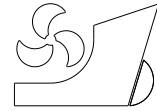


Jun Seok  
Jong-Chun Park\*

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## A FUNDAMENTAL STUDY ON MEASUREMENT OF HULL ROUGHNESS

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Professional paper

### Summary

In this study, an investigation on the hull roughness measurement of a new ship, a 160m class car ferry, was performed. The hull roughness measurement was conducted in the ferry's pre-coated state before launching. For measurement, the TQC manual and ITTC recommendations were considered, and measurements were made in a total of 230 zones below waterline of the ship. Accordingly, the average hull roughness of the car ferry was  $81\mu\text{m}$ , which is relatively low compared to  $150\mu\text{m}$ , the hull roughness of a new ship proposed by the ITTC. In addition, the measurement uncertainty was calculated using the ISO guidelines, and the effect of the number of zones on the hull roughness measurement was examined. Using the measured average hull roughness, we estimated the resistance performance at the design speed of the ship. Accordingly, it was confirmed that the total resistance of the new ship was reduced by approximately 2% owing to a decrease in its frictional resistance increase.

*Key words:* Hull roughness; Measurement; New ship; Resistance; Uncertainty

### 1. Introduction

According to the International Maritime Organization (IMO) report, as presented in Table 1, between 2007–2012, the average carbon dioxide (CO<sub>2</sub>) emission from shipping and international shipping of vessels accounts for 3.1%, and 2.6% of the global emission ([1]).

IMO implements environmental regulations such as the energy efficiency design index (EEDI) and energy efficiency Operational Indicator (EEOI) on ships to reduce carbon dioxide emissions, one of the causes of global warming. In particular, the EEDI is mandatory for new vessels carrying more than 400 gross tonnage and is gradually increasing its restriction until 2025.

**Table 1** Amount of CO<sub>2</sub> emission from shipping

Year	Global CO <sub>2</sub> (million tonnes)	Shipping (million tonnes)	Portion of shipping (%)	International shipping (million tonnes)	Portion of International shipping (%)
2007	31,409	1,100	3.5	885	2.8
2008	32,204	1,135	3.5	921	2.9
2009	32,047	978	3.1	855	2.7
2010	33,612	915	2.7	771	2.3
2011	34,723	1,022	2.9	850	2.4
2012	35,640	938	2.6	796	2.2
Average	33,273	1,015	3.1	846	2.6

Shipyard and ship owners are applying various methods in the building and operating stages to satisfy the above environmental regulations.

The performance of a ship is improved by optimizing its linearity or installing an appendage in the construction stage of the ship to reduce its resistance. In addition, the oil consumption is reduced by optimizing the seaway of a ship during its operation stage, and a periodic hull cleaning minimizes the increase in the hull roughness during sailing to reduce the frictional resistance.

The hull roughness of a new ship is defined as  $150\mu m$  ([2]) if no separate measurement data are available, and it increases over time. However, the amount of increase depends on the type of paint ([3]). In general, the hull roughness is increased owing to the occurrence of fouling phenomena such as barnacles or slime over time.

To suppress such fouling, efforts are being made to reduce the amount generated by using anti-fouling paints or silicone foul release paints, but these do not provide complete prevention. Therefore, a ship-owner monitors the condition of the ship and decides its cleaning plan to keep the ship clean through periodic hull cleaning.

As such, studies in relation to hull roughness have been performed using various approaches. Experimental approaches are mainly based on basin experiments using a plate ([4]-[5]). In recent years, there have been an increasing number of studies on ships using numerical simulation methods ([6]-[15]).

However, the research on hull roughness measurement is relatively insignificant, and the hull roughness is partly measured according to the methods presented by the ship paint or instrument company. This is because the measurement of the hull roughness of a ship is not an essential requirement for the construction of a ship and the focus is on the paint thickness, which can affect the corrosion of the ship rather than the hull roughness due to the coating.

