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Experimental Study of Masonry Wall Strengthened by Polypropylene Fiber Mortar

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***Abstract*—Based on previous studies, the average strength of Indonesia's masonry wall shows a weak compressive strength that increases the vulnerability of buildings with masonry walls towards the seismic load. This study presents an experimental investigation of the masonry wall's flexural capacity strengthened with Polypropylene Fiber (PP Fiber). In general, the experiments were divided into two groups: the masonry wall with PP Fiber in a joint mortar and the masonry wall with PP Fiber in a plastering. The investigation was carried out on twelve specimens. The specimens consisted of three standard masonry wall (DBK) samples as the controlled specimens, which are without plastering and PP Fiber, three masonry wall samples with PP Fiber (DBP) in a joint mortar, three masonry wall samples with normal plastering (DBKP), and three masonry wall samples with PP Fiber in a joint mortar and plastering (DBPP). The experimental investigation proved that the addition of PP Fiber to the mortar mixture at joint masonry mortar could increase the masonry wall's flexural capacity. The results showed that the mortar with 8% PP Fiber improves the compressive strength by 58.46%. The flexural testing showed that 8% PP Fiber to the mortar could increase the flexural capacity to 35.8%. The maximum deflection also increases as much as 38.58% for masonry walls with PP Fiber on mortar and plastering, compared to the masonry wall without PP Fiber. In addition, the presence of Polypropylene Fiber contributes to give a higher flexural capacity.**

***Keywords*—Strengthening; flexural strength; brick wall; plastering; polypropylene fiber.**

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I. Introduction

The wall is a solid structure that limits and sometimes protects an area. Walls limit a building and support other structures; the two main walls are infill walls as fillers only and confined walls as restraints. In buildings, the wall has several functions: to hold the load, divide the whole building's weight, as a silencer and radiation, and as a space separator. In the development world of construction, masonry is often used as a primary material for making the wall [1]–[4]. In Indonesia, the type of wall with masonry dominates compared to other kinds of wall. Based on previous studies, the masonry wall in Indonesia shows a weak compressive strength [5], [6]. This study shows there is a very high vulnerability of buildings using a masonry wall[7]. Hence, it is essential to reduce the building's vulnerability by increasing its load-bearing capacities.

Many researchers have developed some effective strengthening techniques for masonry walls using advanced materials such as CFS, CFRP, Polymer, and other materials[8]–[11]. However, in developing countries, CFS or CFRP will be costly for strengthening projects especially people housing. Hence, we need to find an alternative which is less pricy and easy to apply.

The masonry wall in the construction work is always coated with mortar to increase the masonry's strength. The term often used in Indonesia to refer to a composite material mix between masonry and mortar is a masonry slide pair. The mortar that is often used is a mixture of cement paste with fine aggregate. The increasing of the mortar capacity will substantially increase the masonry wall's capacity since the mortar usually be used as a plastering for the outer wall that confined the brick from out of plane failure. The previous studies show that there was a direct correlation between the compressive strength of mortar and the compressive strength of the masonry wall [12]. The compressive strength of the wall will increase with the addition of the compressive strength of the mortar. Increasing the compressive strength of mortar will also increase the bending capacity of the masonry wall.

The characteristics of the mixture for mortar became the main focus of this study. Normal mortar with a mixture of cement paste with fine aggregate is the most commonly used as masonry mortar pair. The addition of fiber to the mortar mixture is predicted to increase the flexural capacity of the masonry wall. Judging from these problems, researchers are interested in getting the masonry wall's flexural capacity with a normal mortar and fibrous mortar. This study used an experimental method in the Laboratory with a fixed variable are normal mortar and fibrous mortar. Many studies find that fibrous mortar has better performance towards loading [13]–[15]. Flexural capacity testing will be carried out on normal mortar and fibrous mortar and masonry wall specimens with a normal mortar and masonry wall with polypropylene fiber mortar. Mortar test samples are in the form of a 5 cm x 5 cm x 5 cm cube and a masonry wall sample measuring 67 cm x 15 cm x 15 cm.

