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Technical Article

Economic Feasibility Analysis According to Seam Location of Ship Pieces

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ABSTRACT: *The structure of a ship is completed by processing various steel plates and welding these plates. This butt welding of plates is defined as a seam in shipyards, and this study seeks to find a way to decrease costs by reducing the utilization of steel through effective seam arrangement. Seams were defined and classified according to purpose, and examples of "pieces" and "main plates" where seam creation had an economical saving effect were selected. For "pieces," the change in the weight of steel utilized depending on the presence or absence of a seam was calculated, and the resulting change in cost increase was presented. In the case of the "main plate," the quantity of seams does not change, but an example of cost variation due to the appropriate placement of seams is presented. Hence, a large difference was found in the costs of "pieces" depending on seam location. Thus, it was advantageous to create additional seams. For the "main plate," it was found that narrow-width and wide-width materials incur more costs. This study demonstrates that creating seams is economically advantageous but may not be preferred owing to the increased workload from a production perspective.*

1. Introduction

1.1 Overview

The structure of a ship generally comprises steel plates made of various materials. Specifically, the structural properties for building a ship structure involve cutting and shaping multiple plates to fit the form, and then processed materials are welded in a T or butt-joint form. This study examined the optimal arrangement of seams, which are closely related to butt welding, from the economic perspective.

Steel plate accounts for a large portion of ship components, thus being closely associated with production costs. Significant benefits can be achieved for a shipyard by reducing the amount of steel utilized in shipbuilding. Thus, most shipyards are adopting various methods for reducing the amount of steel utilized, and one of them is creating seams.

Typically, steel plates entail sub-constraints depending on steel manufacturer. Here, sub-constraints are commonly associated with thickness and material grade of the steel, as well as width, length, and weight. Butt welds are inevitable when building a large ship with steel plate manufactured under such constraints, and these butt welds are defined as seams at shipyards.

Even the pieces cut to have the same area may have different steel scrap rates depending on the arrangement of seams. The steel scrap rate refers to the remaining portion, or unusable scrap metal pieces, after producing steel parts from the original steel plate manufactured by a steel company. For instance, if each company has one sheet of steel weighing 5 t, Company A may utilize 4 t and process 1 t as scraps, while Company B may utilize 4.5 t and process 0.5 t as scraps. Then, the steel scrap rate of Company A is 20%, while that of Company B is 10%. In such a case, company B has higher price competitiveness. Because the production cost of steel accounts for approximately 30% of the shipbuilding cost, the scrap rate of steel directly affects the cost competitiveness of shipyards.

1.2 Related Work

For shipyards to survive the expensive steel market conditions, efficient seam arrangement should be established considering the constraints of steel manufacturers and production costs of shipyards.

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Against this backdrop, there has been an increasing interest in scraps among shipyards, companies developing related programs, and shipbuilding/marine-related departments, and extensive research has been ongoing in the relevant fields.

Lee and Ryu (2013) classified nesting algorithms largely into no-fit polygon (NFP) and grid representation according to the shape representation technique, where the arrangement process and results and the time required are sensitive to the configuration of the fitness function in both approaches. Specifically, the above study focused on the grid representation and applied various fitness functions to compare the arrangement results of each case. It further proposed the fitting function that produces the most efficient arrangement results appropriate for the characteristics of parts for the shipbuilding industry. Kim et al. (2013) introduced the simulated annealing (SA) algorithm and described the methods for finding optimal solutions. Furthermore, they defined five items to consider when arranging seams of the main plate, which were then reflected in the program developed for the study to output optimal solutions and verified its close association with production costs.

