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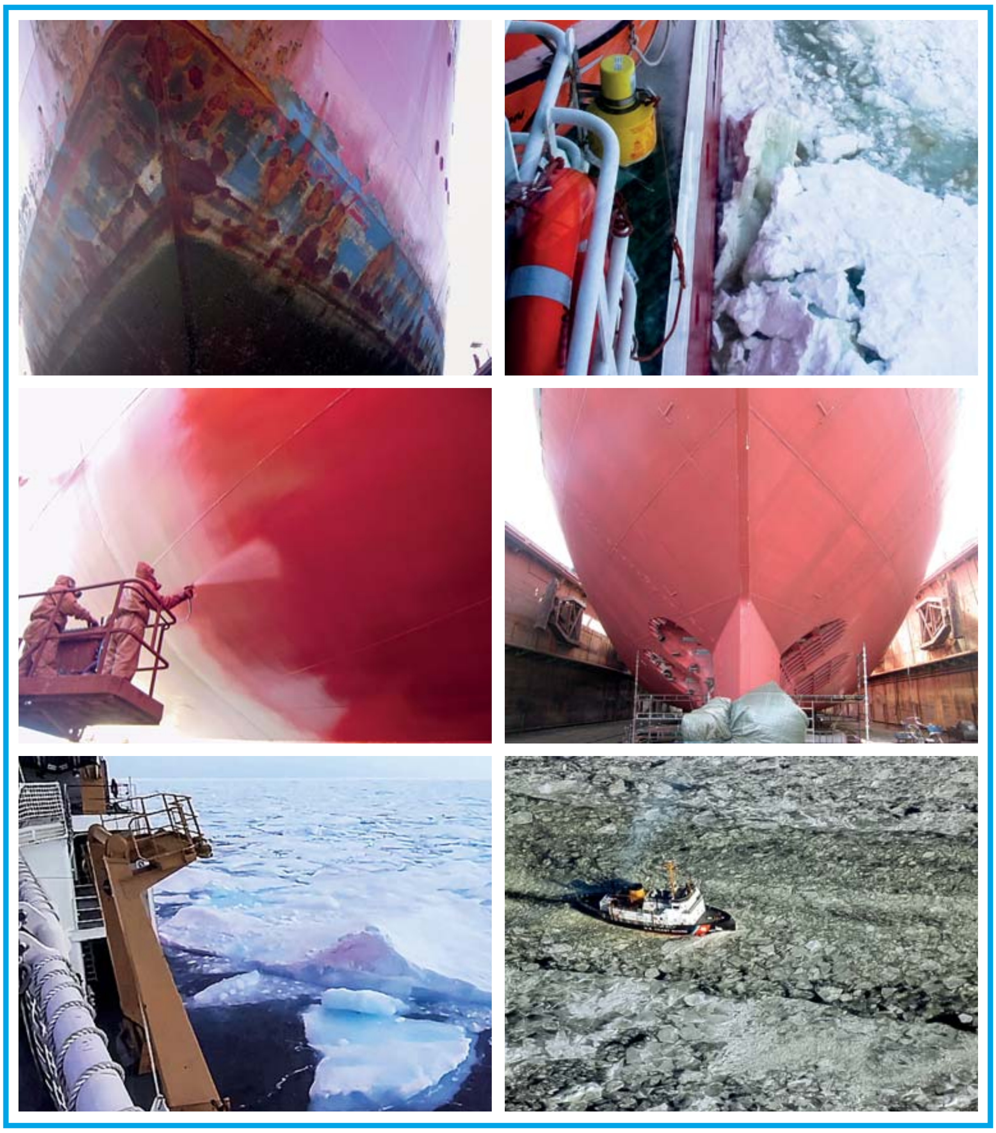
WHITE PAPER

Hull Protection for Ice-going Vessels



Tackling the special coating requirements of the hulls and running gear of ice-going ships and icebreakers

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UNDERWATER TECHNOLOGY

Part I. Introduction

Ice represents a severe hazard to ships. Icy waters, icebergs, packed ice, old ice, first year ice, lava- or gravel-laden ice or any other form of ice are all significantly more challenging to a ship than water. More than in any other marine application, choices regarding ships that will sail in ice can be a matter of life or death.

There are many ice-specific class regulations intended to reduce the risk of that hazard and promote safety for ships sailing in such conditions.

When it comes to choosing a hull coating for icebreakers and ships that sail or trade in icy waters and their rudders and running gear, certain key factors must be looked for.

The first and most important is protection. The steel or other material from which the hull is made must be protected from this harshest of harsh environments. This means a really tough coating which is resistant to the abrasion of the ice, which will adhere under the constant pounding and scraping that accompany sea voyages through ice. It also means a coating that is not brittle or inflexible and therefore subject to cracking or disbonding when the panels that make up the hull flex and bend, even permanently denting, under the impact the ship receives from the ice. As soon as the hull coating is damaged, corrosion of the underlying hull can set in and spread. There is an economic factor here too. Certain ice abrasion resistant hull coatings are certified as such by the classification societies. This certification includes the provision that the coating, if correctly applied to the ice belt, will permit a reduction in the ship's scantlings of up to 1 mm in thickness of steel plate. This can add up to a significant reduction of steel or other substrate and in the overall weight of the vessel.

The fuel efficiency of the hull coating is also very important, especially when one considers current fuel prices. A hull coating that reduces friction and remains smooth over the ship's life cycle will result in tremendous fuel savings for the operator. But this is not just a point of economy. Reduced fuel consumption means fewer noxious, harmful atmospheric emissions such as CO_2, NOx, SOx and Particulate Matter including black carbon. Hull fuel efficiency comes down to two main factors: 1) long-term hydrodynamic smoothness and low friction of the hull; 2) freedom from biofouling, either by repelling it or by removing it before it accumulates to any large degree. While not nearly as significant a factor in icy waters as in temperate or tropical climes, the control of fouling must still be taken into account when choosing the best hull coating for trading or sailing in ice.

A hull coating that reduces friction and remains smooth over the ship's life cycle will result in tremendous fuel savings for the operator.

Low friction is a key property of a hull coating for an ice-going vessel or icebreaker. This permits the vessel to move through ice more rapidly, or at least less slowly, especially when the ice friction is increased by a covering of snow. It also makes it easier for an icebreaker to ram onto and reverse off the ice during icebreaking operations. This is an economic factor but also a safety factor. Less fuel will be consumed by a ship operating in ice which has a low friction coating on its hull. The danger of running out of fuel or having to curtail a voyage is reduced.

