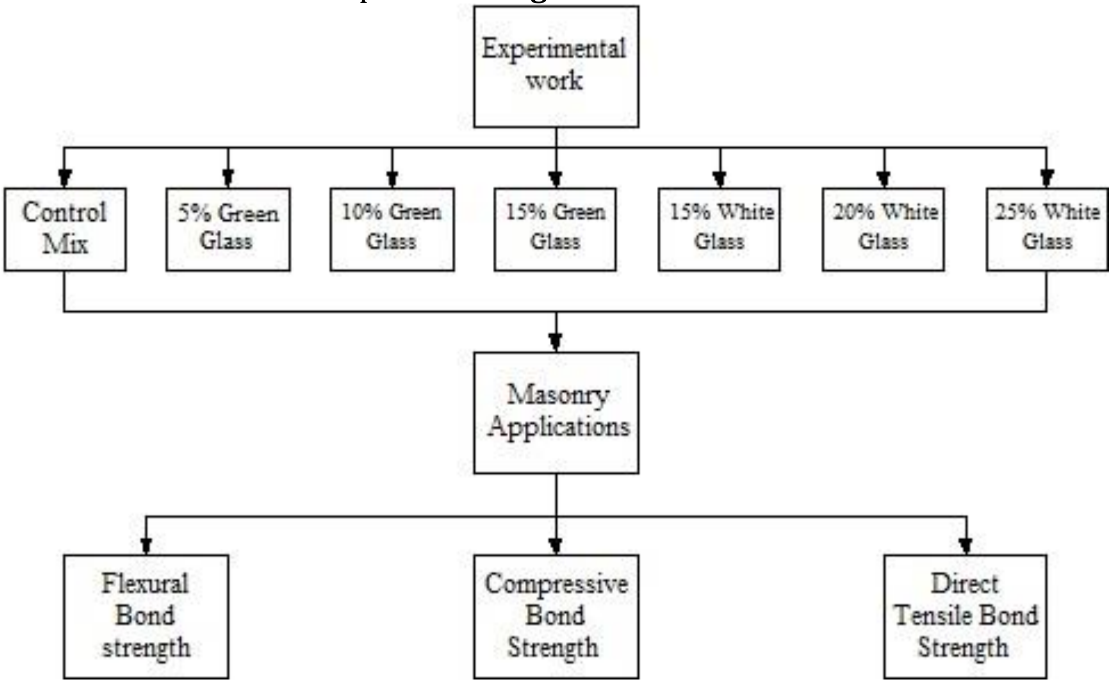


Fig.2 Experimental workflow charts

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 **Table5**. Tap water was used throughout the experiments according to [**ASTM, D1293., 2018**], and the tap water pH was 7.3 at 25 ^{o}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).

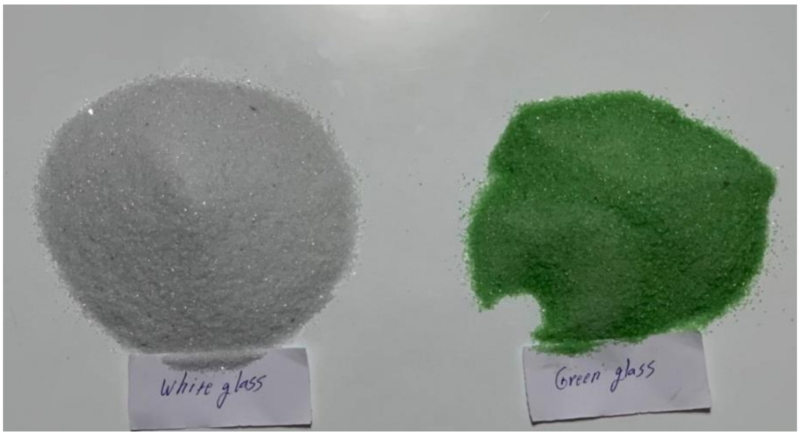


Fig.3 Granulated glass with standard sand grads (0.150 – 1.18 mm) (Scale (1:1))

