MECHANICAL PROPERTIES OF PAPERCRETE CONTAINING WASTE PAPER

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1 Introduction

These days CO_2 emission which made from construction sites because of cement using is globally issued. On the other hand, people's desire to live eco-environment is continuously increasing. In order to resolve these kinds of matters, this study carried out. Papercrete is a new composite material using waste paper as a partial replacement of portland cement. By using the waste paper, papercrete is not only reducing the amount of cement using but also making environmentally friendly building materials.

This study aimed to evaluate the fundamental mechanical properties such as compressive and splitting tensile strength of papercrete containing waste papers as a partial replacement of portland cement. And it also analyzes the stress-strain relation of papercrete to evaluate the ductile behavior of papercerte.

2 Experimental programs

2.1 Papercrete Mix Proportions

Newspaper was used for this experiment among lots of waste papers. Paper mainly consists of cellulose fiber and inorganic materials so it used binder by replacing with cement because it was expected that cellulose fiber of newspaper combine well with cement paste well.

In this study, for papercrete specimens tested, 3 mixing variables were decided; water-binder ratio, sand-binder ratio and paper-cement replacement ratio.

Waste paper was used as a replacement of portland cement at 5%(PA mixing), 10%(PB mixing) and 15%(PC mixing) by weight, respectively. PA mixing was separated according to different water-binder ratio(w/c) of 45%, 60%, 85% to investigate water-binder effect which is usually main variables for strength of mortar and concrete. And PB and PC mixing were separated by different sand-binder ratio of 100%, 75% and 50% to evaluate the effect of sand related to shrinkage because waster paper have high water absorption so high shrinkage of papercrete was expected after curing. And water-binder ratio of group PB and PC was 85%. Each specimen included 5% superplasticizer to alleviate the problem on workability because of high water absorption of waste paper. The mix proportions of papercete are shown in Table.1.

2.2 Experimental Procedures

Total 45 sized 100*200mm cylinder specimens produced in the laboratory and 27 specimens were for compressive strength test and 18 specimens were for splitting tensile strength test.

To prevent becoming clumped condition when waste

Specimens	Water/Binder	Paper/Binder	Sand/Binder	Ingredients (kg)				
				Waste paper	Water	Cement	Sand	SP
PA1	0.45	0.05	1.00	50	450	950	1000	50
PA2	0.60	0.05	1.00	50	600	950	1000	50
PA3	0.85	0.05	1.00	50	850	950	1000	50
PB1	0.85	0.10	1.00	100	850	900	1000	50
PB2	0.85	0.10	0.75	100	850	900	750	50
PB3	0.85	0.10	0.50	100	850	900	500	50
PC1	0.85	0.15	1.00	150	850	850	1000	50
PC2	0.85	0.15	0.75	150	850	850	750	50
PC3	0.85	0.15	0.50	150	850	850	500	50

Table.1. Mix proportions of papercrete

papers mixed with water, waste paper was chopped very small condition before mixing to distribute evenly in the papercrete mix. Then it mixed with portland cement and sand with dry condition using the handmixer during 2minutes. And then it mixed with water and superplasticizer during
3minutes using the handmixer.
The produced specimens were cured in laboratory at a temperature of 20℃ and relative humidity about 60% until they were removed from their molds. The molds were removed from specimens after 7 days from casting.
The process of making specimens followed KS F 2403 for method of making concrete specimens, KS F 2405 for compressive strength test and KS F 2423 for splitting tensile strength test.

3. Experimental Results

The density, shrinkage, compressive strength and splitting tensile strength test results are given in Table.2. The density was measured after 60 days from casting and also the compressive strength and splitting tensile strength test was carried out at 60 days.
The results obtained with cylinder specimens are given Table.2, and each strengths was calculated average of 3 specimens for compressive strength and 2 specimens for splitting tensile strength, respectively.

3.1 Density and Shrinkage

As shown Table.2, the replacement ratio of waste paper of papercrete is correlated to their density. The average density of group PA(paper replacement ratio 5%) was 1.88g/cm³, And it was reduced to 15% and 22%, respectively, when replacement ratio of waste paper was increased to 10% and 15%. The density of the papercrete has trend of decreases as a higher waste paper was included. Due to the low density of the waste paper, it reduced the overall density of the specimens.
As shown Table 2, group PB and PC has similar trend. In PB mixing, density of papercrete reduced to 1.62g/cm³ and 1.55g/cm³ from 1.64g/cm³ by sand-binder ratio reduced from 1.00 to 0.75 and 0.50.
Because absolute quantity of cement was decreased but absolute quantity of sand was increased by decreasing the sand-binder ratio. Specific gravity of cement is larger than sand so total density of papercrete was reduced. Fig.1. indicates the trend of decreasing density of papercrete according to increase of paper replacement ratio.
Shrinkage of papercre is shown in table.2. The average shrinkage of papercrete of group PA was 1.33% and group PB was 3.07% and group PC was 3.70%, respectively. It means paper replacement ratio of papercrete affected increase of shrinkage a lot. At group PB and PC, decrease of sand-binder ratio made increase of shrinkage.