Environmental considerations are very important. The Arctic, the Baltic, the Great Lakes, the Antarctic, southern South America and many other environments where ships operate in icy conditions tend to be relatively pristine when compared to the much more traveled sea routes and other waterways. Certain pollutants such as black carbon are much more harmful in the same volume in polar waters than in tropical or temperate zones. These areas are particularly sensitive to the invasions of alien species and to the effects of heavy metals and other toxic substances such as those leached by biocidal antifouling coatings and many foul-release coatings.

A further aspect which must be considered when choosing a coating for the hull of ice-going ships is the ease of application and maintenance of the coating. Does it require special conditions and equipment for application? How long will it last? Does it need frequent and expensive repair or replacement in dry-dock? If so, how difficult and/or expensive is it to repair/replace? Can it be safely cleaned in the water without damage to the coating or harm to the marine environment?

These then are the main points which can be greatly influenced, for better or for worse, by the choice of coating used on the hulls of ice-going vessels and icebreakers:

1. Protection and safety.
2. Economy of operation and reduction of total ownership costs.
3. Environmental sustainability.
4. Ease of application.

This White Paper examines the subject, the types of coating available and the best approach to choosing the right coating for the hull and running gear of ice-going ships.

Part II. Climate of change

For icy waters, particularly the Arctic Ocean, shipping traffic is in a major state of flux. This has been big news, attributed to climate change and receding summer ice, opening heretofore impassable ship routes and making Arctic travel possible or easier. Reports are somewhat conflicting on the subject but in general the forecasts are for increased or greatly increased shipping in icy waters.

Offshore oil and gas exploration and production activities in Polar regions, particularly the Arctic, are increasing. The reserves of oil and gas in Arctic regions are estimated to be about one quarter of the world's proven sources.[1] The countries that border the Arctic Ocean are all increasing or planning to increase their shipping activities in the icy waters of the Arctic region. Remote offshore vessels are expected to stay on station for long periods of time without going to dry-dock. This poses a challenge to hull coatings in that they need to protect the vessel from corrosion and be cleanable for underwater inspections in lieu of dry-docking (UWILD) by classification societies. Toxic antifouling coatings and other soft coatings are not appropriate for ice-going vessels since they are easily damaged or scraped off by contact with the ice. The additional factor of not going to dry-dock as in the case of off-shore exploration, production and storage vessels imposes severe requirements for toughness and durability on the coating used to protect the hulls of such vessels.

Work was started by the IMO in 2009 on a Polar Code supposed to recommend or dictate safety and environment-related conditions and precautions specifically for vessels operating in polar regions. A number of suggestions were put forward, and preliminary work was done, concentrating more on the safety aspects than the environmental ones. These suggested or desired requirements included the use of ice abrasion resistant, non-toxic hull coatings, and measures for preventing hull-borne invasions of non-indigenous species in the form of biofouling, which would mean ships sailing into Polar regions having a macrofouling-free hull. While work on the Polar Code had not been completed at time of original publication of this White Paper, shipowners and operators planning to sail in these waters need to take the possibilities into consideration as they build new vessels or replace the hull coating on ships in service.

If delays on developing an acceptable Polar Code continue, it is quite likely that individual ports and States affected will develop and impose their own requirements. This is far from optimum since the various nations and authorities involved are unlikely to come up with the same set of regulations, and ships traveling between and among the various ports and States will need to keep track of and follow different sets of rules. Far simpler would be a rapidly completed, IMO-led Polar Code which can be agreed on by all affected States.

These various factors are all coming together to pressure shipbuilders, shipyards, shipowners and ship operators to make the correct decisions concerning the application and repair of hull coatings on ice-going vessels.

The question is, how does one choose the best hull coating system for this harsh and unforgiving environment?

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1 Cambos, Philippe, *et. al.* "Technical Challenges Associated with Arctic LNG Developments: A Class Society Approach," Bureau Veritas, Paris, (2013).

Part III. Issues with Hull Coatings for Ice-going Ships

What are the special requirements for hull coatings on ice-going ships?

Ice damages and destroys all but the toughest hull coatings.

The most important consideration is the harshness of the environment. Ice damages and destroys all but the toughest hull coatings. This is clearly visible when the ship comes to dry-dock after a season in the ice. The hull paint, even dedicated, ice-class paint, is usually badly depleted, damaged or worn away to bare steel.

As the coating is damaged or destroyed, the direct contact of seawater with steel begins the corrosion process. This corrosion eats away at the hull which then becomes thinner and less able to withstand the forces of sea and ice. It is a vicious circle which begins with the failure of the coating. This is an economic consideration as well as a point of safety. A worn hull will more easily be holed than one which had been well-protected and has not lost its thickness.

Collision with or pressure from ice also causes the plates that form the ship's hull to flex and deform, at least temporarily. This means that a coating which is brittle or inflexible or which is poorly bonded can disbond under the stress caused by contact with ice.

The hull of an ice-breaking Antarctic supply vessel after a single season in the ice with a specialized, industry standard, ice abrasion resistant coating.

Some background information is useful before getting down to the specific challenges that confront the hull coating when ships are trading in ice or breaking ice.

Not all ice is created equal

Ice comes in different forms, shapes, sizes and conditions. Some ice is more of a challenge or threat than other ice.

The following information and definitions are taken from "Annex A Terminology for Ice, Navigation and Ship Design" of the Canadian Coast Guard's publication *Ice Navigation in Canadian Waters.*[2]

Sea ice ranges in its thickness and permanence, and therefore harshness to shipping, from **new ice**, recently formed, which reaches thicknesses of 15 - 30 cm, to **first-year ice** which is of not more than a season's growth but ranges from 30 to over 120 cm in thickness. Beyond that there is **second-** and **multi-year ice** which is thicker and stands higher out of the water than first-year ice.

In addition to varying in age and thickness, ice comes in different forms: **pancake ice** consists of small circular pieces of ice, 30 cm to 3 m in diameter and up to 10 cm thick. **Ice cakes** are relatively small pieces of ice up to 20 m across. **Floes** are fairly flat pieces of ice ranging from 20 m to 10 km across. **Fast ice** is attached to and remains fast along the shore and can be first- or multi-year ice extending for hundreds of kilometers along the coast.

