COMPRESSION PERFORMANCE OF TRADITIONAL PLASTER THROUGH MATERIAL EXPERIMENT

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ABSTRACT: This paper reports the result of material experiments on Japanese traditional plaster, focused on the compression performance. Plaster has been used as the finish of building planes as walls, floors, substrate of roofs and so on. However there has been only a few studies about the material properties of them. In this research, in order to investigate the basic characteristics of the material, we performed compression tests to several mixing of plaster. The specimens are taken from each step of constructing a wooden lath and plaster wall which was made along with the specification of a cultural property building, Former Date County Office in Fukushima. As the result of this experiment, the average compression strength of each mixing pattern was clarified.

Key Words: Plaster, Lath, Compression Experiment, Hemp Fiber

INTRODUCTION

‘Lath and Plaster’ wall had been one of the most common inner wall of modern timber buildings in Japan before World War Ⅱ. However, there are only a few researches on the material properties and structural characteristics of plaster [1], because it has been considered only as a finishing material. However, in some previous researches on the lateral strength of modern plaster wall, it is suggested that plaster has the effect of increasing stiffness and strength of wall [2]. Therefore the material properties of Japanese plaster should be clarified for appropriate evaluation of the seismic performance of modern plaster wall. For these reasons, the objective of this paper is to clarify the material properties of Japanese plaster, especially compression performance, through material experiments.

(a) Plastering on timber lath

(b) Plaster Material

Figure 1. Construction of Plaster Wall

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Method of Experiment

We performed the compression experiments of plaster to investigate relationship between compression stress and strain, which is one of the main phenomena happening between laths of plaster walls. The experiments were performed against several mix patterns of Japanese plaster; hydrated lime, sand, adhesive, hemp fibers. The results were compared with each pattern and with mud for traditional wall.

The loading apparatus is shown in **Figure 2**. The experiment was a static push over vertical loading test. The vertical load was applied to the specimen by 0.5mm/min and the force (compression resistance) of the plaster and vertical displacement was measured by using two displacement transducers (CDP-50, Tokyo Sokki) and a load cell (TCLM-50kNB, Tokyo Sokki). When the strength reached to 80% of maximum strength, or fractured, the test was stopped. In many cases, distinct maximum strength or fracture were difficult to be observed, so we kept pressuring until the limit of measuring displacement.

Specimen

The specimen is a mixture of the plaster consisting of slaked lime (calcium hydroxide), water, adhesive, and fiber. The adhesive was made by boiled *Chondrus ocellatus Holmes,* a type of see weed which has been used in traditional Japanese wall construction. The mixing ratio of each layer depends on that of a cultural heritage building, *Former Date County Office* built in 1886 in Fukushima. The Compression test was conducted on 18 specimens. The mixing ratio of them is shown in **Table 1**.

The specification of specimens are shown in **Table 2**. They were formed in plastic molds which were 100mm height and 50mm diameter. During the curing period (2010.12-2014.7, Tokyo), the specimens were kept in room temperature. After curing, they were demolded and polished to 90mm height. The average weight of the specimen was from 144 to 266 g, the average specific gravity was 0.84 to 1.56. The compression area was from 1698 to 1908 mm^2 in average.

