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Reuse of Wastewater Treatment in Cement Mortar

Wael.Ibrahim[1], Fakhry. Abdel-Hamid[2] and Gehad.Nabil[3].

1. Assistant Prof Civil Engineering Department Faculty of Engineering Mataria- Helwan University Cairo. Egypt.
2. Assistant. Prof. Irrigation & Drainage Engineering, Faculty of Engineering Mataria- Helwan University, Cairo. Egypt.
3. Master student. Civil Engineering Department, Higher Institute of Engineering at 15 May, Cairo, Egypt.Wael.ibrahim@rwth-aachen.de,wael.ibrahim@m-eng.helwan.edu.eg, *gehadnabil199@yahoo.com*.
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ملخص البحث:.

الهدف من البحث هو دراسة تأثير استخدام مياه الصرف الصحي المعالجة على المونة الأسمنتية في تشييد الحوائط من الطوب الطفلي , وتمثل تلك النقطة أحد الحلول لمشكلة ندرة مياه الشرب في الكثير من أنحاء العالم مما يستوجب إيجاد مجالات جديدة لإستخدام مياه الصرف المعالجة وتقليل إستخدام المياه الصالحة الشرب ولذلك تم عمل برنامج عملي مكون من ثلاث مراحل. المرحلة الاولى : وتشتمل تقييم الخواص الكيميائية والميكانيكية للمواد المستخدمة في الاختبارات. المرحلة الثانية: وتشتمل على إختبار مكعبات من المونة المصنوعة من المياه الصالحة للشرب والمونة المصنوعة من مياه الصرف الصحي المعالجة معالجة ثنائية طبقا للكود المصري لتصميم وتنفيذ اعمال المباني .المرحله الثالثه: بناء مناشير البناء من الطوب بإستخدام نوعي المونة السابق ذكرهما ، حيث تم إجراء اختبارات (مقاومة الضغط، مقاومة القص، مقاومة الشد) وبالتالي تم تقييم مناشير البناء تحت تأثير أحمال الضغط وأحمال القص وكذلك أحمال الشد طبقا لكل نوع مونة مستخدمة. وقد أظهرت النتائج أن قيم مقاومة ضغط المناشير وكذلك مقاومتهم للقص والشد تقارب قيم العينات بالمونة المصنوعة من مياه الشرب العادية .

<u>الكلمات المفتاحية</u>: مياه الصرف الصحي المعالجة، المونة، مقاومة الضغط، مقاومة القص، مقاومة الشد، مقاومة الانحناء

Abstract:

This thesis includes a study of the effect of using treated wastewater on cement mortar and masonry walls, the potable water is considered scarce in many of the world's countries, and finding applications for treated wastewater reuse is very effective in preserving potable water resources. Therefore, an experimental program consisting of three phases was developed. The aim of first phase is to evaluation of the chemical and mechanical properties of the materials used in the specimens. The second phase includes testing of mortar cubes made from potable water and mortar made from secondary treated wastewater, according to the Egyptian code for designing and executing masonry works. The third phase is studied masonry prisms' using two types of mortar is mentioned above, where tests were conducted (compressive strength, shear strength, in plane tensile strength, flexural tensile strength for out of plan bending). The results showed minor change for strength prisms values, which constructed by using mortar made from secondary treated wastewater compared to prisms constructed by using mortar made from

Key Words: Treated Wastewater, Mortar, Axial compressive strength, Shear Strength, In-Plane tensile strength, Out-Of-Plane tensile strength.

1. Introduction

The rapid development in different industries in last years has led to the generation of huge amounts of wastewater .Thus, in this study it is studied to replace potable water (PW) with secondary treated wastewater (STWW) for use in mortar and masonry works, this would allow for preservation of enormous amounts of domestic fresh water. And recently many wastewater treatment plants has been established or planned to be established in Egypt.

This research aims to evaluate the potential of reused treated wastewater in mortar and masonry in order to preserve fresh water for drinking purposes, we made a comparison between treated wastewater and potable water and their usage .the experimental mortar specimens of both water, from treated wastewater and potable water tested at the lab and compared between the results after 1, 3, 7, and 28 days. and we studied the resistance of compressive strength, shear strength, tensile strength and bending moment of the masonry prisms made from potable water (PW) and the prisms which made from treated waste water (STWW), and finally we made a comparison between experimental and theoretical results. The main objectives of this research are studying the affection of the treated wastewater on the mortar, masonry walls, and its strength. The suitability of using the experimental study divided into two phases:

Phase I: Masonry specimens and mortar made from potable water and secondary treated wastewater were tested.