Lee et al. (2004) defined an algorithm for part arrangement of a flat bar of ship reinforcements and proposed a method for generating an efficient processing path for efficient arrangement and numerical control cutting utilizing common or continuous cutting. Sheen (2012) attempted to solve the nesting problem without constraints on the shapes being arranged or the boundary shapes of the materials being arranged, utilizing an expert system, which is a knowledge-based inference system. Sheen further provided solutions for four sample cases of nesting, including block puzzles with different characteristics, general nesting, nesting of shipbuilding steel materials, and nesting of materials with heterogeneous boundary shapes employing the proposed method. Elkeran (2013) suggested a guided cuckoo search algorithm, which differs from conventional nesting algorithms. He proposed a novel solution for nesting problems while focusing on optimizing search and generating good layouts based on a hybrid algorithm that integrates a search feature. It further explored methods to enhance the efficiency of nesting through grouping.

Lee et al. (2011) defined the properties of steel areas and studied the part arrangement that can minimize scraps. They proposed methods for bitmap-based sliding part arrangement, steel shape-based rearrangement, and part arrangement and demonstrated the changes in the scrap rate by applying the algorithm to the actual hull nesting. Shim et al. (2009) explained the background and method for reducing the scrap rate. Particularly, the research described the types of feature shapes of parts and examined group arrangements by extracting feature shapes considering cutting efficiency and then collecting and grouping similar patterns. Ryu and Kim (2004) explained several genetic algorithms and performed nesting arrangements employing the NFP method. The optimal solution was found by applying the arrangement order of crossbreeding, mutation, and reproduction. The identified optimal solution was then compared with existing results to find any issues.

Na et al. (2021) attempted a different approach by applying deep learning technology to the part pairing stage of ship parts nesting. A dataset was constructed for training the deep learning network utilizing geometric information of the parts. The geometric information of the parts was input as coordinates to classify and pair similar parts utilizing the NFP-based arrangement method, ultimately improving the performance of the ship parts nesting algorithm.

In addition, related research efforts are continuously put forth in studies by Park et al. (1997), Park and Lee (1997), Park and Kim (1999), and Ryu et al. (2006). Similarly, studies are ongoing to find methods for lowering steel scrap rates, where nesting program developers and shipyards jointly research to develop programs for determining the optimal arrangement of cut parts. The relevant programs include the CADMATIC (n.d.) plate nesting module, an automatic steel-cutting nesting program E-NEST (CACAM, n.d.), and Dr. Nesting (n.d.).

While research has actively been conducted on nesting algorithms, there is a lack of research on efficient seam creation for ships. Therefore, conducting research on efficient seam creation and expanding the research outcomes horizontally to other fields will be advantageous for reducing the overall cost of shipbuilding. This study compared the economic feasibility of arranging seams on pieces with many irregular shapes, which significantly increases steel scrap rates, and of a specific case where scrap rates remain unchanged but the production cost decreases.

2. Seam Types and Correlation with Pieces

This section distinguishes seams according to purpose and introduces the factors influencing seam creation in ship pieces.

2.1 Type of Seams

A seam is classified as follows according to purpose.

(1) Main plate seams created by considering width extra or constraints arising from the facility and production efficiency of a steel manufacturer

- The main plate refers to the steel sheet that forms the foundation of the blocks comprising the ship (e.g., deck or bulkhead).
- Width extra refers to additional costs incurred when ordering steel that is wider or narrower than the typical material produced by the steel manufacturer.
- Seams can be additionally created depending on a shipyard's production facility (cutting, pre-processing, etc.).

(2) Piece seams created by considering the steel scrap rate

- Pieces correspond to this type, which is the main focus of this study.

(3) Processing seams created to prevent interference between blocks or parts during assembly and mounting

- Seams can be appropriately created in the interference area or installed afterward, depending on the assembly order.

- Seams can be created and installed afterward when they do not necessarily cause interference but entail extent-related issues.

(4) Seam type which locally increases the thickness of the insertion plate from requiring reinforcement depending on whole ship analysis or local analysis results.

- When heavy structures protrude upwards on the corner or upper side
- When outfitting holes are drilled in major load-bearing parts

Items (1), (3), and (4) can be considered essential and indispensable (designs can consider other options, but standards cannot be changed), while Item (2) can be altered depending on the judgment of a designer (efficiency) within a shipyard. This study focused on the optimal seam location of ship pieces considering the economic feasibility of Item (2), which is the seam of ship pieces.

