ISSN: 2586-6036
JWMAP website: http://accesson.kr/jwmap
doi: http://dx.doi.org/10.13106/jwmap.2026.vol9.no4.9

A Study on the Improvement of Bonding Strength with High Strength Pontoon Structures

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Received: August 11, 2026. Revised: August 21, 2026. Accepted: August 30, 2026.

Abstract

Purpose: The purpose of the study is to strengthen durability, secure safety, and reduce the economic burden by identifying the causes of deterioration in durability of existing PE pontoon structures (natural factors, design and construction problems, and materials and maintenance factors) and presenting directions for improvement of materials used**. Research method (manufacturing method)** : It is a research method (manufacturing method) on high-strength pontoon structures with strong high strength bolts and nuts with strong horizontal and vertical bonding structures between pontoon blocks, respectively, using high-strength polyethylene /polyaramid/teflon resin mixtures as pontoon materials**.Research Results** : It is a high-intensity sea-level pontoon structure that does not cause the pontoon structure to unravel, destroy, and disengage from the coupling device even due to waves, typhoons, and other collision torsions of floating objects floating on the sea.**Conclusion** : By improving the pontoon material and bonding method of this study, quality and safety were ensured by always maintaining high strength quality, improved bonding of connections, durability, corrosion resistance, maintenance, reduction of environmental impact, aesthetic perspective, and durability deterioration factors.

Keywords : High-strength pontoon, increased durability, improved connections, safety, economic feasibility, aesthetic vision.

JEL Classification Code: O32, L60, L65

1. Introduction

1.1. Background and purpose of the study

Due to the structural weakness of the existing pontoon polyethylene (PE) and polypropylene (PP) quality, economic losses and facility safety problems exist due to frequent damage caused by impact on the eyepiece facility during the construction of the maritime bridge (Suspension Bridge L=2.11Km) between Ganghwado and Gyodongdo, but the demand for pontons is increasing rapidly and the marine development and leisure industry continues to grow. However, the pontoon structures that are currently commercially installed and operated are dependent on polyolefin synthetic resins or low-cost imports considering only processability. As a result, the following serious safety and quality problems are continuously exposed and the motivation for this study was stimulated.

Physical and environmental vulnerability: When high-energy external forces such as waves, strong winds, typhoons, and tsunamis collide with marine floats, the current polyolefin-based pontoon is easily damaged and cracked due to lack of structural strength. In addition, there is a limit to the rapid decrease in durability due to exposure to ultraviolet (UV) rays and biological corrosion caused by shellfish habitat.

Structural degradation with temperature change: Due to the limitations of glass transition temperature (Tg) and thermal properties, polylefin resin softens in a high-temperature environment (tropical area, etc.), causing the structure to become soft and change its frictional force, which leads to decreased walking sensation, bad smell, and poor aesthetics. In a low-temperature environment, it has the problem of both extremes that are easily destroyed even with a slight impact due to rapid low-temperature brittleness.

Structural instability of coupling parts: Existing folding devices, simple fitting grooves, and surface screw fastening methods cannot withstand stress concentration under repetitive wave load conditions, and the coupling mechanism is frequently deviated or loosened. This causes a chain collapse of the entire structure, causing large-scale maritime safety accidents.

Therefore, it is urgent to develop a high-functioning pontoon system that can overcome the critical defects of existing materials and bonding methods and maintain long-term structural integrity even in extreme marine environments.

1.2. The scope of the study

In order to overcome the material and structural limitations of existing polyolefin-based fonts, this study is conducted by limiting the scope of the study as follows. In terms of content, the research scope includes accelerated weathering test environments that simulate high temperature softening and low temperature brittleness of pontoon materials and bonding mechanisms through analysis of existing domestic and international research patents and prior literature (Korea Open Patent 1987-4863A, US7,044,076B2, etc.), and tensile, impact, friction, and fatigue failure experimental conditions based on ISO and ASTM standards that can overcome high temperature softening and low temperature brittleness. The research scope includes high-binding pontoon and inter-block mechanism (modular combination method) design and construction methods that can resist extreme external forces such as typhoons and tsunamis, as well as environmental and conditions.

1.3. Research Methods

This study is conducted by adopting a multi-faceted methodology that combines material engineering approach and structural mechanical analysis. The research method was conducted with **[Literature and Research, Patent Data Analysis] ➔ [Alternative Material Mixing and Specimen Manufacturing] ➔ [Mixing and Specimen Evaluation] ➔ [Bonding Structure FEA Analysis] ➔ [Trial Product Demonstration Test]**. Prior art research and patent precision analysis were conducted by categorizing the failure mode of the existing combination method based on the presented domestic and international patents (KR, US, JP, EP) and the articles of the Korean Civil Society, and dynamically identifying the structural weaknesses.

Mixing and Specimen Manufacturing of High Functional Alternative Materials: To compensate for the shortcomings of existing PE and PP materials, a new material specimen is designed and manufactured based on engineering plastic or glass fiber reinforced plastic (FRP) and modified polymer resin that have excellent mechanical strength and easy glass transition temperature (Tg) control. The evaluation test for material properties and facilitating environment is a mechanical test, and tensile strength, flexural strength, and Charpy impact tests are performed using an universal testing machine (UTM) in accordance with ASTM standards.The environmental degradation test evaluates softening and low-temperature brittleness by performing gap tests in low-temperature environments below -20°C and high-temperature environments above 60°C, and UV resistance is verified through UV promotion tests. **Combination mechanism optimization through numerical analysis (FEM)**: Using ANSYS or ABAQUS software, a three-dimensional finite element analysis (FEA) is performed for new pontoon block combinations. By analyzing the repetitive stress distribution by wave and tide, we derive the optimal geometric coupling shape to disperse the stress concentration.