Phase II: Comparison between the results of the specimens. The compression, shear strength, in plane tensile strength, and flexural tensile strength for out of plan bending.

2. Experimental program and test set-up

This study discusses the possibility of reuse treated wastewater in cement mortar and masonry work. The experimental program of the current research work consists of masonry prisms. The materials used in prisms are cement, sand, potable water (PW), Secondary treated wastewater (STWW), And bricks. Masonry prisms were tested according to the available national specifications.

In this study two types of mortar were tested.

Type of mortar where two types were

a- Cement mortar made from potable water (PW).

b- Cement mortar made from secondary treated wastewater (STWW).

2.1 Mechanical properties of bricks

Bricks should be uniform in color, shape, and size, in the experimental program clay bricks were used. The standard size of the bricks must be preserved. Two brick factories have been selected (DAHAB, ELARAB). The mechanical Properties of bricks had been determined by carrying out tests such as (compressive strength test and absorption test). The tests were carried out according to the Egyptian code for the tests as follows:

2.1.1 The absorption test

The brick units were placed in water for 24 hours, then weighed, and then dry it in the oven to re-weight it, and the percentage of the unit absorption was calculated from this equation :

Absorption (%) = ((Y-X) / X) *100

Y = Weight the brick after submerged in water for 24 hours (Kg).

X= Weight the brick after drying in the oven (Kg).

The average absorption percentage ratio for DAHAB and ELARAB is (7.28%, 6.69 %) respectively.

2.1.2 The compressive strength test

The compressive strength must be determined to establish the quality of the masonry units. The units were capped with wood at top and bottom to achieve uniform load on the bearing surface. Testing machine in the properties and strength of material laboratory, higher institute at 15th may, Helwan, Egypt. The axial compression strength of the units were calculated from divided the failure load by the area and then calculated the- average compressive strength. Average compressive strength for DAHAB and ELARAB (4.60, 4.66 MPA) respectively.

2.2 Properties of mortar

The initial purpose of the mortar was to fill the voids between masonry units. It also add strength to masonry and provide resistance to penetration of light, wind, water as well as bond the units together. Also the purpose of mortar is to transfer the gravitational force uniformly through the block, the tying effect being achieved by friction and the staggered pattern of the blocks. The strength of the mortar effects the strength of the masonry in compression, tension and flexure. According to the Egyptian Code for designing and executing masonry works, two types of mortar were tested; mortar made from potable water and mortar made from treated wastewater.

The experimental mortar samples of both water from potable water and treated waste water will testing at the lab and compare between the results after 1, 3, 7, and 28 days. The compression test for cubes of mortar made from potable water and mortar made from secondary treated waste water has been performed. The average compressive strengths of tested mortars after 1,3,7 and 28 days for mortar made from potable water and mortar made from secondary treated wastewater was (2 and 3) N/mm2, (4 and 4.5) N/mm2, (12.5 and 13) N/mm2, (20.6 and 20.9) N/mm2 respectively.

2.3 Properties of masonry

Masonry is a composite material composed of units and mortar, so we will measure the interaction of these materials as prisms to determine the characteristics of masonry, where these tests for masonry will be as axial compression test, shear strength test, flexural Tensile strength test and in plane strength test.The procedures of these tests are as follows.

2.3.1 Axial compression test

Compression tests of masonry prisms are used as the basis for assigning design stress and, in some cases, as a quality control measure. Its importance has made prism compressive behavior a major research focus and potential correlation with other strength characteristics have been investigated .Test machine capacity and specimen height limits as well as other practical considerations have led to use of prisms as the main type of compression test specimen rather than full-scale specimen.there are variable factors that affect the prism compressive strength, these factors include the prism capping, prism shape, type of masonry bond, unit strength, mortar type , mortar strength, the joint thickness and workmanship. In this research, the compressive prism consisted of five brick units, including mortar bedding of 10 mm thicknes,Since the mechanism of this test was to transfer the load from the top to the bottom of the prism so it was necessary to make a capping from the gypsum to provide a flat surface that allows uniform distribution of the load on the loaded area .as shown in figure1. the masonry prisms have been constructed using two different types of mortar: cement mortar made from (PW) and cement mortar made from (STWW).