2.2 Factors Affecting Creation of Scrap Seams and Advantage/Disadvantage

Pieces generally refer to structures inside a ship's hull, comprising medium and large structures such as decks, girders, and floors, as well as small components, including brackets, collar plates, and flat bars. Therefore, ship pieces tend to have irregular shapes compared to shell shapes and various thicknesses, thus significantly increasing the steel scrap rate. Because it is a factor directly associated with the economic feasibility of a shipyard by increasing the production cost, efficient seam creation is mandatory for reducing the steel scrap rate.

The following factors affect the creation and quantity of seams in ship pieces.

(1) Steel cost (the greatest influential factor)

- For example, irregularly shaped materials are fabricated more closely to rectangles as the number of created seams increases, reducing the amount of wasted steel. Consequently, the steel usage efficiency increases.

(2) Amount of welding in butt joints

- As the seam lengthens, the weld length also increases, which results in increased workload.

(3) Number of cut parts

- An increased number of parts due to created seams results in an increased workload for material management.

(4) Deformation due to cutting

- There is a high probability of cutting deformation when cutting pieces that have a longer length than the width. Deformation can be minimized if seams are created in the width direction at appropriate intervals. In this case, the number of seams increases, but the reduction in field rework due to deformation has a more significant impact.

Table 1 summarizes the advantages and disadvantages with respect to the increased seam quantity.

Table 1 Comparison of increasing seam quantity

Seam quantity	Few seams	Many seams
Advantage	Increase in production efficiency (reduced weld length and inspection point)	Decrease in steel cost; Reduced deformation by cutting
Disadvantage	Increase in scrap >> Increase in steel cost	Decrease in production efficiency

3. Economic Feasibility of Seam Creation

3.1 Selection of Comparison Targets and Prerequisites

This study examines two cases where seam creation can induce economic savings. The cases entail the main plate and small pieces, which will be further explained in Section 3.2. In addition, the ship type was designated as a container ship, built in a series of five vessels. Because container ships have a large amount of curvature due to their linear characteristics and relatively heavy structural weight, they were selected for this study as the impact of steel savings is particularly pronounced.

For economic analysis, the following assumptions were made in terms of steel prices and welding-related costs (see, Table 2). First, the steel price was set at 1.1 million KRW per ton (Kwon, 2022). Furthermore, the welding-related costs were assumed based on the standards of welders in the construction industry, similar to the shipbuilding sector. It was set at 240,000 KRW per day and 40,000 KRW per hour (30,000 KRW per hour + facility usage amounting to 10,000 KRW per hour, which includes complex costs such as production time, increased number of managed parts, etc.; construction industry wages in the first half of 2023). Here, the welding efficiency was conservatively assumed based on practical standards. It was assumed to be 10 m per hour for automatic welding and 2 m per hour for manual welding.

Table 2 Target selection and prerequisites

Item	Precondition
Ship type	Container (5 ship series)
Steel cost	1,100,000 KRW/t
Welding & ETC cost	240,000 KRW/d 40,000 KRW / (man/h)
welding efficiency	SAW Welding 10 m/h CO_2 Welding 2 m/h

3.2 Cases Where Seam Creation is More Economically Advantageous

3.2.1 Case 1: Economic seam creation of small pieces

The shape illustrated in Fig. 1 is predominantly found in a container ship. Almost every block incorporates structures in the shapes of "ㄱ," "ㄴ," and "ㄷ," especially in T-Blocks (transverse bulkhead blocks). It is assumed that materials with these shapes are abundant in T-Blocks, with an average quantity of around 40 pieces per block.

