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Test and Evaluation Procedure of Foam Core Materials for Composite Ships

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Abstract : *Sandwich structures are general-purpose structures that can reduce the structural weight of composite ships. Core materials are essential for these structures, with polyvinyl chloride (PVC) foams being the most popular. These foam core materials are subjected to various tests in the development process, and must satisfy the performance requirements of several ISO and ASTM standards. Therefore, a procedure for evaluating the performance of foam core materials was proposed in this paper. In addition, prototypes were fabricated using a commercial PVC foam core product in accordance with the structural design of an 11 m fiber-reinforced plastic yacht. Then, a case study was conducted on the proposed evaluation procedure. The proposed procedure facilitates the understanding of the performance requirements and evaluation of core materials used in composite ships and is expected to be utilized in developing core materials for marine structures.*

Key Words : *Composite ship, Sandwich structure, Core material, PVC foam, Type approval*

1. Introduction

Sandwich panel structures have been widely used in ships because they can considerably reduce the structural weight of ships. These structures have been mainly applied to deckhouses and other outfits in large vessels, and to primary structures (such as decks) in small vessels (Kortenoeven et al., 2008; Sujiatanti et al., 2018).

In particular, the utilization of sandwich structures is very high in small vessels in which composite laminates are used as the main hull materials (Oh et al., 2018). Composite laminates can reduce the structural weight of a ship owing to their excellent specific strengths compared to metals. The hulls of small vessels, which represent the main portion of such vessels, are usually constructed using composites, because composite laminates are easy to manufacture and the raw material cost is extremely low (Oh, 2019). Ship structures fabricated using composite materials, such as fiber-reinforced plastic (FRP), mainly consist of three structure types (Fig. 1). These are a single-skin structure in which cloth and resin are impregnated into a multi-layered shape, a sandwich structure fabricated by placing core materials between single-skin structures, and a top-hat structure primarily serving as a stiffener (ISO, 2008). Among these, the sandwich and top-hat structures include core materials between two laminate skins, which can increase structural strength and reduce weight by increasing the cross-sectional area of the core materials with low density (Oh et al., 2019). In addition, core materials have been used in vessels and several industrial structures mainly for weight reduction because they are easy to manufacture and economical (Park, 2018).

According to ISO standards and rules of classification societies that deal with the design and production of small craft, core materials (Fig. 2) are classified into balsa wood, polyvinyl chloride (PVC), and polyurethane (PU) (ISO, 2008; Registro Italiano Navale (RINA), 2015).

Specifically, foam core materials have been widely used for shipbuilding owing to their low weight, low moisture absorption, easy processing and molding, and relatively low cost. Polyethylene terephthalate, PVC, and styrene acrylonitrile have been broadly

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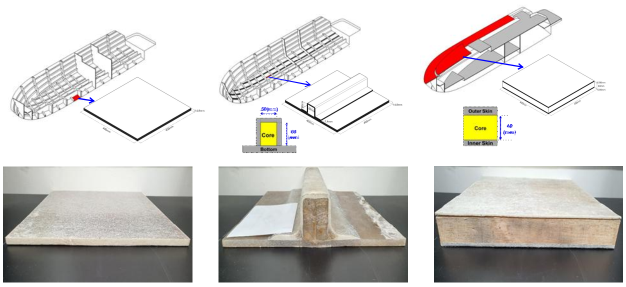

(a) (b) (c)

Fig. 1. Hull structure types of FRP ships (a) single-skin laminate for hull plate, (b) top-hat structure for stiffener, and (c) sandwich structure for weather deck (Oh et al., 2019).

(a) (b) (c)

Fig. 2. Core materials for marine structures: (a) balsa wood, (b) PVC, and (c) PU.

utilized as core materials. Among these, PVC and PU can be applied to the sandwich structures of composite ships.

However, most of these widely used core materials in composite ships are dependent on imports. Moreover, it is difficult to find domestic cases regarding the development and certification of core materials (Jang et al., 2018). Even if such composite materials are developed, it is difficult to pass the complicated tests and evaluation procedures of classification societies, which are composed of several ISO and ASTM standards. Therefore, this study summarized the evaluation procedures and related test methods for core materials developed for use in the composite structures of small vessels, which are conducted using ISO standards and classification societies. In addition, a case study was conducted by fabricating sandwich structure prototypes using a commercial PVC foam core.