In this permanent, a composite material mixed with polyolefin, polyaramid, and Teflon resin was applied as a pontoon material, and a horizontal and vertical coupling structure was introduced at the connection between pontoon blocks. In addition, a high-strength pontoon structure was designed and manufactured using a high-strength bolt and a nut to improve the bonding area of the connection part.

1.4. Expected Effects

The development of a high-strength/high-durable pontoon system to be derived through this study is expected to create the following expected effects in academic, technical, economic,and industrial aspects. The technical and academic aspects contribute to the development of related studies by securing source technology for marine polymer materials and establishing a resin mixing technology and database for floating structures that can respond to extreme climate changes (high temperature and low temperature), and the presentation of structural stability design standards can be used as basic data for standardizing floating structure design standards by proposing a new concept modular combination mechanism that can withstand repetitive fluid loads. In the economic and industrial aspects, the life cycle cost (LCC) of marine facilities is optimized by drastically reducing maintenance costs and periodic replacement costs and disaster recovery costs due to life-extension damage, stamping, and departure from the joint. Preventing marine safety accidents In the event of natural disasters such as typhoons and tsunamis, the social and safety aspects fundamentally prevent the collapse of floating bridges and offshore workplaces due to pontoon loosening and damage to prevent human and property damage. Marine environmental protection contributes to the prevention of marine ecosystem pollution by blocking the leakage of plastic microcrumbs and internal fillers that occur during pontoon damage.Strengthen import substitution and export competitiveness, reduce dependence on the absence of low-cost, low-quality imported plastic, and lay the groundwork for reverse export of domestic pontoon structures based on high value-added technology.

Figure 1 : Examples of Durability Degradation

2. Subject

2.1. Material and Structural Design of the Pontoon for Floating Structures

By researching and testing a new engineering plastic material on the deterioration of the durability safety of PE pontoon, we propose a next-generation high-stability, high-quality, and economical pontoon system that can withstand the extreme environment and repeated mechanical fatigue by combining a high-strength material for water-based structures with a strong fastening system. As shown in Table 1, the new material of the pontoon is based on 90-100 parts by weight of a resin composition obtained by mixing polyethylene, polyaramide, and Teflon resin at a weight ratio of 1:1:1, and includes 4.5 to 5.5 parts by weight of a Kaler filler, 2.5 to 3.5 parts by weight of a Kaler polymer bead, 0.5 to 1.5 parts by weight of an artificial wood pattern, and 2.5 to 3.5 parts by weight of an artificial marble.

Table 1: The mixing ratio of pontoon's new materials

Category	Detailed materials	Mxing ratio	Key roles and core functions	Purpose
Polyethylene	Chemical stability	1	Warning, lightweight,non-toxic, heat resistant, and resistant to repeated bending	Side dish container, delivery container, masker filter, car parts
Polyaramid	High-performance synthetic fiber	1	High strength, 5 to 6 times stronger than steel,heat resistance, self-extinguishing properties	Bulletproof clothing, bulletproof helmets, optical cables, aerospace components
Teflon ressin	Chemical resistance	1	Non-adhesive, heat resistance(-260°C to 260°C),corrosion resistance	Pen, rice cooker, clothing, Goatax, semiconductor valve
Color filler	Inorganic oxide particulate coloring	4.5~5.5	Giving beautiful color + UV protection and improving mechanical durability (particle diameter: 0.1-5 μm)	Provides beautiful color and improves durability
Polymer bead	Giving a three-dimensional effect	2.5~3.5	Implementation of a three-dimensional effect + formation of fine irregularities on the surface prevents slipping when walking (particle diameter: 0.1 to 1.0 mm)	Natural coloration
Artificial pattern	Patterning on the outside	0.5~1.5	A colorful and natural pattern is added to the exterior of the resort/everyday pontoon	Wallpaper, Paper
Artifical marble	Giving a three-dimensional effect	2.5~3.5	Synergy with polymer beads, luxurious appearance and surface hardness reinforcement	Natural coloration

Note : ASTM D4976 Specification and Peacock (2000) Handbook of Polyethylene (Marcel Dekker). Polyethylene, Polyaramide, Teflon resin: Main material (adjacent facilities, industrial use). Calor fillings, polymer beads, artificial patterns, artificial marble (resorts, bridges, swimming pools, marine houses) additives, three-dimensionality, coloration

2.2. Background of selection of new material mixing cost

Existing Pulliethylene (PE). Pullipropylene (PP)-based pontoon has excellent processability, but it contains complex durability defects such as high-temperature softening (softening temperature about 100~120°C), low-temperature brittleness (shock strength decreased below -20°C), ultraviolet deterioration, and biological corrosion. To overcome this, this study proposes a new composite material in which three high-performance resins are mixed at a weight ratio of 1:1:1.