So in this paper, a study on the measurement of hull roughness is performed that has not been studied extensively to evaluate effect of roughness for frictional resistance.

## 2. Hull roughness measurement

### 2.1 Hull roughness measuring instrument

The instrument used to measure the hull roughness is the Hull Roughness Analyzer DC-9000 model manufactured by the TQC company as shown in Fig. 1. This model can measure the surface roughness ( $R_t$ ) based on the measurement length using a physical measurement sensor, and its specifications are listed in Table 2 (TQC [16]).

The measurement value  $R_t$  is the peak-to-valley value, which is the difference between the maximum value and minimum value in the measurement interval, and for the ship, the value measured in a 50-mm-interval is used, which is denoted as  $R_{t(50)}$ .

The measured  $R_t$  value can be expressed as the mean hull roughness ( $MHR$ ) of a zone, as given in eq. (1), and the instrument generally uses the average of twelve  $R_{t(50)}$  values. The average hull roughness ( $AHR$ ), which represents the hull roughness of a ship, is the mean value of the  $MHR$ , as given in eq. (2), and can be weighted.

$$MHR = \frac{1}{n} \sum_{i=1}^n R_{t(50)i} \quad (1)$$

$$AHR = \frac{\sum_{j=1}^m (MHR)_j}{\sum_{j=1}^m w_j} \quad (2)$$

Here,  $n$  is the number of measurements,  $m$  is the number of measurement points, and  $w$  is a weight function, typically 1.

**Table 2** Specifications of DC-9000

Item	Data
Memory capacity	4000 series of measurements
Sensor depth	205 mm
Sensor width	80 mm
Sensor height	40 mm
Sensor weight	approx. 630 g
Accuracy	$\pm 5$ microns or $< 2\%$ , whichever is greater



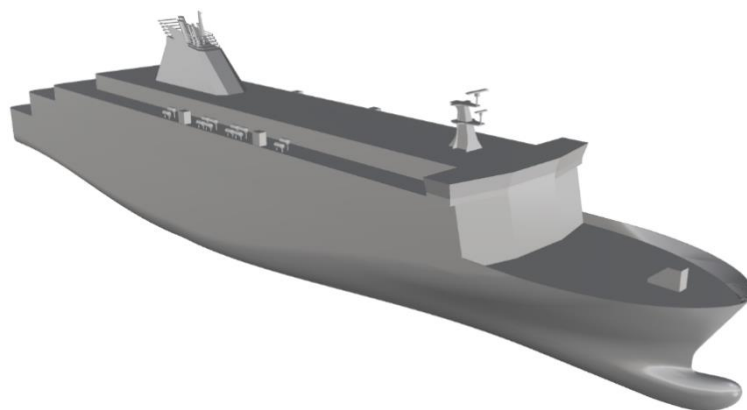
**Fig. 1** Hull roughness gauge (DC-9000)

## 2.2 Hull roughness measuring method

The target vessel for measuring the hull roughness is a 160m class car ferry, as shown in Fig. 2, and its specifications are listed in Table 3.

**Table 3** Principal particular of 160m class car ferry

Item	Dimensions
Length Over All	160.0 m
Length Between Perpendiculars	148.0 m
Breadth	24.8 m
Design Draft	5.5 m



**Fig. 2** Three-dimensional model of the ship

Measuring process of hull roughness is divided into three step as shown in Fig. 3.

In the first step, it is necessary to arrange the zones before the measurement to measure the hull roughness. For the measurement zones, it is recommended to measure more than 100 zones in the side area (Port & Starboard) and bottom area under the draft, and to measure at least thrice at the measurement points ([16]-[17]). In this study, as shown in Fig. 4, the

measurement is performed in a total of 230 zones, with 51 zones in the port and starboard area each and 128 zones in the bottom area.