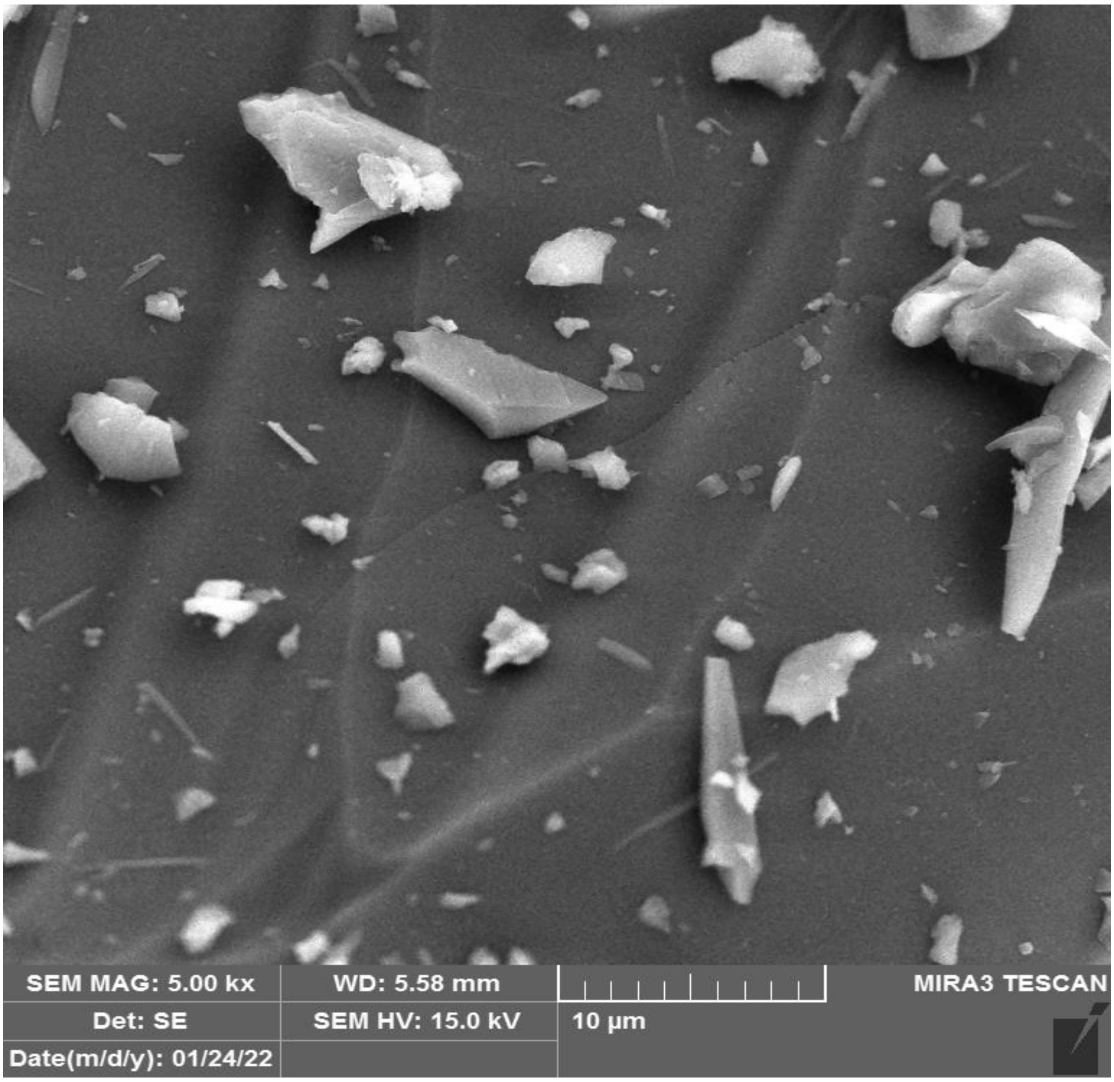


Fig.4 Particle structure of white glass using SEM test

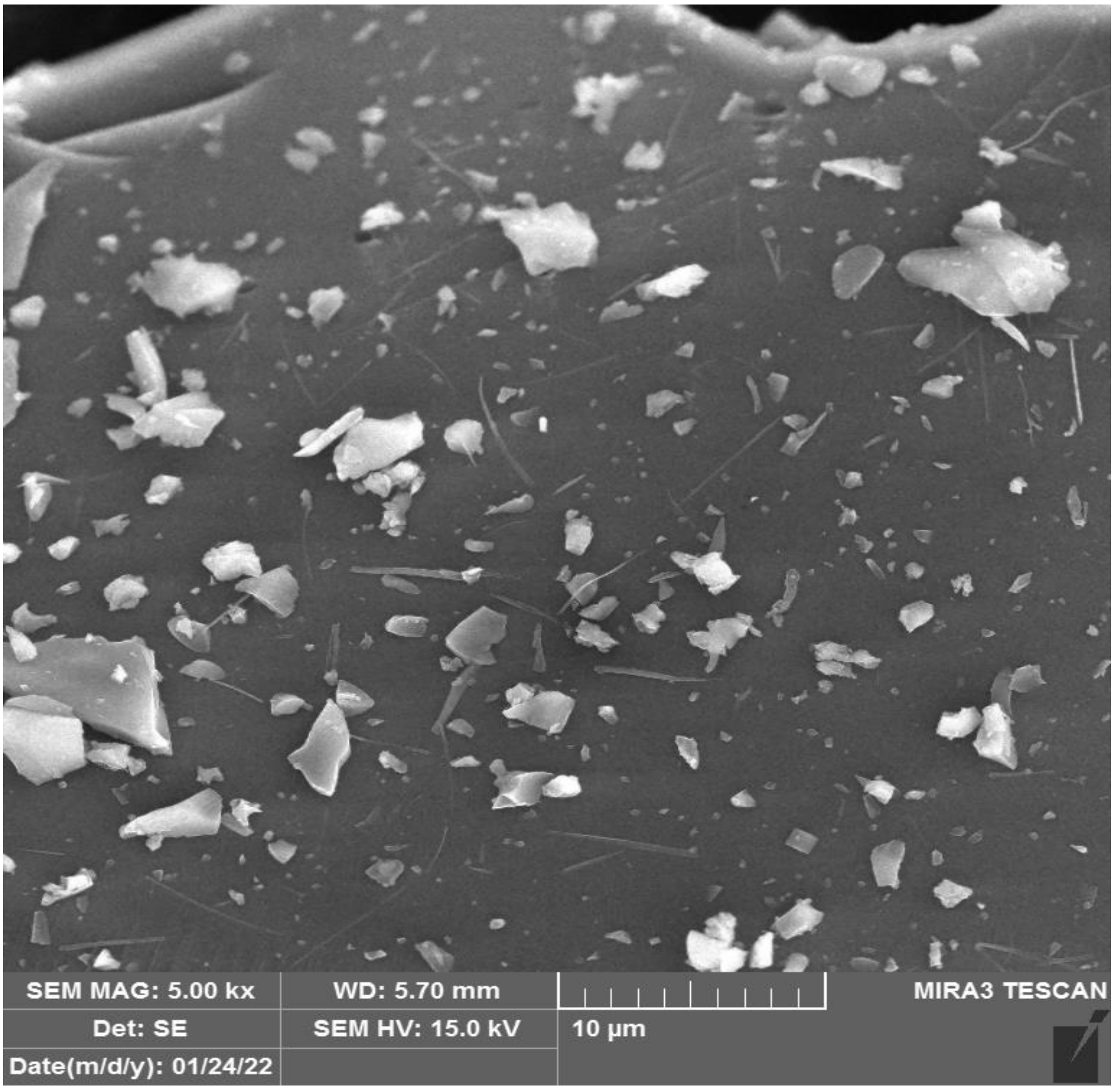


Fig.5 Particle structure of green glass using SEM test

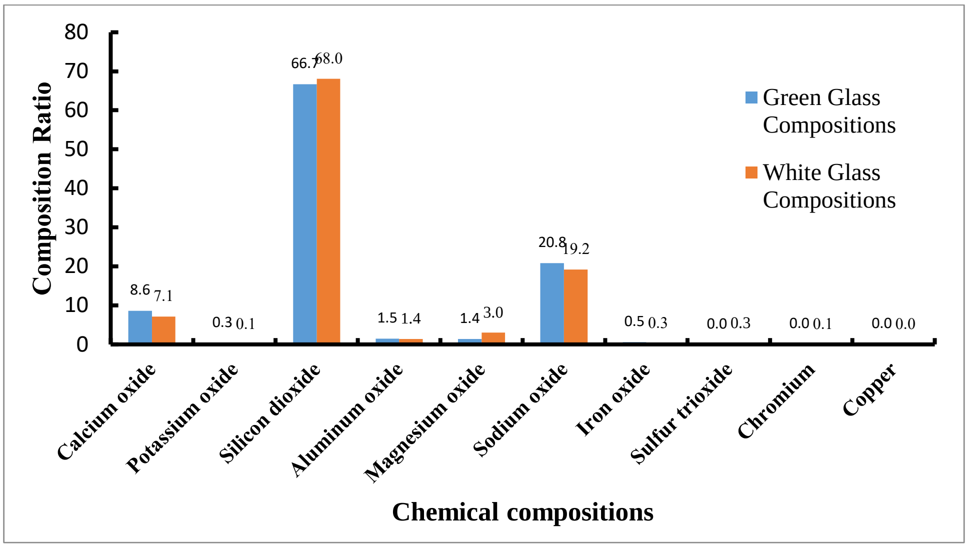


Fig.6 Chemical composition of white and green glass

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/m^3	1403 kg/m^3	ASTM C29., 2017

Table 2 Chemical composition of cement

Composition name	Composition percentage (%)	Allowable limit (%)
SiO_2 (Silicon dioxide)	19.12	-
Al_2O_3 (Aluminum oxide)	4.53	6 (max)
Fe_2O_3 (Iron(III) oxide)	4.55	6 (max)
CaO (Calcium oxide)	62.52	-
MgO (Magnesium oxide)	3.75	6 (max)
SO_3 (Sulfur trioxide)	2.42	3 (max)
K_2O (Potassium oxide)	0.47	-

Na_2O (Sodium oxide)	0.12	-
CO_2 (Carbon dioxide)	2.53	-
LSF (Lime Saturation Factor)[1]	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	cm^2/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/cm^3

