THE STUDY OF PVA REINFORCED EXTRUSION PRODUCTS

SHINYA INADA, YOSHINORI HITOMI AND AKIRA IMAGAWA

Industrial Materials R&D Department, Kuraray Co., Ltd., OKAYAMA, JAPAN

ABSTRACT

In 1970, a Japanese manufacturer had developed extruded cement products based on the technology of extrusion for clay tile. Extruded cement products have unique features, for example, 3D and hollow design, heat and sound insulation, and so on. These features could potentially allow extruded cement products to be adaptable to a wide range of application uses.

However, in fact, the range of application uses of extruded cement products is limited to certain fields due to lack of bending strength of the products. The conventional extruded cement products are based on autoclaved curing, so the products can only achieve low bending strength.

In this study, we show the solution to the low strength problem of conventional extruded cement products by introducing Kuralon™ (PVA fiber) reinforcement based on natural curing. This newly introduced idea will contribute to high bending strength of extruded cement products and enable them to explore new application uses such as roofing sheet, external wall for high-rise building and civil construction.

KEYWORDS:

PVA fiber, extruding, fiber reinforced cement, natural curing, bending strength

INTRODUCTION

History of extruded cement products

In 1970, after almost ten years in development, a Japanese manufacturer brought extruded cement products to the Japanese market. The development had started based on the production technology of clay tiles and bricks. It was at the time when products manufactured by Hatschek process (Hatschek products), such as corrugated sheet and flat sheet, flourished in the market. However, the development team had believed that cement products would have a huge potential with decorative surface and flexible cross-section structure.

The challenge for the development was to overcome the problems caused by the difference between clay and cement. For example, low plasticity of cement caused the difficulty of shape retention. Also, short working life of cement made the continuous extrusion harder. Given these problems, it had been believed that the development of cement extrusion products was almost impossible. However, the development team overcame these problems by optimizing composition, machinery and the production process.

Since their introduction, extruded cement products have expanded their sales and become one of "must have" building materials for construction in the Japanese market. Behind the success of extruded cement products, there was the change of construction method.

At the time, there had been a rush to build more homes and commercial buildings in Japan as the economy grew rapidly. However, the conventional construction was based on wet construction method using concrete blocks for walls. The process of making walls in this way was time-consuming, causing the short supply of homes and commercial buildings.

To meet their demands, eventually dry construction methods, such as prefab construction, were introduced to the market. Dry construction methods required manufactured panels (JIS certified products) for walls, which contributed to fast construction and stable quality of construction. The spread of dry construction method has driven the growth of extruded cement products. Also its unique hollow design has attracted attention with designers and consumers.

Advantages of Extruded Cement Products

Extruded cement products have many advantages over Hatschek products. Firstly, the top die of extruder allows flexible cross-section structure in terms of thickness and shapes. Also the high plasticity of the matrix enables deep-embossing and 3D design. Furthermore, thick and hollow products have excellent heat and sound insulation properties.

However, the current commercial products are based on autoclave curing. For this reason, the products have the problem of low bending strength and require a certain thickness to cover the problem.

A comparison between Hatschek products and extruded cement products is shown in Table 1.

Table 1– Difference between Hatsheck and Extrusion process

		Hatschek Process	Extrusion Process
Process	Matrix state	Slurry	Mortar paste
	Volume of process water	Large - Recycling water - Drain water	Small
	Water treatment system	Necessary	Not necessary
	Curing process	Natural or Autoclave	Natural or Autoclave
	Productivity	4-12t/hr	4-12t/hr
Compositio	Pulp	Needle Kraft Pulp	Leaf Kraft Pulp
Products	Thickness of products	3-18mm	15-100mm -- High bending load
	Lengh of products	1800-3500mm	~5000mm (Endless)
	Design/Embossing	Shallow	Deep --: Design
	Cross section of products	Solid	Solid or Hollow --> Heat insulation Sound insulation
Properties	Expression of bending strength	Number of layers	Thickness --> High bending load
	Bending strength	ex. 20-40 MPa (Natural curing)	max. 20 MPa (Autoclave curing)

Taking advantage of flexible cross-section structure, extruded cement products have expanded in application uses. Extrusion cement products are currently used as external wall for housing and low to medium-rise buildings, internal wall, flooring, stairway and louver.

Purpose of this Study

Although extruded cement products are used for many application uses, the range of them is limited to certain fields due to lack of bending strength of the products. The conventional extruded cement products are based on autoclaved curing, so the products can only achieve low bending strength. With high bending strength, extruded cement products could explore new application uses such as roofing, external wall for high-rise building and civil construction.