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure 1. Samples of prisms under axial compression test before testing.

2.3.2 Shear test

Masonry shear walls were intended to resist shear forces due to in-plane lateral loads plus to the effect of axial load and bending. Test to measure the shear strength along mortar bed joints have not been standardized, and as a result, many variations have been developed. Some types of tests that have been used: triplet, modified triplet, couplet and off-axis compression. So, in this research the triplet type has been carried out. The shear stresses at failure were calculated using the following formula $\tau = \frac{P}{2A}$

Where:

τ = shear stresses

P = failure load

A = net area of contact between the two blocks

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure. 2. Samples of prisms under shear test before testing

2.3.3 In – plane tensile strength

In load bearing masonry buildings, shear walls carry vertical loads and resist the lateral in-plane loads due to wind or earthquakes. This combined loading creates principal tension stresses in the wall leading to tensile cracking when the tensile strength of the masonry was exceeded. The splitting tension test has been very useful for developing an understanding of the factors affecting in-plane tensile strength of masonry. Factors affecting in-plane tensile strength such as:

1- Orientation of the principal tension stress.

2- Mortar type.

3- Strength of masonry unit.

Where the splitting tensile strength determined from the following equations:

$$Ft = \frac{2P}{\P A} \quad \text{when } \theta = 0°$$

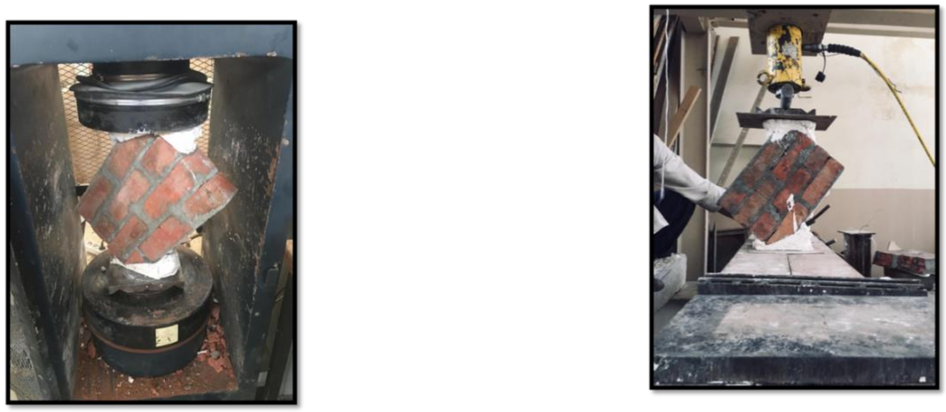
$$Ft = \frac{P}{A} \quad \text{when } \theta = 90°$$

$$Ft = \frac{0.707P}{A} \quad \text{when } \theta = 45°$$

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure. 3. Samples of prisms under in-plan splitting tensile test with θ = 0°.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW. Figure. 4. Samples of prisms under in-plan splitting tensile test with θ = 90°



a. Prism constructed using mortar PW.   b. Prism constructed using mortar STWW.

Figure .5. Samples of under in-plan splitting tensile test with θ = 45°

2.3.4 Flexural tensile strength for out of plane bending

The flexural tensile strength of masonry for out of plane bending relates to the resistance of walls subject to lateral loads from wind, earthquake, or earth pressure, and to eccentric load or direct bending due to gravity loading. Flexural tensile strength is usually referred to in terms of direction of the tension, that is, either normal to the bed joints, f''m, or parallel to the bed joints, f'tp.

Where the flexural tensile strength determined from the following relation:

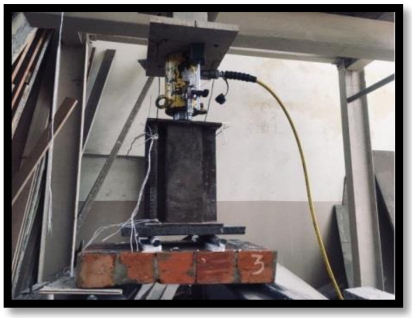
f't =   f't → Flexural tensile strength
M → Bending moment
I → Moment of Inertia

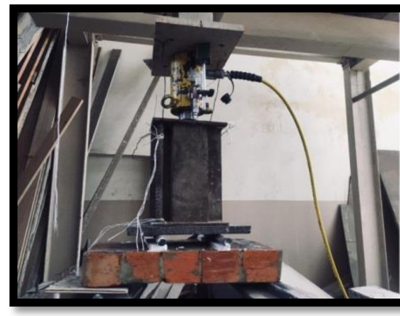
2.3.4.1 Tension normal to bed

The method used in this research to determine the flexural tensile strength in this case was ASTM E518. , where this method uses beam tests of stack-bonded prisms with prisms heights at least 450mm and either third-point loading, as shown in Figure 6.