2. Test and Evaluation Procedures for Foam Core Materials used in Marine Structures

Core materials can be used in composite structures after their quality approval by classification societies, mainly through type approval. Most of the approval procedures for composite materials are similar because they are composed of ISO and ASTM standards.

This study summarized the evaluation procedures for foam core materials that can be used in composite ship structures based on the type approval rules (Rules for the Type-Approval of Components of Composite Materials Intended for Hull Construction) and design rules (Rules for the Classification of Pleasure Yachts Part B: Hull and Stability) of RINA as well as the related ISO and ASTM standards, which are internationally applied for the certification of small craft.

Regarding core materials such as PVC foams, only composite materials that attained approval from classification societies must be used in the sandwich structures of FRP yachts. RINA also provides rules for the type approval of composite materials (RINA, 1997), where the requirements of core materials to be used in the construction of composite ships are listed. Furthermore, the requirements for core materials in constructed sandwich structures are defined.

In summary, foam core materials must possess the required mechanical properties, such as the appropriate density range and minimum shear strength according to density, for the design of laminate structures of composite ships. Foam core materials must also have the appropriate compatibility to prevent heterogeneity when applied to sandwich structures. They must be closed-cell types for their exposed cases and have a particular level of resistance when exposed to seawater and fuel oil. In other words, they must satisfy the required resistance conditions when exposed to the marine environment. Finally, the core materials applied to sandwich structures must guarantee the structural performance at an appropriate or higher level.

Therefore, the core materials to be used must have the basic mechanical properties and satisfactory resistance when exposed to the marine environment. They must also be compatible with other raw materials that are used in fabricating the sandwich structures of composite ships.

2.1 Foam core material density for the design of sandwich structures

As mentioned previously, the foam core materials to be used in the structures of composite ships must have the basic mechanical properties, mainly density and shear strength. Such properties affect the structural design because they determine the laminate thicknesses of the inner and outer skins of the sandwich structures. The regulations of each classification society also provide relevant criteria and formulas (Table 1).

Table 1. Minimum shear strength depending on density (RINA, 2015)

Material	Density (kg/m^3)	Minimum shear strength (N/mm^2)
Balsa end grain	104	1.6
	144	2.5
PVC, cross-linked	80	0.9
	100	1.4
PVC, linear	80-96	1.2
Polyurethane	90	0.5

Table 1 lists the minimum shear strengths for three types of core materials, i.e., balsa wood, PVC, and PU, depending on the density, which are suggested by RINA. ISO 845 (ISO 845, 2006) "Cellular Plastics and Rubber - Determination of Apparent Density" is suggested as the density measurement procedure for core materials. ISO 1922 (ISO 1922, 2018) "Rigid Cellular Plastics - Determination of Shear Properties" or ASTM C273 (ASTM C273/C273M-19, 2019) "Standard Test Method for Shear Properties of Sandwich Core Materials" is suggested as the procedure for shear strength measurement. These standards must be satisfied, because they are conditions suggested by the rules of classification societies.

2.2 Requirements of foam core materials suitable for the marine environment

Core materials must satisfy stricter requirements for mechanical properties and resistance to the marine environment. While the mechanical properties described in the previous section were based on the rules of structural design for determining the laminate thicknesses, the requirements described in this section are the basic mechanical properties for core materials and they are approval conditions for their use as structural materials for composite ships. Moreover, as mentioned previously, the basic requirement that core materials must be resistant to the external environment is an important approval condition.

2.2.1 Evaluation of mechanical properties of foam core materials

Core materials must satisfy the requirements for tensile strength, tensile modulus of elasticity, compressive strength, compressive modulus of elasticity, shear strength, and shear modulus of elasticity. These are measured in accordance with ASTM D1623 (ASTM D1623-17, 2017) "Standard Test Method for Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics," ASTM D1621 (ASTM D1621-16, 2016) "Standard Test Method for Compressive Properties of Rigid Cellular Plastics," and ASTM C273 "Standard Test Method for Shear Properties of Sandwich Core Materials." Table 2 summarizes the information on the test methods and specimens.

