Investigating the Behaviour of Plaster Mortared Rural Masonry Walls

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ABSTRACT

Turkey is located on the Alpine-Himalayan earthquake zone. %92 of its land is faced with earthquake hazard. Even in low intensity earthquakes, major damages have been observed in masonry structures. Masonry structures which are built without any technical support constitute the %40-45 of the structures in Turkey. Therefore, these structures cause losses of lives and remarkable economic in earthquakes. Studies on earthquake resistant structural designs focus on reinforced concrete and steel structures. Researches on masonry structures which are especially preferred in rural areas in Turkey. However, earthquakes negatively affect the masonry structures more than reinforced concrete and steel ones. In the scope of this study, behavior of plaster mixed walls which increase the strength of masonry structures is studied. For this purpose, strength values of normal plaster mixed regular walls with blend bricks and polypropylene and steel fiber mixed masonry walls are analyzed. Double-row and 45x45 mm sized normal mortared wall which is specially produced by 1:2 scaled blend bricks having 100x50x30 mm size values and walls that are formed by polypropylene and steel fiber additives are exposed to biaxial load in several angles. Stress-envelope equations are obtained due to strength of masonry walls bonded by plaster mixed blend bricks. Obtained curves make an important contribution to determine the realistic behavior of polypropylene and steel fiber plastered masonry walls.

INTRODUCTION

The wall is a composite material consisting of brick and mortar. The low shear and adherence strength of the mortar causes it to constitute a weak surface at joints. When a horizontal load is applied on a brick wall, the cracks generally occur in the mortar, and the segregations happen at the joining points of the brick and the mortar. Walls constructed using masonry bricks is a material that is resistant to pressure, and weak under horizontal loads. Numerous studies were carried out in order to overcome this weakness. The studies were generally aimed at increasing the adherence of the brick and the mortar. In these studies that were carried out, usually additives were included in the mortar in order to increase the tensile strength of the wall. The experimental studies carried out with the aim of increasing the strength, stiffness and ductility of the masonry structures were compared with the numerical models that were created, in order to determine the levels of increase occurring in the strength, stiffness and ductility of the masonry structures [1-5]. Various strengthening methods were developed in order to increase the strength of the masonry structures which were found to be inadequate against earthquakes. Significant improvements were obtained in the stiffness, strength and ductility of buildings with masonry walls, by strengthening the brick surfaces with various materials (FRP, wires, fiber materials, wire mesh, reinforcements, steel and wood plates, unused tires) [6-8].

MATERIALS AND METHODS

The masonry bricks used in the construction of the walls were especially produced with 1:2 scale and 100x50x30mm dimensions. The masonry brick moulds were prepared for the production of the bricks. The brick clay produced using clayed soil was poured into moulds and left in the sun to dry as shown in Figure 1.

Figure 1 The masonry bricks dried under the sun

The bricks that completely dried under the sun were stacked with coal placed between them and were ready to use following a brick burning procedure which lasted approximately 7 days in Figure 2. 12 experiments were conducted on the masonry bricks plastered with normal, polypropylene and steel fiber reinforced plasters.

Figure 2 The masonry bricks ready to use and stacked with coal

For the bricks that were used in the experiments, the compressive strength value was 2.65 MPa, modulus of elasticity was 125 MPa, and tensile strength was 0.5 MPa. In the grout mortar used as binder, the sand: lime: cement: water ratio was 20/2/3.6/1.7. The compressive strength and modulus of elasticity values obtained for the grout mortar were 2.68 and 2100 MPa, respectively, and the tensile strength value obtained from the bending test was 0.325 MPa. The wall samples that were prepared had the dimensions 400x400x100mm. The horizontal and vertical jointing gap used between the walls was 10 mm.

The masonry brick walls constructed were also plastered with polypropylene and steel fiber reinforced materials under its traditional application. Since the effect of the additive materials in the plastering applied were researched, the type of sand and cement used were kept fixed. In the reinforced plaster mortar, 2% polypropylene and 2% steel fiber was used. Normal plaster was denoted with N, 2% steel fiber added plaster mortar with S2, 2% polypropylene was denoted using P2, respectively. The mechanical properties of the plaster material obtained from the experiments are shown in Table 1.

The maximum grain diameter of the sand used in the mortars was 4 mm. Portland cement (CemII-42,5) was used in the mortars. After the plasters were applied, the samples were cured in the laboratory at 7 days, and afterwards left in a dry environment for 3 days and then tested. In the experiments, the vertical load was applied with the help of a 250 kN capacity hydraulic jack at 30^o, 45^o, 60^o, 90^o angles, as shown in Figure 3. The loads were applied constant, with 0,1 mm/s intervals. The load was applied on the steel upper hood using hydraulic jack. Linear voltage displacement transducers (LVDT) were placed on the point of application and the double sided plaster surfaces in order to determine the displacements. The values read by the LVDT and were transferred to the computer through the data collection system and simultaneously recorded.