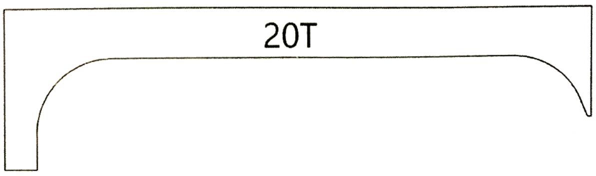

Fig. 1 Typical bracket shape in T-block of container ship

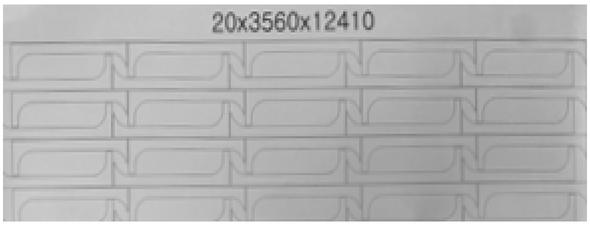

Fig. 2 General arrangement of 40 pieces in Case 1

Fig. 2 illustrates the arrangement of 40 target parts on a single circular steel plate, where the parts are repetitively arranged considering the geometric characteristics of the pieces. In this case, the estimated total weight of steel, considering the discarded steel, was 6.94 t. When converted into monetary value and considering a series construction of five vessels, the total cost of steel was approximately 38 million KRW. This case is defined as Case 1-1.

Here, a single seam was created in a piece having the shape illustrated in Fig. 1 to minimize the discarded steel, and the optimal location for creating the seam was identified.

Fig. 3 presents the detailed shape and dimension of the target piece where the thickness is 20 mm and the quantity is defined as 40. The efficient seam arrangement was determined by selecting various seam locations and comparing the resulting scrap rates. Because the area within 100 mm from the round end (R.END), which often receives shipowner/classification comments, was excluded, seam locations were defined as the minimum of R.END + 100 mm, and the locations of each seam were selected as Points 1–5 in the figure (Case 2-6).

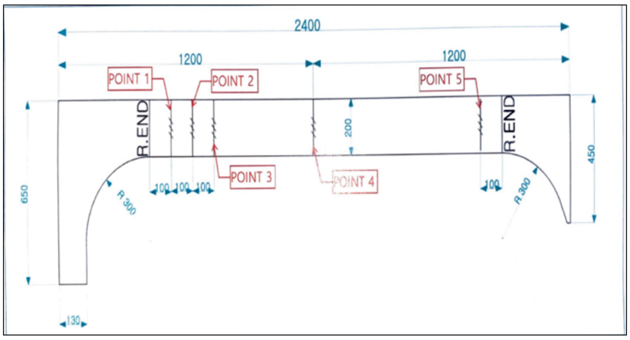

Fig. 3 Dimension of target piece and location of each point

The steel scrap rate can be calculated with the equation below.

$$\frac{Used\ steel\ weight\ -\ pieces\ weight}{Used\ steel\ weight}\times 100 \qquad (1)$$

Based on the results at Points 1–4, the scrap rate decreased as the seam location approached the R.END and increased as it moved away. This result can be interpreted as the discarded steel area increasing as the seam location moves away from the R.END because the available options for arrangement decrease. Point 5 has the highest scrap rate due to the geometric characteristics at both left and right ends (refer to Fig. 4 and Table 3). Therefore, creating the seam at Point 1, which is closest to the R.END, is optimal from an economic aspect, and such a trend can be inferred for other similar structures.

If creating two seams is considered, simultaneously applying at both Points 1 and 5 will result in a very low scrap rate; Fig. 5 illustrates the