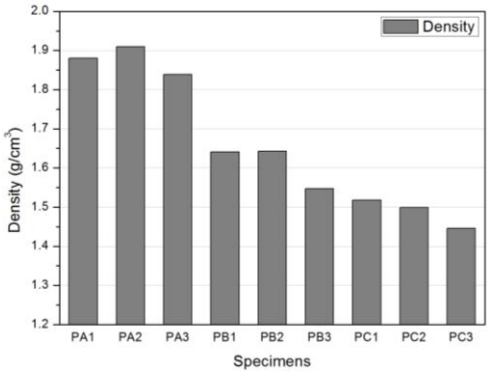

Fig.1. Density of papercrete.

3.2 Compressive Strength

The average compressive strength of group PA was 34.05MPa, group PB was 21.2MPa and group PC was 16.19MPa, respectively.
Table.2 shows that Group PA which included 5% paper had similar compressive strength. PA1 was

Specimens	Shrinkage (%)	Density (g/cm³)	60-days strength (MPa)		
			Compressive	Splitting tensile	fpc/fsp
PA1	2.2	1.88	34.05	3.638	9.35
PA2	0.4	1.93	33.47	2.960	11.31
PA3	1.4	1.82	34.68	4.205	8.26
PB1	2.0	1.64	19.81	2.833	7.00
PB2	4.1	1.62	20.87	2.744	7.62
PB3	3.1	1.55	22.92	3.138	7.30
PC1	3.4	1.51	14.80	2.247	6.58
PC2	3.7	1.49	16.40	2.579	6.36
PC3	4.0	1.44	17.37	2.755	6.29

Table.2. Density, shrinkage, compressive strength splitting tensile strength of papercrete

34.05MPa, PA2 was 33.47MPa and PA3 was 34.68MPa, respectively. These test result indicates that water-binder ratio was hardly affected compressive strengths of papercrete. Waste paper featured high water absorption, so when it mixed with water, paper absorbed lots of water their surface. But when it compacted to the mold, absorbed water of surface was emitted out of mold. So water-binder ratio was hardly affected compressive strengths of group PA.

The test result of PA3, PB1, PC1 specimens is shown in Fig.2. And strength was 34.68MPa, 19.8MPa and 14.80MPa each. The result showed that the compressive strength was rapidly reduced when more replacement ratio of the waste paper included in papercrete. The absorbed water of paper made cement paste through cement hydrate reaction but when paper include more water which was needed for cement hydrate reaction, it became surplus water which made decrease of strength. Thus, the reduction of compressive strength of PB1 and PC1 which include more waste papers were made.

Compressive strength of PB and PC mixture which included 10% paper replacement ratio was slightly increased by reducing sand ratio. Although specimens included same paper-cement ratio, in group PB, compressive strength of PB1 was 19.8 MPa and PB2 was 20.87MPa, and PB3 was 22.92MPa which are indicated Fig.2. The reason of difference is evaluated that low sand ratio made increase of cement quantity which affected compressive strength by making more cement paste. As a result of increase of cement paste, compressive strength of papercrete was increased.

Fig.3. shows compressive strength of papercrete according to variables. Papercrete containing waste paper is evaluated that compressive strength of papercrete governed paper-cement replacement ratio.

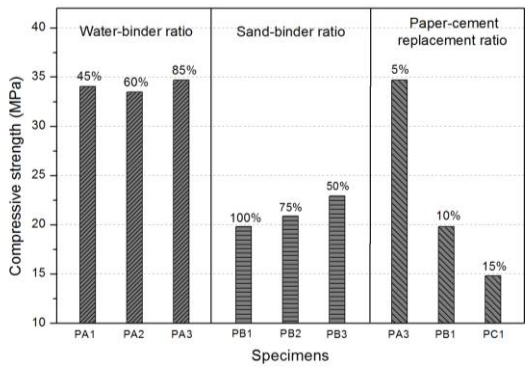

Fig.2. Compressive strength of papercrete according to the mixing variables; water-binder ratio, sand-binder ratio and paper-cement replacement ratio.