Table 2. Test method, number of specimens, and specimen size for each mechanical property

Item	Number of test specimens	Size
Tensile strength and modulus of elasticity (ASTM D1623)	5	$L \times B \times T$ $(50 \times 50 \times 25\,mm)$
Compressive strength and modulus of elasticity (ASTM D1621)	5	$L \times B \times T$ $(60 \times 60 \times 25.4\,mm)$
Shear strength and modulus of elasticity (ASTM C273)	5	$L \times B \times T$ $(260 \times 50 \times 25\,mm)$

2.2.2 Resistance of core materials to the marine environment

The next test item is the resistance of core materials to the marine environment. In this evaluation step, changes in the volume, mass, and tensile strength of the core materials due to temperature and during their exposure to seawater and fuel oil, which are environmental agents, are mainly evaluated.

The resistance-to-temperature test is conducted in accordance with the approval rule of RINA as follows. Three specimens of each core material of size 300 mm × 100 mm × 10 mm are heated in a stove at 45 and 60 °C for 30 min to compare their tensile strengths before and after heating. The tensile strength after heating at 45 °C must be 90 % or higher compared with the tensile strength before heating, and the tensile strength after heating at 60 °C must be 80 % or higher. Table 3 summarizes the procedure for the resistance-to-temperature test.

Table 3. Resistance-to-temperature test method

Item	45 °C	60 °C
Specimens	L × W × T (300 mm × 100 mm × 10 mm)	
Heating time	30 min	
Test method	1. Three specimens are heated in a stove to (45/60 °C)	
	2. To be subjected to the tensile test immediately after removal from the stove $0.9R_m \leq$ for specimens heated 45 °C $0.8R_m \leq$ for specimens heated 60 °C	

L : Length of test specimens
W :Width of test specimens
T : Thickness of test specimens
R_m *: Tensile strength of the material as supplied*

Table 4. Resistance-to-environmental-agents test method

Item	Seawater	Fuel oil	Lube oil
Specimens	L × W × T (300 mm × 100 mm × 10 mm)		
Test Method	1. Three specimens are immersed in seawater, fuel oil, lube oil at ambient temperature for 24 h		
	2. Afterward, the specimens are kept hanging in air for 24 h to allow dripping		
	3. The specimens are measured and weighted to check the variation in volume △V and weight △G with respect to dry volume and weight prior to immersion △V≤~1 % △G≤~6 %		
	4. Tensile test after immersion $0.9R_m \leq R_m$		

L : Length of test specimens
W : Width of test specimens
T : Thickness of test specimens
△V : Variation in volume of test specimens
△G : Variation in weight of test specimens
R_m *: Tensile strength of the material as supplied*

The next test item is the resistance of core materials to seawater, fuel oil, and lube oil, which can be in contact with the materials during operation of the vessels. This test is also conducted in accordance with the approval rule of RINA as follows. Three specimens of each core material are immersed in seawater, fuel oil, and lube oil at ambient temperature for 24 h and then dried for 24 h to examine the changes in their volume and weight before and after immersion. The volume change rate and weight change rate must not exceed 1 % and 6 %, respectively. Moreover, the tensile strengths before and after immersion must be compared. The tensile strength after immersion must be 90 % or higher compared with that before immersion. Table 4 summarizes this test procedure.

Concerning the tensile strength evaluation for the above two tests, a procedure is proposed in accordance with ASTM D1623 "Standard Test Method for Tensile and Tensile Adhesion Properties of Rigid Cellular Plastics."

2.2.3 Compatibility with resin and gel coats

Among the structure types of composite ships, the sandwich and top-hat structures contain core materials. These structures are fabricated through the adhesion of core materials to the top and bottom laminations. In this case, resins, such as polyesters, act as adhesives. Therefore, core materials must be compatible with resins. They must also be compatible with gel coats, which are used in large quantities during the construction of composite ships. Sandwich structure prototypes are required for the evaluation of compatibility with resins and gel coats. The approval rule of RINA proposes the fabrication of a prototype as shown in Fig. 3.

The proposed laminate thickness of the single-skin type is between 3 and 4 mm, and the proposed weight fraction of glass fiber, i.e., the glass fiber content (Gc), is between 0.45 and 0.50. It is proposed that the shear strength test be conducted for at least 10 sandwich structure prototypes fabricated using the proposed values. The procedure of ASTM C273 "Standard Test Method for Shear Properties of Sandwich Core Materials" must be followed.

