Properties and Applications of Fiber Reinforced Cement Building Materials

by
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Synopsis

Extrusion molding is one method for producing complex shaped, deep-patterned and hollow building material of Fiber Reinforced Cement (FRC).

This paper reports on properties and applications of external walls, frameworks and other housing components made of FRC.

1. Introduction

Sumitomo Metal first took interest in fiber reinforced cement (FRC) back in the early 1970s when studying steel fiber (SF). SF was developed because of the need for fiber reinforced cement concrete. The manufacturing technology for a wavy steel fiber was developed in-house, the first process of its kind in the industry, and was later applied to the fields of civil engineering and architecture [1),2)].

There followed the development of carbon fiber reinforced cement (CFRC) as a substitute for asbestos. It used carbon fiber (CF) made from coal tar. Here, the basic technology for extrusion molding was established and applied to making free access floor panels [3),4)].

Research and development was later expanded to include FRC materials which used other types of reinforcing fiber than CF. Production technology for external building materials was jointly developed by Nichiha, Ltd. and Sumitomo Metal Industries, Ltd. which marked the start of manufacture and sales of extrusion molded external walls and frameworks by Sumikin FRC [5),6)].

FRC materials account for more than 50 % of all external building materials for housing applications. JIS A 5422 "Fiber reinforced cement siding" was adopted on January 1, 1995, and on September 26 of the same year, we obtained approval for manufacture.

Today, demand for extrusion molded external building materials is high because they suffered considerably less damage in the Great Hanshin Earthquake than mortar walls.

This paper reports on properties and applications of external walls, frameworks and other housing components made of FRC which Sumikin FRC is currently involved in.

2. Manufacturing Technology and Features of FRC Building Materials

Generally, fiber reinforced building materials are manufactured with one of the three methods given in **Table 1**: extrusion molding, the Hatschek Process and casting molding. Each method has its own merits and demerits. As can be seen from the given data, extrusion molding offers greater freedom in designing product profile and is well suited for flexible production and high quality products, etc.

With respect to extrusion molded FRC building materials, strength, heat insulation, sound insulation, durability, design and workability are taken into account on designing profile, dimensions and density. These properties are summarized in **Table 2.** In practical application discussed herein density is between 0.9 and 1.0 g/cm^3 and thickness is less than 40 mm. They are mostly used, as external walls and

Table 1 Comparison of manufacturing methods of FRC building materials

		Extrusion molding	Hatschek process (Circular mesh type)	Hatschek process (Long mesh type) & Dry forming } + Pressing	Casting mold (Pour in-place, spray, centrifugal)
Description		Raw materials are mixed and kneaded. Then, continuous forming is performed with an extruder.	FRC slurry is drawn out and shaped with a circular drawing machine.	FRC is long-drawn, dry-formed and pressed to shape.	FRC is introduced into the cast by pouring, spraying or other means, where shaped.
Major form specs.	Specific gravity	0.8~2.0	1.0~	0.3~2.0	Freely set
	Thickness	10~100 mm	3~10 mm	4~25 mm	
	Width	30~1 200 mm	600~1 200 mm	455~1 200 mm	
	Length	Freely set, max. 5.0 m	1 800~3 030 mm	1 800~3 030 mm	
Features		1. Deep patterns 2. Complex profiles 3. Hollow sections	1. Suited for thin sheet production 2. Poor design flexibility 3. Easily damaged when frozen	1. Shallow patterns 2. Not applicable with complex profiles	1. Thick materials
Product field (Example)		Mid to high grade products (External walls for housing, thick hollow sections for buildings)	Standard products (Asbestos straight)	Standard to high grade products (External walls for housing)	ALC, GRC, concrete framework