Table 2: Properties and Expected Effects of New Materials

Composition material	Physical properties	Role (Bundiling basis)	Key Specifications
Polyethylene	Tensile strength 20–37 MPa, Softening temperature 100-130°C, Density 0.93–0.97 g/cm ³	Securing basic lightweight, chemical resistance, and non-toxic properties. Maintaining processability with existing pontoon main materials	ASTM D4976 ISO1872
Polyaramid	Tensile strength 30–36 MPa (5 to 6 times higher than steel), pyrolysis temperature>400℃	Providing extremely high strength and heat resistance. Role of structural skeleton in shock, twist, and fatigue loads	ASTM D7565 ISO10618
Teflon ressin	Coefficient of friction 0.04–0.10, Heat-resistant range - 260 to +260°C, Best chemical resistance	Reducing the wear of bonded surfaces, preventing corrosion resistance, and preventing low temperature brittleness. Securing the applicability of wide range of temperatures	ASTM D3294 ISO13000
Color Filler (Inorganic oxide)	particle diameter 0.1–5 μm, UV absorption rate >90%	Suppressing photoacidification deterioration by applying aesthetic color + UV blocking → Improving surface durability	ASTM G154
Polymer bead	particle diameter 0.1–1.0 mm	Formation of fine irregularities on the surface → Anti-slip (improved friction coefficient)	
Artificial pattern / Artificial marble		Responding to the demand for beauty for resorts and leisure activities + Reinforcing surface hardness	

Note : DuPont™ Kevlar® Technical Guide (2017)

2.3. Engineering feasibility of mixing ratio (1:1:1)

Comparison of properties by blending ratio (PE: PA: PTFE)
• Mix ratio (2:1:1) → PE reinforcement (focused on workability) → Low tensile strength → Concerns over brittleness and failure due to increased PE content
• Mix ratio (1:2:1) → PA reinforcement (strength-focused) → High tensile strength and wear resistance → Vulnerable to high temperatures and UV rays, resulting in reduced durability
• Blend ratio (1:1:2) → PTFE reinforced (focused on abrasion resistance and corrosion resistance) → High water resistance and moisture resistance → Deformation occurs at high temperatures
• The basis for mixing the three components of the mixture ratio (1:1:1) in equal weight ratios is as follows.
• When using PE alone, issues such as high-temperature softening and low-temperature embrittlement persist→ By adding PA and PTFE, the Tg and pyrolysis temperature increase
• When PA is used alone, processing becomes difficult and costly→ By diluting PE, we ensure cost-effectiveness and moldability
• When using PTFE alone, molding temperature issues (above 327°C) → With dispersion blending within the PE/PA matrix, extrusion molding is possible (at 180°C)
• Equally blended in a 1:1:1 ratio→ Each component is not dominant, allowing the drawbacks of each resin to complement each other, resulting in an optimal blending point that balances physical properties and processability.

In Example 2 of Table 6 (PE/PA/TEF 95 weight portion), it recorded a bond strength of 542 N, tensile strength of 335 N, indentation strength of 305 HRC, and softening temperature of 181°C, demonstrating the highest performance among the three-day-old examples (90/95/100 weight portions). This experiment experimentally proved that the maximum synergistic effect between the main raw materials and additives is achieved when the ratio is 95 in the 95 weight portion.

2.4. Engineering Evidence for Mixing Materials and Structural Design

The pontoon above has a cube shape, and the structure excluding the coupling part is manufactured by a semi-finished extrusion method. In order to secure structural strength, the wall thickness is 30 mm or more, and the corners are rounded to prevent stress concentration. In addition, in order to cope with compression and bending stress, a lattice structure is locally applied to improve bending stiffness, and it is designed to enable water pressure dispersion and ductility failure. The safety factor of the entire structure was to be at least 2~3, and pin (nut) and bolt fastening methods were adopted for coupling between pontons. This increases the tensile load and torsional strength to improve the ability to respond to waves and shocks, and contributes to suppressing the vertical movement caused by waves. In high temperature areas sensitive to temperature, polyolefin is widely used as the main raw material for pontons, which are sea and floating structures, due to its availability and processability. However, due to the unique thermal properties of the polymer, it reacts sensitively to external temperature changes, which leads to a decrease in user safety and durability of the structure. In this study, in order to improve the material and overcome the thermal limitations of the existing polyolefin materials that retreat at high temperatures and break at low temperatures, new materials that are resistant to climate change and external shocks were researched and developed.

Table 3: Engineering Evidence for Mixing Materials and Structural Design

Design and Mixing Items	Applied Data/ Specifications	Limitations to be resolved (Existing PE issues)	Engineering/physical grounds (resolutions)
Basic resin improvement	Polyethylene:polyaramid:Teflon Resin = 1:1:1	High temperature flaking (combustion) and freezing at low temperatures (low temperature brittleness breakdown)	PE/PA/TEF(1/1/1) Strengthen durability and overcome temperature sensitivity with the bonding strength of high-strength materials
Structural Wall Thickness	30 mm or more (hollow extrusion)	Damage and deformation of exterior walls due to external impact and wave loads	Thickness visualization increases the moment of physical inertia to ensure fundamental structural strength
corner design	Rounding Processing	A phenomenon in which a load is concentrated at a right angle and cracks start	Extend long-term fatigue life by dispersing stress concentration
Internal reinforcement	Local lattice structure	The phenomenon of bending the center of the pontoon due to water pressure and upper load	Increase structural flexural stiffness to distribute water pressure and induce ductile breakdown instead of sudden breakdown
Fastening system	Pin (nut) and bolt engagement+ (dual protection structure)	Waves wear and tear of joints during up-and-down/twist motion	Increase structural flexural stiffness to disperse water pressure and induce ductility breakdown instead of rapid breakdown
Safety rate design	At least 2 to 3	Unpredictable marine climate and risk of major accidents in the event of a ship collision	Ensure minimum safety rate for structures to withstand extreme situations based on ASTM / ISO standards

Note : Chemours™ Teflon® PTFE Properties Handbook (2020)

2.5. How to make a pontoon

The manufacturing method of Pontoon is as shown in [Figure 2]: polyethylene 30–33.3 wt., polyaramide 30–33.3 wt., and Teflon resin 30–33.3 wt. are added into the mixer and mixed at room temperature for 10 minutes, then the color filler 4.5–5.5 wt., color polymer bead 2.5–3.5 wt., artificial wood grain 0.5–1.5 wt., and artificial marble 2.5–3.5 wt. are added sequentially and stirred at 120°C for 20 minutes, then the mixer temperature is raised to 120°C–140°C and mixed for an additional 40 minutes, and the resin mixture at 120°C–140°C is passed through an extruder at 180°C for 15–20 seconds to volatilate the lubricant,A method for manufacturing high-strength pontoon characterized by promoting inter-particle bonding and then pouring the high-temperature resin mixture discharged from the extruder outlet into a cube-shaped molding die to form it [Figure 2].