In this study, we aimed to achieve high bending strength of extruded cement sheets by introducing Kuralon™ (PVA fiber) reinforcement. We researched the properties of Kuralon™ (PVA fiber) reinforced extruded cement sheets based on natural curing.

EXPERIMENTAL PROCEDURE

Specimen

Base compositions evaluated in this study are shown in Table 2.

Table 2 – Composition in this study

	Cement wt%	Aggregate wt%	Additive wt%	Fiber wt%	W/C
Without fiber	50.0	37.5	12.5	0	0.56
With fiber	49	37.5	12.5	1	0.56
	48.5	37.5	12.5	1.5	0.56

Cement: OPC
Aggregate: Calcium carbonate, Silica sand
Additive: Silica fume, Pulp, Methyl Cellulose

Characteristics of fiber evaluated in this study are shown in Table 3. PVA fibers named Kuralon™ shown in Table 3 were produced by Kuraray Co., Ltd.

Table 3– Characteristics of fibers in this study

	Diameter μm	Tensile strength MPa	Young's modulus GPa
Kuralon™ A	27	1560	39
Kuralon™ B	40	1560	41

Specimen Preparation and Evaluation Item

Specimens were prepared as follows;

Dry-mix cement, aggregate and additive with the twin shaft kneader
↓
Add water and mix with the twin shaft kneader
↓
Add fiber and mix with the twin shaft kneader
↓
Extrude the composition and cut to the predetermined length
↓
Curing at 20° for 14 days

The extruder used in this study in shown in Figure 1. The details of extruder used are shown in Table 4. The kneader used in this study is shown in Figure 2.

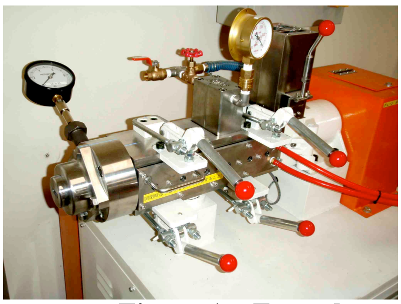


Figure 1 – Extruder

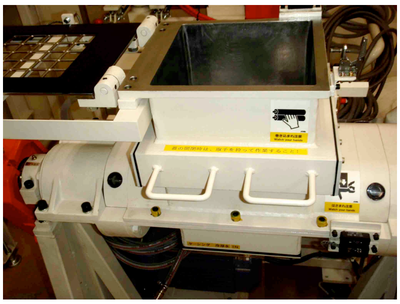


Figure 2 – Kneader

Table 4– Dimension of extruder parts

Part	Dimension
Screw diamerer	50mm ϕ
Die (Solid)	60mm x 10mm
Die (Hollow)	40mm x 20mm (hollow ratio = 30%)

The evaluation Items in this study are shown in Table 5. The test method for evaluation item 4 is shown in Figure 3.

Table 5 – Evaluation item and Standard

	Evaluation item	Unit	Standard
1	Bulk specific gravity	kg/m^3	JIS A 5430
2	Bending strength	N/mm^2	JIS A1408
3	Charpy impact strength	kJ/m^2	JIS K 7111
4	Falling ball impact strength	-	JIS A1408
5	Dimensional changes	%	JIS A 5430

Impact test
Evaluation method Based on JIS A 1408
Sample size Thickness 9-12mm×Width 330mm ×Length 400mm
Dropping height of weight□ 0.8m
Spherical weight□ 1.05kg
Supporting method of test specimen□
Opposite site simple support (Span: 200mm)

Figure 3 - Test method for evaluation item 4 (Falling ball test)

The specimens for evaluation item 1, 2, 3, 5 are solid and hollow pieces as shown in Figure 4. The specimen for evaluation item 4 is an extruded cement roof tile as shown in Figure 5. It was prepared by using larger-scale extruder and pressing machine.

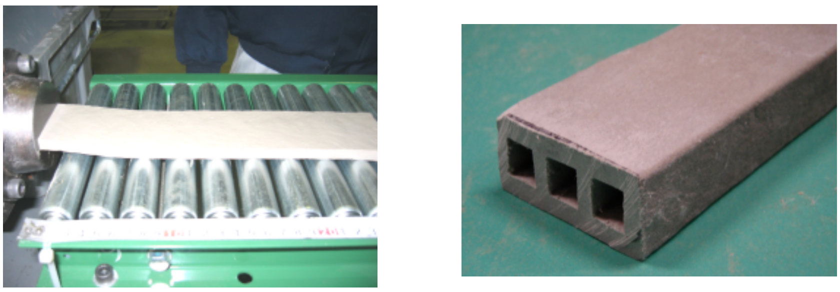


Figure 4 - Samples for evaluation item 1, 2, 3, 5 (Solid and Hollow extruded sheet)