Table 2 Types and profiles of extrusion molded FRC building materials

Building material	Profile dimensions (mm)				Base material density (g/cm^3)	Production at Sumikin FRC
	Profile shape*	Thickness (t)	Width (W)	Max.length (l)		
1. External walls for housing (including ceiling eaves)	Backgourged	12~25	455~1 000 Standard product	3 030	0.9~1.0	15~23^{t}
	Hollow					–
2. Framework for housing	Backgourged	18~270	455~270	3 030	0.9~1.0	18~40^{t}
	Hollow					–
3. External walls for steel frame factories, warehouses, etc.	Backgourged	18~200	455(Standard product)	3 030	0.9~1.0	15~23^{t}
	Hollow	15~25	303(Standard product)		1.8~2.0	–
4. External and partition walls for office buildings	Hollow	30~100	450~1 200	5 000	1.8~2.0	–
5. Other (Sound insulation walls, stairs, permanent molds)	Hollow	10~100	200~1 000	5 000	1.8~2.0	–

* Backgourged shape Hollow shape

frameworks in housing, and external walls in steel frame office buildings and stores.

3. Properties and Applications of FRC Building Materials

3.1 External Walls for Housing

3.1.1 Properties

External walls for housing are designed according to builder and owner specifications. At present, our brand name; Moen Siding S has properties which satisfy these specifications. It is completely asbestos-free and light weight (0.95 g/cm^3 in density), and offers good workability (can be directly sawed and nailed), good resistance to freezing-thawing damage and dimensional stability over time.

Asbestos was eliminated by adding methyl cellulose to the pulp and plastic fiber. Weight, workability and resistance to freezing-thawing damage were obtained using an aerated mixing technique developed in-house. Dimensional stability was ensured by autoclave curing [5].

Figures 1 and **2** show measured results from accelerated freezing tests and nailing tests, respectively [5]. In the accelerated freezing tests (**Fig. 1**), actual conditions of use were simulated. The lower end of

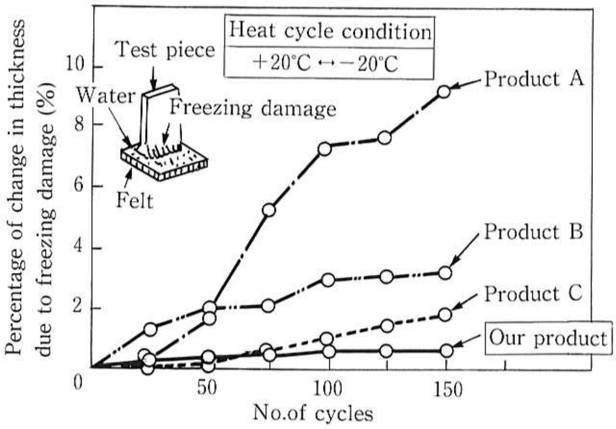


Fig. 1 Results from accelerated freezing test on external wall materials

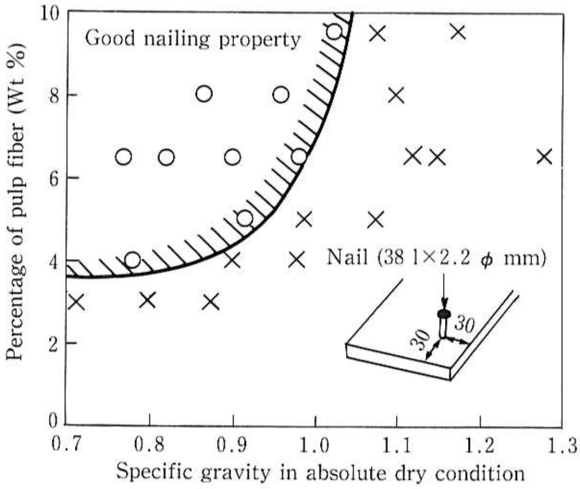


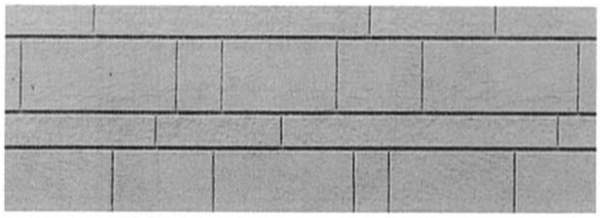
Fig. 2 Results from nailing test on external wall materials

the product was immersed in water and repeatedly frozen and thawed between -20 and +20°C every 5 hours. Our product hardly showed any signs of swelling because the incorporated foam we developed absorbs volumetric expansion which normally occurs as the water freezes, while products of other manufacturers swelled badly. Moreover, only minimal cracking occurred in our product when directly hammered with nails for two reasons: first, specific gravity is low because there is a large void between the wall and backing ; and second, a high ratio of pulp fiber is used (**Fig. 2**).

