A study of the ice-resistant protective coatings effect on the deterioration of the outdoor covering of ice vessels and icebreakers

M V Kitaev¹, P O Pastukhov² and V A Surov¹

¹Department of Ship building and Ocean engineering, School of Engineering, Far Eastern Federal University, Vladivostok, Russia, kitaev.mv@dvfu.ru
²Far Eastern State Technical Fisheries University, Vladivostok, Russia

Abstract. The study examines the regularities of the outer coatings deterioration of ice class vessels and icebreakers, as well as the effect of ice-resistant protective coatings on deterioration rates. As the initial data, the results of measurements of residual thicknesses from the DEFHULL computer database were used. A comparison of the normative values of the outer coatings deterioration rates for ice class vessels presented in the current version of the RMRS Rules and the values obtained as a result of processing the DEFHULL database data was carried out. The results and conclusions were used in developing the proposals for amending and supplementing the RMRS Rules regarding the purpose of corrosion and abrasion surcharges when determining the thickness of the outer coatings of ice class vessels.

1. Introduction

According to the current Rules of the Russian Maritime Register of Shipping (RMRS) [1], when determining the thickness of the outer coatings of ice class ships and icebreakers, it is possible to reduce the corrosion and abrasion surcharges by special consideration. However, the outer coatings deterioration rate is clearly independent of the intensity of the ice load, which differs for different areas of the vessel hull [1] that leads to heavier structures. If there is a lot of statistical information on the measurements of the residual thickness of the vessel coatings (defection), this statement is not obvious. The goal of this study is to investigate the effect of ice-resistant protective coatings on the outer coatings deterioration of ice class vessels and icebreakers.

To achieve this goal, the following tasks were solved:
1. Analysis of actual deterioration rates of the vessel and icebreakers outer coatings in areas of ice reinforcement.
2. Analysis of the relations of the deterioration rates of the vessel and icebreakers coatings and the ice load intensity.
3. Assessment of the effect of protective ice-resistant coatings on the deterioration rate of the vessels and icebreakers outer coatings in areas of ice reinforcement.

To solve the tasks, we used the data of measurements of the residual thickness of the vessels and icebreakers outer coatings from the DEFHULL computer database [2, 3].

2. Analysis of actual deterioration rates based on the results of residual thicknesses

To analyze the actual deterioration rates, the results of measurements of the residual thickness of the outer coatings of vessels and icebreakers from the DEFHULL database were processed (Tables 1, 2).
Table 1. Defection data on ice class vessels.

| Ice strength category | Number of vessels | The number of sheets of outer coating | Number of measure-ments | Average number of measure-ments on one sheet |
|-----------------------|-------------------|--------------------------------------|-------------------------|-------------------------------------------|
|                       | Dry cargo | Liquid | Fishing | Tugboat | Total |                            |                          |                           |
| Ice1                  | 9    | 3     | 12      | 0      | 24     | 1275 | 4205 | 3.3                     |
| Ice2                  | 38   | 13    | 109     | 9      | 169    | 15283 | 69302 | 4.5                     |
| Ice3                  | 19   | 8     | 47      | 1      | 75     | 7212  | 32896 | 4.6                     |
| Arc4                  | 30   | 6     | 6       | 1      | 43     | 7920  | 35477 | 4.5                     |
| Arc5                  | 7    | 5     | 0       | 24     | 36     | 4167  | 18190 | 4.4                     |
| Arc6-Arc9             | 5    | 0     | 0       | 0      | 5      | 613   | 2430  | 4.0                     |
| TOTAL                 | 108  | 35    | 174     | 35     | 352    | 36470 | 162500 | 4.5                    |

Table 2. Defection data on icebreakers.