Table 1 The mechanical properties of the plaster material

Sample	Compressive strength (Mpa)	Tensile Strength (Mpa)	Modulus of Elasticity (MPa)
N	**2.68**	**0.325**	**2100**
P2	**7.05**	**0.561**	**5189**
S2	**4.26**	**0.657**	**6650**

Figure 3 Experiments at 30^o, 45^o, 60^o, 90^o angles

RESULTS AND DISCUSSIONS

12 wall samples were subjected to vertical loading at 30^0, 45^0, 60^0, 90^0 angles, the maximum load, shear strength, stiffness, ductility and consumed energy levels were calculated for all samples. At the end of the experiments, the relationships between loads and displacements were tried to determine as shown in Figure 4.

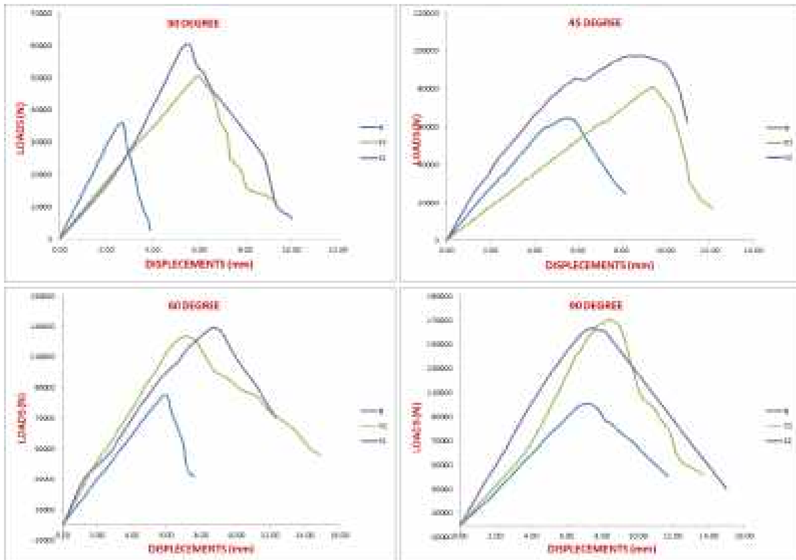

Figure 4 The relationships between loads and displacements

At the end of the experiments was observed that the reinforced plaster applications were very effective on the load carrying capacity of the walls. The maximum load values which can be seen in the curves in Figure 9 are shown in Table 2. In Table 2, the rates of increase in the load capacity of the walls plastered with reinforced plaster mortars and the walls with normal plaster mortar which were used as reference samples are compared.

Table 2 The maximum load values the load capacity of the walls

Angles	**Values**	**The wall samples with reinforced plaster mortar**		
		N	P2	S2
30^0	The maximum load (N)	36033.5	50357.4	60084.8
	The rates of in the load capacity	**1.00**	**1.40**	**1.67**
45^0	The maximum load (N)	64346.0	80722.2	97453
	The rates of in the load capacity	**1.00**	**1.25**	**1.51**
60^0	The maximum load (N)	84886.5	123377.7	129054.8
	The rates of in the load capacity	**1.00**	**1.45**	**1.52**
90^0	The maximum load (N)	100417.5	170565.2	162849.5
	The rates of in the load capacity	**1.00**	**1.70**	**1.62**

When normal plastered brick walls are taken as reference samples, the greatest increase in load carrying capacity was 1.67 times, in the S2 sample for experiments carried out under 30^0, 1.51 times in the S2 sample under 45^0, 1.52 times in the S2 sample under 60^0, and 1.62 times in the S2 sample under 90^0. The shear strength values of the samples were obtained with the help of eqn (1), using the maximum load values obtained from the experiments.

$$\tau = \frac{\cos\alpha * p}{h * t} \tag{1}$$

The shear strength values obtained using eqn (1) and the shear strength ratios obtained according to the reference sample are shown in Table 3. According to the results of the experiment, it was seen that the reinforced plasters had a significant effect on the shear strengths of the wall. In Table 3, the shear strength and shear strength rate of the walls plastered with reinforced plaster mortars and the walls with normal plaster mortar which were used as reference samples are compared.