3.3 Splitting Tensile Strength

As indicated Table.2, the average splitting tensile strength of group PA, PB and PC specimens were 3.6MPa, 2.90MPa and 2.53MPa, respectively. When specimens included higher replacement of waste paper, splitting tensile strengths were decreased. Similar to the results of compressive strength, increases of the paper-cement replacement ratio reduced the splitting tensile strength of papercrete.

Coefficient of brittleness is the value of the compressive strength divided by splitting tensile strength of papercrete. In the Fig.3, The graph of coefficient of brittleness is reducing by increasing the paper-cement replacement ratio. This result indicates that splitting tensile strength of papercrete shows ability well because of tensile performance of waste paper. Depending on this experimental result, increase of paper-cement replacement ratio helped rise of ductile behavior of papercrete.

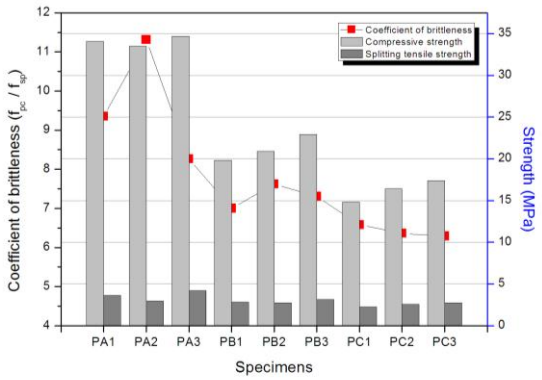

Fig.3. Compressive strength, splitting tensile strength and coefficient of brittleness of papercrete.

3.5 Stress- Strain Curve

The stress-strain curves of papercrete with different waste paper contents are shown in Fig.4. It illustrates that the replacement ratio of waste paper has remarkable influences on the stress-strain curves of papercrete.

The stress-strain curves showed that ultimate strain ranged of 0.002-0.003, 0.005-0.007 and 0.008-0.010 when included waste paper replacement ratio of papercrete is 5%, 10% and 15%, respectively. The result presented the ultimate strain of the stress-strain curves was certainly increased according to increases of replacement ratio of waste paper. And graph shows that after peak load, Group PB specimens behaved more ductile than 5% included waste paper group PA. And also group PC behaved more ductile than group PB. The reason of these results is because of the combination between

cellulous fiber of waste paper and cement paste increased the ductile ability of papercrete.

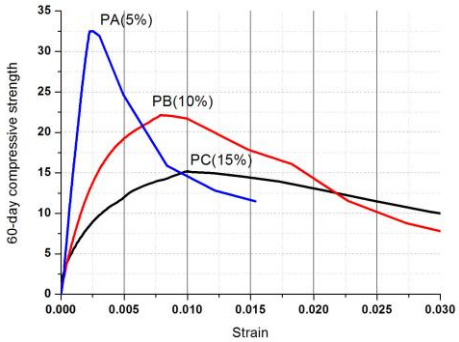

Fig.4.Stress-strain curves according to paper replacement ratio group PA, PB and PC.

4. Conclusion

In this paper, experimental results for the mechanical properties of waste paper under uniaxial compression loading are presented. From this investigation, the following conclusions can be followed:

(1) The density of papercrete was decreased when the replacement ratio of waste paper of papercrete increased. When paper replacement ratio was 5%, density was measured 1.88g/cm^3, and it was reduced to 15% and 22%, respectively by increasing paper ratio 10% and 15%.

(2) The shrinkage of papercrete was increased according to increase of paper-cement replacement ratio.

(3) The average compressive strength of group PA which include 5% paper-cement replacement ratio was 34MPa and water-binder ratio hardly affected compressive strength of papercrete. The compressive strength of group PB(paper replacement ratio 10%) and PC(paper replacement ratio 15%) was increased slightly by decreasing sand-binder ratio to 0.75 and 0.50.

(4) The compressive strength of group PA(5%) was 34MPa. And it was reduced to 38% and 53%, respectively, when replacement ratio of waste paper was increased to 10% and 15%. According to paper replacement ratio, compressive strength affected rapidly.

(5) The splitting tensile strength of group PA was 3.60MPa, PB was 2.9MPa and PC was 2.53MPa. The splitting tensile strength also decreased by including higher replacement ratio of waste paper.

(6) The stress-strain curves showed that ultimate strain ranged of 0.002-0.003, 0.005-0.007 and 0.008-0.010 when included waste paper replacement ratio of papercrete is 5%, 10% and 15%.

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