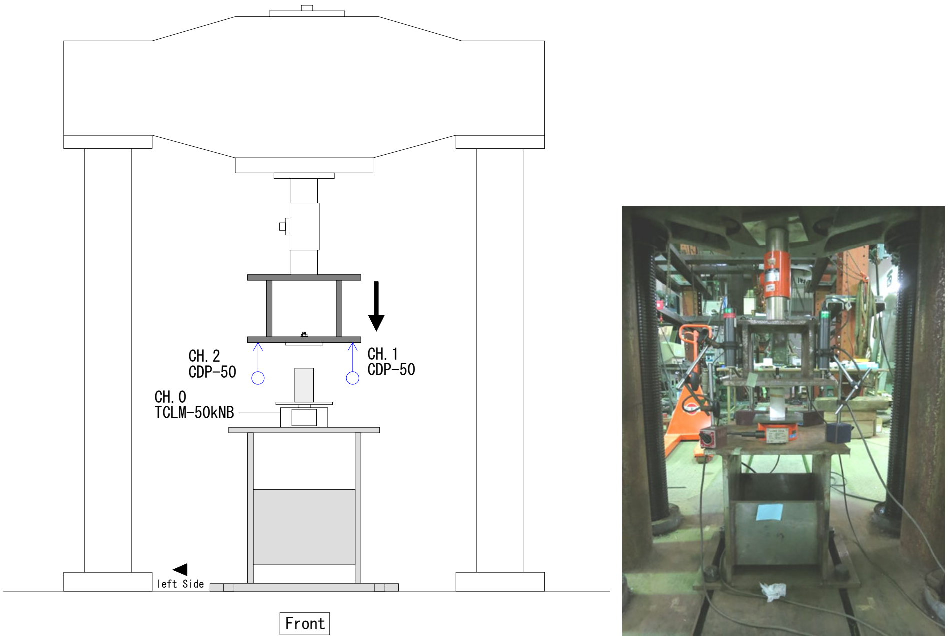


Figure 2. Apparatus of compression experiment

Table 1. Mixture of plaster specimen

Types of Coating Material		Thickness	Components of Plaster				Ratio of Sand to Plaster [in Volume]
			Slaked Lime	Chondrus Glue	Manila Hemp Fiber	Bleached Manila Hemp Fiber	
		mm	kg	g	g	g	
Base Material	Raw Plaster	–	20	1200	800	0	0
Basecoat	Undercoat	2	20	1200	800	0	10:1
	Basecoat	3	20	1200	800	0	6:4
Middlecoat	Cover Hemp Twine	3	20	700	700	0	6:4
	1st Layer	6	20	700	700	0	5:5
	2nd Layer	3	20	700	700	0	5:5
Finishcoat	1st Layer	1	20	1000	0	600	0
	2nd Layer	1	20	600	0	600	0

Table 2. Specification of specimen

				Weight	Height[L, R Ave.]	Diameter [Up,Mid,Base,Ave.]	Section	Volume	Specific Gravity	Speed
Coating Phase	Specimen			g	mm	mm	mm^2	cm^3	–	mm/min
Basic Material	Raw Plaster *'Ki-jikkui'*	A	1	147.0	91.5	49	1886	173	0.85	0.5
			2	144.1	90.0	48.8	1868	168	0.86	1
			3	147.1	90.8	50.0	1962	178	0.83	1
		Ave.		146.1	90.8	49.3	1905	173	0.84	–
Undercoat	Raw Plaster: Sand 10:1	B	1	190.1	96.0	47.5	1774	170	1.12	10
			2	190.3	89.7	47.9	1801	161	1.18	1
			3	192.6	90.5	46.7	1714	155	1.24	1
		Ave.		191.0	92.1	47.4	1763	162	1.18	–
Basecoat/ Hemp Twine Covering	Raw Plaster: Sand 5:5	C	1	236.1	90.0	47.0	1734	156	1.51	1
			2	236.4	91.1	48.3	1828	166	1.42	1
			3	235.1	90.1	48.3	1829	165	1.43	1
		Ave.		235.9	90.4	47.8	1797	162	1.45	–
Middlecoat No.1 and No.2	Raw Plaster: Sand 5:5 + Slaked Lime	D	1	263.8	91.5	49.3	1909	175	1.51	1
			2	266.1	90.6	48.9	1879	170	1.56	1
			3	270.7	91.2	48.3	1834	167	1.62	1
		Ave.		266.9	91.1	48.8	1874	171	1.56	–
Finishcoat	Finishcoat 1st Layer	E	1	162.5	91.7	47.2	1747	160	1.01	1
			2	158.6	91.7	47.2	1749	160	0.99	1
			3	158.8	91.0	46.9	1728	157	1.01	1
		Ave.		160.0	91.5	47.1	1741	159	1.00	–
	Finishcoat 2nd Layer	F	1	174.2	91.2	46.1	1670	152	1.14	1
			2	169.2	92.1	47.3	1753	162	1.05	1
			3	172.7	92.2	46.1	1670	154	1.12	1
		Ave.		172.0	91.8	46.5	1698	156	1.10	–

Result of the Compression Test

The result of the stress strain relation of the compression experiment is shown in **Figure 3**. The vertical axis shows the shear stress (N/mm^2), the horizontal axis shows the strain. The maximum compression stress and strain is shown in **Table 3**.