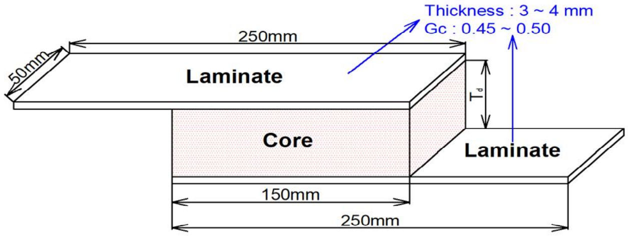

Fig. 3. Test specimen for compatibility with laminating resuns and gel coat (RINA, 1997).

$$\tau = \frac{P}{150 \times 50} \quad (1)$$

τ : Shear stress (N/mm^2)

P : Load at which rupture of the specimen begins (N)

The load must be measured when the rupture of the specimen begins. The result is applied to Equation (1) to derive the stress (τ) that corresponds to the load (P). Regarding the judgment criterion for compatibility evaluation, the stress (τ) derived by applying the test result of each specimen to Equation (1) must be equal to or higher than the longitudinal shear strength of the core material.

2.3 Structural requirements of foam core materials applied to sandwich structures

Although core materials applied to sandwich structures do not directly act as structural materials, they must satisfy the minimum density and shear strength requirements to secure the cross-sectional moment of area. In this regard, various tests have been proposed. This section presents the structural requirements on the shear strength of core materials for fabricated sandwich structures. RINA approval proposes the fabrication of sandwich structures as follows.

For the fabrication of inner and outer skin laminates, the proposed weight fraction of glass fibers is between 0.45 and 0.50, as with the compatibility evaluation. The two skin laminates must have the same thickness, i.e., between 3 and 4 mm. The thickness must not exceed 21 % of the core height. It is proposed that the shear strength by four-point bending tests be conducted for at least five sandwich structure prototypes fabricated using the proposed values. In this case, the procedure of ASTM C393 (ASTM C393/C393M, 2016) “Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure” must be followed. This test examines whether the original shear strength of a core material is maintained when it is applied to a sandwich structure.

Fig. 4 summarizes the evaluation procedures described above for core materials to be used in the sandwich structures of composite ships along with the related processes, standards, and regulations. The evaluation procedures can be classified into five groups. Subsections 2.1, 2.2.1, and 2.2.2 describe the tests for the core materials themselves. Subsections 2.2.3 and 2.3 are for sandwich structures fabricated using the core materials.

3. Application of Test and Evaluation Procedures

To develop foam core materials and apply them to sandwich structures of composite ships, the conformity conditions of the evaluation procedures summarized above must be satisfied. In this study, a product was selected from commercial foam core materials used in marine structures. The core material itself and sandwich structure prototypes fabricated using the core material were subjected to the evaluation procedures. The procedures for the evaluation of the core material itself were distinguished from those for the evaluation of the sandwich structures (Fig. 4).

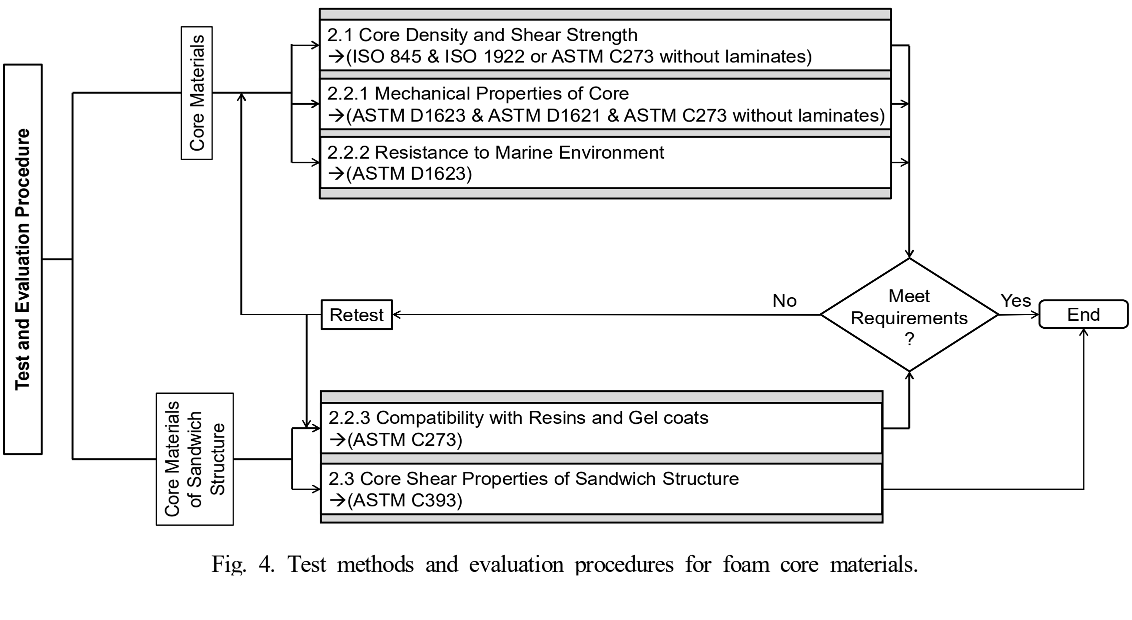

Fig. 4. Test methods and evaluation procedures for foam core materials.