| Ice strength category | Defection year | The number of sheets of outer coating | Number of measure-ments | Average number of measure-ments on one sheet |
|-----------------------|----------------|--------------------------------------|-------------------------|-------------------------------------------|
| Icebreaker6           | 2005 | 284 | 829 | 2.9 |
|                       | 2010 | 161 | 483 | 3.0 |
|                       | 2016 | 376 | 1695 | 4.5 |
| Icebreaker7           | 2008 | 353 | 1441 | 4.1 |
|                       | 2013 | 386 | 1497 | 3.9 |
| Icebreaker8           | 2007 | 267 | 1129 | 4.2 |
|                       | 2012 | 400 | 1300 | 3.3 |
| Icebreaker8           | 2011 | 427 | 1511 | 3.5 |
| TOTAL                 | 2654 | 9885 | 3.7 |

To automate the statistical data processing, Excel and Visual Basic for Applications were used. The algorithm for processing the statistical data (actual measurements of the residual thickness of the outer coatings) in the areas of ice reinforcement is as follows:

1. The formation of a primary data array, taking into account the location of the sheets of the outer coating relative to the side, belt and location along the length of the vessel from the databank DEFHULL;
2. Processing the data array in accordance with the methodology for assessing the reliability of the results of measurements of residual thicknesses [4];
3. The determination of the values of indicators characterizing the deterioration rate by the formulas:
   - the average value (AR) of the deterioration rate is determined by the formula
     \[ U_{cp} = \frac{1}{n} \sum_{i=1}^{n} U_i \]  
   - standard deviations (SD) are calculated by the formula
     \[ \sigma = \sqrt{\frac{\sum_{i=1}^{n} (U_i - U_{cp})^2}{n}} \]  
   - estimated deterioration rate
where $k$ - coefficient characterizing the probability of residual thickness appearance into the analyzed range of values. It is further assumed for vessels of ice classes $k = 2$, and for icebreakers $k = 3$; $n$ is the number of measurements in the selection.

4. Graphical imagination and analysis of the results.

3. Analysis of the dependence of the deterioration rate of the outer coverings on the vessel exploitation period

In order to analyze the dependence of the outer coatings deterioration rates on the exploitation period of the vessels, the data characterizing the results of measurements of residual thicknesses are divided into time intervals with an interval of 5 years, which corresponds to the frequency of inspection of vessels in operation.

Figures 1 to 4 show the results of processing the outer coatings deterioration rates for vessels and icebreakers. As a result of the analysis, it was found that the outer coatings deterioration rates in areas of ice reinforcement increase up to 16–20 years of operation, and decrease after 20 years of operation. This pattern is clear for the frontal (Figure 1) and middle (Figure 2) areas of the outer deterioration of high ice class vessels. The decrease in deterioration rates in the period after 20 years is probably due to the implementation of repair work related to the replacement of sheets of the outer coatings. According to the results obtained, the outer coatings deterioration in the stern of the vessel is uniform (Figure 3).

A similar result, associated with a decrease in the deterioration rate of the outer coating sheets depending on the exploitation period, is also noted for icebreakers (Figure 4). At the same time, we note that when analyzing the results of measurements of residual thicknesses for vessels presented in Table 3, the facts of repair work on the replacement of individual sheets of the outer coating, which affected the decrease in deterioration rates, were defined.

As a result of processing the measurements of the residual thickness of the vessels outer coatings (Tables 1 and 2), the maximum calculated deterioration rates for vessels of different ice classes and regions along the length of the hull were determined by formula (3) (Table 3).

**Figure 1.** Deterioration rates of the outer coatings in the frontal region, mm/year.
Figure 2. Deterioration rates of the outer coatings in the middle region, mm/year.

Figure 3. Deterioration rates of the outer coatings in the stern region, mm/year.