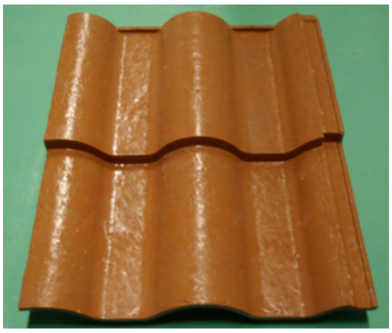


Figure 5 – Sample for evaluation item 4 (roof tile)

Fiber Dispersion and Fiber Damage

In this study, the specimens were prepared with the consideration of fiber dispersion and damage.

Fiber dispersion is important in maximizing bending strength of the fiber-reinforced cement composite. The same holds true for extruded cement composite. In order to achieve homogeneous fiber dispersion, it is necessary to find the optimum conditions in terms of process, composition and type of fiber.

Also fiber dispersion affects extrusion process and quality of the sheet. Correlation between fiber dispersion and surface quality of the sheet is shown in Figure 6. When fiber is not mixed enough, fiber remains undispersed in the composite and cannot reinforce the sheet properly. On the other hand, when fiber is mixed too much, it forms fiber ball in the composite. This causes the problem of extruding homogeneously and rough surface of the sheet.

Moreover, as excessive mixing damages fiber, fiber cannot give its best performance. Correlation between fiber damage and fiber tenacity retention is shown in Figure 7. Fiber damage is represented by black mark. Larger number of black marks the fiber has, more damaged the fiber is.

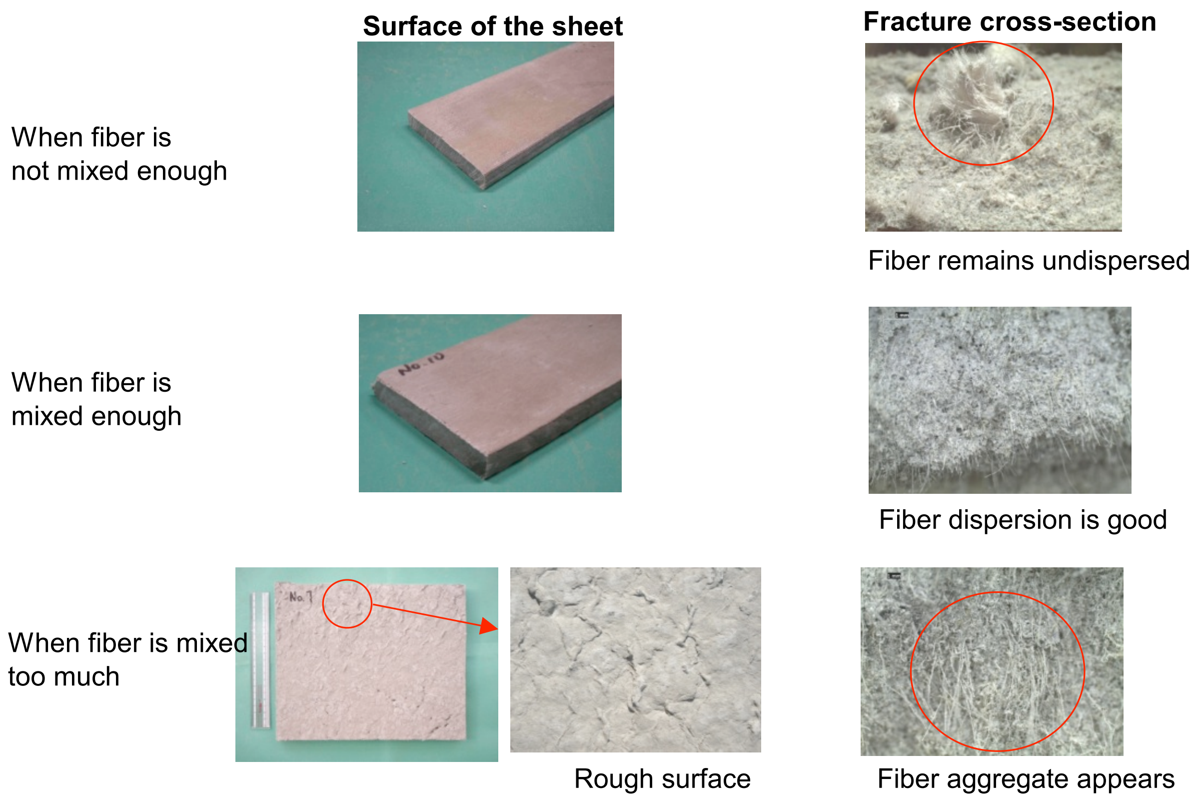
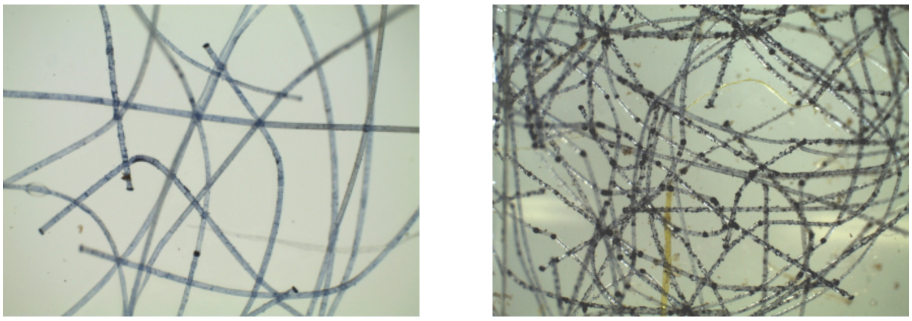