In the next step, measuring instrument should be calibrated using calibration plate as shown in Fig. 5 just before measurement. Also set the measuring length of  $R_t$ . After measurement, send the measuring data to PC and calculating the  $MHR$  and  $AHR$ .

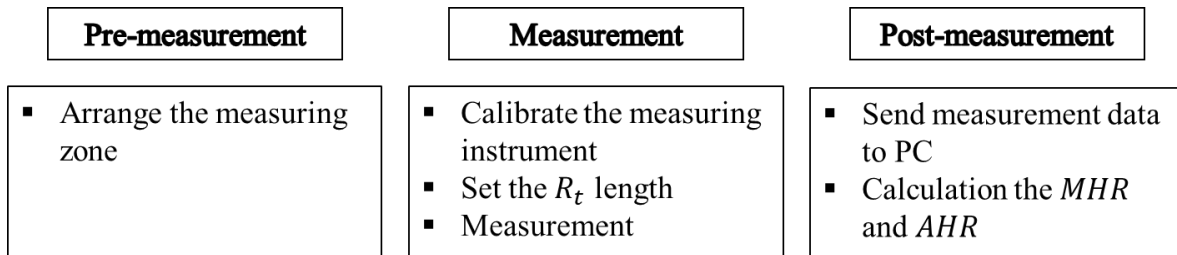
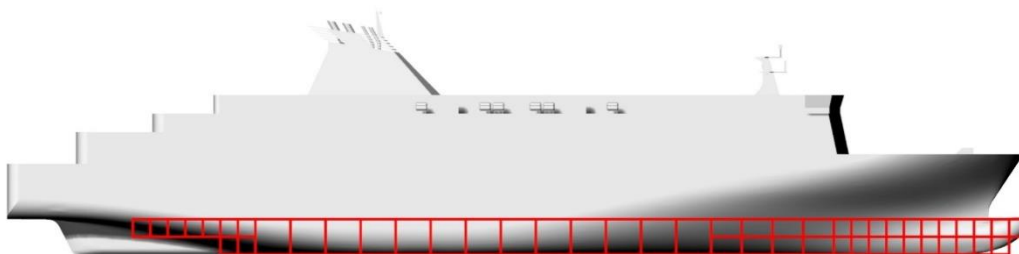
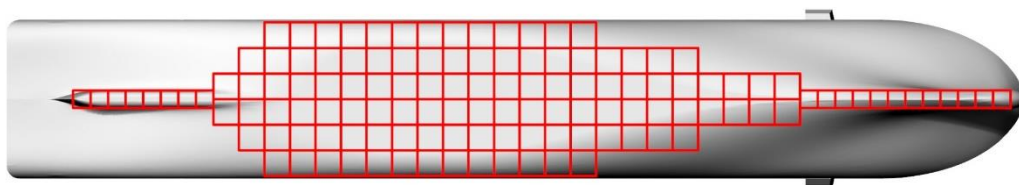


Fig. 3 Measurement process of hull roughness



(a) Side (Port and Starboard)



(b) Bottom

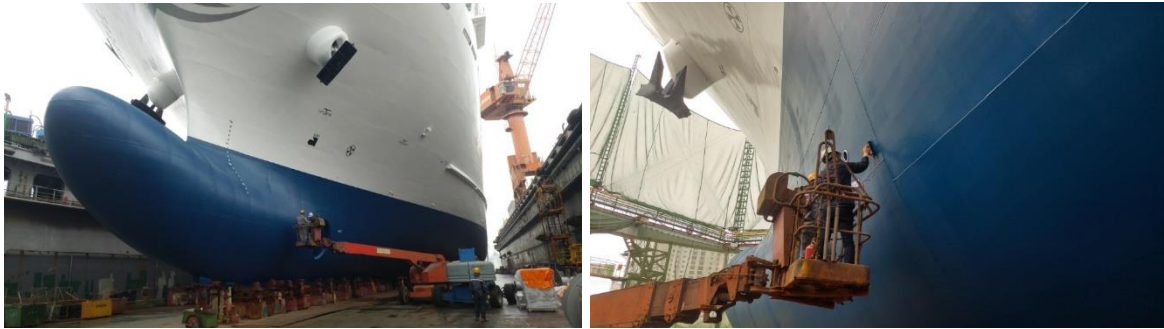
Fig. 4 Measurement zones for the hull roughness