3.1 Selection of the foam core material and fabrication of sandwich structures

For the case study on the evaluation procedures, AIREX C70.90 (3A Composites, 2020; Fig. 5) was selected. AIREX C70.90 has achieved type approval for marine structures and can be applied to the hull, decks, and bulkheads of composite ships. It has been widely used in railway and aviation industries and in marine structures. This product is a closed-cell, cross-linked polymer foam suitable for the design rule of small craft mentioned above. Table 5 presents the mechanical properties of AIREX C70.90, as provided by 3A Composites. These properties will be used for the application of the evaluation procedures and comparison of results.

Fig. 5. AIREX C70.90 closed-cell, cross-linked polymer foam.

Table 5. Mechanical properties of AIREX C70.90

Item		AIREX C 70.90	
Density (kg/m^3)		Average	100
		Typ. range	90 - 115
Tensile	Strength (MPa)	Average	2.7
		Minimum	2.2
	Modulus of elasticity (MPa)	Average	84
		Minimum	65
Compressive	Strength (MPa)	Average	2.0
		Minimum	1.7
	Modulus of elasticity (MPa)	Average	130
		Minimum	110
Shear	Strength (MPa)	Average	1.7
		Minimum	1.4
	Modulus of elasticity (MPa)	Average	40
		Minimum	34

Because PVC is foamed and molded, it is necessary to cut it according to the dimensions of the structural design results. Therefore, the structural design of a composite ship is required for the case study. Here, the structural design was obtained using the sandwich-structure ship model of the 11 m FRP yacht developed by RIMS (RIMS, 2017). In addition, the PVC foam was cut by referring to the rule scantling result of the sandwich structure, and sandwich structure prototypes were fabricated.

Figs. 6 and 7 illustrate the structure layout and midship section of the target yacht, respectively. Based on the structural design results, the foam core was cut to a thickness of 25 mm and used for the fabrication of the core specimens to be used in all the evaluation procedures. As shown in Fig. 4, it is necessary to fabricate a sandwich structure using the core material to perform the evaluations described in Subsections 2.2.3 and 2.3. It was fabricated by referring to the bottom plate of the hull depicted in Fig. 7, which shows the dimensions of the sandwich structure of an actual hull bottom plate. However, because the inner and outer laminates of the sandwich structure for testing (Fig. 3) must have the same thickness, it was fabricated in accordance with the specimen fabrication rule by referring to the design.

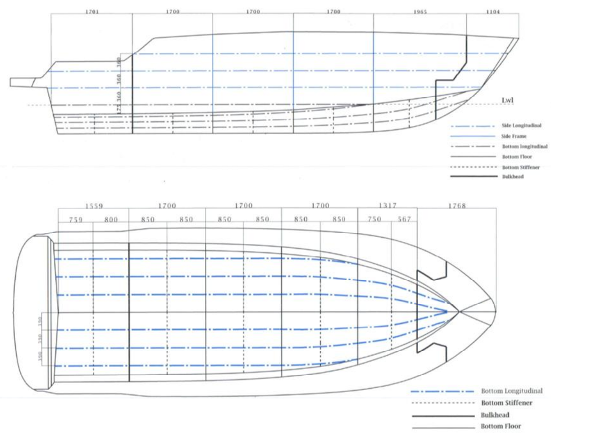

Fig. 6. Structure layout of 11 m sandwich-structure yacht.

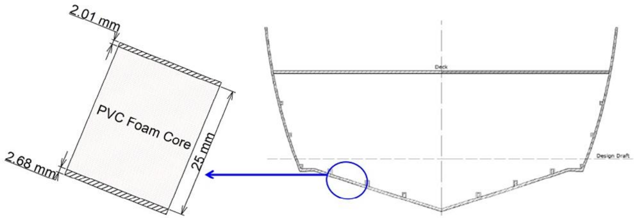

Fig. 7. Midship section of 11 m sandwich-structure yacht.