Ice cover is a term used to indicate the ratio of the area of ice to the total area of water, expressed in tenths. Thus **consolidated** or **compact ice** would have a concentration of 10/10 with no water visible. **Open ice** would have a concentration of between 4/10 and 6/10 where floes are generally not in contact with each other but have open water in between. **Bergy water** has some ice of land origin but is freely navigable. The entire range is from 10/10 consolidated ice to 0/10 ice free water with all stages in between. Ice of land origin includes **glacial ice, glaciers** and **ice shelves**. From these, **icebergs** and **ice islands** of various types, sizes and denominations break off. These can extend from 1 - 75 or more meters above the sea and can have an area as small as 20 sq m or as large as 500 sq km or more.

Some ice-related ship terms

Technology has built up over the years with regard to making ships fit for sailing in icy water. Nomenclature has been developed to describe the special measures taken to strengthen ships and make them ice-worthy. Some of these terms need to be explained for a full understanding of this White Paper in case the reader is not familiar with them.

The **ice belt** is the area of the ship which is strengthened to withstand ice loads at the ice draft water line.

Ice draft is the draft at which the ship must be in order for the ice-strengthening of the hull structure to be of value.

An **ice horn** is a wedge-shaped structure placed above the rudder in order to protect it when the ship goes astern into ice.

Ice-strengthened is the term used to refer to the added strength built into the hull of an ice-going ship so that it can operate safely in ice-covered waters.

Ramming describes the action of driving the ship, usually an icebreaker, as far forwards into and onto the ice as possible and then backing it out and repeating the process. An icebreaker is driven forward up onto the ice and uses its weight to break the ice. This

2 Canadian Coast Guard, *Ice Navigation in Canadian Waters,* (2012).

action can be repeated by going astern and driving forward over and over again to break a path through the ice.

Ice classes

Out of the need for strengthening ships for ice navigation have come a series of classifications or categories which are used by the classification societies to describe a vessel's suitability for traveling in ice-covered waters. Unfortunately there is not just one system of such classification but several issued by different classification societies or bodies. However, the correlation between the various designations is not too complicated and the principles in use are what is important here.

The following table shows ice-class notations as used by DNV classification society.[3]

The Finnish-Swedish Ice Class rules have a notation system of their own. These rules were developed for merchant ships navigating in first-year ice in the Baltic. They cover the ship's ability to advance through ice, and concern engine output and hull strength. The structural strength of the hull and propulsive machinery of the ship need to be able to withstand expected ice loads with a margin of safety.

The Swedish-Finnish ice class designations are as follows:

1. ice class IA Super; ships with such structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers;
2. ice class IA; ships with such structure,

Ice Class Notations

MANAGING RISK

Baltic		Polar Class	
		PC1	Year-round operation in all Polar waters
		PC2	Year-round operation in moderate multi-year ice conditions
		PC3	Year-round operation in second-year ice which may include multi-year inclusions
		PC4	Year-round operation in thick first-year ice which may include old ice inclusions
		PC5	Year-round operation in medium first-year ice which may include old ice inclusions
1.0 m first year ice	ICE-1A*	PC6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
0.8 m first year ice	ICE-1A	PC7	Summer/autumn operation in thin first-year ice which may include old ice inclusions
0.6 m first year ice	ICE-1B	-PC1 to PC6 may be assigned additional notation ICEBREAKER	
0.4 m first year ice	ICE-1C		

3 Morten Mejlænder-Larsen, "Role of IACS in Arctic Shipping," (October 2008).

engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary;

3. **ice class IB; ships with such structure, engine output and other properties that they are capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary;**
4. **ice class IC; ships with such structure, engine output and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary;**
5. **ice class II; ships that have a steel hull and that are structurally fit for navigation in the open sea and that, despite not being strengthened for navigation in ice, are capable of navigating in very light ice conditions with their own propulsion machinery;**
6. **ice class III; ships that do not belong to the ice classes referred to in paragraphs 1-5.**[4]

The classification society regulations require a "corrosion allowance" for ice-class ships which means added thickness to the scantlings to compensate for wear from ice abrasion. Usually this is an additional 2 mm in thickness of the plates. Where a recognized ice abrasion resistant coating is used and on condition that the surface is thoroughly and properly prepared and the coating correctly applied, this corrosion allowance can be reduced to 1 mm.[5] This shows the importance of correct selection of coating and its standard application.

This ice abrasion resistance recognition or certification is not lightly given. The Swedish-Finnish rules state the following:

When considering the laboratory testing, the following testing procedure could be followed:

- **Resistance to abrasion (Taber abraser test)**
- **Impact resistance**
- **Adhesion strength**
- **Extensibility (flexibility) e.g. according to ASTM D4145**

In addition, the following corrosion tests could be considered:

- **Cyclic corrosion test or salt spray test - Water immersion test**
- **Cathodic disbondment test.**[6]

Additional factors

In addition to frozen fresh or salt water, ice can contain highly abrasive material and particles such as, for example in the Antarctic regions, volcanic lava, or gravel. This makes an already harsh environment for ship hulls and their coatings into an even more extreme source of abrasion and potential damage.

The ice can also be covered with snow of varying depth. This can greatly increase the friction which the ship's hull undergoes when in contact with ice.

Friction is the force resisting the relative motion of solid surfaces, fluid layers and material elements sliding against each other. For a ship moving through water, the forces of skin friction, also known as drag, are considered. For a ship moving through and in contact with ice, dry friction applies since both objects are solid. Both skin friction and dry friction affect the hull of a vessel moving through icy water.

Coefficient of friction is a numerical

4 Finnish Transport Safety Agency, *Maritime Safety Regulation*, "Ice Class Regulations and the Application Thereof," (23 Nov. 2010).
5 TraFi Swedish Transport Agency, "Guidelines for the Application of the Swedish Finnish Ice Class Rules," p. 20 (Dec. 2011).
6 *Ibid.*

value by which friction can be measured or indicated and compared. The coefficient of friction depends on the materials involved. For example, steel on ice has a relatively low coefficient of friction whereas rubber on concrete has a much higher coefficient of friction. The usual values for dry friction of most common materials are between 0.3 and 0.6. A coefficient of friction of 0 would mean no friction at all. Rubber against other materials can have a coefficient of friction between 1 and 2.

Friction is a very important element in ice navigation and icebreaking.