Table 3 The shear strengths of the walls

Angles	**Values**	**The wall samples with reinforced plaster mortar**		
		N	P2	S2
30^0	The shear strength	0.780	1.090	1.301
	The rates of shear strength	**1.00**	**1.40**	**1.67**
45^0	The shear strength	1.137	1.427	1.727
	The rates of shear strength	**1.00**	**1.25**	**1.52**
60^0	The shear strength	1.061	1.542	1.613
	The rates of shear strength	**1.00**	**1.45**	**1.52**

When normal plastered brick walls are taken as reference samples, the greatest increase in shear strength was 1.67 times, in the S2 sample for experiments carried out under 30^0, 1.52 times in the S2 sample under 45^0, 1.52 times in the S2 sample under 60^0. The shear strength value in eqn (1) is proportional to the load carrying capacity values. Therefore the shear strength rates are similar to the load carrying capacity increase rate. The stiffness values of the wall samples were calculated as the slope of the region where the load-displacement curve was linear. The results obtained are shown in Table 4.

Table 4 The stiffness values of the wall samples

Angles	Values	The wall samples with reinforced plaster mortar		
		N	**P2**	**S2**
30^0	**The stiffness**	141	86	114
	The stiffness ratio	**1.00**	**0.61**	**0.81**
45^0	**The stiffness**	133	87	115
	The stiffness ratio	**1.00**	**0.65**	**0.86**
60^0	**The stiffness**	147	178	149
	The stiffness ratio	**1.00**	**1.21**	**1.01**
90^0	**The stiffness**	149	223	231
	The stiffness ratio	**1.00**	**1.50**	**1.55**

When the stiffness values of the samples with reinforced plaster mortars were compared with the values of the reference samples, a significant difference between the stiffness values was observed. Therefore, it can be said that the reinforced plaster is effective on the stiffness of the samples. It is thought that creating a good adherence surface between the wall and the reinforced plaster has a positive effect on the initial stiffness values of the samples in reinforced plaster applications. The deformation ability of the wall samples were calculated using eqns (2-3).

$$\mu_{0.85} = \frac{\Delta_{0.85Pmak}}{\Delta_{Pmak}} \quad (2)$$

$$\mu_{0.5} = \frac{\Delta_{0.5Pmak}}{\Delta_{Pmak}} \quad (3)$$

In the equations; $\mu_{0.85}$ and $\mu_{0.50}$ represent the deformation ability, $\Delta_{(0.85Pmak)}$ and $\Delta_{(0.50Pmak)}$ represent the vertical displacement values corresponding to the 0.85 and 0.50 levels of the maximum load on the decreasing arm in the load-displacement curve of the relevant sample, respectively. In Table 5, values related to the deformation ability of the samples are given.

Table 5 The deformation ability values of the samples

Angles	**Samples**	Δ_{Pmak}	$\Delta_{0.85Pmak}$	$\Delta_{0.5Pmak}$	$\mu_{0.85}$	$\mu_{0.5}$
30^0	**N**	2.589	2.863	3.301	1.106	1.275

	P2	5.925	6.826	7.426	1.152	1.253
	S2	5.606	6.182	8.259	1.103	1.473
45^0	**N**	5.477	6.329	7.591	1.156	1.386
	P2	9.466	10.300	10.919	1.088	1.153
	S2	8.799	10.447	10.992	1.187	1.249
60^0	**N**	5.956	6.348	7.095	1.066	1.191
	P2	7.175	8.713	11.875	1.214	1.655
	S2	8.688	10.612	11.789	1.221	1.357
90^0	**N**	7.116	8.501	11.050	1.195	1.553
	P2	8.443	9.473	11.439	1.122	1.355
	S2	7.367	8.427	12.809	1.144	1.739

When the results obtained from Table 5 are examined; it was seen that the reinforced plaster application increased the samples' ability for deformation. The reinforced plaster mortars increased the deformation ability of the samples and created a covering effect on the samples by not leaving the samples during the experiment. Thus, rupture of the samples was prevented and ductile behavior was obtained. This effect increases especially in the polypropylene fiber samples. In polypropylene additive samples, after the mortar and brick samples are ruptured in the inner structure, the polypropylene fiber plaster crust swells and takes damage in Figure 5.

Figure 5 The polypropylene fiber plaster sample failure

The highest deformation ability is observed in polypropylene fibered and then the steel fibered walls. The normal plastered samples have shown a lesser deformation ability compared to the reinforced plasters. The amounts of energy consumed by the samples during the experiment were calculated using the area below the load-displacement curves of the samples. Area values for the wall samples used in the study are given in Table 6.