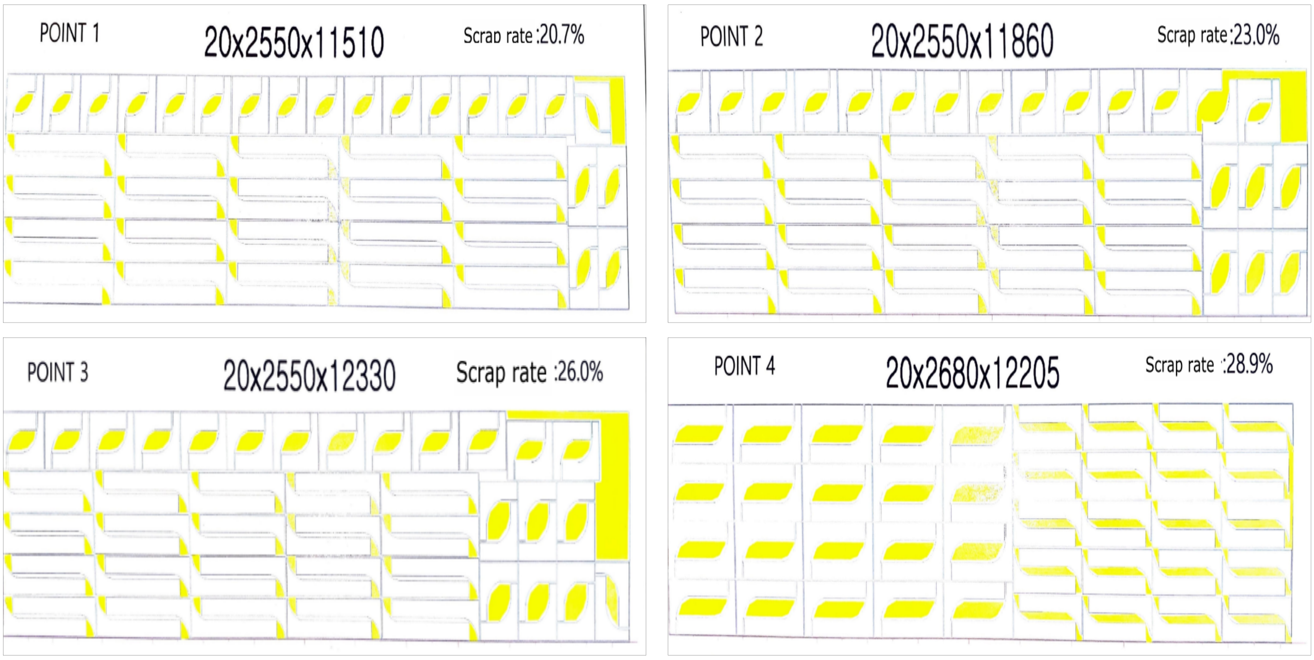

Fig. 4 Scrap rate of steel plates by Points 1–4

Table 3 Weight and scrap rate of steel utilized at each point

Case	Seam	Piece weight (t)	Steel weight (t)	Scrap rate (%)	Cost (KRW)	Reduced cost (Case 1-1 base)	ETC.
Case 1-1	None	3.65	6.94	-	38,150,000	-	
Case 1-2	Point 1	3.65	4.61	20.7	25,340,000	12,810,000	2
Case 1-3	Point 2	3.65	4.75	23.1	26,130,000	12,020,000	3
Case 1-4	Point 3	3.65	4.94	26.0	27,170,000	10,980,000	4
Case 1-5	Point 4 (Center)	3.65	5.14	29.0	28,270,000	9,880,000	5
Case 1-6	Point 5	3.65	5.53	33.9	30,420,000	7,730,000	6
Case 1-7	Point1+5	3.65	4.49	18.6	24,700,000	13,450,000	1