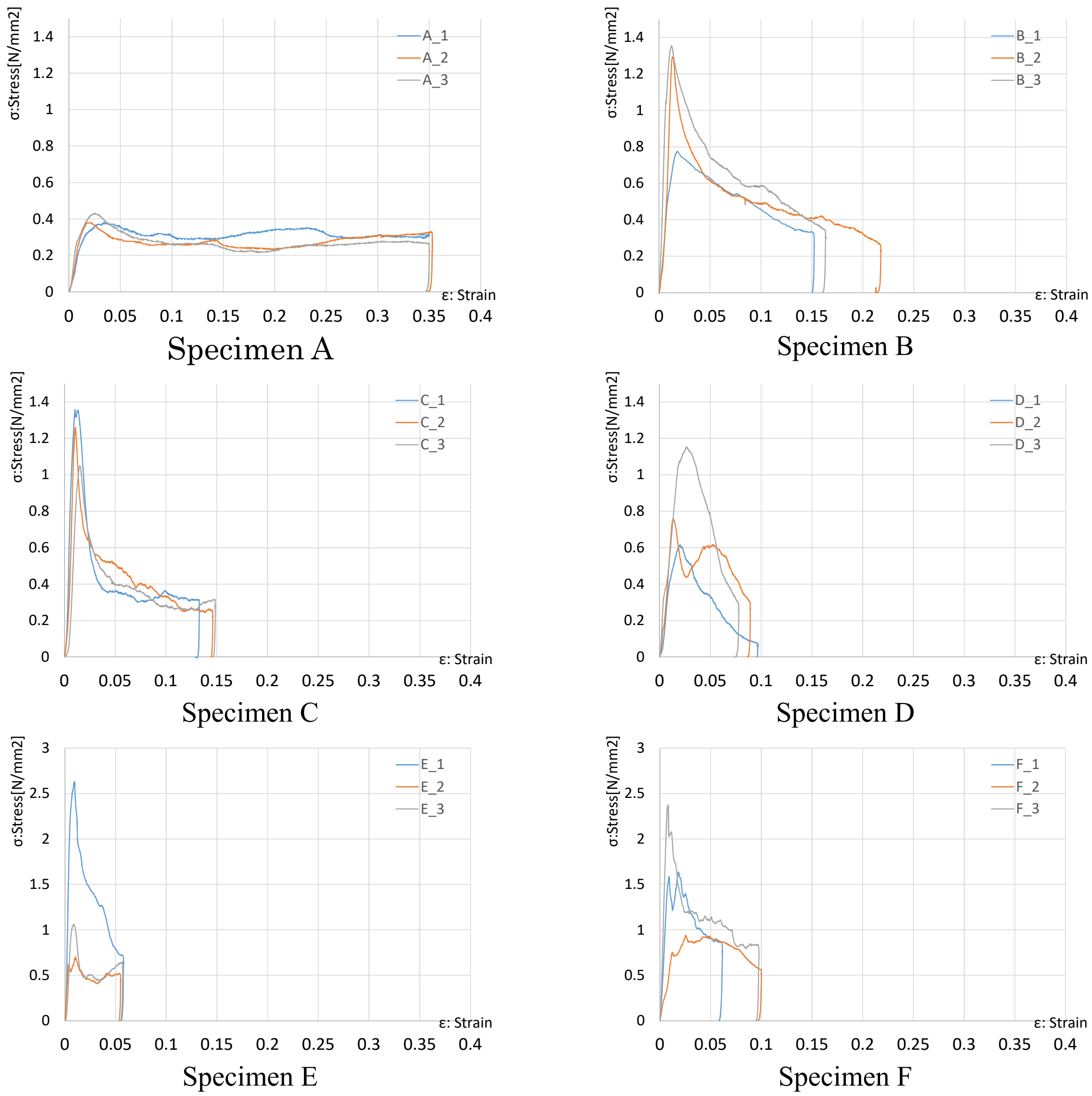


Figure 3. Stress-Strain relationships

Table 3. Summary of the result

Specimen			A				B				C			
		No.	1	2	3	ave.	1	2	3	ave.	1	2	3	ave.
Maximum	stress	N/mm^2	0.38	0.38	0.43	0.40	0.78	1.29	1.35	1.14	1.36	1.26	1.05	1.22
	strain	–	0.034	0.022	0.026	0.027	0.018	0.013	0.012	0.014	0.010	0.011	0.015	0.012
Specimen			D				E				F			
		No.	1	2	3	ave.	1	2	3	ave.	1	2	3	ave.
Maximum	stress	N/mm^2	0.62	0.76	1.15	0.84	2.63	0.70	1.06	1.46	1.63	0.94	2.38	1.65
	strain	–	0.020	0.013	0.026	0.020	0.009	0.011	0.009	0.010	0.018	0.025	0.008	0.017

Specimen A

Progress of destruction: As the test progresses, the center cracks occurred and then both strength and stiffness decreased, finally crashed from the bottom. **Figure 4** shows the destruction progress of Specimen A.