Figure 4. Deterioration rates of the icebreakers outer coatings in the frontal region, mm/year.
Table 3. Defection data on icebreakers.

| Ice class     | Deterioration rate $u$, mm/year for different areas (on vessel length) |
|---------------|-----------------------------------------------------------------------|
|               | Frontal  | Middle  | Stern    |
| Ice1          | 0.172    | 0.130   | 0.122    |
| Ice2          | 0.215    | 0.167   | 0.142    |
| Ice3          | 0.243    | 0.209   | 0.150    |
| Arc4          | 0.290    | 0.231   | 0.134    |
| Arc5          | 0.300    | 0.264   | 0.168    |
| Arc6-Arc9     | 0.394    | 0.250   | 0.121    |
| Icebreaker6   | 0.260    | 0.126   | 0.058    |
| Icebreaker7   | 0.291    | 0.171   | 0.111    |
| Icebreaker8   | 0.450    | 0.359   | 0.279    |
| Icebreaker9   | No data  |         |          |

4. Analysis of the relations between the deterioration rates of the outer coverings and the intensity of the ice load

The outer coatings of vessels are the subjects to significant deterioration when operating in ice conditions. It is due to both corrosion and abrasion of the coatings when the vessel moves in ice. With increasing the intensity of the ice load, the deterioration increases accordingly. The RMRS rules [1] declare the average annual thickness reductions only for three regions in length, and in fact only for two - frontal and intermediate (A and A1) and middle and stern (B and C). In the case of icebreakers, the number of regions reaches 16 (Figure 5). Formally, two values for the ice belt of the vessel, not related to its size, do not quite justifiably apply to all areas of the underwater part of the hull, overstating their weight and the cost of protective coatings.

![Figure 5. Areas of icebreaker ice strengthening.](image)

Studies [5] allowed us to suggest a relations between the intensity of ice loads (MPa) and the average annual decrease in thickness (mm/year) of the outer coatings:

$$u = 0.1 \cdot (1 + p^{2/3}),$$

where $p$ – ice load intensity according to the 1990 Rules.

Formula (4) requires adjusting the ice load values due to changes in the existing Rules compared to the 1990 Rules and allows differentially determining the average annual decrease in the thickness of the outer coatings, taking into account the characteristics and different areas of the vessel.
To correct formula (4), we processed the average annual decrease in the thickness of the outer coatings as a function of the intensity of the ice load. All vessels presented in Tables 1 and 2 were grouped depending on the intensity of the current ice load (Figure 6).

Figure 6. Average annual decrease in the thickness of the outer coatings as a function of the intensity of the ice load.

As a result of processing the statistical data, dependence (5) was obtained to determine the average annual decrease in the thickness of the outer coatings of vessels and icebreakers depending on the intensity of the ice load:

\[ u = 0.1 \cdot (1 + 0.8 p^{2/3}) \]  

5. The effect of protective coatings on the deterioration rate of the outer coatings of vessels and icebreakers

The addition for corrosion deterioration of the coatings in the area of ice reinforcements in accordance with the current Rules is determined by the formula:

\[ \Delta s_{u0} = 0.75 T u, \]  

where \( T \) - the planned exploitation period of the vessel, years.

The estimation of effect of protective coatings on the abrasion and corrosion deterioration of the outer coatings of vessels and icebreakers was fulfilled based on an analysis of the dependences of deterioration rates in the area of ice reinforcements on the durability of coatings. By this way we plotted the graphs (Figure 7), approximating the actual values of the deterioration of the sheets of the outer coatings of ice class vessels in the frontal region, and calculated by the formula (6) depending on the exploitation period. The initial deterioration rates are in Figure 1.
Figure 7. Assessment of the effect of coatings on corrosion additions.

Figure 7 shows the straight lines emerging from zero and being tangent to the curves approximating the actual values of deterioration of sheets of the outer coatings of ice vessels in the frontal region, and which are analogues of the average annual decrease in the thickness of the outer coatings according to the RMRS Rules. As a result, the formula for determining the deterioration of the outer coatings in the area of ice reinforcements, taking into account the use of protective coatings, can be represented as:

$$\Delta s_{u0} = 0.75Tu \cdot k,$$

where $k$ – the coefficient of accounting for the presence and durability of protective coatings.

In Figure 7, the durability of the coatings is determined by the intersection of the approximating curves characterizing the actual values of the deterioration of the sheets of the outer coatings of vessels and icebreakers, with the abscissa axis. As a result, it was found that for icebreakers the coating resistance is up to 2 years, for vessels of the Arctic categories of 2,5 to 5 years, and for other vessels from 5 or
more years. The analysis results shown in Figure 8 are confirmed by the practice of exploitation of ice class vessels and icebreakers [6, 7].