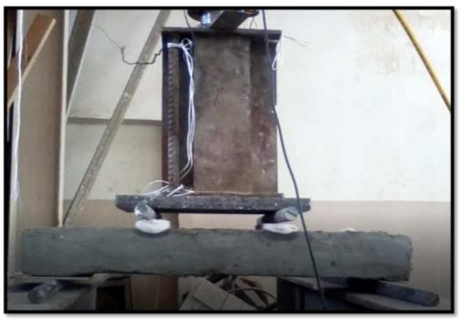
2.3.4.2 Tension parallel to bed joint

The test methods were developed to determine tensile bend strength normal to the bed joints. However, with some modification, researchers have adopted them to tests for tension parallel to bed joints. For the prism beam tests, the length parallel to the bed joints must usually be at least four units, as shown in Figure 7.





a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.
Figure. 6. Prisms under tests for flexural tension normal to bed joints.



a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.
Figure. 7. Prisms under tests for flexural tension parallel to bed joints.

3. Experimental results

Masonry prisms

The results of prisms' test, these tests were: axial compression test, shear strength test, in-plane tensile strength and out of plane tensile strength as mentioned following.

3.1 Axial compressive test

The failure modes for samples were a shear compression failure as shown in figure 8. Vertical cracking were formed along the height of the masonry units , these cracks is vertically in bricks because of the lateral tensile stresses in the bricks and then followed by cracks in the bed joints of mortar by increasing the vertical load, samples were constructed by using mortar made from (STWW) have higher resistance to axial compression than samples were constructed by using mortar made from (PW) because the strength of mortar had affected on the compressive strength of assemblages.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure .8. Failure mode of masonry prisms under axial compression test.

3.2 Shear strength test

The real mode of failures of the prisms, which the joint slip failure normally occurs along the interface between the mortar and the unit for both types of mortar. as shown in figure 9. The average shear strength of the prisms were constructed by using mortar made from (PW) and mortar made from (STWW) was (1.72 and 2.20) N/mm2 respectively. From results, it can be inferred that samples were constructed by using mortar made from (STWW) have a higher shear resistance than samples constructed by using mortar made from (PW) because the shear strength of assemblages affected by the contact area between the mortar and block interface.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure .9. Failure mode of masonry prisms under shear test.

3.3 In plane tensile strength

To carry out this test three samples were constructed by using mortar made from (PW) and another three samples were constructed by using mortar made from (STWW) have been constructed in each case of load.

3.3.1 In case of line loads normal to the bed joints

In case of the line loads normal to the bed joints, the cracks started along the block then it moved along the block and the mortar interface at the head joint in case of assemblages were constructed by using mortar made from (PW) and using mortar with (STWW) , cracks in the assemblages made from (PW) occurred at loads (132, 129 and 127.5) KN respectively and cracks occurred in the assemblages made from (STWW) at loads (145, 136 and 131.1) KN respectively as shown in figure10. And the average in plane tensile strength in this case of loading for prisms were constructing by using mortar made from (PW)and mortar made from (STWW) was (7.05 and 7.49) N/mm2 respectively.So, the samples were constructed by using mortar made from STWW have higher resistance to splitting tensile than the samples constructed by using mortar made from in case of splitting tension parallel to bed joints And the Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 0 shown in figure 11.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Figure 10. Failure mode of prisms under in-plan splitting tensile test with θ = 0°