II. Material and Method

A. Polypropylene

Polypropylene (PP-Band) is a cheap material but has a high deformation ability [12], [16], [17]. PP-Band has been tested through axial tensile testing [12]. The test results show that PP-Band has a large deformation capacity, 13% axial trade (Figure 1). The residual modulus of elasticity ranges from 3200 MPa to 1000 MPa. With excellent deformation capability, this material can provide high flexural capacity.

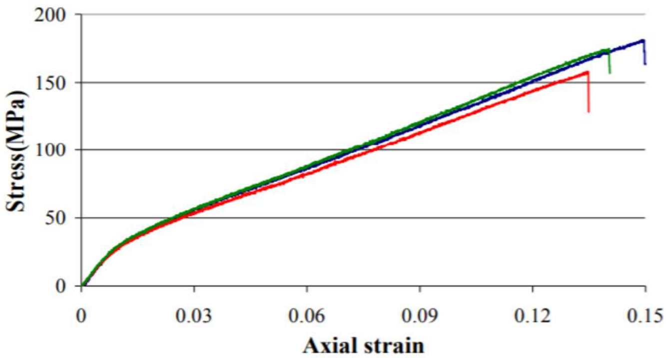

Fig. 1 Behavior of PP-band under tension [12]

The objective of this study is to utilize PP fiber as an addition to the mortar mix. The PP fiber was used in this study has a white color and exceptionally light, as shown in Figure. 2.

Fig. 2 Polypropylene fiber

Figure 3 shows the stress and strain curves of 3 PP-Bands samples from 3 similar polypropylene materials and three types of FRP (CFRP, AFRP, and GFRP). PP-Band and FRP are subject to an axial tensile force. Stress and strain curves show that PP-Band has relatively low tensile strength and stiffness but has better deformation capability than FRP.

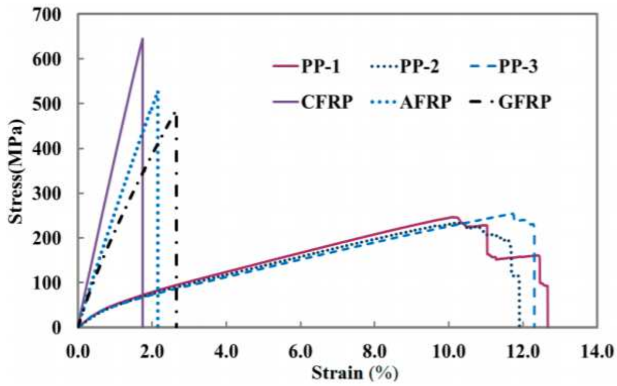

Fig. 3 Strain and stress curve of PP-band and FRP [7]

B. Mortar

Mortar is a mixture of cement paste material with fine aggregate and is often used as an outer layer in a masonry wall installation. Mortar functions as a binder in a masonry wall, and it becomes a unified structure. 2 main components configure the wall, namely mortar, and masonry. Mortar is a mixture of cement, sand, and limestone and will be added with polypropylene fibers. When mixed with water, this mixture is thicker than normal mortar. Mortar is often used to attach objects such as masonry or stones to blend. The thickness of the mortar should not exceed the masonry's thickness, while in Indonesia, the thickness of the mortar is often used 1-2 cm[18].

C. Masonry Wall

A Masonry wall is one of the most popular types of materials used in the construction field. In Indonesia, the use of masonry material as a construction wall continues to increase because masonry is easy to obtain and cheap. Unfortunately, the results of the statistical data show [19] that most of the use of masonry walls does not meet the minimum standards required in SII-0021-1978 [18]. Both in terms of quality standard dimensions, color, texture, and even minimum strength.