Fig. 8 displays the cut PVC foam and sandwich structure prototypes fabricated using it. As described in Subsection 2.3, both the inner and outer skin laminates had a thickness of 3.2 mm, and the weight fraction of E-glass fiber was also 0.45, as proposed. For the fabrication of the laminates, Mat-CSM 450, which is an E-glass fiber cloth from KCC (KCC, 2020), was used. As for the resin, KER 9100, an epoxy resin from Kumho P&B Chemicals (2020), was used.

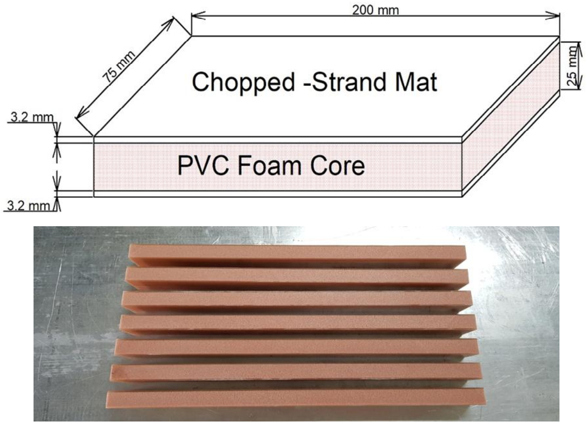

Fig. 8 Sandwich structure using AIREX C70.90.

3.2 Evaluation of foam core materials

The prepared foam core material was subjected to the three evaluation procedures shown in Fig. 4, i.e., the procedures described in Subsections 2.1, 2.2.1, and 2.2.2.

3.2.1 Foam core density and shear strength

As mentioned previously, this evaluation procedure is not a test for the approval of the material from classification societies, but for evaluating whether the material satisfies the density and corresponding shear strength required by the design rules of composite ships.

In the case study, five cases were tested for density by cutting the specimens in accordance with ISO 845 (Fig. 9). Each specimen was placed in a desiccator at 23 °C for 72 h before measuring its density. For the volume change of each specimen, the average value of three measurements was used. The density of each specimen was calculated using Equation (2), and the results are summarized in Table 6. The average density of the specimens was 103.315 kg/m^3, which was slightly higher than 100 kg/m^3 (provided by 3A Composites).

Fig. 9. PVC foam core specimens for density measurement.

$$\rho = \frac{m}{V} \times 10^6 \tag{2}$$

m : Mass of the test specimen (g)

V : Volume of the test specimen (mm^3)

Table 6. Results of the density measurement test

Item	#1	#2	#3	#4	#5
Length (mm)	60.067	60.133	59.970	59.920	60.120
Breadth (mm)	60.137	60.033	60.073	60.077	60.080
Thickness (mm)	25.263	25.250	25.447	25.237	25.357
Volume (cm^3)	91.256	91.153	91.674	90.847	91.589
Density (kg/m^3)	102.612	102.861	104.086	103.140	103.878

A test was conducted for each core specimen to measure the shear strength corresponding to its density. Five cases were measured in accordance with ASTM C273 (Fig. 10). The shear strength was measured as shown in Fig. 10. According to the design rules of RINA, when the density of a core material is 103.315 kg/m^3, its shear strength must be at least 1.4 MPa. The test results showed that the measured average shear strength was as low as 0.5 MPa because a rupture occurred on the surface in contact with the jig, whereas no rupture occurred in the core. This is a failure phenomenon that frequently occurs in ASTM C273 tests, but a satisfactory value could not be obtained because five cases corresponding to the minimum requirements were tested. However, it can be judged that there are no conformity issues considering that the shear strength value provided by 3A Composites is 1.7 MPa (Table 5).

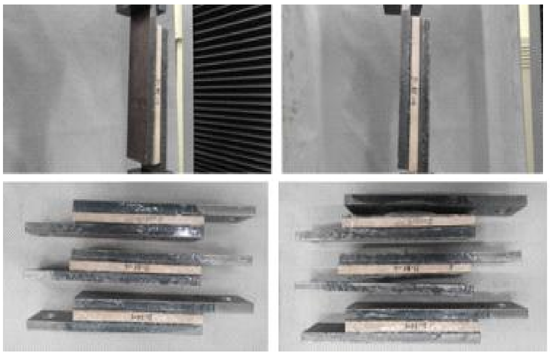

Fig. 10. Shear strength test of PVC foam core specimens.