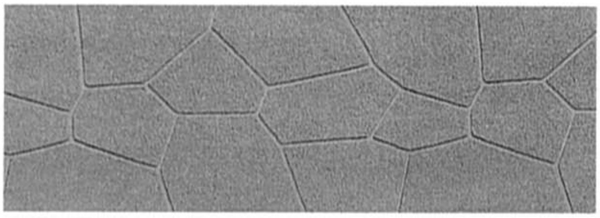
3.1.2 Applications

External walling does much for the outer appearance of a residential house. This explains the recent rise in demand for fashionable designs and greater durability. In response, we developed technology for deep patterns and high grade coating. Two design applications are shown in **Photos 1** and **2.**

Nonetheless, conventional techniques of anchoring posed problems to external walls of the sort. Nails hammered into the backing left the nail head exposed to the outside surface of the wall (**Fig. 3** [**1**]), which is quite unattractive. To do away with the problem, we came up with an anchoring technique that uses aluminum or stainless steel brackets (**Fig. 3** [**2**]) and successfully hides the nail head [6].



(1) Layered brick look (455×3 030×18ᵗmm)



(2) Interlacing stone look (455×3 030×18ᵗmm)

Photo 1 Types of new external wall designs

Photo 2 New design external wall applied to residential house

Another marked trend seen recently is that home builders are shifting to prefabrication and the use of panel materials, rather than having each wall erected on-site one by one. And more recently, builders are using vertically mounted panels (910 to 1 000 mm) as opposed to the standard horizontally mounted panel (455 wide). Here, in addition to fashionable design, products need to be light-weight. **Table 3** gives external walls by the mounting technique.

Also, the use of eaves board is on the increase. Though the location is different from the external wall, eaves boards are being used on ceilings and roof projections as seen in **Fig. 4.**

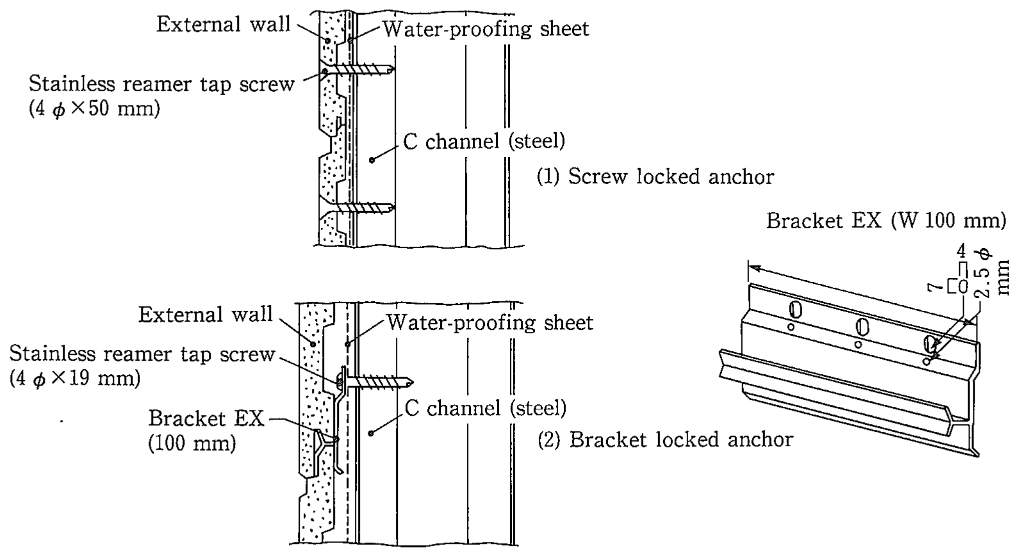


Fig. 3 External wall anchoring techniques (Screw locked anchor vs.Bracket locked anchor)