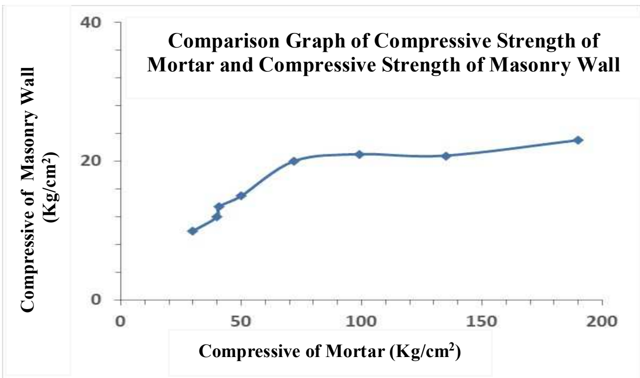

Fig. 4 Comparison of mortar and masonry wall compressive strength [10]

Masonry walls with mortar lining are the most commonly used structural elements. One of the most prominent weaknesses in the use of mortar as a masonry wall layer is the brittle mortar's nature and has very low tensile strength [20]. The fact that masonry wall with ordinary mortar layers has brittle material properties makes this experiment interesting by adding fiber to the mortar mixture, thereby increasing the modulus of elasticity of the masonry wall. The collapse of the masonry wall due to an earthquake is the leading cause of injury and even death. When earthquakes occur, the masonry wall with normal brittle mortar increases the likelihood of shear and bending failure. The normal mortar that is often used is a mixture of cement paste with fine aggregate. Figure 4 is the results of a study showing a graph of the relationship between normal compressive strength and mortar compressive strength of a wall. It was seen that the increase in mortar strength was also accompanied by the addition of the compressive strength of the masonry wall. It can be said that the compressive strength of the masonry wall is strongly influenced by the compressive strength of mortar [21], [22]. Table 1 above shows the type of mortar sample specification and the number of each sample. The mix design of PC and Sand for mortar was 1 PC and 3 Sand. PP fiber weight is increased gradually to 28% of PC weight. The total number of mortar samples is 25 specimens[23].

TABLE I
TOTAL SAMPLE OF MORTAR

No.	Sample ID	Specification				Number of samples
		PC (gr)	Sand (gr)	Water (gr)	PP Fiber (gr)	
1	Mortar Normal	500	1500	250	0	5
2	Mortar PP Fiber 0,5 %	500	1500	250	250	5
3	Mortar PP Fiber 1 %	500	1500	250	500	5
4	Mortar PP Fiber 1,5 %	500	1500	250	750	5
5	Mortar PP Fiber 3 %	500	1500	250	1500	5
6	Mortar PP Fiber 8 %	500	1500	250	4000	5
7	Mortar PP Fiber 13 %	500	1500	250	6500	5
8	Mortar PP Fiber 18 %	500	1500	250	9000	5
9	Mortar PP Fiber 23 %	500	1500	250	11500	5
10	Mortar PP Fiber 28 %	500	1500	250	14000	5
Total Sample of Mortar						**25**

Table 2 presents the specification of masonry wall specimens, including their dimension, joint mortar thickness, and plaster thickness. There are three samples for each type of specimen. The total number of wall wallets is 12 samples. This research tested these 12 samples with flexural testing to find the flexural capacity of each sample and find the effect of polypropylene fiber mortar that applied to the masonry or brick wallet [23].

TABLE II
TOTAL SAMPLE OF MASONRY WALL

No.	Sample ID	Dimension					Number of sample
		Length (mm)	Width (mm)	Thick ness	Mortar Joint (mm)	Pilaster Thickness (mm)	
1	Masonry Wall with Mortar Normal (DBK)	670	150	90	30	0	3
2	Masonry Wall with PP Fiber Mortar (DBP)	670	150	90	30	0	3
3	Masonry Wall with Pilaster Normal (DBKP)	670	150	150	30	30	3
4	Masonry Wall with Pilaster PP Fiber (DBPP)	670	150	150	30	30	3
Total Sample of Masonry Wall							**12**

The wall dimension is adjusted based on the universal testing machine bearing distance—the flexural testing results in the flexural strength and displacement for each specimen. The step of the research method is presented in Fig. 5.