Fig. 5 Calibration plate of hull roughness gauge(DC-9000)

### 3. Measurement result

As shown in Fig. 6, the measurement of the ship was performed on the floating dock, with the final painting completed before launching, using a mobile crane in the side area. The calibration of measurement instrument was performed according to the manual before measurement. The measurement was performed by two personnel for measuring the bottom area and side area and took approximately 4 hours.



**Fig. 6** Measurement of hull roughness

The measurement results are shown in Fig. 7 and summarized in Table 4.

The minimum value of the  $R_{t(50)}$  measured in the port area is  $23\mu m$  and maximum value is  $386\mu m$ . Using the results of ten  $R_{t(50)}$  values, excluding the maximum and minimum values in each zone, the minimum  $MHR$  is  $51\mu m$  and maximum  $MHR$  is  $241\mu m$ . In this case, the zones where the maximum and minimum values are measured are shown in Fig. 8 (a).

The minimum value of the  $R_{t(50)}$  measured in the starboard area is  $19\mu m$  and maximum value is  $384\mu m$ . Based on the measured results, the minimum and maximum  $MHR$  is  $51\mu m$  and  $241\mu m$ , respectively, when calculating the  $MHR$  for the port area. In this case, each zone where the maximum and minimum values are measured is shown in Fig. 8 (b).

The minimum value of the  $R_{t(50)}$  measured in the bottom area is  $16\mu m$  and maximum value is  $317\mu m$ , which are relatively small compared to the results of the side areas (port and starboard). The minimum  $MHR$  is  $38\mu m$ , and the maximum  $MHR$  is  $214\mu m$ . This is because the bottom area is relatively flat compared to the side areas. At this time, each zone where the maximum and minimum values are measured is shown in Fig. 8 (c).

The  $AHR$  using the  $MHR$  of each zone is  $101\mu m$  for the port area and  $81\mu m$  for the starboard area, showing that that the latter is approximately 20% lower than that of the former. Additionally, the bottom area has an  $AHR$  of  $73\mu m$ , which is approximately 20% lower than the average of  $91\mu m$  for the side area. Finally, the  $AHR$  of the 160m class car ferry, obtained by combining the results of the side area and bottom area, is  $81\mu m$ . Although this value is approximately 46% lower than the ISO-based  $150\mu m$  hull roughness of a new ship, it is still within the range of  $80\text{-}150\mu m$  as suggested by Hudson et al. [18] for the hull roughness of a new ship.

**Table 4** Summary of the hull roughness measurement

Area	Roughness ( $\mu m$ )
------	-----------------------

	Minimum $R_{t(50)}$	Maximum $R_{t(50)}$	Minimum $MHR$	Maximum $MHR$	$AHR$
Port	23 (P-49)	386 (P-46)	51 (P-18)	241 (P-47)	101
Starboard	19 (S-44)	384 (S-21)	34 (S-41)	212 (S-21)	81
Bottom	16 (B-85)	317 (B-122)	38 (B-54)	214 (B-122)	73
Total	-	-	-	-	81