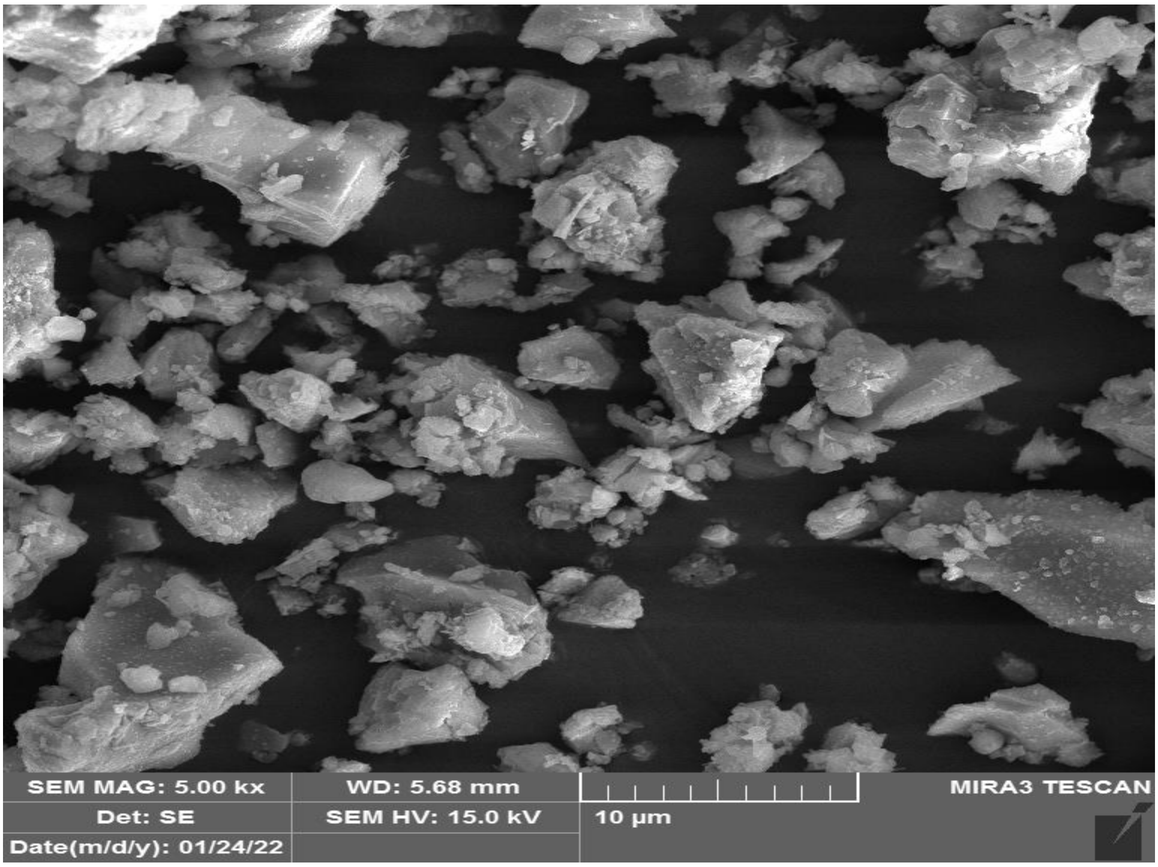


Fig.7 SEM, Microstructure of cement particles

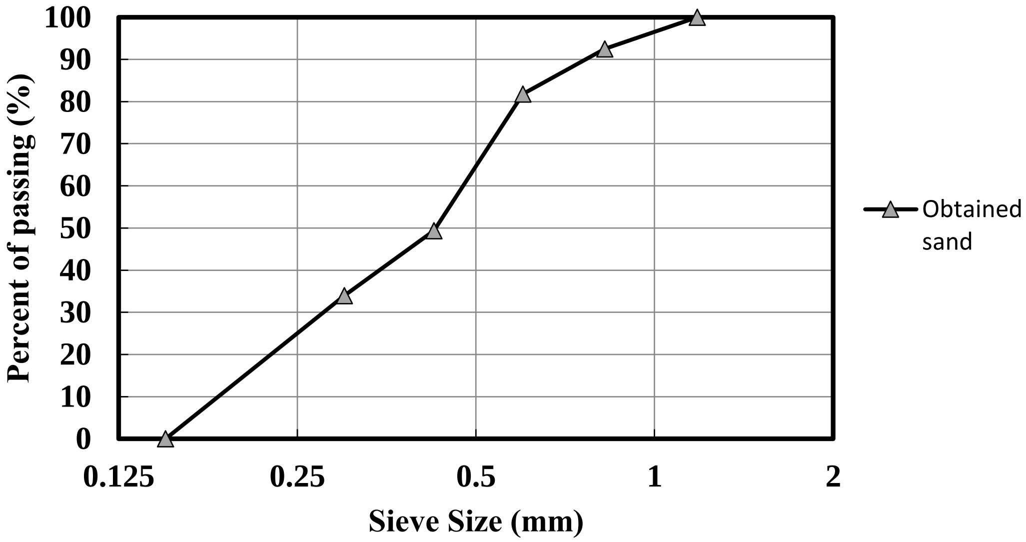
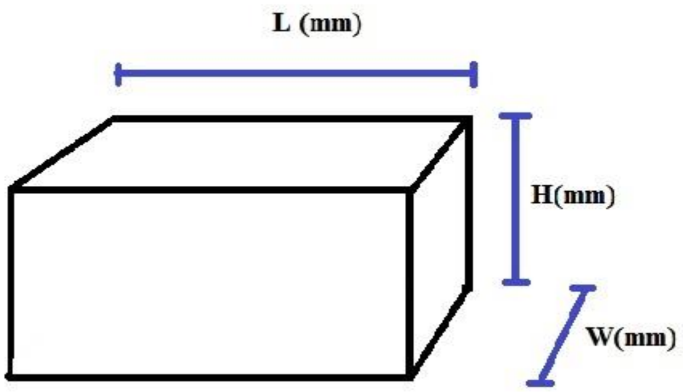


Fig.8 Sieve analysis of used sand

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/m^3	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/m^3)	Cement (kg/m^3)	Sand Content (kg/m^3)	Glass Content (kg/m^3)
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