Table 6 The amounts of energy consumed by the samples

Angles	Samples	$A_{0.85Pmax}$	$A_{0.5Pmax}$	$A.O_{0.85Pmax}$	$A.O_{0.5Pmax}$
30^0	N	57741	67999	1,00	1,00
	P2	195638	214641	3,39	3,16
	S2	187478	271421	3,25	3,99
45^0	N	249752	303996	1,00	1,00
	P2	454189	488575	1,82	1,61
	S2	707924	746789	2,83	2,46
60^0	N	293217	338390	1,00	1,00
	P2	666364	944942	2,27	2,79
	S2	860024	958548	2,93	2,83
90^0	N	498121	669666	1,00	1,00
	P2	862267	1072263	1,73	1,60
	S2	827070	1336736	1,66	2,00

In the area calculation; the areas under the parts reaching the 0.85 and 0.50 levels of the maximum load level on the decreasing arm of the load-displacement curve were taken into consideration. In Table 6, the values belonging to the reinforced samples are given by proportioning to the average of the values belonging to the reference samples. When normal plastered brick walls are taken as reference samples; the rate of increase in the area below the part until the 0.85 level of the maximum load level was 3.39 times for the P2 sample in the experiment carried out at 30^0 angle, 2.83 times for the S2 sample at 45^0 angle, 2.93 times for the S2 sample at 60^0 angle, and 1.73 times for the P2 sample at 90^0 angle. The rate of increase in the area below the part until the 0.50 level of the maximum load level was 3.99 times for the S2 sample in the experiment carried out at 30^0 angle, 2.46 times for the S2 sample at 45^0 angle, 2.83 times for the S2 sample at 60^0 angle, and 2 times for the S2 sample at 90^0 angle. The highest energy consumption was observed in steel fibered walls, followed by polypropylene fibered walls.

The envelope curves drawn using the σ and τ values obtained from the maximum loads following the 30^0, 45^0, 60^0 diagonal and 90^0 distributed force tests carried out on the 12 wall samples plastered with normal, polypropylene and steel fiber reinforced mortars are shown in Figure 6.

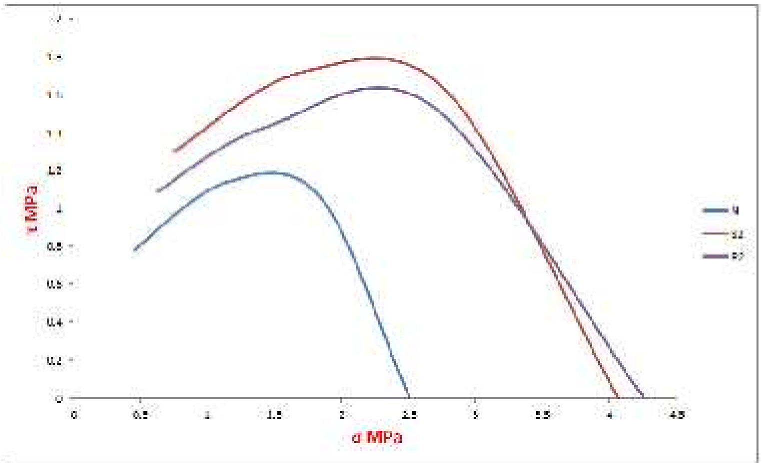

Figure 6 σ and τ values obtained from the maximum loads

The load consumption in the wall samples occur in the form of shear and pressure failure, according to the vertical and horizontal components of the load applied. In the case of shear failure, the strength equation is expressed as given below.

$$\tau = \tau_o + \mu\sigma \qquad (4)$$

Here, μ is defined as the coefficient of friction between the brick and the mortar, τ as the tension during the shear failure and τ_o basic shear adherence tension. The shear stress obtained from Figure 12 according to the wall types are shown in Table 7. In the shear failure equations obtained from Table 7, the smallest friction was 0.422 in P2 sample and the largest was 0.520 in N sample. Largest adherence was 0.975 in S2 sample and the smallest adherence was 0.546 in N sample.

Table 7 The shear stress obtained according to the wall types

Samples	**The shear stress equation**
N	$\tau = 0.546 + 0.520\,\sigma$
P2	$\tau = 0.825 + 0.422\,\sigma$
S2	$\tau = 0.975 + 0.434\,\sigma$

conclusion

In this study, 12 wall samples 400x400x100 mm sized were constructed using 1:2 scaled 100x50x30mm sized masonry bricks. The walls were plastered using normal and polypropylene and steel fiber reinforced plaster mortars and were exposed to vertical loads at various angles. In the tests carried out, significant increases in the load carrying capacities of the samples produced using reinforced plasters was obtained. According to the test results, it was observed that the reinforced plaster application was very effective on the shear strengths of the walls. The reinforced plasters significantly increase the stiffness of the walls. It is thought that the increase observed in the initial rigidities in the reinforced plaster applications is due to a good adherence surface between the wall and the reinforced plaster. Through the reinforced plaster application deformation ability of the samples increased. The reinforced plasters did not peel completely from the surface throughout the experiment and created a covering effect and increased the deformation ability of the walls. Thus, the rupturing of the samples was prevented and ductile behavior was obtained. Highest energy consumption was observed in the steel fibered walls, and then polypropylene fibered walls. In the envelope curves drawn following the experiment, using the σ and τ values obtained from the maximum loads, it was observed that the highest adherence was obtained from steel fiber reinforced plaster mortars.

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