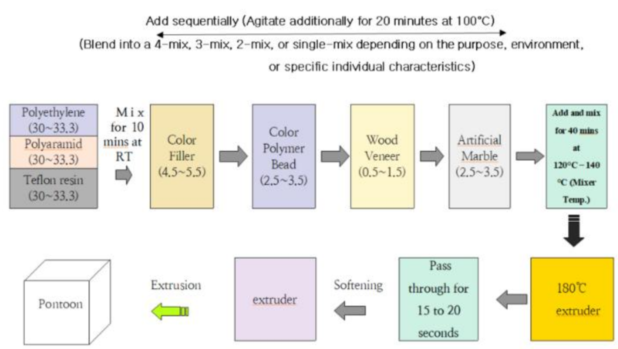


Figure 2 : Manufacturing method

2.6. Manufacturing process parameter basis

The mixed extrusion temperature and time are input and stirred and discharged step by step in consideration of the processing characteristics of each material as shown in Table 4.

Table 4: Manufacturing process

Process stage	Temperature	Time	Basis
Additives and Agitation	RT(25°C)	10 min	Initial uniform dispersion of PE powder and PA

			fiber
Additives and Agitation	100°C	20 min	Equal dispersion of additives such as calor fillers and beads in the resin
Heating mixing	120~140°C	40 min	Entry into the complete melting section of PE, combining PA fiber and matrix
Extrusion	180°C	15~20 SecB	Maintain the dispersion of PTFE particles and soften and mold the entire mixture
Molding and cooling	RT	Natural cooling	Securing dimensional stability after injection of cube mold

2.7. Specific experimental evaluation for the study

The following measured the durability of pontoon materials (tensile strength, indentation strength, and softening temperature) and the bonding strength of the bonding structure in this research paper.First, to evaluate the bonding strength of Pontoon's joint structure, as described in the research explanation, the Pontoon was manufactured in the dimensions =30 cm × 30 cm × 30 cm, and produced in three types each for width, depth, and height, and then conducted experiments 1, 2, and 3, and produced the Pontoon samples shown in [Table 5]. When manufacturing a sample for an experiment as a full-scale sample, if it is combined in three layers—width, length, and height—it is difficult to measure the bonding strength due to the scale of the measuring equipment. Therefore, samples were manufactured in the maximum possible size within an easily measurable range for evaluation, using the sample dimensions of width × length × height = 10 cm × 10 cm × 10 cm, and the experiment was conducted. As a sample for comparative testing, a sample manufactured and distributed in the market using the same material and bonding method as commercially available pontoon (PE) was used and tested according to the specifications shown in the example. The bond strength was measured using a largeInstron used to determine the tensile strength of materials, and the bond strength was expressed by comparing it with the experimental and comparative examples, showing the relative value when the comparative bond strength was set to 100. The tensile strength was measured by repeating the test five times and taking the average value, and the margin of error is about ±10% based on the standard deviation.

In the case of comparison in measuring bonding strength, the measure is the strength of loosening of the fastening device or the detachment of the fastening device from the pontoon block. In the case of a pontoon with a bolt-nut fastening structure in this experiment, the measurement of bonding strength can be said to measure the strength at which the fastening mechanism breaks the pontoon block.

Next, for durability evaluation, specimens measuring 10 cm by 1 cm were fabricated from pontoon material for this study, and for comparison, specimens of the same material as commercially available pontoons, also measuring 10 cm by 1 cm, were fabricated for comparison. Durability evaluation was conducted by measuring the failure strength, indentation strength, and softening temperature of test samples and comparison samples, and then performing a relative comparison. The failure strength was measured by assessing the failure strength of a single pontoon block. After mounting the test specimen on an instron, tensile forces were applied from both ends to measure the tensile strength at which failure occurred, and the relative value was presented based on the tensile strength used as a reference of 100. The penetration strength measured was the force required to penetrate to a certain depth when measured with a Pontoon block indentation tester, and it measured the force required to penetrate 2 mm. It indicated the relative value when the comparison example was set to 100. The annealing temperature was measured using the standard equipment DSC. The following sample procedure composition ratios are shown in [Table 5], and the measurement items and evaluation results are presented in [Table 6]. The test conditions were 23±2°C, 50±5% RH, and a crosshead speed of 5 mm/min. Each item was repeated n=5 times.