Fig.10 Direct tensile sample under load machine

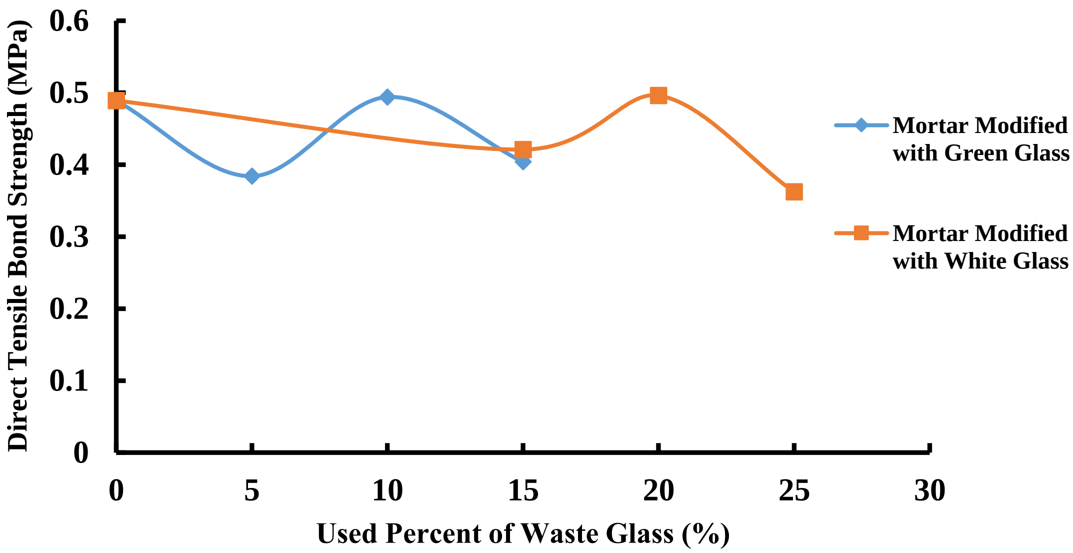


Fig.11 Direct tensile bond for all mixes

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:

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

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

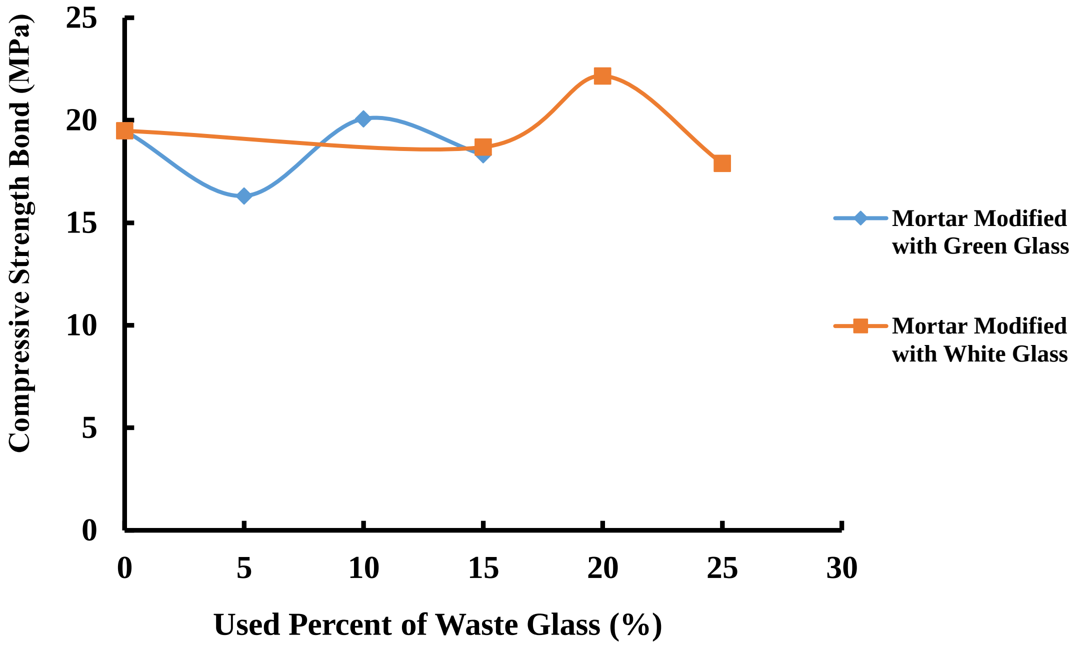


Fig.14 Compression bond for all mixes

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

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:

Fig.15 Failure Mode for compressive bond strength

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:

$$R = \frac{(P+0.75*Ps)*l}{b*d^2} \quad (1)$$

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

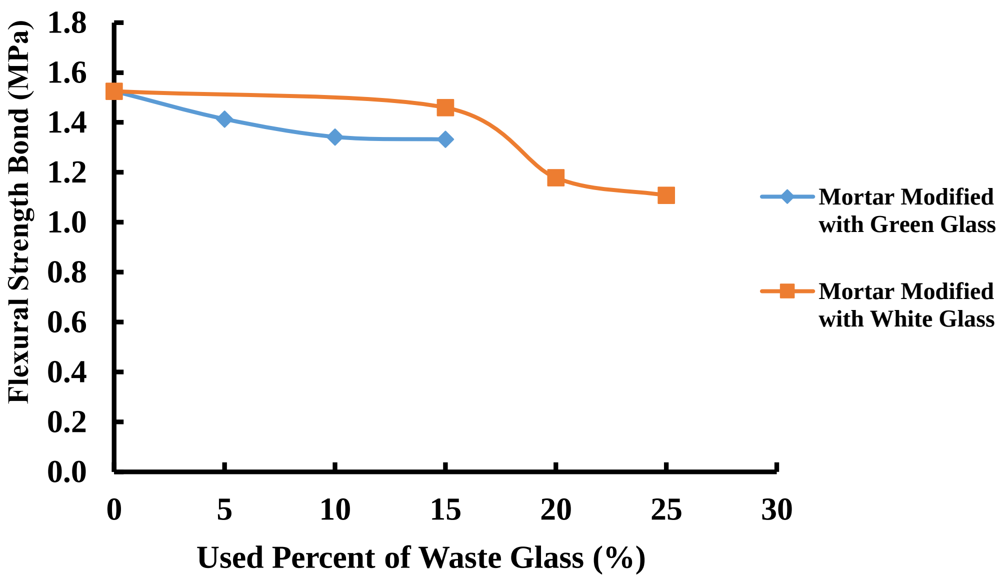


Fig.18 Flexural bond for all mixes

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.

References:

Abdulhameed, H., Mansi, A., Mohammed, A., Abdulhameed, A., & Hanoon, A. (2021, December). Study the use of Nano-limestone and Egg-shell Ash in Eco-friendly SCC: an Experimental and Statistical Evaluation Based on Computer Programming. In *2021 14th International Conference on Developments in systems Engineering (DeSE)* (pp. 509-514). IEEE.

Abdulhameed, A. A., Al-Zuhairi, A. H., Al Zaidee, S. R., Hanoon, A. N., Al Zand, A. W., Hason, M. M., & Abdulhameed, H. A. (2022). The Behavior of Hybrid Fiber-Reinforced Concrete Elements: A New Stress-Strain Model Using an Evolutionary Approach. *Applied Sciences*, *12*(4), 2245.

Abaas, tahseen and K Abbas , D. Z. . (2022) "Production Load–bearing Concrete Masonry Units by Using Recycled Waste Crushed Clay Bricks; A Review", Journal of Engineering, 28(10), pp. 13–27. doi: 10.31026/j.eng.2022.10.02.

Abdulhameed, A. A., Hanoon, A. N., Abdulhameed, H. A., Banyhussan, Q. S., & Mansi, A. S. (2021). Push-out test of steel–concrete–steel composite sections with various core materials: behavioural study. *Archives of Civil and Mechanical Engineering*, *21*(1), 1-21.

Al shemaree, zainab and Aljalawi, N. . (2022) "Some properties of Reactive Powder Concrete Contain Recycled Glass Powder", *Journal of Engineering*, 28(10), pp. 42–56. doi: 10.31026/j.eng.2022.10.04.

Altufaily, M. A. M., & Abdulhussein, T. B. (2019). Reuse of Crushed Glass and Aluminum Filings Wastes as Partial Replacement of Sand in Concrete Mixture. *International Journal of ChemTech Research*, *12*(1), 329-338.

ASTM C29 / C29M-17a, Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C33 / C33M-13, Standard Specification for Concrete Aggregates, ASTM International, West Conshohocken, PA, 2013, www.astm.org

ASTM C62-13a, Standard Specification for Building Brick (Solid Masonry Units Made From Clay or Shale), ASTM International, West Conshohocken, PA, 2013, www.astm.org

ASTM C67-17, Standard Test Methods for Sampling and Testing Brick and Stractural Clay Tile, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C109 / C109M-21, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens), ASTM International, West Conshohocken, PA, 2021, www.astm.org

ASTM C115 / C115M-10e1, Standard Test Method for Fineness of Portland Cement by the Turbidimeter (Withdrawn 2018), ASTM International, West Conshohocken, PA, 2010, www.astm.org

ASTM C117-17, Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C128-15, Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM C136 / C136M-19, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM International, West Conshohocken, PA, 2019, www.astm.org

ASTM C150-05, Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA, 2005, www.astm.org

ASTM C187-16, Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste, ASTM International, West Conshohocken, PA, 2016, www.astm.org