Table 3 Types of FRC external walls by attaching technique

Product (Workable width: mm)	Attaching technique		Type of backing	Production at Sumikin FRC	User
	Attaching	Locking			
Standard product (455)	Horizontal attaching	Nail, Screw	Wood (Framing, Framework) Steel frame	Mid grade product	Builders
		Bracket		High grade product	
	Vertical attaching	Nail, Screw		–	Builders
		Bracket		–	
Wider products (910～1 000)	Vertical attaching	Nail, Screw			house maker
		Bracket		High grade product	

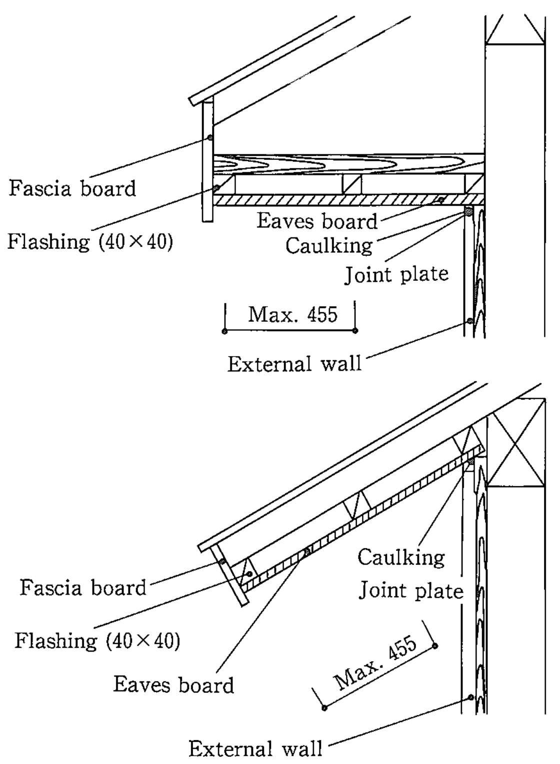


Fig. 4 Applications of FRC eaves board

3.2 Housing Framework

Metal (aluminum and steel) and wood trimmings have commonly been used to accent home exteriors, but because of their texture and durability, FRC materials have rapidly come under strong demand. Framework is available as barge-board, end rails, outside angle columns, attached columns, top rails and more. **Figures 5 (1)** and **(2)** show some applications using barge-board and end rails.

Frameworks made by us (brand name: Auty) have almost the same properties as our Moen Siding S. **Tables 4 (1)** and **(2)** list product properties. Framework in general is nailed to the backing, but a recent trend with color finished materials is to use bracket anchors in order to preserve the design.

3.3 External Walls for Steel Houses

Steel houses are rapidly becoming popular in the USA and abroad. In order to introduce this building technique into Japan, six furnace manufacturers are heading up corporate research, with the support of