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Depending on how old the hull is, the coefficient of friction between ice and the bare steel of uncoated hull platings is usually between 0.2 and 0.3. The friction between ice and a low friction hull coating is more likely to be in the range of 0.05 - 0.17 which is considerably lower.[7] The difference can be seen in the following example. The level of power needed to force a ship with an uncoated hull forward that was stationary in ice, corresponds to a speed of advance of 3 knots. The power required for a ship with a low-friction coated hull in similar conditions corresponds to a speed of 0.5 knots.

Prior to the 1970s there were no suitable coatings for the hulls ice-going ships and coatings that were used would wear off within a few days of deployment in ice-covered waters. Thus the tendency was to leave hulls uncoated and increase the thickness of the plates to allow for wear and corrosion. The bare steel corroded rapidly and the hulls became quite rough, increasing friction considerably. Thus low friction, ice abrasion resistant coatings were a boon to any ships operating in icy waters, helping reduce fuel costs.

Anything which reduces the friction between the hull and the ice is of value. In the case of icebreaker which must ram the ice and often reverse and ram again, a low friction hull enables this operation to be carried out with a lower output of power and consumption of fuel than with a higher friction hull. In the case of any ship traveling through ice covered waters, a low friction hull can greatly reduce the amount of fuel consumed to travel the same distance at the same speed. This has an additional value of creating fewer emissions of noxious gases and particulate matter which are particularly unwanted in polar regions. Lower fuel consumption adds up to reduced atmospheric emissions, all other factors being equal. A low friction hull depends mainly on the type of coating used and the state of that coating.

Hull coating requirements

Thus the two key requirements for ice-class hull coatings are corrosion protection of the hull and a low friction surface.

Corrosion must take into account adhesion and abrasion resistance. Basically the coating has to stay on the hull and withstand the onslaught of the ice without disbonding or sustaining damage. An added factor of corrosion protection is undercreep and how to prevent it. If a coating permits undercreep, then when it is damaged the resulting area of corrosion spreads to adjacent areas under the coating. With the best corrosion protection undercreep is almost entirely eliminated. This results from their high adhesion to the substrate so that a scratch or chip does not result in corrosion spreading underneath the coating to adjacent areas.

Low friction needs to be measured over the life of the coating and the hull, not simply when the ship is launched. A short-lived

7 Sodhi, D. S., Northern Sea Route Reconnaissance Study – A Summary of Icebreaking Technology," CRREL, (June 1995)

coating, even if initially low friction, may be fine for weeks or months but will be damaged and need to be patched or repaired, thus degrading over time and becoming rougher and rougher until eventually the only answer is to blast the hull back to bare steel and reapply the full coating. But during the time that the ship is continuing to sail with a damaged and roughly repaired hull coating, the power and therefore fuel required to propel it through ice-covered waters will be much more than with a smooth hull. Thus a low friction coating can be defeated if it is relatively easily damaged by the ice, requiring frequent spot blasting and repair or even replacement.

From an environmental point of view, any coating used on a ship which travels in ice covered waters needs to be non-toxic. With toxic coatings, heavy deposits of highly toxic material are simply scraped off onto the ice, posing an environmental hazard. These substances are already hazardous when leached at their normal rate. But when scraped off in concentrated amounts, this hazard is multiplied.

The only hull coatings which are really suitable for protecting the hulls of ice-going vessels including icebreakers are hard, resilient coatings certified as ice-abrasion resistant. The best hull coatings for ice-going ships are also low friction coatings which remain smooth for their entire service life.

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The reason is quite simple. Soft coatings such as biocidal antifouling coatings or foul-release coatings cannot withstand the abrasion of the ice and are scraped off. Their protective powers are severely limited. When damaged and patched they leave a very rough hull. They do not protect against corrosion and they also have high friction. When soft coatings are also toxic they fail to meet the requirements for ice-going ship hull coatings on all major points.

Mäkinen *et al.* (1994) listed the requirements of a good, low-friction coating. Their list is quoted in full here:

> **3. SEARCH OF NEW COATING MATERIALS**
> **3.1 Requirements of Low-Friction Coating of Icebreaking Ships**
> **The requirements for a good, low-friction coating on an icebreaking ship can be grouped into three categories:**
>
> **I: Requirements for low friction:**
> - **The coating must be smooth, in other words its surface roughness must be small with a low R value.**
> - **The coating must have a large contact angle with the water.**
> - **The surface must have low surface conductivity, specific heat capacity and density.**
>
> **II: Other requirements for a good ice-breaker coating:**
> - **The coating must have good wear resistance.**
> - **The coating must have good bond strength with the base material, i.e. steel in the shell plating.**
> - **The coating must sustain high normal pressures.**
> - **The coating must stand the deformation of the base material.**
> - **The coating must stand low temperatures and temperature changes.**
> - **The coating must maintain its properties in water.**
> - **The price of the coating must be reasonable.**
> - **The anti-fouling properties are desirable, but the coating must not pollute**

the environment.

III: General requirements for the coating method:

- **The coating method must be applicable in large (ship) scales.**
- **The coating method must be applicable in shipyard conditions.**
- **The coating method must allow preparation of smaller, damaged areas afterwards.**[8]

Ease of Application

There are some other factors which must be taken into account even with a tough, low friction coating. There are a few coatings for ice-going ships which are hard and smooth and even have fair longevity but which are difficult to apply, require special conditions or equipment and therefore add time and expense in the new build phase and during dry-dock application, repair or reapplication. This can be quite a drawback.

The special requirements often include dual feed spray equipment which is designed to cope with the very short pot life that some of these two-part paints suffer from. The special conditions often include tenting the hull and heating it and the environment to make application of the paint possible. This is, understandably, quite an expensive, time-consuming and difficult procedure. In many yards the specialized equipment and the personnel trained in its use are simply not available. Economically, it adds up to greater expense in the application which raises the cost of such coatings considerably.

Cost of frequent replacement

A drive towards false economy can lead shortsighted shipowners/operators to apply the cheapest available coating to an ice-going ship and then replace the coating on an annual basis to try to prevent corrosion from taking too heavy a toll on the hull. Often this is simply a general purpose epoxy coating.

A drive towards false economy can lead short-sighted ship-owners/operators to apply the cheapest coating possible to an ice-going ship….

It doesn't take many seasons of dry-dock and coating repair and replacement to catch up and make this cheap solution a very expensive one.