3.2.2 Mechanical properties of foam core

The tensile, compressive, and shear strengths of the core specimens were measured in accordance with the aforementioned ASTM D1623, ASTM D1621, and ASTM C273 standards. The tensile and compressive strength tests were conducted using the prepared specimens exhibited in Fig. 11 and Fig. 12, respectively. The shear strength test in accordance with ASTM C273 was omitted because it was the same as the test conducted above.

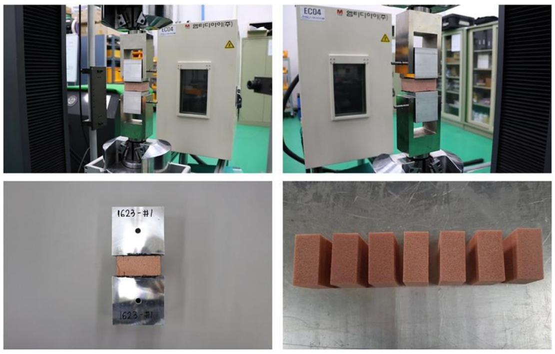

Fig. 11. Tensile strength test of PVC foam core specimens.

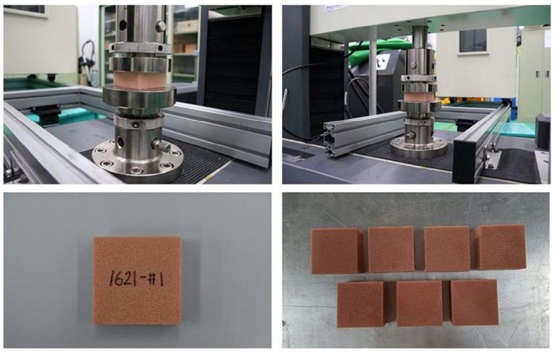

Fig. 12. Compressive strength test of PVC foam core specimens.

The test results showed that the average tensile strength of the five cases was 3.06 MPa, which was slightly higher than the value provided by 3A Composites (2.70 MPa). The average compressive strength was 2.33 MPa, which was also slightly higher than 2.00 MPa.

3.2.3 Resistance to the marine environment

To evaluate resistance to marine environments, resistances to temperature, seawater, fuel oil, and gasoline (which are environmental agents) were examined in accordance with the type approval regulations of RINA for composite materials (RINA, 1997).

First, the resistance of the core specimens to temperature was evaluated. After heating the specimens on a stove at 45 and 60 °C for 30 min, they were withdrawn and their tensile strengths were measured immediately in accordance with ASTM D1623. This was repeated for three cases (Fig. 13). As for the evaluation criteria of the resistance-to-temperature test, the tensile strengths after heating at 45 and 60 ℃ must be 90 % and 80 %, respectively, or higher compared with that of the control core specimen before heating.

The average tensile strength of the core specimens measured in accordance with ASTM D1623 was 3.06 MPa as mentioned above. After heating at 45 °C, the average tensile strength of the specimens increased to 3.17 MPa, which satisfied the 90 % criterion. After heating at 60 °C, the average value reduced to 2.98 MPa, but it was still higher than the 80 % criterion.

(a)

(b)

Fig. 13. Resistance-to-temperature test at (a) 45 °C and (b) 60 °C.

Subsequently, the resistance to seawater, fuel oil, and gasoline was evaluated using three cases. The core specimens were immersed in each solution for 24 h (Fig. 14) and then dried by hanging for 24 h. Their tensile strengths were also measured in accordance with ASTM D1623 (Fig. 15). The volume and weight changes of the core specimens due to these three solutions, which are highly likely to be contacted by the core materials in vessels, were evaluated. The volume change rate and weight change rate before and after immersion must not exceed 1 % and 6 %, respectively. In addition, the tensile strength must be 90 % or higher compared with that of the control core specimen. The seawater immersion results showed that the volume and weight change rates were 0.20 % and 1.86 %, respectively. After immersion, the tensile strength slightly increased to 3.15 MPa. For the immersion in fuel oil, the volume and weight change rates were 0.30 % and 0.50 %, respectively. The average tensile strength was slightly reduced to 2.99 MPa, which satisfied the judgment criterion.

Fig. 14. PVC foam and sandwich structure specimens immersed in seawater.