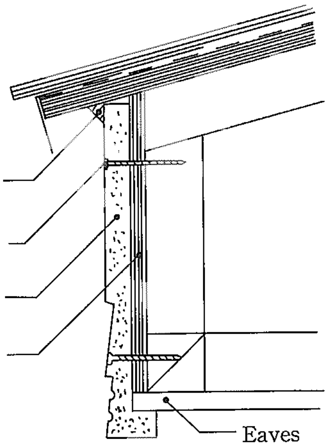


Fig. 5 (1) FRC barge-board application

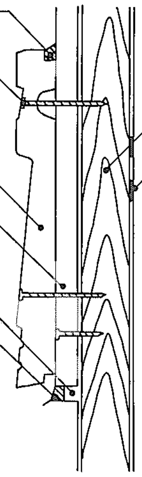


Fig. 5 (2) FRC top rail application

Table 4 (1) Properties of Sumikin FRC external walls

Property	Unit		23 mm*	20 mm*	18 mm*
Weight	kg/m²		19	16	15.5
Specific gravity			0.95	0.95	0.95
Percentage of water content	%		10	10	10
Bending fracture load	kg		220	150	120
Bending deflection	mm		3	4	4
Coef.of extension with water absorption	%		0.05	0.05	0.05
Opposite pull-out strength of nail head	kg		200	200	160
Opposite pull-out strength of screw head	kg		220	220	180
Bracket holding strength	kg		120	120	120
Thermal resistance	m²h°C/kcal		0.10	0.10	0.10
Thermal conductivity	kcal/m²h°C		0.12	0.12	0.12
Transmission loss for sound	dB	500 Hz	31		
	dB	1 000 Hz	31		
Impact resistance	kg·m		2.5	2.0	2.0
Resistance to freezing damage			good	good	good
Story deformation angle	rad		Min.1/120 rad		
Wind pressure resistance	kg/m²		23 mm products (Screw-anchored)	No abnormality when pressurized to 360 kg/m²; Failure when depressurized to 880 kg/m²	
			20 mm products (Screw-anchored)	No abnormality when pressurized to 360 kg/m²; Failure when depressurized to 260 kg/m²	
Water tightness	kg/m²		20~160 kg/m². However, joint seal or waterproof sheet recommended.		

* Board (Backgourged type in all cases)

Table 4 (2) Properties of Sumikin framework

Property	Unit	
Specific gravity		0.90
Percentage of water content	%	10
Resistance to freezing damage*		good

Same test method (**Fig. 1**) used as for external walls.

the Ministry of Construction, into applications for the Japanese climate. A general residential style is expected to be approved in 2 to 3 years time.

As part of our research and development of external walls and frameworks for housing, we developed, in cooperation with Nichiha Co, Ltd. and Sumitomo Metal Industries, a technique for installing external wall materials of proven heat insulation capability. The technique has already been applied to a test house owned by Sumitomo Metal Industries (**Photos 3** and **4**).

The technique is suitable for insulating a home with FRC material. Moreover, as shown in **Fig. 6**, it

Photo 3 Application on test steel house (Kashima Messe)

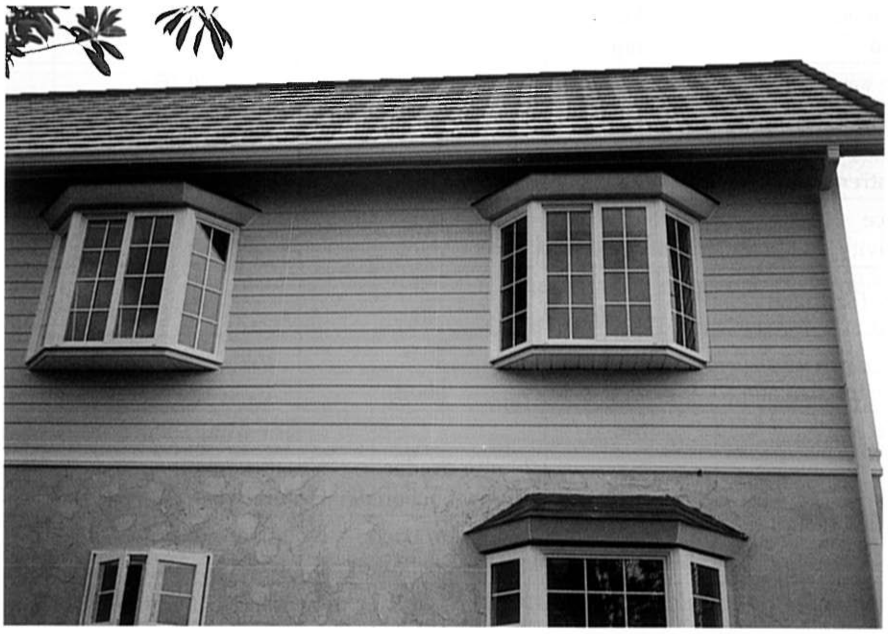


Photo 4 Moen Siding S on steel house (Moen Siding S Louver 18 mm)

requires relatively simple parts and can be easily and accurately matched to the backing. It can also be mounted on OSB and is low-cost.