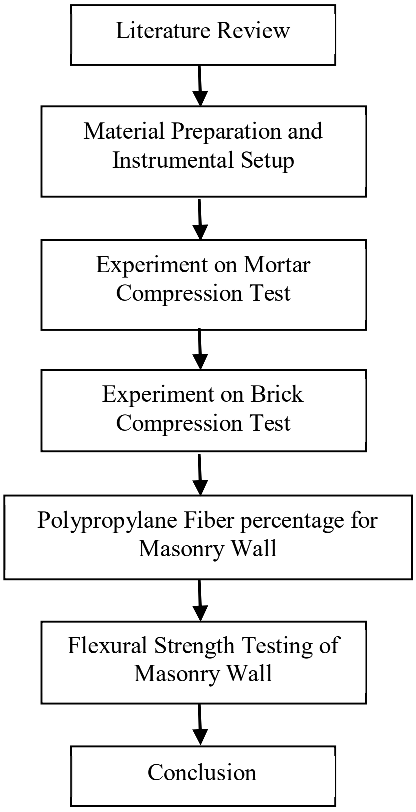

Fig. 5 Flowchart of Research Methodology

This study used the experimental method, starting from a literature review about PP material and the masonry wall's flexural strength. The important step from this study is to obtain the optimum percentage of PP fiber that will be used as the additional material for mortar and plaster. Once the percentage of PP fiber was obtained, the masonry wall is constructed.

III. Results and Discussion

A. Compressive Strength

The first step in this study is to obtain the percentage of additional PP fiber that will be used for the wall wallet. The PP fiber percentages are 0.5%, 1%, 1.5%, 3%, 8%, 13%, 18%, 23%, and 28% to the weight of cement. This mortar compressive strength test is carried out to determine how much normal mortars and mortars own compressive strength value with polypropylene fibers. Compressive strength is defined as the ratio between the load given to the cross-sectional area of the tested mortar sample, expressed in kg / cm². A total of 50 mortar samples were produced from this test—respectively 5 for normal and mortar samples with different polypropylene fibers. A comparison of the maximum load that each mortar sample can hold can be seen in Table 3.

From Table 3, it can be seen that there is a significant increase in the compressive strength of mortar with the addition of polypropylene fibers at a percentage of 8%. The maximum load that can be resisted by 8% polypropylene fiber mortar is 4082 kgf with a compressive strength of 163.28 $kg/cm^{2,}$ while there is a decrease in maximum load on polypropylene fiber mortar with a percentage of 13% that is 1950 kgf with a compressive strength of 78 kg/cm^2. As for normal mortar, the maximum load that can be carried is 3656 kgf with a compressive strength of 103.04 kg/cm^2. From Table III can be calculated that the percentage increase in cement mortar compressive strength is 58.46% for the use of 8% percent polypropylene fiber and a decrease of up to 46.66% for the use of 13% polypropylene fiber.

TABLE III
FLEXURAL STRENGTH OF SPECIMEN

No	PP Fibre Content (%)	Max Load (Kgf)	Comp. Strength (Kg/cm^2)
1	0	2576.00	103.04
2	0.5	2506.00	100.24
3	1	2788.00	111.52
4	1.5	2418.00	96.72
5	3	3214.00	128.56
6	8	4082.00	163.28
7	13	1950.00	78.00
8	18	2786.00	111.44
9	23	548.00	21.92
10	28	1218.00	48.72

This mortar compressive strength test is based on SNI 03-6825-2002 [5]. The procedure for making samples, from material preparation to printing specimens to testing the compressive strength of mortar, can be seen in Figure 6.