Stiffness and strength: At about 0.02 to 0.04 strain, the specimen yielded and recorded the maximum strength. The shear failure with diagonal cracks occurred at about the maximum strength. The strength reached about 0.40 N/mm^2. The initial stiffness of three specimens are all similar.

(a) A_2 Disp:0mm (ε :0) (b) A_2 Disp:6mm (ε :0.067)

Figure 4. Specimen A: Progress of destruction

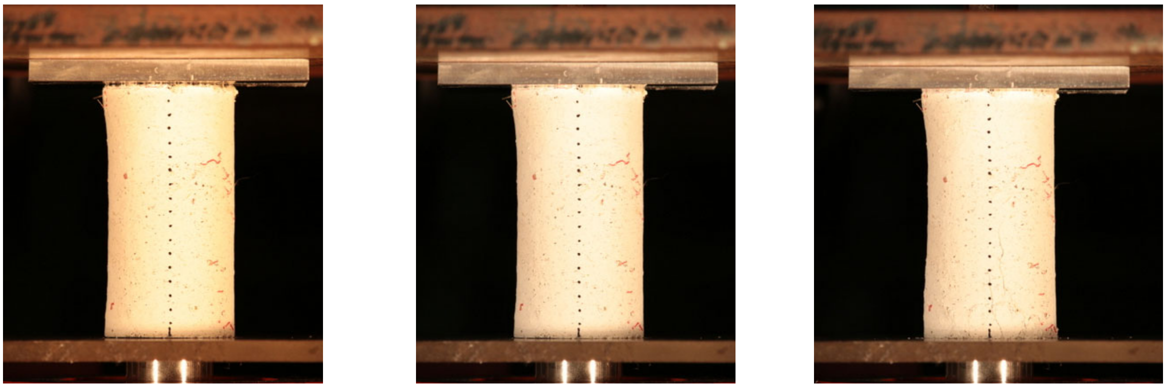
Specimen B

Progress of destruction: As the test progress, the center cracks occurred and then both strength and stiffness decreased, finally crashed from the bottom. **Figure 5** shows the destruction progress of Specimen B.

As the compression progressed, the bottom of specimens began to expand and after the maximum strength, center cracks occurred and the strength decreased sharply.

About B1, the compression speed was 10 times compared to others, it broke earlier than others.

About B2 and B3, there were a little difference between their initial stiffness, the maximum strength and the elastic modulus were similar.



(a) B_2 Disp:0mm （ε :0) (b) B_2 Disp:1.2mm P_{max} （ε :0.013) (c) B_2 Disp:3mm （ε :0.034) Center crack

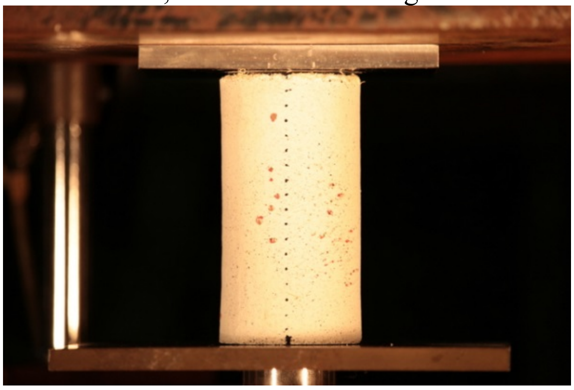
Figure 5. Specimen B: Progress of destruction

Specimen C

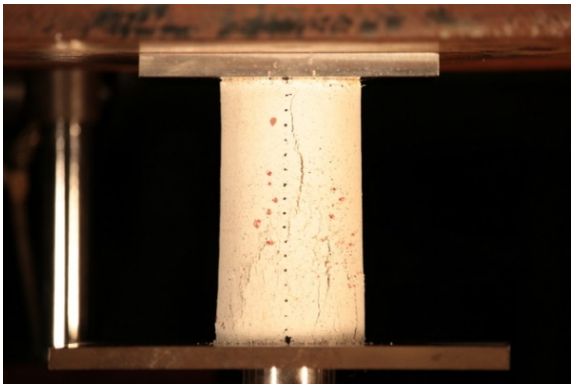
Progress of destruction: At the point, center cracks occurred, then extend to cross cracks, finally crushed from the bottom. So the progression of damages were similar to those of Specimen B series. **Figure 6** shows the destruction progress of Specimen C.