3.4 External Walls for Steel Frame Office Buildings and Stores

External walls designed for steel frame office buildings and stores are different than those used with wooden frame houses. In order to simplify backing work with lipped steel channel and other complex members, the tendency today is allow more span to the structure steel bed than the 450 mm common with wooden frames. Moreover, with factory roofs and the sort, waterproof sheet and insulation are not laid under external walling. Moreover, steel frame repeatedly expand and contract with

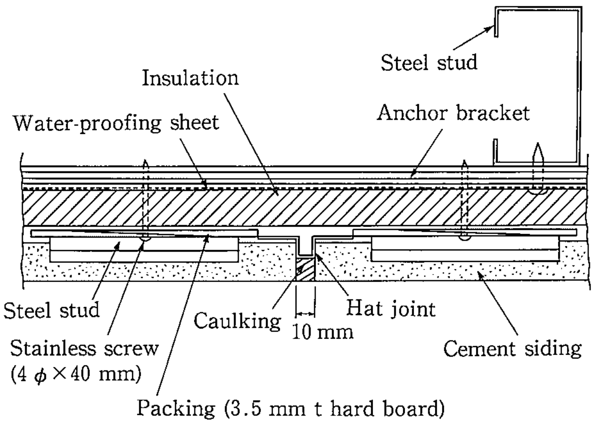


Fig. 6 FRC material used in external insulation structure

changes in temperature, thus the structure is readily deformed. Consequently, external walls used with steel structures and wooden structures require diverse product properties.

In other words, external walls need to be flexibly very strong and rigid, water tight, dimensionally stable and highly capable of following deformation, besides being light-weight and thin.

Moen Siding S is one practical application that satisfies these requirements.

Figure 7 shows the relationship between bending stress and span to structure steel bed. Here, bending stress is caused by wind pressure. **Table 5** gives

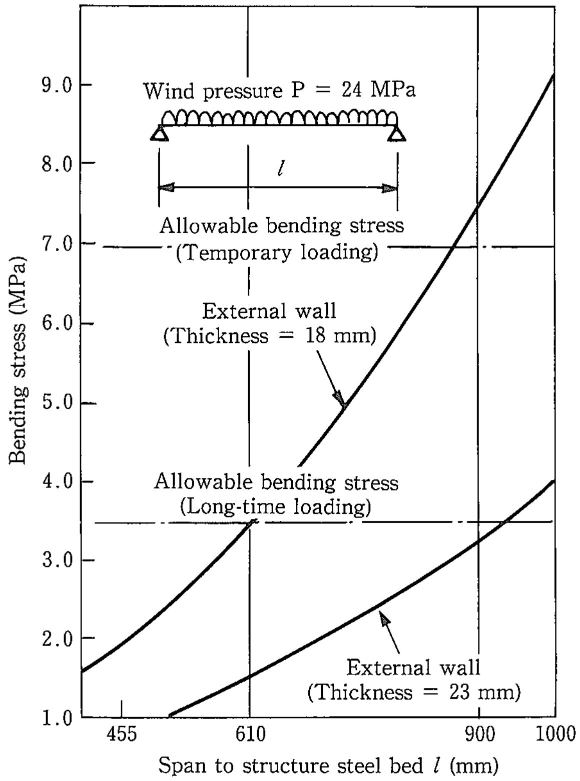
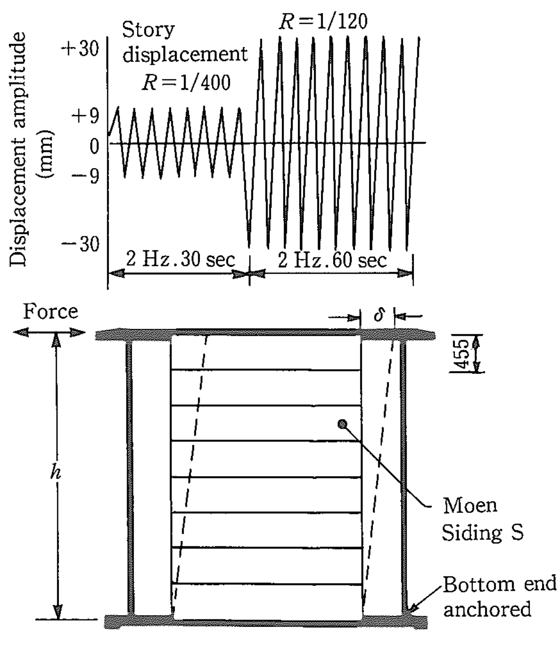