Fig. 6 Compressive test on mortar

Figure 7 shows a relationship graph of the addition of polypropylene fibers towards the compressive strength of mortar. The chart above provides information that the addition of 8% polypropylene fiber provides maximum compressive strength. The increase reached 58.46%. The result of the mortar test supports the finding of some other studies where the addition of polypropylene fiber can increase the quality of the mortar and reinforced concrete [24]–[28]. Polypropylene fiber can increase the mortar and reinforced concrete properties towards dynamic load [29], [30][31], [32].

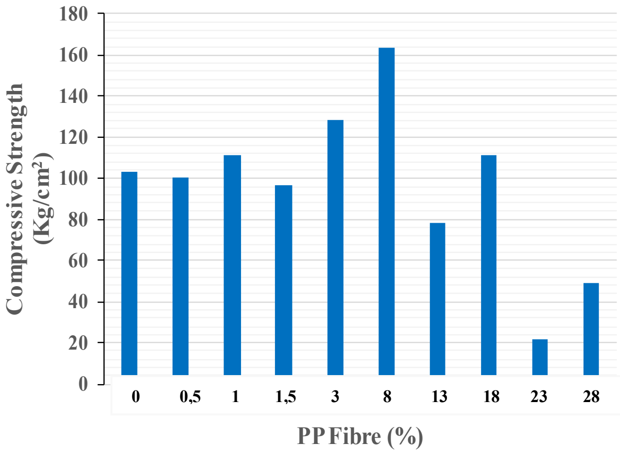

Fig. 7 Compressive strength with polypropylene[23]

B. Flexural Strength

For testing the masonry wall flexure, a pair of masonry walls of 67 cm x 15 cm x 15 cm is used for a masonry wall pair with plastering and 67 cm x 15 cm x 9 cm for a pair of masonry walls without plastering. After the sample is made, an experimental test is carried out on the flexural capacity of the masonry wall. The samples are masonry walls with normal mortar and masonry walls with polypropylene fiber mortar.

The composition of the mixture is one part by weight of cement + three parts by weight of sand + water weighing 60% - 70% by weight of cement (1 pc: 3 ps) and the addition of polypropylene fibers by 8% of the total weight of cement. Figure 6 shows a cement mortar mixture that has been added by polypropylene fiber. The control sample means that the addition of polypropylene fiber to the cement mortar is not carried out.

Fig. 8 Mixture of mortar and polypropylene fiber

The masonry wall bending capacity test is carried out on the 7th day after the sample is printed. There are 12 samples of masonry walls to be tested. It consists of 3 control masonry wall (DBK) samples, three masonry wall samples with polypropylene fiber (DBP), three control masonry wall samples with plastering (DBKP), and three polypropylene fiber's masonry wall samples with plastering (DBPP). The Universal Testing Machine does flexural capacity testing in the Laboratory of Material.

The setting up of the following test specimen dimensions can be seen in Figure 9 and Figure 10. The test is carried out by the three-point loading method with one centralized loading and two pedestals, tested with a Universal Testing Machine with a capacity of 1000 kN. This Universal Testing Machine is connected to a control computer that calculates maximum load data and deflection in specimens. Besides producing load vs. deflection output, a computer also produces output stress and strain graph as well as a load vs deflection.