(a)

(b)

(c)

Fig. 15. Tests on resistance to marine environmental agents: (a) seawater, (b) fuel oil, and (c) gasoline

3.3 Evaluation of sandwich structures with PVC foam

3.3.1 Compatibility with resins and gel coats

The compatibility of the sandwich structure prototypes, which were fabricated according to the specimen fabrication method presented earlier (Fig. 3), with epoxy resin was evaluated. The specimens were designed as illustrated in Fig. 16, and five cases were tested in accordance with ASTM C273 (Fig. 17).

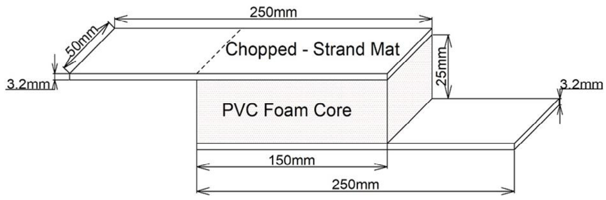

Fig. 16. Dimensions of the sandwich structure prototype for the compatibility test.

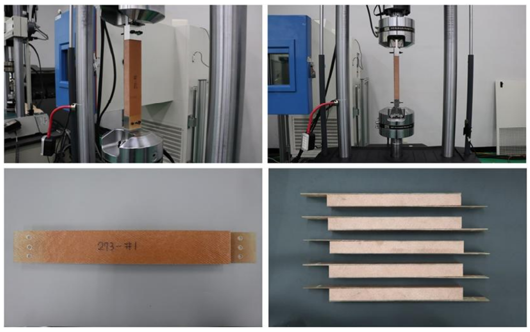

Fig. 17. Sandwich structure prototype compatibility test.

In the test, the load at which rupture began was measured to be 6,430 N. The average stress (τ) was calculated as 0.86 MPa using Equation (1). However, the compatibility test results could not be evaluated because the shear strength measurement in accordance with ASTM C273, which was conducted as described in Section 3.2.1, failed. Nevertheless, it could be judged that there were no conformity issues considering that the shear strength provided by 3A Composites is 1.7 MPa (Table 5).

3.3.2 Core shear properties of sandwich structure

The shear strength of the sandwich structure with the core material from 3A Composites was evaluated in accordance with ASTM C393 for the five cases. Although the evaluation should have been performed under the four-point bending load condition, a three-point bending test was conducted due to the test environment condition (Fig. 18). ASTM C393 allows both three- and four-point tests.

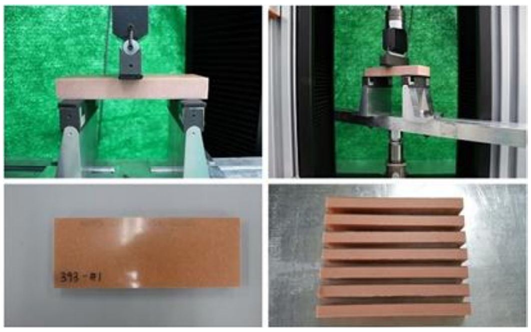

Fig. 18. Shear strength test of sandwich structure.

In the sandwich structure, the rupture of the laminate and core material occurred twice due to beam flexure. The test results showed that the average facing stress was 66.04 MPa and the average shear strength of the core material was 1.57 MPa. These test results do not present threshold values for evaluation, and it is necessary to compare the test values with catalog values of the control core material.

The density provided by 3A Composites is 100 kg/m^3 and the shear strength ranges from 1.4 to 1.7 MPa (Table 5). The density of the core specimen obtained from this test was 103.315 kg/m^3. For this case, the RINA rule suggests that the shear strength should be equal to or higher than 1.6 MPa. Therefore, it can be judged that some of the values provided in the catalog and the test values may be unsuitable. However, it is necessary to test more cases.

4. Conclusion

For composite ships, the sandwich structure is a special structure type, and core materials are essential. PVC foam core materials are among the most popular. This paper presented a summary of the test methods and evaluation procedures for testing and verifying the performance of core materials for vessels during their development. For a case study, the sandwich structure of an 11 m FRP yacht was designed, and prototypes were fabricated by selecting a commercial PVC foam core product. In addition, the case study was conducted using the prototypes based on the summarized test methods and evaluation procedures.

The proposed summary of evaluation procedures for the performance of foam core materials made it easier to understand the requirements and performance of core materials to be used in marine structures. It is expected that the results of this study will be utilized for the development of PVC foam core materials in the future.

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