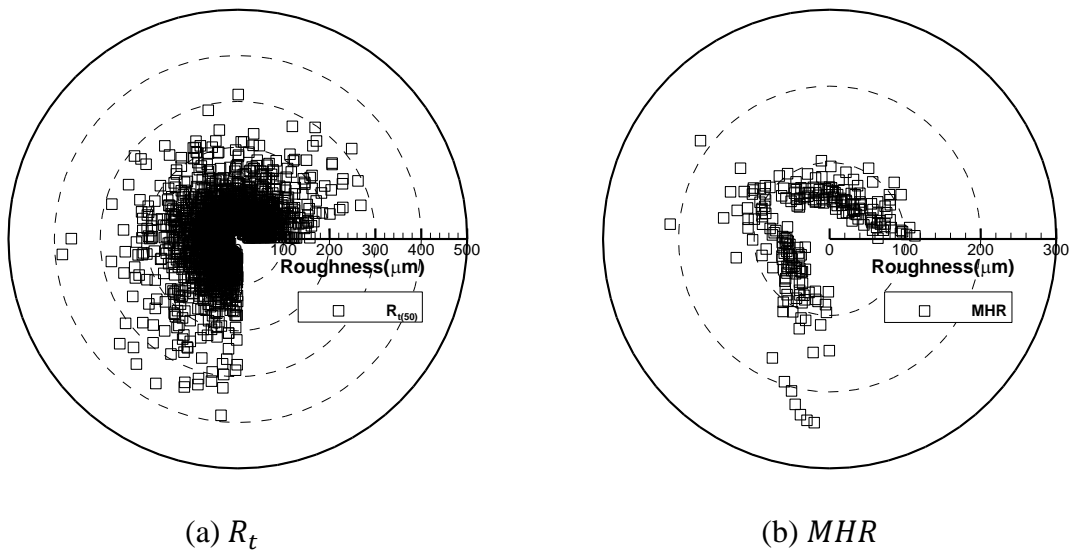
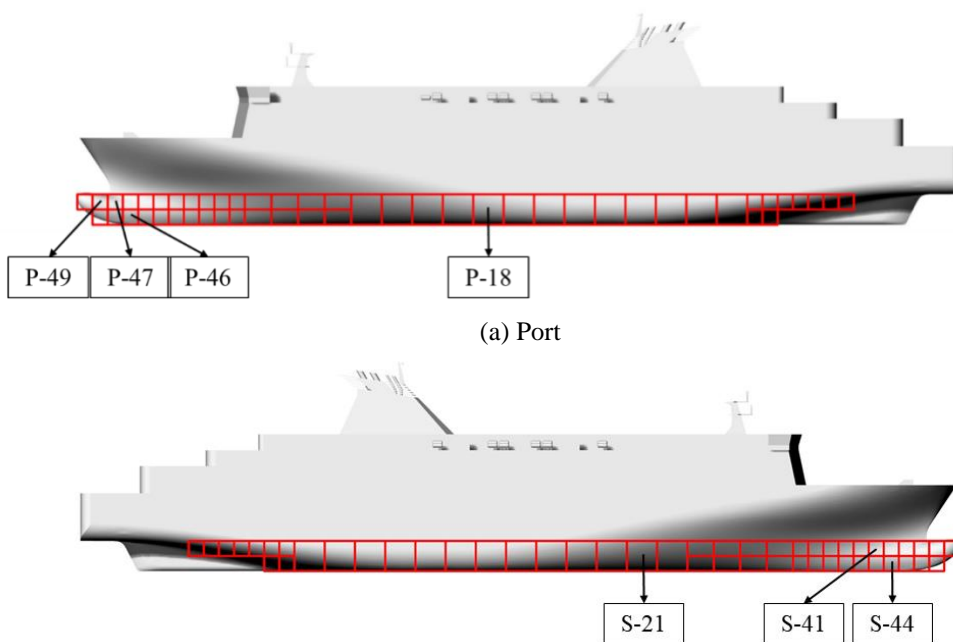
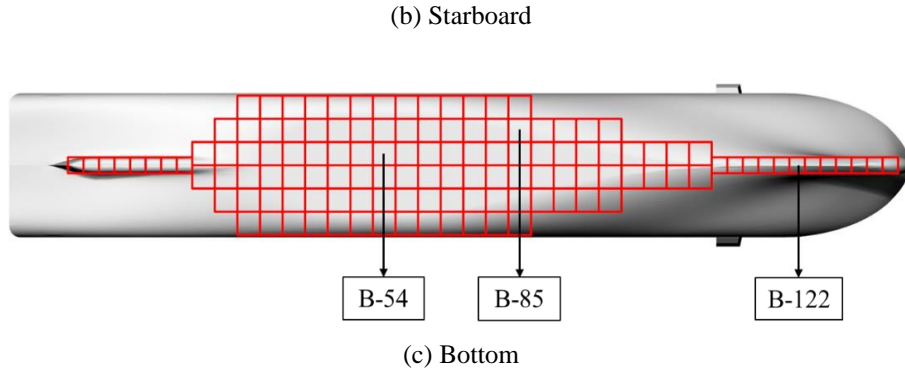