Strength and Stiffness: Both C1 and C2, the maximum strength were about 1.2-1.3kN/mm^2 at 0.01

strain. After that, the strength sharply decreased to about 25%. Though the progress of destruction was same as on C3, the maximum strength was about 70% of others'.



(a) C_1 Disp. 0mm [ε :0]



(b) Disp. 3mm [ε :0.033]

Figure 6. Specimen C: Progress of destruction

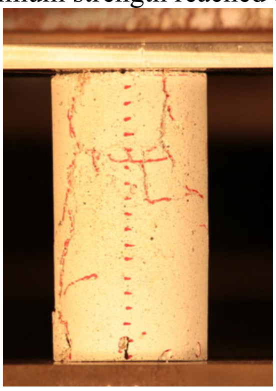
Specimen D

Progress of Destruction:

On all three specimens, at first the top was crushed and then the cracks extended from the top to the bottom. **Figure 7** shows the destruction progress of Specimen D.

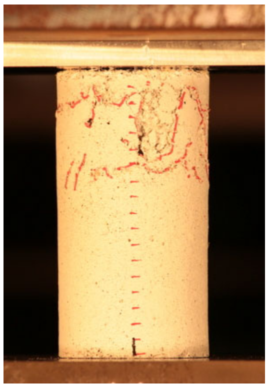
Strength and Stiffness:

Strength and stiffness vary widely in all specimens. In D-3 which had relatively small cracks, the maximum strength reached to about 2.2kN, almost same as C series.

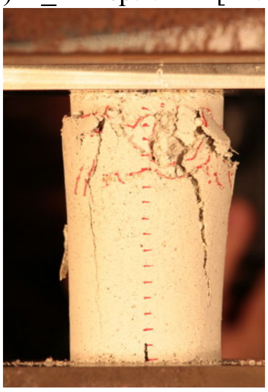


(a) D_1 Disp. 0mm [ε :0]

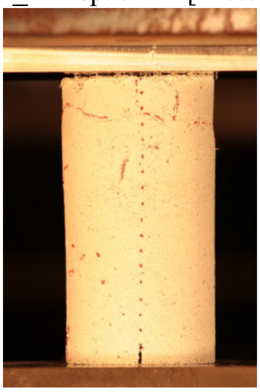
(b) D_1 Disp. 3mm [ε :0.033]



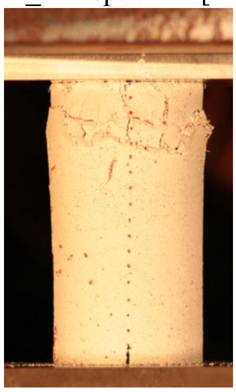
(c) D_2 Disp. 0mm [ε :0]



(d) D_2 Disp. 4mm [ε :0.044]



(e) D_3 Disp. 0mm [ε :0]



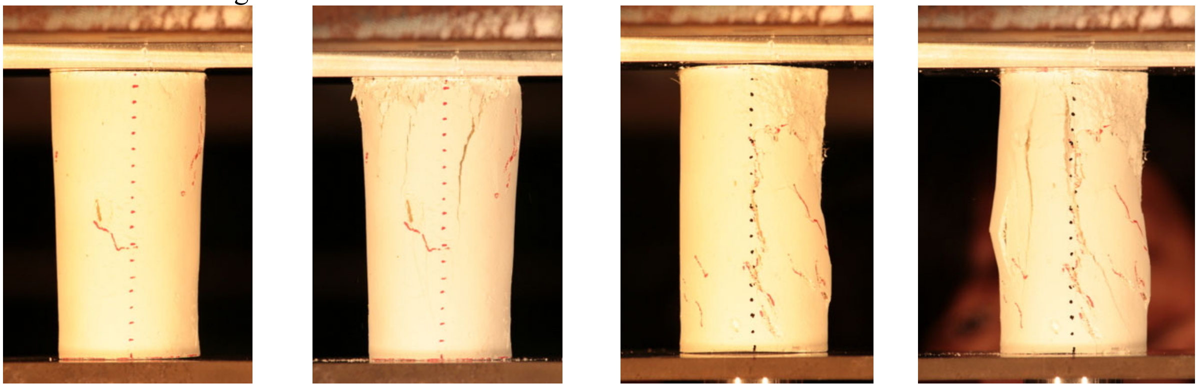
(f) D_3 Disp. 2.4mm [ε :0.026]