Table 5: Composition ratio of the embodiment

Category	**Example 1**	**Example2**	**Example 3**	**Etc**
PE/PA/TEF(1/1/1)	90	95	100	Main ingredient of pontoon
Color filler	4.5	5.0	5.5	Object, Environment, Individual
Color polymer bead	2.5	3.0	3.5	Add according to characteristics
Artificial wooden pattern	0.5	1.0	1.5	
Artificial marble	2.5	3.0	3.5	

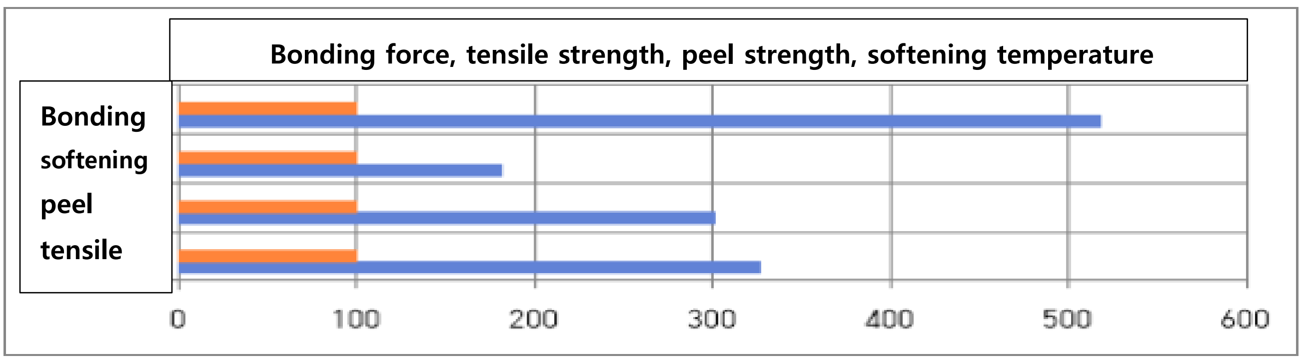
Note : PE (Polyethylene), PA (Polyaramid), PEF (Teflon Resin)

Configuration Ratio Examples 1 to 3 [Table 5] of the embodiment and the test and evaluation results of the configuration ratio physical properties of the embodiment are shown in [Table 6].

Table 6: Evaluation results of the bonding strength and durability of the bonding structure (standard deviation of the mean of five repetitions)

Category	Measurement equipment (Unit)	Example 1	Example 2	Example 3	Comparative example	Average of examples ± Standard deviation
Binding force	Instron (N)	495 N	542 N	517 N	100 N	518.0±23.5
Durability (tensile strength)	Instron (N)	320 N	335 N	327 N	100 N	327.3±7.5
Durability (Stiffness)	Indentation (HRC)	298 HRC	305 HRC	302 HRC	100 HRC	301.7±3.5
Durability (Softening temperature)	DSC (mW)	182°C	181°C	182°C	100°C	181.7°C±0.6°C

Note 1 : Compare manufacturing of specimens with width*length=10cm*1cm



Note 2 : ISO 527-1:2019 ,ASTM D638,ASTM E18, DSC ASTM E1356

Figure 3: (Comparison graph of Bonding force, tensile strength, peel strength, softening temperature)

2.8. Data analysis summary

As shown in Table 6, this research experiment shows that in the case of pontoon, the optimal mixing ratio of Example 2 [PE/PA/TEF (95%)] shows excellent values in bonding strength (542N), tensile strength (335N), imprint strength (305HRC), and mechanical properties.

The superiority of the bonding structure, comparison (existing PE pontoon) loses its bonding force due to loosening or separation, but the bolt-nut bonding structure of this study demonstrated a high bonding force of up to 5.4 times (Example 2) by maintaining the bond until the block itself was destroyed**.** The tensile strength and the taken strength of the pontoon block itself are superior to the comparative example, indicating that the material does not change with time even if used at high temperatures and underwater for a long time, and the softening temperature is high, so even if used in tropical regions, deformation does not occur at all.
In particular, in the bonding structure between pontoon blocks, it has a horizontal and vertical bonding structure to exert a strong bonding force, resulting in small destruction or loosening due to external impact or natural environment, and if necessary, an external bonding structure can be added to form a strong bonding structure. [Table 7] shows the evaluation of the coupling force and durability of the coupling structure and the results.

Based on the experimental data (Table 6, Table 7), the comparison between the existing (PE) and the high-strength pontoon is as follows.

• Bonding strength: 5.4 times (54%) improvement compared to the comparative example (PE pontoon) → 54% increase in bond strength
• Tensile strength: Example maximum value 335N (Tensile failure load), Softening temperature: Existing 100℃ → 181.7℃ (approximately 81.7% improvement), Expected durability: Existing 10~20 years → 20~30 years (approximately 50~100% improvement)
• Corrosion rate: LCA analysis reduced marine ecotoxicity by 50-60%, test specification (ASTM, ISO)

Table 7: Comparison Table of Relativity between High Strength Pontoon (PE/PA/PEF) and PE Pontoon

Category/Type	PE/PA/PEF High-strength Pontoon	Relativity	P.E Pontoon(Polyethylene)
Weight	Lightness	< (=)	Very Lightness
Structural Strength	High Strength	>	Low/Middle
Coherence	Very High	>	Low
Durability	Very High	>	Low
Corrosion Resistance	Very Good (No rust)	>	Good (No rust)
Maintenance	No Maintenance Cost	> , (=)	Almost No Maintenance Cost
Fire Safety	Unaffected by UV	>	Affected by UV
Environ mental Effect	Good	>	Middle
Esthetic, Visual	Very Good(various color)	>	Simple
Life Span	20~30 year	>	10~20 year

2.9. Long-term durability evidence

2.9.1. Material Property-Based Lifetime Forecast

The **PE/PA/TEF** composite material of this study is expected to have a service life of 20-30 years or more compared to the expected life (10-20 years) of the existing PE pontoon by improving the softening temperature of 181.7 ℃ and tensile strength by more than 3 times. This is based on the following material scientific evidence.