From the point of view of longevity and total ownership cost, the least expensive solution would be a coating which could be applied once and which would then last the life of the hull without the need for any extensive repair or for full replacement of the coating. Assuming that such a coating is reasonably priced, even if much more expensive than the cheap paint designed to be replaced every year, the initial investment would rapidly pay off and soon become far more economical. In terms of asset protection and total ownership cost, the more effective coating has many advantages.

8 Mäkinen *et al.*, "Friction and hull coatings in ice operations," IceTech '94 5th Intl Conf on Ships and Marine Structures in Cold Regions; 16-19 March 1994; Calgary, Canada. Pprs. Pub by SNAME, Arctic Section, Calgary, Canada. Ppr E [22 p, 27 ref, 5 tab, 22 fig].

Part IV. Past and Present Solutions

Following is a brief history of ice coatings up until 1995, taken from the same paper quoted above.

> Prior to the early '70s, no surface material was available which could withstand interaction with ice, particularly heavy ice. Thus, the practice was to apply only anti-fouling paint to icebreaking hulls to minimize/eliminate biological growth on the hull surface. Such a paint application would be worn off during the first few days of heavy ice operations. Thus, in ice, and from the point of view of ice-ship hull friction, a bare steel plate was accepted as the surface quality of a ship's hull. It was understood that, when a ship was relatively new and the shell plates were not badly corroded, the friction between the ice and the ship's surface was relatively low, but increased considerably for older vessels with corroded shell plates.
>
> Intensified research on the ship hull/ice friction phenomenon was initiated in the early '70s. Tests conducted by Oy Wärtsilä Ab Shipbuilding Division (the predecessor of Kvaener Mass-Yards Inc.) clearly demonstrated the importance of friction on ice resistance. These experiments led to further investigation on the qualities of different materials, aimed at discovering and developing a material which would exhibit higher ice resistance capabilities than those of the conventional paints used on a ship's hull.
>
> These tests and the resulting development efforts of Wärtsilä Shipbuilding Division were fully reported at the first SNAME Icetech Symposium in Montreal in April, 1975. The paper, entitled "Influence of Friction on ice Resistance. Search for Low Friction Surfaces", comprehensively describes all the work carried out until that time. The experiments formed a credible basis for the assessment of the importance of the ice/ship's hull/friction phenomenon and also established a basis for further development of the subject.
>
> Since the mid-70s research has continued. The two-component, solvent-free epoxy, Inerta 160, was extensively adopted after the tests carried out in the early '70s. That paint has proved to be a practical and relatively good solution for all ships operating in ice. Further developments were undertaken to assure proper application methods for the paint. The few competing paints introduced into the market failed to obtain acceptance due to a lack of demonstrated capability or impractical application methods.
>
> Inerta 160 is currently by far the most widely used exterior hull paint on ice-going vessels. The product and its application methods have been comprehensively developed, resulting in confident use and risk free application of Inerta 160. It was realized, however, that for heavy arctic ice operations a better solution should be adopted, although the application of Inerta 160 was a definite

> **improvement compared to the previous method, which was no special paint application at all.**
>
> **This led to a continuation of the search for other improved materials. The research concentrated particularly on the use of stainless steel.[9]**

That was the state of hull coatings for ice-going ships in 1995. A great deal of fruitful research in the intervening years has resulted in great advances in this field, in particular the development of glassflake technology and the use of different resin matrices. This will be covered fully in Part V of this White Paper.

Today there are several options on the market when it comes to hull coatings for ice-going ships. In general, ships that are built as icebreakers or which are designed to break heavy ice or which sail in ice all year round, tend to have special ice-class coatings applied. There are a relatively small number of these coatings and each major paint manufacturer tends to offer at least one such specialized ice paint.

As an example, a Lloyd's Register list of recognized abrasion resistant ice coatings dated July 2013 lists a total of eight different coatings from six manufacturers.

Cargo ships that trade in ice in winter, such as in the Baltic, still often use a fairly inexpensive epoxy coating, knowing that it will mostly be removed by one season in the ice and that it will have to be replaced the following spring or summer. As already covered, the economic wisdom of this approach does not usually stand up to close scrutiny. Nevertheless, the appeal of a lower initial cash outlay, uncertainty of the future business climate, short life expectancy of the ship and other factors often lead to this approach to protecting, or at least covering, the hull of ice-going vessels.

Other vessels such as cruise ships which tend to meet icy water only occasionally, often take no special precaution when it comes to hull coatings but simply continue to use the biocidal antifouling, foul-release or even hard coatings which they have applied for more temperate waters. As has been discussed, all these coating types, with the exception of hard coatings, are quite unsuited to icy conditions.

9 *Ibid.*
10 Lloyd's Register Group, "Lloyd's Register Recognised Abrasion Resistant Ice Coatings," (July 2013).

Part V. Best available technology

For reasons covered in great detail in Hydrex White Paper 13 *Conquering Corrosion in Offshore Vessels*, the best possible corrosion protection of hulls in water is a combination of a tough, flexible, durable resin with large aspect ratio glass flakes. When the correct formulation is used, this type of coating is impenetrable and impermeable and also stands up better than any other to impact and abrasion such as that experienced by ice-going vessels.

With in-water conditioning using the right equipment and tools, this type of coating can be made very smooth as more of the glass is exposed. The result is a coating which falls well within the requirements for a low friction ice coating.

Of the eight coatings listed in Lloyd's Register Abrasion Resistant Ice Coatings, six are based on epoxy resins, some glassflake reinforced and some not. Epoxy resins can provide a low friction coating and generally perform well, but the epoxy tends to continue the curing process indefinitely and thus eventually becomes brittle and inflexible. Over time this makes it easier for the coating to crack, chip and become disbonded with the flexing of the steel plates of the hull. It tends not to last as long as other types of resin such as polyester or vinylester.

Thus, if an ice coating is intended to last many years without damage, without chipping or becoming rough due to mechanical damage and ice impact, it is necessary to use a base resin which has excellent adhesion but remains flexible even when fully cured and does not disbond under the stresses of passage through ice.

Most of the certified ice coatings are glassflake reinforced. However, it must be noted that not all glass flakes are created equal. This is again covered in detail in Hydrex White Paper 13 *Conquering Corrosion in Offshore Vessels* and can be summarized simply here. The best glass flakes for coating reinforcement are large aspect ratio (large ratio of area to thickness), C or ECR type glass, manufactured by the spun method. The simple statement "glass reinforced" covers a wide range of possibilities, some much more effective than others.