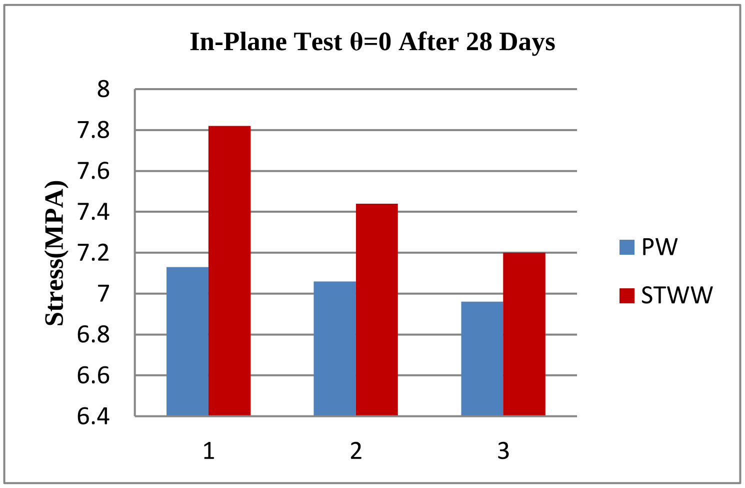


Figure. 11. Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 0.

3.3.2 In case of line loads parallel to the bed joints

In case of line loads parallel to the bed joints, the cracks started along the block and the mortar interface at the bed joints and then passing through it only in both cases of assemblages were constructed by using mortar made from (PW) and assemblages were constructed by using mortar made from (STWW).failure cracks in the assemblages were constructed by using mortar made from (PW) occurred at loads (6.36, 7.1 and 8.1) KN respectively, while failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (6, 7 and 9.6) KN respectively as shown in Figure 12, and the average in- plan tensile strength in this case of loading of prisms were constructed by using mortar made from PW and mortar made fromSTWW was (0.27 and 0.28) N/mm2 respectively, it can be conclude that the samples were constructed by using mortar made from (STWW) have higher resistance to splitting tensile than the samples constructed by using mortar made from (PW) in case of splitting tension normal to bed joints. And the Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 90 shown at Figure 13.

a. Prism constructed using mortar PW.

b. Prism constructed using mortar STWW.

Figure .12. Failure mode of prisms under in-plan splitting tensile test with θ = 90°

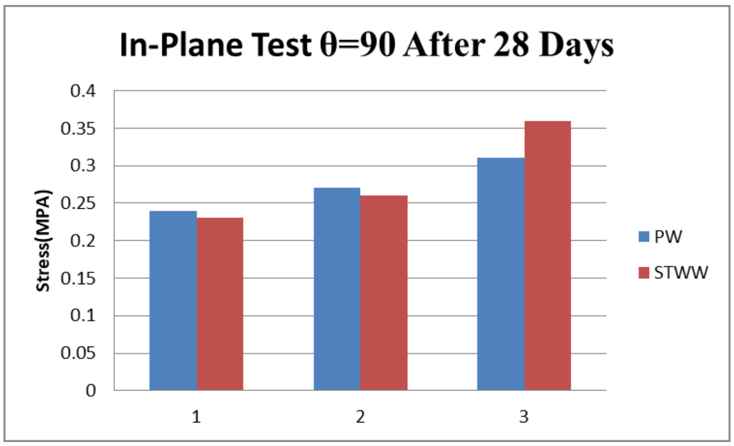


Figure 13: Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 90.

3.3.3 In case of line loads oriented at 45° from the bed joints

In case of line loads oriented at 45° from the bed joints the cracks started along the block and the mortar interface at the head joints and passing through the block and the mortar interface at the bed joints in both cases of assemblages were constructed by using mortar made from (PW) and assemblages were constructed by using mortar made from (STWW). failure cracks in the assemblages were constructed by using mortar made from (PW) occurred at loads (16.7, 19.5 and 25.5) KN respectively, while failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (10.34, 16.76 and 17.95) KN respectively as shown in Figure 14. The average in plane tensile strength in this case of loading of prisms were constructed by using mortar made from (PW) and mortar made from (STWW) was (1.59 and 1.14) N/mm^2 respectively. So,the samples were constructed by using mortar made from (PW) have higher resistance to splitting tensile than the samples constructed by using mortar made from (STWW) in case of line load orientated at 45° from the bed joints.And the Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 45 shown at Figure 15.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW . Figure .14. Failure mode of prisms under in-plan splitting tensile test with θ = 45°