Fig. 7 Relationship between bending stress under wind pressure and span to structure steel bed in external walls

Table 5 Earthquake resistant capacity tests on Sumikin FRC external walls

Type of external wall (Thickness: mm)	Span to structure steel bed (mm)	Mounting technique	Test results: Story deformation angle		Remarks (Test conditions)
			Static force	Dynamic force (2 Hz, 60 sec)	
Moen Siding S (Flat, 23)	610	Screw-anchored	No abnormality observed	No abnormality observed	
Moen Siding S (Louver, 18)	600	Screw-anchored	Same as above	Same as above	
Moen Siding S (Flat, 18)	610	Bracket-anchored	Same as above	Same as above	

results from dynamic tests on Moen Siding S that were performed in order to evaluate earthquake resistant capacity. Both in the case of screw and bracket anchors, story deformation angle produced during an earthquake satisfied the 1/120 design tolerance. Also, a 610 mm span to structure steel bed proved sufficient against a presumed wind pressure of 240 kg/m² on stories below 16 m in height. Bending stress resulted a 1.5 ~ 3.5 MPa, which is less than the 7 MPa allowable unit stress for temporary loading (or 2/3 the fracture strength). Therefore, no problems are foreseen in usage.

However, with taller steel frame structures (above 16 m) which are subjected to a higher degree of wind pressure, or when the span to structure steel bed is a wider 900 to 1500 mm, bending stress and deformation exceed the allowable limits, thus Moen Sliding S is not applicable.

In this field, there is much need for hollow and wide products of highly dense material and with good dynamic properties. This is what we can expect from future developments and applications.

Figure 8 shows the relationship between specific gravity and flexural strength in extrusion molded materials. **Table 6** compares flexural strength between a hollow section of 25 mm in thickness and sheet material of the same profile area. It can be seen that raising specific gravity from the 0.9 used in **Fig. 7** to 1.8 more than doubles flexural strength. Also,

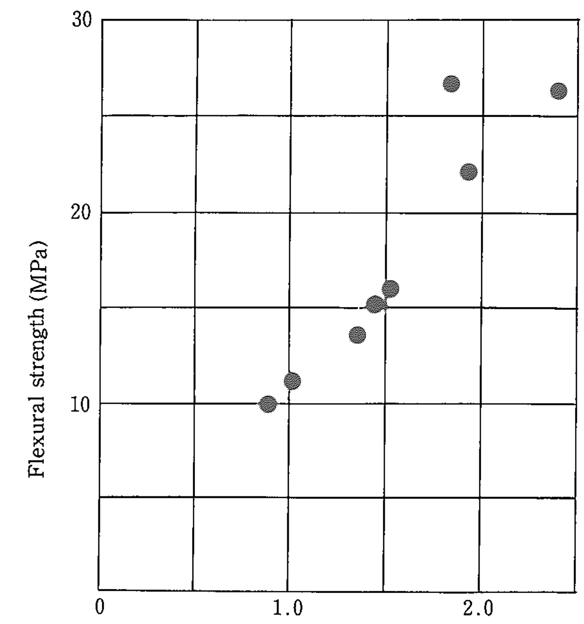
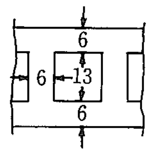
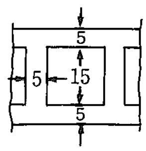
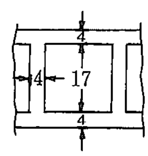


Fig. 8 Relationship between flexural strength and specific gravity in extrusion molded materials