…not all glass flakes are created equal.

Thickness varies among the certified coatings but many of them are applied to a dry film thickness (DFT) of 500 µm or less, which is not very thick when long-term resistance to ice abrasion and damage is the prime concern. In general, the thinner the coating, the more frequently it will need to be repaired or replaced.

The certified coatings vary in application requirements. Some require dual-feed, hot airless spray equipment and demanding environmental conditions whereas others can be applied under normal conditions using single-feed airless spray equipment. This can be an important consideration in making a final choice of coating.

In general terms, the best all around abrasion resistant ice coating for icebreakers and ice-going vessels would have all the following features and properties:

1. Abrasion resistant ice coating certification from the major classification societies.
2. A base consisting of a resin which cures

fully without becoming brittle or inflexible and has superior adhesion properties.

3. Glassflake reinforced with large aspect ratio, C or ECR type spun glassflakes. The glass flake content should be as high as possible within the bounds of maintaining flexibility and toughness of the coating. This is a key factor in the mix. The best coatings contain a number of additives to improve bonding and other qualities.
4. Low friction (a coefficient of friction with ice of less than 0.17 is considered low friction). Low friction must continue to be low friction over the years that the coating is in use before it is fully replaced.
5. A DFT of at least 1000 μm for high impact resistance, superior corrosion protection and adequate longevity.
6. Completely non-toxic.
7. Application with normal airless spray equipment and under normal environmental conditions, not requiring specialized equipment such as dual-feed airless hot spray equipment and restrictive environmental conditions in terms of temperature and humidity.
8. Requires adequate preparation of substrate which includes at least grit blasting to create a profile of at least 75 μm and a cleanliness of SA 2.5 or better.

In use, this best available technology for abrasion resistant, low friction ice coatings will give the following benefits:

1. The coating will last intact and smooth for many years in the harshest of icy waters. The currently inevitable extensive spot repairs and coating replacement at each dry-docking will be unnecessary.
2. The hull will remain smooth and retain its low friction properties, saving fuel and reducing emissions.
3. The ship using such a coating will deposit no toxic substances either in the ice or in the water column or sediment of sensitive areas. In other words, the hull will be environmentally sustainable.
4. The coating will lend itself to in-water cleaning to remove biofouling whenever this builds up and cleaning in drydock is impractical.
5. Any mechanical damage will be easy to patch and the resulting repair will leave the hull as smooth as on initial application of the coating.
6. Newbuilds will be able to take advantage of reduced scantlings, less steel and a lighter ship.

Part VI. Case Studies - Ecospeed/Ecoshield

Ecospeed® is a glassflake reinforced abrasion resistant certified, low friction ice coating that meets all the specifications covered above in section V. Best Available Technology. Ecoshield® is an even stronger version of Ecospeed which is designed to protect the ship's rudder and running gear which are more susceptible to wear from cavitation and corrosion damage. The best practice is to apply Ecospeed to the entire hull except for the rudder, thruster tunnel, nozzles and other parts of the underwater hull where Ecoshield would be used for maximum protection. The two are entirely compatible and each can be applied over or under the other.

Two case studies, one of an Antarctic icebreaker/supply vessel and one of a Baltic trading general cargo fleet, both converted to Ecospeed and Ecoshield, will demonstrate the performance of the coating in the real world.

Case Study 1: RRS *Ernest Shackleton*

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The British Antarctic Survey's (BAS) Royal Research Ship (RRS) *Ernest Shackleton* is ice strengthened and capable of a wide range of logistic tasks as well as having a scientific capability. It is primarily a logistics ship, used for the resupply of the BAS's stations, with occasional scientific and specialist tasking. *Shackleton* spends much of every year in the Antarctic where it frequently has to break through ice up to 2.5m thick, often with a high content of lava and gravel which which is especially abrasive and harsh.

Shackleton was initially coated with an industry standard, epoxy-based specialized ice paint in 1995, at build. BAS took over the

RRS Ernest Shackleton routinely has to force its way through ice up to 2.5 meters thick. Antarctic ice additionally carries lava and gravel making it even more abrasive.

Typical state of Shackleton's hull after a single season in the ice using a conventional, industry standard, specialized ice coating.

operation of the *Shackleton* in 1999. The harsh conditions in which the *Shackleton* operates seriously damaged the coating with the result that each season the coating had to be renewed or extensively repaired. Only the recommended coating repair product was used. The photos above show the typical state of the hull in drydock after a single season in Antarctic ice, despite this annual coating repair or renewal.

A variety of problems with the existing coating system led to the search for a better solution which culminated in switching to Ecospeed in 2009. The selection criteria used in choosing the new hull coating for the *Shackleton* are given here by Stephen Lee, then Senior Marine Engineer for BAS. "We looked at all the alternatives including the glassflake STC [Ecospeed] we eventually chose. There were a lot of comparisons between all of the products. Because of the nature of our business and where we operate we also required a paint system that would have significant environmental benefits as well as conforming to the Polar Code and latest classification societies regulations. We required a paint system which was cost-effective in purchase, application and maintenance. We wanted a simplified paint system that no matter where you went in the world a paint contractor would be able to apply it without having to rent in expensive equipment or shielding to ensure application could continue. We also wanted to be able to conduct minor repairs either by the yard paint contractor or our own crews. Ecospeed gives us this capability. Application of some of the more traditional icebreaker paint requires a twin feed paint system which means a great deal more care during the application process as well as ensuring all the environmentals are correct which can include tenting up space heaters around the area that is going to be painted. Comparing the other paints with Ecospeed they're very comparable as far as purchase price and performance generally in the broadest of terms, but the main, huge difference is the actual cost and complexity of application of the paint. The preparation is the same, 2.5 Sa over the hull, but the actual application, not having to get the environmentals right, not having to tent up the area if it's slightly cool, not requiring space heaters, if the area is gingered slightly which may or may not require a sweep blast before you can put the primer on – there's a huge amount of preparation and logistics that have to go into getting the initial coat of traditional ice-going paint onto the hull, whereas with Ecospeed it's minimal as long as you have a good paint inspector, and only minimum environmentals are needed."