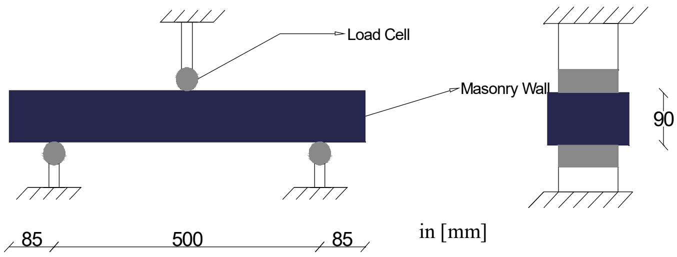

Fig. 9 Setting up experimental masonry wall without plastering

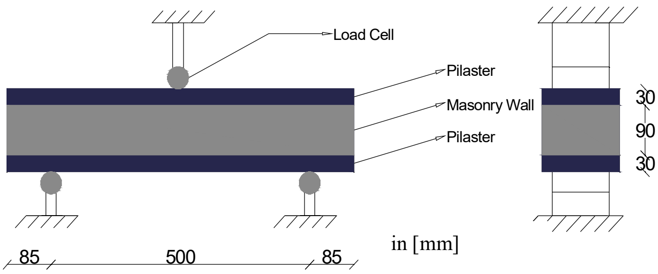

Fig. 10 Setting up experimental masonry wall with plastering.

The following is the experimental testing documentation with the Universal Testing Machine. Figure 11 shows the testing of the flexural capacity for plastered masonry wall samples. For masonry wall samples with plastering, a total of 6 samples, 3 DBKP, and 3 DBPP were tested. The image below is an example of testing a masonry wall sample with plastering. Condition (a) describes the masonry wall sample with plastering before loading; condition (b) describes the sample has been tested until it reaches its maximum capacity and has collapsed.

Whereas Figure 12 shows flexural testing for samples without plastering. There are 6 sample specimens without plastering, namely 3 DBK and 3 DBP. Condition (a) describes the wall sample without plastering before loading; condition (b) describes the sample that has been tested until it reaches its maximum capacity and has collapsed.

After the test object collapses, the maximum load and deflection data are recapitulated from the computer. From the experimental results, there was a significant increase between the masonry wall without polypropylene and the masonry wall that had been added with polypropylene fibers. There was an increase of 80,77% for the plastered polypropylene masonry wall compared to the non-plastered control masonry wall.

(a) (b)

Fig. 11 Flexural test of DBPP

(a) (b)

Fig. 12 Flexural test of DBP

For more details, it can be seen in Table IV. The average of each test object's flexural capacity is collated in the following table. The largest flexural capacity is owned by a sample of plaster masonry walls with polypropylene fibers, which is equal to 1.38 kN.m. The maximum deflection was also achieved by DBPP, which reached 20.49 mm, higher than the DBP deflection, which was 16.12 mm. This result means that there is an effect of increasing specimen capacity after adding polypropylene fibers.

TABLE IV
FLEXURAL STRENGTH OF SPECIMEN

No	Specimen	Max Load (kN)	Deflection (mm)	Flexural strength (kN.m)
1	DBK	1,72	13,51	0,29
2	DBP	1,59	16,12	0,27
3	DBKP	4,99	14,78	0,84
4	DBPP	8,27	20,49	1,38

A significant increase in the flexural capacity of the masonry wall by adding polypropylene can also be seen in Figure 13.

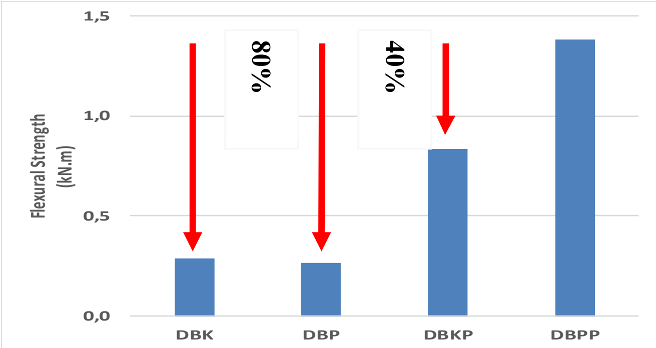

Fig. 13 Flexural strength of specimens

However, they are many kinds of fiber that can be added to mortar and give higher strength. A recent study shows that added mortar with ABACA fiber gives more flexural strength than mortar without fiber [33]. Based on the results, ABACA Fiber showed a higher strength value of 0.7 kN, while polypropylene showed a higher strength value of 4.99 kN.