Figure 6 – Correlation between fiber dispersion and surface quality of the sheet



Retention of fiber tenacity: 90% Retention of fiber tenacity: 60%

Figure 7 – Correlation between fiber damage and fiber tenacity retention

RESULTS AND DISCUSSION

Bending Strength

Results of bending strength of solid pieces are shown in Figure 8. As the dosage of fiber increased, the bending strength of the specimens increased. However, the reinforcing effect varied according to the kind of fiber. In this study, Kuralon^{TM} A showed higher reinforcing effect than Kuralon^{TM} B. This is mainly because Kuralon^{TM} A has higher fiber tenacity. On top of that, as Kuralon^{TM} A is finer, it has the larger surface area and greater adhesion to cement. Therefore it is also assumed that Kuralon^{TM} A maximized its reinforcing effect.

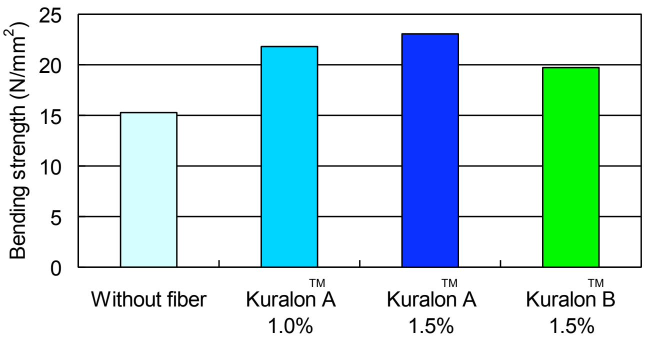


Figure 8 – Results of bending strength of solid pieces

Comparison between solid and hollow pieces is shown in Figure 9. Hollow piece showed lower bulk specific gravity than solid pieces did.

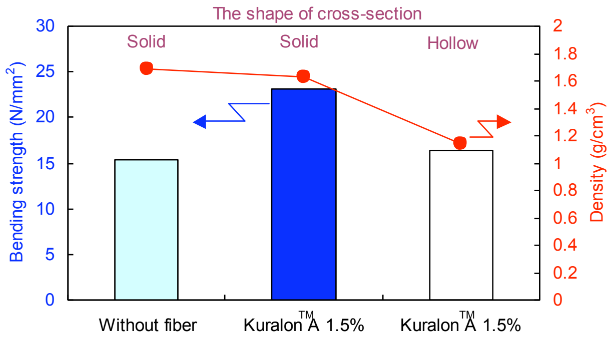


Figure 9 – Comparison between solid and hollow pieces

Charpy Impact Strength

Results of Charpy impact strength are shown in Figure 10. With fiber reinforcement, impact strength of the specimens significantly increased in each composition. Kuralon^{TM} B showed high improvement effect. As Kuralon^{TM} B is thicker and it has a smaller surface area than Kuralon^{TM} A, it is assumed that Kuralon^{TM} B was more pulled out before broken. On top of that, Kuralon^{TM} B has high fiber tenacity, contributing to high impact strength of the Specimen. Also the conventional product based on autoclaved curing was evaluated in terms of impact strength. The result was 1.5kJ/m^2, lower than samples of fiber reinforced extruded cement sheet.