Fig. 7 Results of the hull roughness measurement





**Fig. 8** Location of the maximum and minimum

To confirm the reliability of the measurement results, a measurement uncertainty analysis was performed according to ISO guidelines ([19]).

The measurement uncertainty was calculated by applying two evaluation methods. The A-type evaluation method calculates the standard uncertainty by statistically processing the measurement results using the data from repeated measurements. The B-type evaluation method calculates the standard uncertainty by using specifications of the measurement equipment. Here, the accuracy of the instrument used in calculating the B-type standard uncertainty was  $\pm 5\mu m$  as specified in Table 2 and the standard uncertainty was calculated assuming a rectangular distribution.

For each calculation, the A-type standard uncertainty is  $2.356\mu m$  and B-type standard uncertainty is  $2.887\mu m$ . The standard uncertainty of each is obtained using the root sum square method (RSSM), and the combined standard uncertainty (*C.S.U*) is also calculated by eq. (3).

The expanded uncertainty is calculated assuming a 95% confidence level ( $k = 2$ ) for the final obtained standard uncertainty, and the result is  $7.453\mu m$ . Therefore, the *AHR* of the 160m class car ferry, which is measured in this study, is  $81 \pm 8\mu m$  considering the measurement uncertainty.

$$C.S.U = \sqrt{a^2 + b^2} \tag{3}$$

In addition, to determine the effect of the number of zones, *AHR* was calculated using arbitrary 50, 100, 150, and 200 zones out of 230 *MHR* data. For this, a random function was used for the data extraction, and data was extracted 100 times in each case.

As shown in Table 5, the minimum *AHR* increases and maximum *AHR* decreases as the number of *MHR* increases from 50 to 100. However, when the number of zones is more than 100, the variation is not significant, and tends to converge. Therefore, to ensure the accuracy of the measurement results, 50 zones are not sufficient, instead at least 100 zones should be measured.

**Table 5** Evaluation results with *MHR* number

Number of <i>MHR</i>	Minimum <i>AHR</i> ( $\mu m$ )	Maximum <i>AHR</i> ( $\mu m$ )	Average ( $\mu m$ )
50	70	92	80



100	75	90	81
150	76	88	81
200	75	88	81

The measured hull roughness results were used to estimate the resistance performance at the designed speed. For the resistance estimation, a frictional resistance estimation method considering the hull roughness of the ITTC-57 method and Townsin [20] is used as expressed in eq. (4), and each coefficient is calculated according to eq. (5)-(7).

$$C_T = C_F + C_R + C_A + \Delta C_F \quad (4)$$

$$C_F = \frac{0.075}{(\log_{10} R_e - 2)^2} \quad (5)$$

$$C_A = (5.86 - 0.6 \log R_e) \times 10^{-3} \quad (6)$$

$$\Delta C_F = \left\{ \left[ 44 \left( \frac{AHR}{L_{PP}} \right)^{1/3} - 10 \times R_e^{1/3} \right] + 0.125 \right\} \times 10^{-3} \quad (7)$$

Above,  $C_T$  is the total resistance coefficient,  $C_F$  is the frictional resistance coefficient, which is calculated using the Reynolds number by eq. (5), and  $C_R$  is the residual resistance coefficient, which is used to refer to the model test results.  $C_A$  is the model-ship correlation factor and  $\Delta C_F$  is the frictional resistance increase due to the surface roughness.  $R_e$  is the Reynolds number and  $L_{PP}$  is the length between perpendiculars.