Table 8: Comparison Table of Life Forecasting Based on Material Properties

Deteriorating factors	Limitations of existing PE	PE/PA/TEF Improvement Mechanism of Composites	Relevant test specifications
High-temperature softening	Tg≈100-120°C Deformation in tropical area operation	PA heat-resistant fiber + PTFE heat-resistant matrix rises above Tg180°C	ASTM D648 ISO75
Low-temperature brittleness	Impact strength below -20°C Sudden risk of destruction in winter	The characteristics of PTFE's cryogenic (-260 °C) flexibility are reinforced by the overall low temperature toughness of composite materials	ASTM D256 (Izod impact)
UV deterioration	Color fading and chalking of surface cracks due to photooxidation reaction	Absorption/blocking of UV of inorganic oxide fillers (particle diameter 0.1-5μm, UV absorption >90%)	ASTM G154 ISO 4892
Biological corrosion	Surface damage and weight increase due to attachment of shellfish and marine life	Suppression of bioadhesion with PTFE non-adhesive surface (friction coefficient 0.04~0.10)	ASTM D5765
Repeated fatigue breakdown	Repeated wave load causes joint dislocation and crack propagation	Concentrated distribution of stress with bolt-nut double bond + rounding edge, inducing ductility failure	ASTM E466 (Fatigue Test)
Chemical Corrosion (Sea Water)	Hydrolysis and swelling during long-term sea immersion	PTFE's best chemical resistance + hydrolysis in PA to secure long-term stability of seawater environment	ASTM D1693 ISO4427

2.10. Connection method of pontoon with strong bonding force

[Figure 4] The pontoon bonding method in this research paper is an internal bond (horizontal).It is a double fastening connection method combining (vertical) and external fasteners. The basic internal assembly schematic [Figure 5] and the vertical orientation [Figure 6] are assembled in the same manner. Nut holes (bolt mounting positions) embedded in blocks ① and ② (③)A bolt fastened into a nut groove. ④ A bolt used for final fastening. Bolt fixing screws. The blocks are fastened in four directions—top and bottom, left and right—each 2 times, securing a strong internal connection. An auxiliary fastening structure (external, [Figure 7]) can be additionally installed on the block's outer surface as needed. ① Nut ② Connecting bar crossing the block ③ Bolt. The key feature is that, unlike conventional methods such as the clamping type, bonding type, and barrel type, this new fastening method applies a double fastening of the internal bolt–nut plus the external connecting bar, ensuring that the block does not loosen, break apart, or detach even under waves, typhoons, or collisions. In this paper's study, it is a new bonding method with strong bonding strength, proven through numerous experiments.

Table 9: Method of combining pontoon with strong bonding force and each name

Figure category	A diagram of the coupling structure of the pontoon	Code description for key parts of the drawing	Note
Figure 4	Schematic diagram of pontoon coupling structure	Schematic diagram of pontoon coupling structure	
Figure 5	Horizontal coupling structure of pontoon	①, ②-Nut Groove, ③-Bolt ④-Set Screw for Bolt	
Figure 6	Longitudinal coupling structure of pontoon	①, ②-Nut Groove, ③-Bolt ④-Set Screw for Bolt	
Figure 7	External coupling structure of pontoon	①-Nut,②-Coupling rod ③-Bolt	

2.11.Comparison of Structural Durability Combination Methods

Table 10: Comparison of Structural Durability Combination Methods

Combination method	Characteristic	Fatigue Life	Conformity of marine environment
Existing Snap-fit	Easy to manufacture, low bonding force	Low (departure under repeated load)	Non-conformity (weakness of typhoon and blue)
Engagement of existing surface screws	Intermediate coupling force	Normal (deterioration in strength during corrosion)	Partial fit
This study: Double fastening of internal bolt-nut+ external coupling rod	Highest coupling force (5.4x)	High (maintained until block self-destruction)	Very suitable