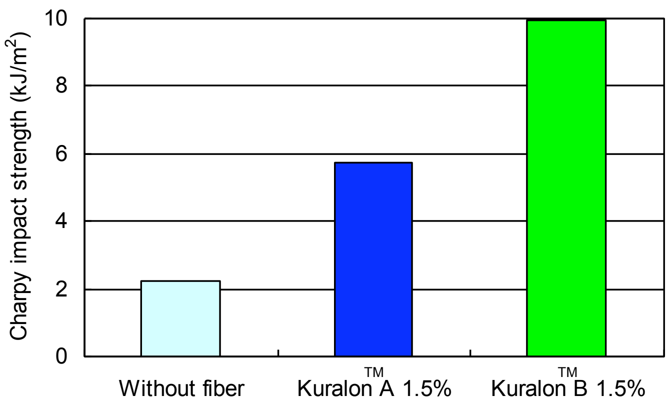


Figure 10 –Results of Charpy impact strength

Falling Ball Impact Strength

Results of falling ball impact strength are shown in Table 6 and Figure 11. The Kuralon^{TM} B reinforced extruded cement tile passed the height of 0.8m. Whereas clay tile, pressed cement tile and concrete tile, which were obtained from the market, did not pass the same height.

Table 6 - Results of falling ball impact strength

	After impact test
Kuralon B reinforced extrusion tile*	Not broken
Clay tile	Broken
Press cement tile	Broken
Concrete tile	Broken

*The recipe was same as Table 2.

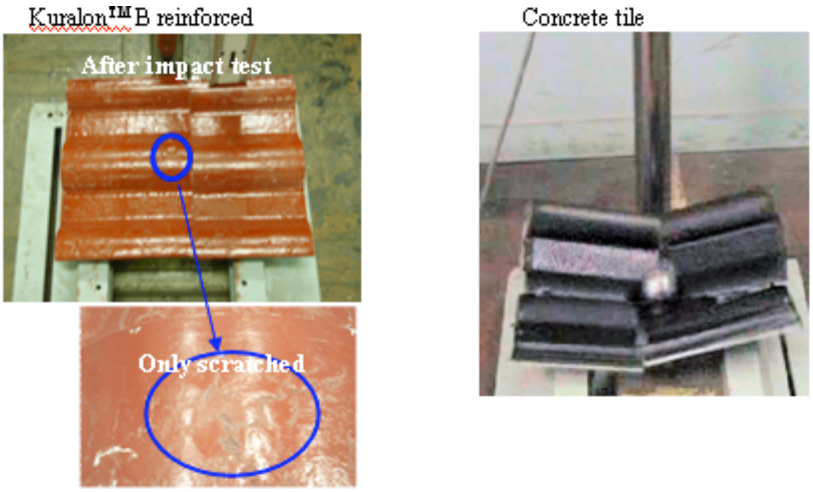


Figure 11 –Results of falling ball impact strength

Dimensional Changes

Results of dimensional changes are shown in Figure 12. All specimen showed approximately 0.1%. Given that dimensional changes of the standard Hatschek products are 0.15 – 0.25% on average, the results in this study are considered significantly low. This is mainly because of high specific gravity of specimens. Also it is assumed that extruded cement sheets in general have lower porosity than Hatschek products because the extrusion process is vacuum system.

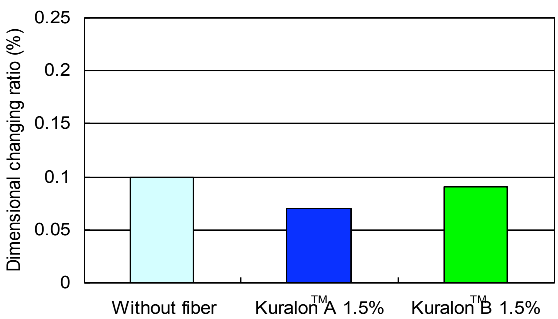


Figure 12 - Results of dimensional changes

CONCLUSION

In this study, we researched properties of Kuralon™ (PVA fiber) reinforced extruded cement sheets based on natural curing. As a result, we found that Kuralon™ (PVA fiber) reinforcement contributed to high bending strength and impact strength of extruded cement sheets.

Also based on the findings in this study, we carried out the further research on the possibility of roofing use for extruded cement sheets. Taking advantage of high plasticity of the matrix, we attempted to make the roofing sheet with 3D design. The sample is shown in Figure 13.

The sample was prepared by putting the sheet on the mould of roofing tile and pressed with low pressure. The sheet formed the shape of 3D design without any cracks and breaks.

Figure 13 - Sample of the roofing sheet with 3D design

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