The calculation results are listed in Table 6. The residual resistance coefficient is determined from towing tank test.  $\Delta C_F$  is approximately 15% smaller than the  $150\mu m$  value considered as the hull roughness of a new ship. Also  $C_T$  decreases by approximately 2%.

**Table 6** Total resistance calculation result depending on hull roughness

Velocity (knots)	$AHR$ ( $\mu m$ )	$C_F$ (E-03)	$C_R$ (E-03)	$C_A$ (E-03)	$\Delta C_F$ (E-03)	$C_T$ (E-03)
21	81	2.640	1.157	0.193	0.476	4.806
	150				0.558	4.888

#### 4. Conclusion

In this study, the hull roughness measurement was performed on the 160m class car ferry using the hull roughness gauge of the TQC company, and the painting of the ship was completed before launching. For measurement, the entire area was divided into a total of 230 zones consisting of 102 zones on the sides (Port 51, Starboard 51) and 128 zones on the bottom area.

Consequently, the maximum and minimum  $R_{t(50)}$  of the port and starboard areas were found to be measured similarly, but the  $AHR$  showed approximately 20% difference. This was because the zones of the port area and starboard area were similar but could not perfectly match the measurement area. For the bottom area, the  $R_{t(50)}$  and  $AHR$  were relatively low compared to the values for the side areas (port and starboard), with the  $AHR$  of the former being

approximately 20% lower than the average of the side area. This was considered to be because the bottom area was relatively flat compared to the side areas.

The uncertainty of the measurement was analyzed according to ISO guidelines. The uncertainty of the measurement was analyzed by considering the standard uncertainty of the measurement values and equipment specification. Also these were combined using RSSM method and assuming a 95% confidence level. Finally, the *AHR* of the ship by considering the uncertainty of the measurement was  $81\pm 8\mu m$ , which was smaller than the hull roughness ( $150\mu m$ ) proposed by the ISO guidelines [2]. However, it was in the roughness range from 80 to  $150\mu m$  as suggested by Hudson et al. [18]. Using the measured *AHR*,  $81\mu m$ , the resistance performance at the design speed of the ship was estimated, which showed that the total resistance was reduced by approximately 2% compared with the *AHR* of  $150\mu m$  owing to the decrease in  $\Delta C_F$ .

As mentioned above, the measurement of the hull roughness of a ship is not an essential requirement. However, it should be performed to accurately estimate ship performance. This is because decreasing the hull roughness of a ship could reduce the ship's total resistance as this study shows. Also it is the one of best ways to reduce fuel oil consumption and carbon dioxide emission from vessel. However, once the ship is launched, there is no way to directly measure the hull roughness without dry-docking, so the measurement should be carried out before launch.

It is expected that the hull roughness of a new ship is lowered compared to that of past ships owing to the improvement in painting and painting skills. However, in this study, this makes it difficult to compare the hull roughness of this one ship with that proposed by the ISO considering various factors such as paint type and vessel type. Moreover, it is difficult to generalize the roughness of all ships using the roughness measurement of the ship performed in this study, and further measurement and related studies on various ship types and ships are required. However, in the future, we could expect that various studies will be performed based on the results of this measurement.

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Submitted: 24.04.2019. Jun Seok, jseok@rims.re.kr  
Research Institute of Medium & Small Shipbuilding, Republic of Korea

Accepted: 11.03.2020. Corresponding author: Jong-Chun Park, jcpark@pnu.edu  
Department of Naval Architecture & Ocean Engineering, Pusan National University