ASTM C188-17, Standard Test Method for Density of Hydraulic Cement, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C191-19, Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle, ASTM International, West Conshohocken, PA, 2019, www.astm.org

ASTM C305-20, Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency, ASTM International, West Conshohocken, PA, 2020, www.astm.org

ASTM C321-12, Standard Test Method for Bond Strength of Chemical-Resistant Mortars, ASTM International, West Conshohocken, PA, 2012, www.astm.org

ASTM C778-17, Standard Specification for Standard Sand, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C1314-16, Standard Test Method for Compressive Strength of Masonry Prisms, ASTM International, West Conshohocken, PA, 2016, www.astm.org

ASTM C1329 / C1329M-16a, Standard Specification for Mortar Cement, ASTM International, West Conshohocken, PA, 2016, www.astm.org

ASTM D1293-18, Standard Test Methods for pH of Water, ASTM International, West Conshohocken, PA, 2018, www.astm.org

ASTM E518-15, Standard Test Method for Flexural Bond Strength of Masonery, ASTM International, West Conshohocken, PA, 2015, www.astm.org

Churilov, S., & Dumova-Jovanoska, E. (2010). In-plane shear behaviour of unreinforced masonry walls. In *Proceedings of the 14th European conference on earthquake engneering, 30th Aug–3rd Sept, Ohrid, FYROM*.

Dehghan, S. M., Najafgholipour, M. A., Baneshi, V., & Rowshanzamir, M. (2018). Mechanical and bond properties of solid clay brick masonry with different sand grading. *Construction and Building Materials*, *174*, 1-10.

Incerti, A., Rinaldini, V., & Mazzotti, C. (2016, June). The evaluation of masonry shear strength by means of different experimental techniques: A comparison between full-scale and laboratory tests. In *Proceedings of the 16th international brick and block Masonry conference, Padova, Italy*.

Kamal, O. A., Hamdy, G. A., & El-Salakawy, T. S. (2014). Nonlinear analysis of historic and contemporary vaulted masonry assemblages. *HBRC Journal*, *10*(3), 235-246.

Lourenço, P. B. (1998). Experimental and numerical issues in the modelling of the mechanical behaviour of masonry.

Maheri, M. R., Motielahi, F., & Najafgholipour, M. A. (2011). The effects of pre and post construction moisture condition on the in-plane and out-of-plane strengths of brick walls. *Materials and Structures*, *44*(2), 541-559.

Ogundairo, T. O., Adegoke, D. D., Akinwumi, I. I., & Olofinnade, O. M. (2019, November). Sustainable use of recycled waste glass as an alternative material for building construction–A review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 640, No. 1, p. 012073). IOP Publishing.

Papadogeorgos, I., & K.. M. Schure. (2019). *Decarbonisation options for the dutch container and tableware glass industry*. PBL Netherlands Environmental Assessment Agency.

Sarangapani, G., Venkatarama Reddy, B. V., & Jagadish, K. S. (2005). Brick-mortar bond and masonry compressive strength. *Journal of materials in civil engineering*, *17*(2), 229-237.

Sathiparan, N., & Rumeshkumar, U. (2018). Effect of moisture condition on mechanical behavior of low strength brick masonry. *Journal of Building Engineering*, *17*, 23-31.

Sathiparan, N., Mayorca, P., & Meguro, K. (2008, October). Parametric study on diagonal shear and out of plane behavior of masonry wallettes retrofitted by PP-band mesh. In *14th world conference on earthquake engineering* (pp. 13-17).

Soran Abdrahman Ahmad (2022). Evaluating the Effect of Waste Glass on the Mechanical Properties and Shear Bond Strength of Mortar. MSc thesis, College of Engineering-University of Sulimani.

Thamboo, J. A., & Dhanasekar, M. (2016). Nonlinear finite element modelling of high bond thin-layer mortared concrete masonry. *International Journal of Masonry Research and Innovation*, *1*(1), 5-26.

Thamboo, J. A. (2020). Material characterisation of thin layer mortared clay masonry. *Construction and Building Materials*, *230*, 116932.

The United States Environmental Protection Agency.(2018).US EPA ARCHIVE DOCUMENT Retrieved http: // www. epa. gov

Zeng, J. J., Zhang, X. W., Chen, G. M., Wang, X. M., & Jiang, T. (2020). FRP-confined recycled glass aggregate concrete: Concept and axial compressive behavior. *Journal of Building Engineering*, *30*, 101288.