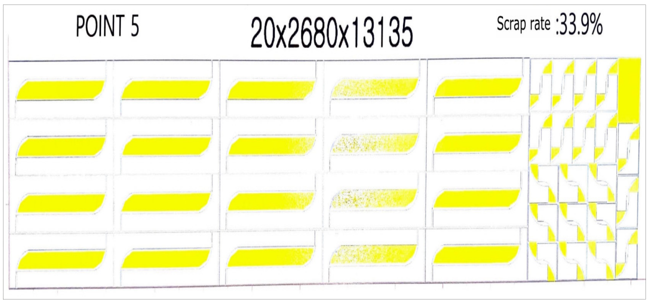

Fig. 5 Scrap rate of case with two seams at Points 1 and 5

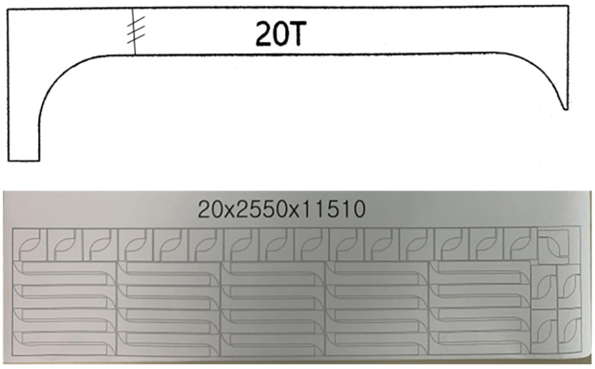

Fig. 6 Arrangement of 40 pieces with one seam in Case 1

part arrangement for this scenario and the calculated scrap rate. However, this case entails an increased number of welding joints from additional creation of seams, thus being an unfavorable choice in terms of production efficiency, especially for many parts.

Fig. 6 illustrates the location of a seam generated at Point 1, which was predicted to be the optimal seam location in the piece. When the inherent symmetry in the shape of the left side is considered, creating seams, as illustrated in the figure below, allows for a repetitive, rotationally symmetric arrangement of the small parts on the left-hand side.

For cost analysis, the target vessel was assumed to be a container ship with a series of five ships, with a steel price assumed at 1.1 million KRW per ton (Kwon, 2022). Because the steel weight per ship for the cutting arrangement presented in Fig. 6 is 4.61 t, the total steel cost amounts to approximately 25.36 million KRW. Approximately 8 m of welding length is added per ship due to the created seam, resulting in a total welding length of approximately 40 m for the five ships. Because manual welding is inevitable considering the installation location, an additional welding cost of approximately 800,000 KRW is incurred. Furthermore, the feasibility of manual or automatic welding was determined based on field practical guidelines. The welding cost was assumed adopting the standards of welding workers in the construction industry, which is similar to the shipbuilding sector, with 240,000 KRW per day and 40,000 KRW per day (30,000 KRW per hour + facility usage amounting to 10,000 KRW per hour; construction industry wages in the first half of 2023).

Comparing the cost of 38 million KRW when arranging materials in the shape of "ㄷ" without seams on the original steel plate against the cost of 25.36 million KRW when creating a seam at Point 1, the cost savings from the steel amount to 12.64 million KRW. Considering the additional welding cost of 800,000 KRW, the overall input cost for creating the seam is calculated to be 1.184 million KRW less. Therefore, generating the seam is advantageous in terms of cost if it results in utilizing less steel plate.

3.2.2 Economical seam creation for rectangular main plate type

It is hard to expect a reduction in scrap rate based on the seam location for rectangular and square-shaped steel sheets. Creating seams can lead to a slight increase in scraps due to the need to maintain gaps between the required parts during cutting and the margin for the outer outline of steel, thus resulting in decreased productivity.

However, adjusting the arrangement of existing seams rather than adding new seams may not reduce the final scrap. However, it can lower the overall steel cost and reduce the overall manufacturing cost of the ship. Determining effective seam location is closely associated with the width extra mentioned previously in Section 2.1. Width extra refers to the additional cost paid when ordering steel that falls outside the range of widths generally produced by the steel mill. The extra price increases as the narrow-width or wide-width sheet metal has the maximum value, and the thickness is higher.