Table 6 Flexural strength ratio of hollow to sheet section

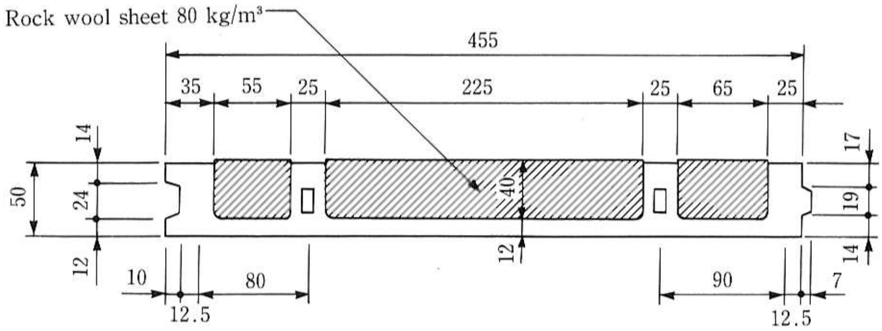
Case	Hollow section dimensions (mm)	Percentage of hollowness	Sheet thickness (mm)	Flexural strength ratio (Hollow: Sheet)
A		35.6	16.1	1.78
B		45.0	13.8	2.41
C		55.0	11.2	3.10

* Thickness of hollow section : 25 mm (constant)
Cross-sectional area of hollow and sheet products was the same in all cases.

because the material is hollow, bending fracture load increases some 1.78 to 3.1 times over. From this, it is safe to say that hollow members made of a highly dense material are suited as external walls for steel frame structures.

3.5 Light-Weight Partition Walls for Hotels and Apartment Buildings

Because of their purpose and use, multistory hotels and apartment buildings require partition walls which are light-weight, sound insulated and fire resistant. In response to these needs, we developed a medium density material with the profile shown in **Fig. 9.** The developed material satisfies the property requirements given in **Table 7** when used in conjunction with rock wool sheet or plaster board, thus is applicable with apartment buildings. The base material has a density of 1.5 g/cm³ and a high flexural strength of 16MPa. Moreover, it is extremely fire resistant and is therefore believed practical in applications other than as partition walls.



FRC panel profile and dimensions (With rock wool sheet attached)

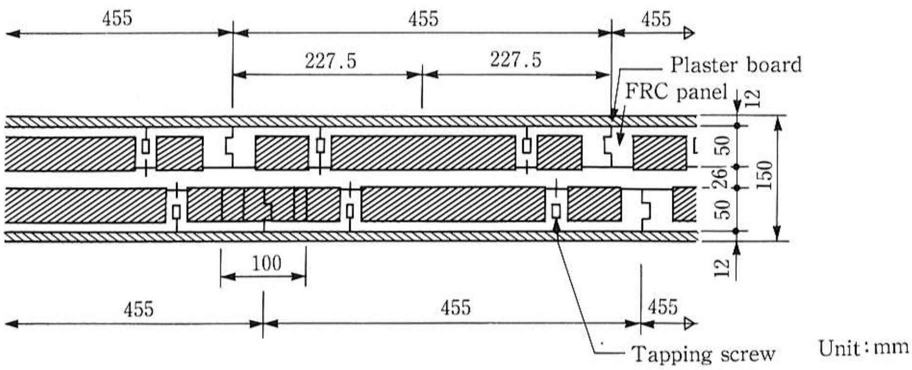


Fig. 9 Profile and dimensions for high sound insulated, fire resistant, light-weight partition wall

Table 7 Properties of light-weight partition wall

Property	Specification
Sound insulation	Equivalent to D-55
Fire resistance	2 hours
Wall thickness	150 mm
Weight	83 kg/m²

4. Future Developments

Till now, Sumikin FRC has primarily developed and produced high grade external walls of low-density, backgourged sheet material for housing. Many of our products have been applied in residential homes and have been favorably accepted. We plan to develop still other building materials with more attractive designs, including external walls, hollow sections and mid to high density sheet materials, by utilizing the features of the extrusion molding method.

Some of these products are listed in **Table 3.** In any case, it will be necessary to understand what exactly consumers require and develop high performance products that can be made with today's production system. In the meantime, technical research groups will have to build stronger ties with construction engineering groups and the sort.

5. Conclusions

This paper has reported on the current state and future development of extrusion molded FRC building materials, i.e. external walls, framework and partition walls. Extrusion molding is applicable where other forming methods are not such as in producing complex and hollow materials of unrestrained profile. We plan to continue our work and develop still other new products for markets which demand high grade materials, bearing in mind the need to expand width, improve design and ensure production of hollow materials.

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