Figure 7. Specimen D: Progress of destruction

Specimen E and F

Progress of Destruction: In both series, the specimens were curved and the surfaces were rough because of the drying shrinkage which were especially remarkable in this mixing ratio. In many specimens, at first central cracks occurred and then they were splitted from the top. **Figure 8** shows the destruction progress of Specimen E and F.

Strength and Stiffness: Compared to other layers, these two have similar mixing of contents, however the structural behaviors varied widely. In every specimen, the maximum strength surpassed 1kN, and also stiffness were high.



(a) E_1 Disp:0mm (ε :0) (b) E_1 Disp:1.2mm (ε :0.013) (c) F_1 Disp:0mm (ε :0) (d) F_1 Disp:2mm (ε :0.022)

Figure 8. Specimen E and F: Progress of destruction

EVALUATION OF THE COMPRESSION STRESS OF PLASTER

We compared the obtained results with each other, and with other material. **Figure 9** shows the maximum compression stress of every specimen and average of each series. The average value of compression stress of each mixing pattern was from 0.40 to 1.65 N/mm^2. In average, raw plaster (series A) was the weakest. Series E and F showed higher strength than others, however in both series the dispersions were bigger than others. Except for series E and F, series B and C showed higher compression stress, in which measurable 'sand' are mixed with slaked lime, adhesive and fibers. On the other hand, compared with the compression stress of mud [3] which was used for another typical traditional wall in Japan, every series of plaster showed higher compression strength.

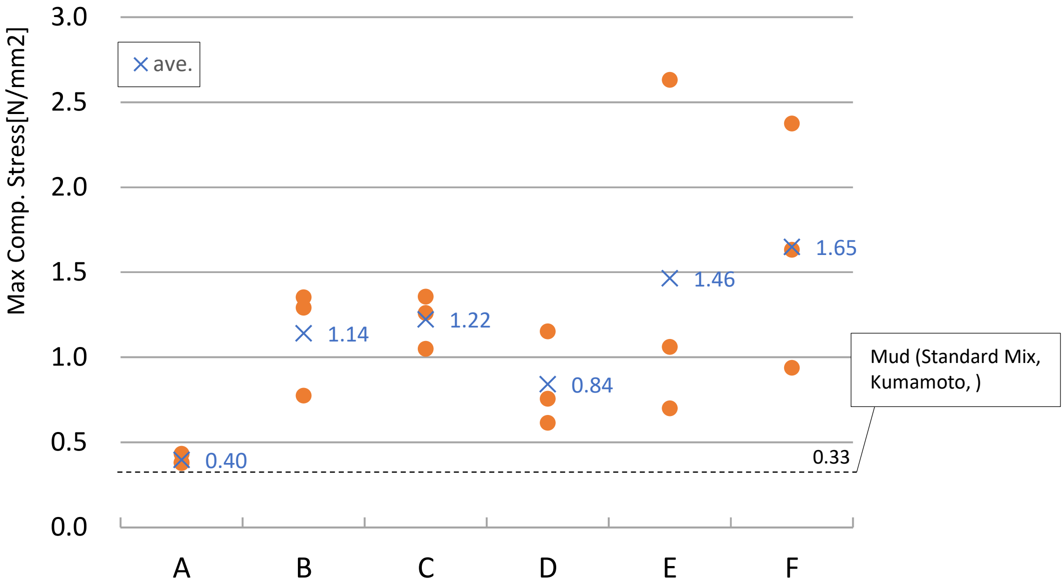


Figure 9. Comparison of maximum compression stress

CONCLUSIONS

This paper reports the result of compression experiments on traditional plaster. The tests were performed on each mixing pattern. As a result of the experiments, the average strength of plaster was from 0.4 to 1.65 N/mm^2. The undercoat and basecoat specimen, series B and C showed higher strength, and finishcoat, series E and F showed highest strength, however the value varied widely. Compared with standard mud for wall, even the raw plaster showed higher strength.

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