"One of the inquiries I made before we put Ecospeed on the first time in 2009 was to see how compatible it was with the ICCP system that the vessel had, because the ship was suffering from the ICCP system not functioning properly. The main problem was not having an adequate paint system. Cathodic protection works best when the hull is undamaged and has a complete paint system covering the hull, unlike in *Shackleton's* case. Cathodic protection as most people understand works in conjunction with the paint. ICCP has never given complete hull protection but with a good paint system it will. Effectively a common ratio I use is 80% protection from paint and 20% protection from ICCP. A failure in one or the other will quickly see a deterioration in the paint system. With *Shackleton's* hull the ICCP continued to be ineffective simply because there was no complete paint system and therefore the ICCP system produced eddy currents around the hull, which resulted in the ICCP continually tripping, rendering

Ecospeed application to RRS Ernest Shackleton's hull in Denmark in 2009.

the system inoperative most of the time. Once we knew what type of paint system we were looking for, we checked into its compatibility with the cathodic system and realized that the actual paint system would act as a dielectric, so we've gone to 2000 microns around the anodes."

In 2009, the *Shackleton* was dry-docked in Denmark prior to its annual trek to the Antarctic. The hull was grit blasted and two coats of Ecospeed were applied, to a total DFT of 1000 µm. The areas around the anodes were given a thicker coating of 2000 µm as a means of ensuring maximum efficiency of the ship's ICCP. The rudder was not coated at that time. Nor was the area above the waterline.

After two seasons in the ice, the *Shackleton* was drydocked again in Denmark; the superintendent, engineers and paint specialists there to check the condition of the hull paint were amazed. After two seasons of battering its way through ice up to 2.5 meters thick with a high content of gravel and volcanic lava adding to its abrasiveness, the hull coating was virtually intact and undamaged. This was in strong contrast to the *Shackleton's* previous drydockings, when almost the entire hull was practically stripped to bare, unprotected steel.

The condition of the paint was carefully inspected. A professional, independent paint inspector took dry film thickness measurements around the hull and found the DFT to be around 970-1000 microns on average. Very little thickness had been lost. Some minor mechanical damage had occurred to the coating but this amounted to some chips and scrapes totaling less than 0.1% of the total surface area. Compared to the virtual

Shackleton's hull after two seasons in heavy ice. The coating is virtually intact with a few very minor scrapes and scratches (bottom right). Note that the boot top area above the water line and the rudder were not coated with Ecospeed in 2009 when the rest of the hull was converted to Ecospeed. They continued with the original coating. Thus the damage to the areas not protected with Ecospeed is quite severe. This omission was rectified during the 2011 docking.

total removal of all the paint which the crew of *Shackleton* had become used to before the application of Ecospeed, the damage was negligible and easily repaired. Only very minor touch-ups were required in drydock.

Stephen Lee, then Senior Marine Engineer for British Antarctic Survey, the BAS's equivalent of a Technical Superintendent, and the Antarctic Marine Engineering (AME) department were instrumental in the initial research which led to replacing the underwater hull coating in 2009. He recalls the reaction of those present when the Ernest Shackleton was first pulled out of the water at Frederikshaven drydock in early 2011. "The biggest thing was the surprise at seeing the areas where you'd expect it to have taken a lot of damage...when she first came out of the water and onto the blocks it was a complete shock to all those present. All of us there commented on the condition of the hull and in particular that there was negligible damage at the bows, merely some scratch marks. None of us there would have predicted this. I then jokingly asked the question, 'Are you sure you've taken this ship to the ice?'"

According to Stephen Lee, the crew of the *Shackleton* reported that they had been pushing into 2 - 2.5 meter thick ice, "...and it's just not touched it – just not touched it at all."

It was seeing the results after two seasons in the ice that led BAS to go up another level and have Ecospeed applied to the boot top area above the waterline so that it covers all the ice belt where mechanical damage normally occurs. The rudder was coated with Ecoshield during the 2011 drydocking so that it too could benefit from the same protection as the hull.

Two more seasons in the ice showed the coating to still be in excellent condition. When the ship was dry-docked in 2013, the

"All of us there commented on the condition of the hull and in particular that there was negligible damage at the bows, merely some scratch marks. None of us there would have predicted this. I then jokingly asked the question, 'Are you sure you've taken this ship to the ice?'"

During the 2011 dry-docking the area above the water line was coated with Ecospeed since it is an area much affected by ice abrasion and subject to damage. The rudder was coated with Ecoshield as it had not been repainted when the rest of the hull was painted in 2009.

amount of repair work due to mechanical damage was again minimal.

The ship had been cleaned inexpertly between dryockings so that, even though the barnacles were removed, the plates where the tenacious crustaceans had been attached were not cleaned off. Ecospeed is strong enough to withstand very aggressive cleaning if needed without suffering any damage. The barnacle plates would not wash off with pressure washing but were subsequently removed with standardly executed in-water cleaning leaving the coating in pristine condition.

The hull coating on the Shackleton *after four seasons in heavy ice is still in excellent condition, in strong contrast to how the hull looked after even a single season in ice with the previous coating system.*

BAS's RRS James Clark Ross *in typical Antarctic conditions (top), state of hull after a season in the ice with industry standard specialized ice coating (above left) and newly coated with Ecospeed in 2014, ready for relaunching.*

Five years of continued success with Ecospeed on *Shackleton* led BAS to switch in 2014 to the same coating for their advanced polar research ship, RRS *James Clark Ross*.

Case Study 2: Baltic trading – Interscan Cargo Fleet.

Case Study 2: Baltic trading – Interscan Cargo fleet

Interscan Schiffahrt is a family owned shipping company based in Hamburg, Germany. Founded in 1973, Interscan has a fleet of 23 container and multipurpose cargo ships ranging in size from 1,723 to 11,800 TDW. The larger container ships (6,288 TDW Karin, 8,201 TDW *Paphos, Pandora, Pioneer*, and 11,800 TDW *Elena, Pauline, Colleen*) are chartered worldwide. The smaller vessels, up to 3,500 tonnes, trade in northern Europe, generally in the Baltic, either on time charter or operated directly by Interscan. All Interscan owned or operated vessels carry International Safety Management (ISM) and International Ship and Port Facility Security (ISPS) certification.

Until 2005, all those ships trading in ice in the Baltic region went through a cycle of having all their underwater hull paint scraped off by the ice each winter and having to drydock to repaint every spring. The paint used was a standard epoxy coating.