Based on the found dependences characterizing the actual values of deterioration, the coefficients are determined that take into account the change (decrease) in the deterioration rate of the outer coatings depending on the resistance of coatings or measures aimed at protecting the hull from corrosion deterioration and ice abrasion:

- \( k = 1.0 \) - for ordinary coatings with a resistance of up to 2.5 years;
- \( k = 0.75 \) - for coatings with a resistance of 2.5 ÷ 5 years;
- \( k = 0.50 \) - for coatings with a resistance of more than 5 years,

as well as for other effective measures to protect the outer coatings from corrosion deterioration and abrasion (ice-resistant coatings in conjunction with an electrochemical protection system; ice-resistant coatings in conjunction with an electrochemical protection system and clad steel, and other options).

The value of the coefficient \( k = 0.50 \) is consistent with the recommendations of the Rules DNV, IACS, LR, determining the structural or operational features of the vessel.

In the proposed version, in agreement with the Register of Ice Vessels, the range of decisions on the designation of additions for deterioration of the outer coatings in areas of ice reinforcement has been expanded taking into account the use of protective coatings, measures and remains with the designer. The designer must take into account the experience and data of the manufacturer of protective coatings (guarantees of certain properties of coatings and their durability in specified operating conditions).

However, during the long-term operation of the vessel there is no guarantee that the owner/operator will always comply with the design conditions and protection recommendations. Therefore, the Register is invited to introduce a requirement in addition to the construction thicknesses of the outer coatings of ice class vessels on the design drawings to indicate the permissible residual thicknesses at which the vessel maintains compliance with the design ice category. Going beyond these values means the need to repair or lower the ice category of the vessel.

6. Conclusion

As a result of the study, the following conclusions can be made:

- measurements of the residual thickness of the outer coatings of vessels and icebreakers were processed, the dependences of the rate of deterioration of the coatings on the exploitation period were built;
- a formula is proposed for determining the deterioration rates of sheets of the outer coatings depending on the intensity of the ice load;
- an assessment of the effect of protective coatings on the deterioration rate in areas of ice reinforcement was made;
- the research results were taken into account when changing and supplementing the requirements of the RMRS in 2019 to the designation of corrosion and abrasion surcharges when determining the thickness of the outer coatings of vessels and icebreakers taking into account the protective coatings [6].

References

[1] Rules for the classification and construction of marine vessels 2020, II - Hull. Russian Maritime Register of Shipping (St. Petersburg. 2017)

[2] Kulesh V A, Zhitnikov A V and Surov O E 2010 The DEFHULL system is an innovative technology in managing the technical operation of the fleet Electronic periodical "Bulletin of the Far Eastern State Technical University" (Scientific journal, No. 3 (5), FESTU; Vladivostok) pp 23-34

[3] Kulesh V A, Pichugin O G and Surov O E 1997 Computer database and examination of the technical condition of the fleet (DEFHULL) State Committee on fisheries of the Russian Federation. Safety of navigation and fishing (St. Petersbourg Vol. 1 (105)) pp 57-61

[4] Zinoviev P V, Kompanets V A and Surov O E 2015 Methodology for assessing the reliability of measurements of residual thicknesses during the detection of vessel constructions Scientific and Technical Bulletin of the Russian Maritime Register of Shipping (No. 40/41, St. Petersbourg) pp 41-48
[5] Kulesh V A 1998 Estimated design and examination of the technical condition of vessel constructions in areas of extreme local loads *Dis. Doctor. Tech. Sciences* (FESTU, Vladivostok)

[6] Kitaev M V, Kompanets V A, Kulesh V A and Surov O E 2018 Development of proposals for the appointment of additions for the deterioration of the outer coatings of ice class vessels and icebreakers *Scientific and Technical Bulletin of the Russian Maritime Register of Shipping* (No. 52/53, St. Petersburg) pp 35-46