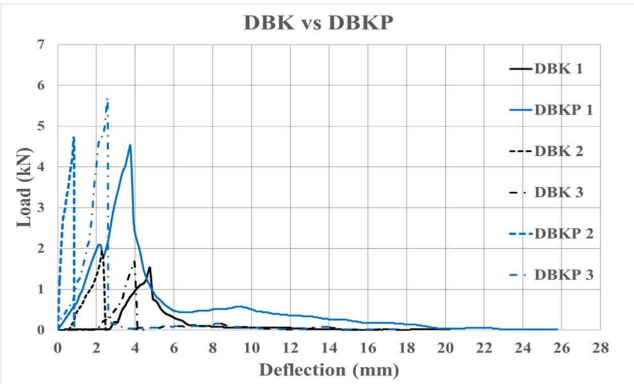

Fig. 14 Load-deflection curves DBK and DBKP

The load and deflection ratio curves in Figure 14 and Figure 15 show the maximum load capacity held by each test object. Figure 14 shows the ratio of maximum load and deflection between DBK and DBKP. The maximum load on the DBKP is an average of 4.99 kN, while the DBK is only 1.72 kN.

The curve in Fig.14 shows that the capacity of DBKP is increase than the DBK. The deflection of DBKP is also more significant than the DBK, which can improve the dissipation energy or the capability of the masonry wall to reduce the collapse probability of the masonry wall. The addition of PP fiber in plastering enables the masonry wall to absorb loading energy, as shown in Fig.15. The DBPP or masonry wall with PP fiber in mortar and plastering show better performance without plastering.

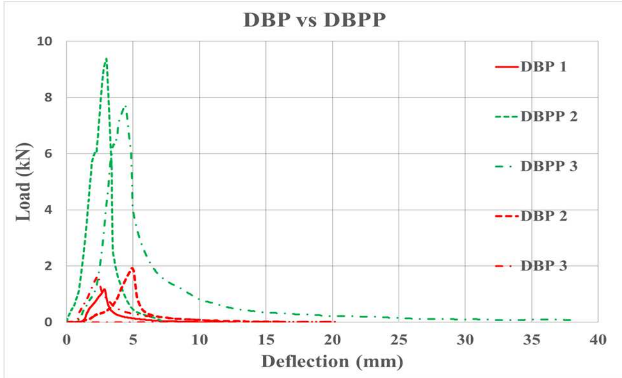

Fig. 15 Load-deflection curves DBP and DBPP

While Figure 15 shows a comparison between DBP and DBPP. All samples experienced a sudden collapse or brittle. However, the load vs. deflection curve in the Figure shows that the polypropylene mortar brick wall is more ductile than without one. The maximum deflection was seen reaching 20.49 mm for DBPP with a maximum load of 8.27 kN. Some previous studies of strengthening of masonry brick that uses polypropylene material have shown an improvement of masonry properties also [8], [32], [34]–[36]. As mortar or concrete can endure high temperatures [37], the addition of polypropylene can increase the capacity of mortar or concrete with polypropylene towards temperature load [38].

IV. CONCLUSION

The flexural testing of 12 masonry wall samples with the addition of polypropylene fibers and without polypropylene fibers has been tested. The results show that the addition of 8% PP fiber to the normal mortar can increase the flexural capacity to 35.8%. The maximum deflection also increases as much as 38.58% for masonry walls with PP fiber on mortar and plastering, compared to the masonry wall without PP fiber. The mortar with 8% PP fiber shows the increment of compressive strength for 58.46%. These results show that the PP fiber mortar that can increase the flexural capacity of the masonry wall can be used as the new strengthening method for the brick red masonry wall to reduce the vulnerability of the masonry wall during the earthquake excitation.

The advantage of this new strengthening method is enabling the building owner to apply the strengthening mortar layer to their existing or new building quickly since this method only requires the addition of 8% PP fiber from PC weight to their normal mortar mix design. In contrast, the PP fiber mortar application to the wall is not different from the normal mortar application.

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