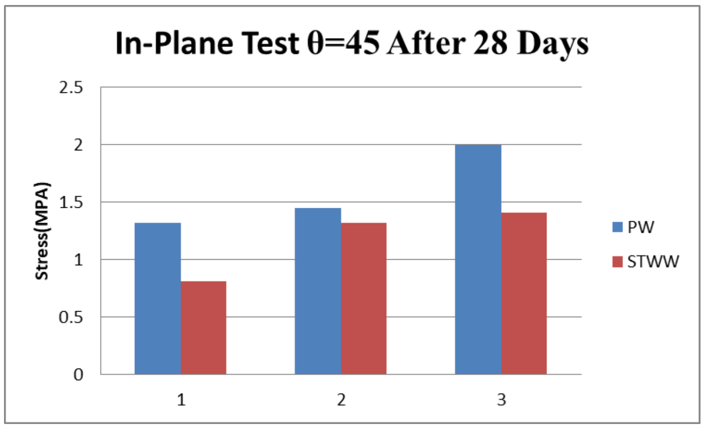


Figure.15. Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 45.

3.4 Flexural tensile strength for out of plane bending

To carry out this test three samples were constructed by using mortar made from PW and another three samples were constructed by using mortar made from STWW have been constructed in each case of load.

3.4.1 Flexural tension normal to bed joints

The Cracks started along the bed joints. For flexural tension normal to the bed joints, failure consists of connecting of the mortar from the unit along the bed joint as shown in figure 16. The failure cracks in the assemblages were constructed by using mortar made from (PW) occurred at loads (3 , 2.9 and 2.9) KN respectively, while the failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (3.75,2.15and2.3) KN respectively,because the cracking load affected by the strength of mortar.and the average flexural tensile strength in this case of loading of the prisms were constructed by using mortar made from (PW)and mortar made from (STWW) was (0.2 and 0.2) N/mm2 respectively.

a. Prism constructed using mortar PW.

b. Prism constructed using mortar STWW.

Figure 16. Failure mode of prisms - out of plane bending tension normal to bed joints.

3.4.2 Flexural tension parallel to bed joints

The cracks started along the head joints and then passing through the bed joints. Cracking in a Toothed Pattern along a Combination of head and bed Joints. For masonry with relatively strong units and weak mortar joints, flexural failure for tension parallel to the bed joints can occur through a combination of tensile and shear connecting in the head and bed joints. Failure cracks in the assemblages were constructed by using mortar with (PW) occurred at loads (1.9,1.3and 1) KN respectively, while failure cracks occurred in the assemblages were constructed by using mortar with (STWW) at loads (1,1.3 and 1.2) KN respectively as shown in Figure17, and the average flexural tensile strength in this case of load of prism were constructed by using mortar made from (PW) and mortar made from (STWW)was (0.51 and 0.56) N/mm2 respectively.

a. Prism constructed using mortar PW.

b. Prism constructed using mortar STWW.

Figure 17. Failure mode of out of plane bending-tension parallel to bed joints.

4. Conclusions

Based on this research presented in this study, the following conclusions could be illustrated:

1. For all tested samples, the stress – strain behavior is almost linear, where the first crack was started and then the failure started.

2. The behavior of mortar in masonry prisms under loading gives signs before failure.
3. Compressive strength of prisms were constructed by using mortar made from (STWW) higher than prisms were constructed by using mortar with (PW)
4. Shear strength of prisms were constructed by using mortar made from (STWW) increased by 28% than shear strength of prisms were constructed by using mortar with (PW).
5. The prisms were constructed by using mortar made from (STWW) have higher resistance to splitting tensile than the prisms were constructed by using mortar made from (PW) in case of line load normal to bed joint by 6%.
6. The prisms were constructed by using mortar made from (PW) have higher resistance to splitting tensile than the prisms were constructed by using mortar made from (STWW) in case of line load oriented at 45° from the bed joint by 39.5%.
7. The prisms were constructed by using mortar made from (STWW) have higher resistance to splitting tensile than the prisms were constructed by using mortar made from (PW) in case of line load parallel to bed joint by 3.7%.
8. The prisms were constructed by using mortar made from (STWW) have almost equal resistance to flexural tensile to the prisms constructed by using mortar made from (PW) in case of splitting tension normal to bed joints.
9. The prisms were constructed by using mortar made from (STWW) have higher resistance than flexural tensile to the prisms constructed by using mortar made from (PW) in case of splitting tension parallel to bed joints by 9.8%.
10. Generally, the prisms which have been constructed by using mortar made from (STWW) are stronger than the prisms have been constructed using mortar made from (PW) at age of 28 days.

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