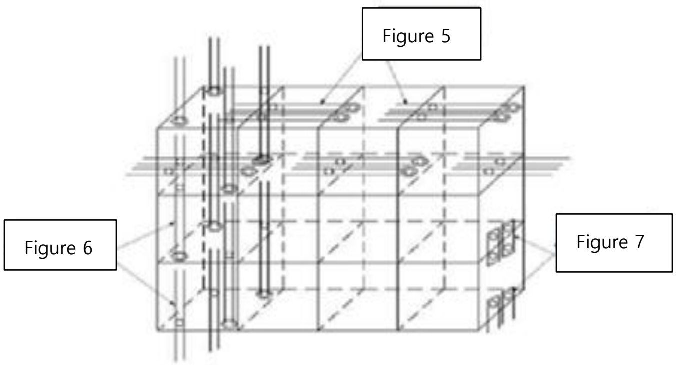


Figure 4 : Schematic diagram of pontoon coupling structure

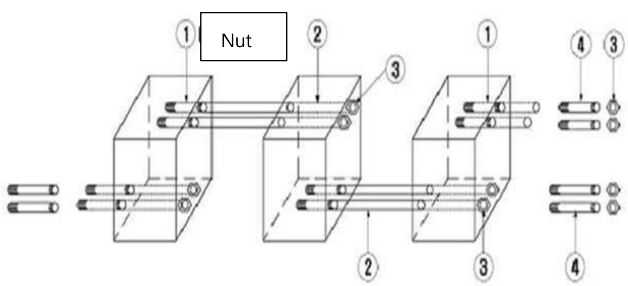


Figure 5 : Transverse coupling structure of the pontoon

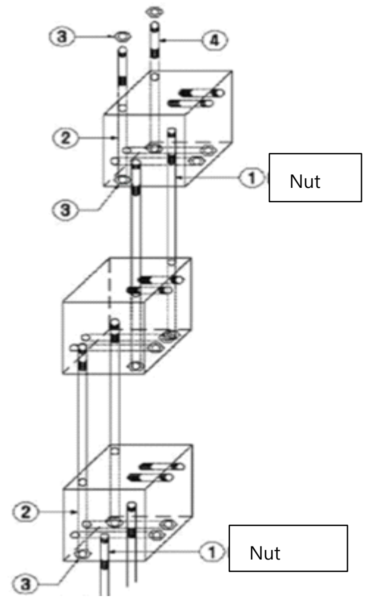


Figure 6 : Longitudinal coupling structure of the pontoon

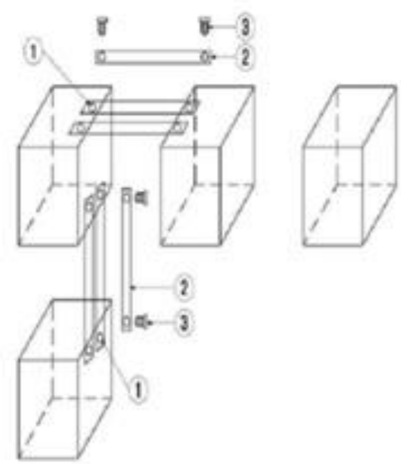


Figure 7 : External coupling structure of the pontoon

2.12. Evidence for environmental impact reduction (LCA analysis)

2.12.1. LCA Analysis Overview

Life Cycle Assessment (LCA) is a methodology that quantifies environmental load throughout life, from raw material collection, manufacturing, use and disposal of a product (ISO14040/14044).

This section compares the environmental impact of the existing PE pontoon and the PE/PA/TEF composite pontoon of this study.

Table 11: System Boundaries and Functional Unit Definitions Table

LCA Category	Details of settings
Functional Unit	20 years of service with an area of 1m² of marine pontoon
System Boundaries	Raw material collection → Resin manufacturing → Mixing/extrusion molding → Installation/operation → Replacement/disposa
Comparison criteria (base scenario)	Existing PE pontoon (10-15 years of life → 1.5 replacement assumptions within 20 years)
Improvement Scenario	PE/PA/TEF composite pontoon (life 20-30 years → replacement less than once within 20 years)
Application criteria	ISO 14040, ISO 14044, EN 15804 (based on EPD for construction products)

In this section, the environmental impact of the existing PE pontoon and the PE/PA/TEF composite pontoon of this study is compared.

Table 12: Comparative Analysis by Environmental Impact Category

Influence category	Existing PE pontoon (standard = 100)	PE/PA/TEF (This Study)	Improvement rate	Reduction mechanism
GWP(kgCO_2 -eq)	100	About 55~65	35~45% decrease	Reduction of replacement cycle by half → reduction of manufacturing energy and CO_2
Marine ecotox	100	About 40~50	50~60% decrease	Non-adhesive surface of PTFE → Minimization of microplastics and marine pollution
ADP (kgsb-eq)	100	About 70~80	20~30% decrease	Reduce the total consumption of raw materials by extending their lifespan
Water footprint (m³)	100	About 60~75	25~40% decrease	Optimization of resin manufacturing process integration
EP(kgPO_4-eq)	100	About 50~65	35~50% decrease	In case of damage, the leakage of runoff (filling material, etc.) is blocked
Amount of waste generated (kg/FU)	100	About 45~55	45~55% decrease	Double life span → Less than half of disposal within the same functional unit

Note : The figures in Table 12 are the estimation range based on the above assumption conditions and may be modified when the actual LCA data are obtained. The GWP reduction of 35–45% is mainly attributable to the reduction of CO_2 in the manufacturing stage due to the reduction of the replacement cycle (0.5 reduction), and is consistent with the analysis results of Chen et al. (2021) [18] for the same composite resin structure (the reduction of GWP of 30-50% when the life of similar composites is extended). The 50-60% reduction in marine ecotoxicity is a key mechanism for inhibiting microplastic dropout due to PTFE non-adhesive surface properties, and this figure is a qualitative estimate based on the HDPE structure surface wear data of Yang et al. (2020) [16]. Basis [16], [17], [18]

2.12.1. LCA Analysis Overview

① Prevent microplastic contamination

In the existing PE pontoon, microplastics continue to leak due to surface wear caused by waves and collisions. PE/PE composite materials improve the peeling strength by about 3.1 times and PTF significantly reduces the surface wear rate with an adhesive surface to suppress marine microplastic contamination.

② Carbon reduction through extended product life

Based on the functional unit of 20 years, PE pontoon requires about 1.5 replacements (assuming a 15-year lifespan), while PE/PA/TEF pontoon provides the same service with less than one replacement. When the carbon footprint of the pontoon 1m is estimated at about 5 to 8kg CO_2-eq, it is expected to reduce greenhouse gas by about 2.5 to 4kg CO_2-eq/m with only 0.5 replacement savings.

③ Indirect environmental effect of reduction of maintenance work

Maritime maintenance work involves incidental carbon emissions such as ship fuel combustion and heavy equipment use. A significant decrease in the number of breakaway fractures (at all times the coupling force of 5.4 times) also contributes to indirect carbon reduction by reducing the frequency of such maintenance.

Table 13: Additional data for LCA completion

LCA stage	Required Data	Collection method
Collection and transportation of raw materials	PA fiber, Carbon footprint of PTFE raw materials (kg CO_2-eq/kg)	Ecoinvent DB, Supplier EPD
Manufacturing process	Extrusion power consumption (kWh/ton), wastewater and scrap generation	Plant Energy Meter Measurement
Operational Phase	Annual maintenance count and ship fuel usage	Field maintenance history data
Phase of disposal	Recyclability (PA/PTFE recycling rate), landfill and incineration ratio	Domestic Plastic Waste Statistics
Comparison Scenario	PE pontoon real life data in the same sea area	Contractor maintenance records

3. Conclusion

3.1. Research experiments on high-strength pontoon

The main conclusions drawn through repeated experiments are as follows. This study developed a new material mixing design and an innovative double bonding method to fundamentally solve the structural and material defects of the existing polyolefin-based (PE/PP) pontoon such as high-temperature softening, low-temperature brittleness, joint separation, and UV deterioration.