The width of steel plates produced by domestic steel mills currently ranges from 3000 to 3600 mm. For analyzing the economic feasibility, it is assumed that the cost of width extra is 50,000 KRW per ton for both narrow- and wide-width. This study examined the main plate,

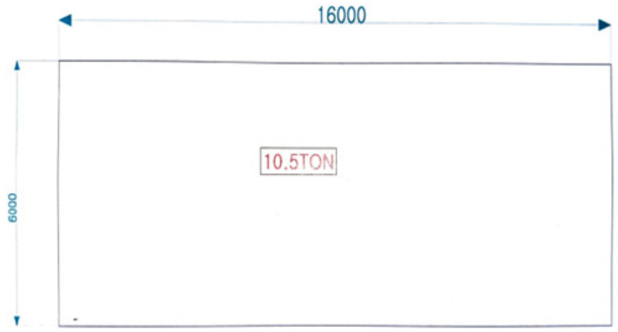

Fig. 7 Dimension of main plate

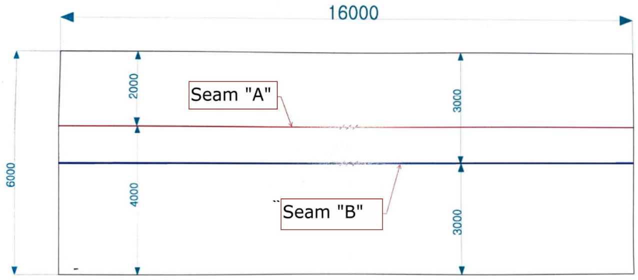

Fig. 8 Two cases of seam positions related with extra width

Table 4 Comparison of steel costs considering extra width

Breadth (mm)	Weight (t)	Steel price (KRW)	Extra width cost (KRW)	Sum (KRW)
2,000 4,000	10.5	11,550,000	525,000	12,075,000
3,000 3,000	10.5	11,550,000	0	11,550,000

which has a width of 6000 mm, as illustrated in Fig. 7. Seam creation is inevitable because the width of the target main plate is greater than the producible width of the steel mill. As illustrated in Fig. 8, it is assumed that Seam “A” has widths of 2000 and 4000 mm, while Seam “B” has a width of 3000 mm. Table 4 presents the comparison of steel costs for three steel sheets with respect to width.

4. Conclusion

From the perspective of higher economic feasibility, it was observed that creating seams in materials with small piece shapes is economically advantageous regardless of steel price. Furthermore, creating seams in the pieces closer to R.END is more advantageous to lower the scrap rate. This study has found that appropriately generating seams to reduce scrap rates is more advantageous than the increased welding costs due to seam creation in the current high-priced steel market. This outcome proves that there is ultimately a difference in the production cost. It was also found that adjusting the location of seams without adding additional seams can create economic benefits.

Most shipyards strive to lower production costs from many different perspectives (Na, 2018). In addition to the seam creation mentioned previously, other efforts are put forth to minimize costs by placing small parts in scrap areas or through joint arrangements between blocks. Certain approaches are avoided from the production perspective because the welding amount increases. The reason is that seam creation results in cost savings in shipbuilding construction costs, but the increase in welding length and inspection points at actual worksites increases workload. From the perspective of economic feasibility, the advantage or disadvantage of seam creation varies depending on the fluctuation of raw material prices. This study requires further review if the fluctuation of steel prices becomes greater. The findings of this study are expected to facilitate shipyards to save costs as the steel price rises.

Our future research will involve finding the optimal seam location by incorporating nesting methods and programs. Because the effects of seam creation are insignificant for a single material, greater cost savings can be achieved by discovering other targets through which seam creation can be more advantageous depending on the nesting method and applying them horizontally to other fields. In addition, the scope will be expanded to investigate the effects of seam creation on a wider range of pieces having various shapes, as well as efficient seam arrangement in the shell. Ultimately, research extending beyond the efficient seam arrangements for determined shapes will be conducted to explore structural determination that induces optimal seam locations.

Conflict of Interest

Tak-Kee Lee serves as a member of journal publication committee of the Journal of Ocean Engineering and Technology. However, he had no role in the decision to publish this article. No potential conflict of interest relevant to this article was reported.

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