In 2005 the then superintendent engineer decided to test the environmental and fuel saving benefits of a then novel, environmentally benign, hard, glassflake reinforced surface treated composite (STC) coating system, Ecospeed. MV *Patriot* was the first ship coated. The *Patriot* was in need of a full reblast at the time due to the build-up of multiple layers of epoxy, so the time was right to prepare the hull fully and apply Ecospeed. The *Patriot* is an 82.3 m LOA, 12.5 m beam, 3000 DWT, ice class E2/Finnish 1B general cargo vessel with a

MV Patriot before Ecospeed (top) showing the condition of the hull after each year of trading in ice using a conventional epoxy coating. This type of coating hd to be replaced annually after being virtually entirely removed during the winter. The hull was grit blasted (bottom left) and then given two coats of Ecospeed to a DFT of 1000 µm.

4.95 m draft and a design speed of 11.5 knots.

In June 2005 in drydock in Klaipeda, Lithuania, the underwater hull of Interscan's MV *Patriot* was blasted down to nearly white steel and was then given two coats of the STC, each about 500 µm DFT.

Two other Interscan vessels were recoated in the following two years. The first was the *Karin*, a 6,288 DWT, 100 m LOA ice class E3/Finnish 1A general cargo vessel. The second was the *Phantom*, the 3,220 DWT 82 m, ice class E3/Finnish 1A general cargo vessel.

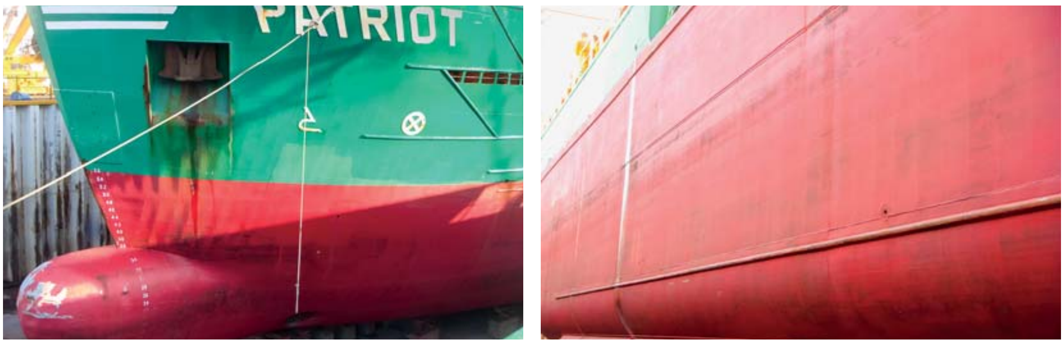
The *Patriot* was docked in November 2006 and after a year of trading in ice it was found that there was virtually no damage whatsoever to the coating, in strong contrast to Interscan's previous experience with underwater hull coatings.

Docked again in 2010, the coating was still found to be in excellent condition and needing almost no repair or touch-up.

Seven years after Ecospeed was applied Michael Tensing, in charge of Interscan's charter operations, said, "Now we are in 2012, she was here recently and the paint still looks good. That's the best advertisement you can have. For sure you don't have to do that much to the paint. It's only a bucket of paint for touch-ups, just cosmetics at the anchor or if you have mechanical damage or something." As he points out, there really is no other coating that could stand up to seven years of trading in ice and still remain intact and not in any need of repainting or repair beyond very minor touch-ups.

The success with the first three ships led to the further application of Ecospeed to four newbuilds in 2008 and 2009 in Gdansk, Poland: the *Paivi*, February 2008, the *Tim*, June 2008, the *Pernille*, October 2008 and the *Widor*, January 2009. All these ships are in the 3,000 - 3,500 DWT range, all ice class

MV Patriot after the first year of trading in ice with Ecospeed on the hull. The coating is virtually undamaged.



MV Patriot again in drydock after five years of trading in Baltic ice with Ecospeed on the hull. Minor mechanical damage requiring only very small touch-ups.

MV Paivi *ready for launching, with Ecospeed on the hull.*

E1, 2 or 3/Finnish 1A or 1B, all just over 82 m LOA general cargo vessels.

All these ships were coated with the STC at newbuild stage which is the ideal time to apply the coating, giving Interscan a total of seven ships using Ecospeed on their underwater hull.

Michael Tensing who ultimately took the decision to apply Ecospeed to the Interscan ships, has no regrets about his decision: "We had a special survey at Frederikshaven on the *Phantom*, 3,000 tonner, last year after the winter. I can tell you that was quite a surprise to the shipyard at Frederikshaven. We were the worst client the shipyard ever had! All that was required was simply cleaning. The paint job consisted only of one bucket for touch-ups. To my mind, for the Baltic it's the best product I have ever seen." That was after four years of trading in ice every winter.

When the first Ecospeed application was done in 2005, Interscan crunched some numbers and worked out that if the Ecospeed coating lasted more than 3.8 years without needing replacement, the company would have made the payback and be making money. That time period has been greatly exceeded for the first three vessels and will soon have been reached for all seven. So far all the ships have kept their coating in excellent condition.

The *Patriot* and the *Karin* have both had in-water cleaning since the coating was applied. In the case of the Baltic, very little fouling is seen to attach and this is cleaned off when the ship sails in ice in winter. The *Karin* was trading in tropical waters, however, and the hull became quite badly fouled, as is expected with a non-toxic coating. She was allowed to go too long without cleaning and lost 3 knots. The hull was eventually cleaned in Trinidad and she immediately went back to her design speed of 15 knots.

"To my mind anyway another major benefit is that when you go into drydock you don't have to rely on the weather any more which sometimes holds you in the dock," says Michael Tensing. "If it's raining for two weeks or so then you cannot leave due only to this point of repainting, because you completed all the other work. It makes less than no sense. From that respect alone I would always do it again."

Part VII: Conclusion

When considering the best possible protection for the hull and running gear of an ice-going vessel, there are a number of factors which must be taken into consideration, including tough corrosion protection, low friction, longevity, ease of application, toxicity and others. These have been well covered above.

Specifications and claims made on paper may or may not bear out in the real world. The real test is when the hull meets the ice and, not only that, when the hull continues to meet the ice over a period of years. Then the true picture emerges.

Ecospeed has been tested and proven to outlast and remain smoother than even leading, industry standard certified ice coatings when used in the harshest of environments.

To find out more about Ecospeed, visit the following websites:

www.ecospeed.be
www.ecospeed.us

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