3.1.1. Proof of excellence of new materials (PE/PA/TEF composite resin)

The composite material containing polyethylene (PE), polyaramid (PA), and Teflon resin (PTFE) at a weight ratio of 1:1:1 served as an optimal mixing point to complement the shortcomings of any one component.

In Example 2 (PE/PA/TEF 95 parts by weight), binding force 542N, tensile strength 335N, stamping strength 305HRC, and softening temperature 181°C were recorded, and the performance was significantly improved in all items compared to the existing PE pontoon.

This is to overcome the softening problem in a high-temperature environment (100°C or higher) and the brittleness destruction problem in a low-temperature environment (-20°C or lower).

3.1.2. Effectiveness of double bonding (inner bolt-nut + outer bonding rod)

By applying an internal coupling structure consisting of two nut grooves and bolt-fixing screws each in the horizontal and vertical directions of the pontoon block, and an external coupling structure with a coupling rod, bolt, and nut added to the outer surface of the block, the maximum coupling force was achieved about 5.4 times compared to the existing fitting coupling method.

It was experimentally demonstrated that even in the torsional load caused by the collision of waves, typhoons, and marine floats, the deviation of the coupling mechanism did not appear until the block itself was destroyed.

3.1.3. Environmental Benefits and Economic Effects

According to the Life Cycle Assessment (LCA) analysis, the composite resin pontoon in this study is estimated to reduce global warming potential (GWP) by 35–45%, marine ecological toxicity by 50–60%, and waste generation by 45–55% compared with conventional PE pontoons. The key contributing factors are the reduced replacement cycle due to life extension (from the previous 10–15 years → to 20–30 years) and the suppression of microplastic pollution caused by PTFE's non-adhesive surface characteristics. This is expected to reduce maintenance costs and optimize the lifecycle cost (LCC) of offshore facilities.
3.1.4. Technical novelty and future challenges

The PE/PA/TEF composite resin and internal and external double bonding method applied in this study are new technologies that have not been previously used in the pontoon field, and their originality has been secured through related patents (Korea Patent No. 10-08364444).

In the future, it is expected to contribute to standardizing design standards and strengthening the global competitiveness of domestic technologies through long-term empirical tests in actual sea conditions, advancement of ANSYS/ABAQUS-based finite element analysis (FEA), and establishment of complete LCA data according to ISO 14040 standards.

In conclusion, this study is meaningful in dramatically improving the safety and economic feasibility of the marine water structure sector by simultaneously achieving high-strength quality, improved connection bonding, durability and corrosion resistance, improved maintenance convenience, reduced environmental impact, enhanced aesthetic value, and extended use period through improvement of pontoon materials and innovation of bonding methods.

References

1. Korea Patents & Utility Models

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[2] Republic of Korea Public Patent 1987-4863A — Initial design of a pontoon structure.

[3] Republic of Korea Published Patent 1998-84998A — Improvement of the material of floating structures.

[4] Hong Jae-seon (2018).A high-strength pontoon structure with strong bonding. Korean Patent No. 10-0836444.

[5] Korean Utility Model Publication 20-255981Y1 — Water Rescue Structure Coupling Device.

[6] KR100203020 B1 — Polyolefin composite structure.

2. International Patents

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3. Academin Papers & Journal

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[16] Kim, J. & Park, S. (2019). Fatigue performance of bolt-nut coupled floating dock connectors under wave loading. Marine Structures, 64, 122–137.
[17] Journal of the Korean Society of Civil Engineers. “A Study on the Aging Characteristics of Plastic Members for Water Surface Structures.”

4. Application Test Specification (ASTM / ISO)

Specification number	Specification name	Applicable item
ASTM D117	**Salt spray tes**	Corrosion resistance of seawater
ASTM D256	Plastic Zoid Impact Strength	Low-temperature brittleness assessment
ASTM D648	Load deformation temperature	High-temperature softening resistance
ASTM D1693	Environmental Stress Cracking of Ethylene Plastic	Durability of Marine Environment
ASTM D3294	PTFE Tape Test	PTFE Material Specification
ASTM D4976	PE resin specification	PE raw material quality standards
ASTM D7565	Aramid fiber tensile test	Material properties of PA raw materials are checked
ASTM E466	Metallic/nonmetallic fatigue test	Repeated wave load fatigue
ASTM G154	Non-metallic material UV exposure	UV weather resistance
EN 15804	Construction Product EPD Core Rules	Environmental performance mark
ISO 4427	For PE pipes and fitting water supply	Underwater PE Material Standards
ISO 14040	LCA Principles and Framework	Totality Evaluation Methodology
ISO 14044	LCA Requirements and Guidelines	Environmental Impact Quantification

5. Utilization Interpretation Software

.Finite Element Analysis (FEA) : ANSYS Mechanical / ABAQUS - Analysis of Stress Concentration and Wave Loads at Junctions

.LCA Software : SimaPro 9.x or GaBi ts (linked with Ecoinvent 3.x DB) - Quantification of environmental impact Fatigue Life Prediction: nCode DesignLife / fe-safe — Weibull probabilistic life prediction

.Statistical analysis : SPSS / R / Minitab - conducting ANOVA, t-tests, and regression analysis