IACS Unified Requirements for Polar Ships

Background Notes to

Materials

Prepared for:

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Summary

<Text: objectives, description>

Background: Materials

1. Current regulations

In the existing rules of individual classification societies for polar ships, as well as in the recently approved IACS UR S6.2&3 and Canadian ASPPR, the material selection is based on the concept that structural members operating in cold environment under high impact loads are to be made of higher steel grades. However, like in other aspects of the polar structural rules, the specific material requirements by different regulatory bodies differ considerably from each other. As a result, in spite of the very limited list of steel grades, different rules may not necessarily require the same steel grade for a structural member of a polar ship, and the difference may sometimes range wide.

2. Basic differences between the steel grades

According to IACS UR W11, steel grades A, B, D and E of normal strength and AH, DH, EH and FH of higher strength are distinguished based on the impact test requirements. For the normal-strength steel grades the requirements to their chemical composition, tensile properties (ultimate strength, yield point, elongation) and absorbed energy of CVN test are identical. The only difference is in the CVN-test temperature and in the amount of steel to be tested depending on the condition of steel supply (type of product, deoxidation method, and plate thickness) - see Table 1. The amount of steel to be tested depends on the plate thickness, deoxidation method, product type, and thermal treatment. No impact tests are required for grade A in thickness up to 50 mm and for grade B up to 25 mm, regardless of the type of thermal treatment, product type and deoxidation method.

Table 1. Testing temperatures and average absorbed energy levels for normal-strength steels

grade	**A**	**B**	**D**	**E**
temperature, °C	20	0	-20	-40
av. absorbed energy (long/trans.)**, J**	27/20	27/20	27/20	27/20

For the higher-strength steel grades (AH, DH, and EH), the requirements to chemical composition, tensile properties and impact test's absorbed energy are indiscriminate to steel grades and depend only on steel's nominal strength. (For grades FH the required chemical composition differs slightly.) And again, only the impact test temperatures and the amount of steel to be tested are different for the steel grades. For plates up to 50 mm thick the impact test temperatures and average absorbed energy values are given in Table 2. For plates up to 50 mm thick the amount of steel to be tested depends on plate thickness (except EH and FH, where each piece is to be tested), as well as on thermal treatment, steel grade and strength.

Table 2. Testing temperatures and average absorbed energy levels for higher-strength steels

grade	**AH**			**DH**			**EH**			**FH**		
nominal strength, kg/mm^2	32	36	40	32	36	40	32	36	40	32	36	40
temperature, °C		0			-20			-40			-60	
av. absorbed energy (long. dir.)**, J**	31	34	41	31	34	41	31	34	41	31	34	41

av. absorbed energy (trans. dir.)**, J**	22	24	27	22	24	27	22	24	27	22	24	27

CVN testing temperature is an arbitrary limiting value, which does not characterize the ductile-to-brittle transition temperature range, but simply confirms that the sample fails in a ductile mode at the testing temperature and above. It should be noted, however, that the transition temperature itself is not a stable material characteristic. It depends on testing technique (CVN, NDT, CTOD, DT, etc.), material defects (which relate to scale factor, i.e. to plate thickness), loading rate, stress state and level [as shown in Fig.1 of ASTM E208], structural restrains and other factors. Nevertheless, when more detailed information on the steel in question is not available, the CVN testing temperature can be interpreted as the coldest temperature to which the ductility of the steel is tested, i.e. as a reference point for the service temperature of the structure in question.

3. Shortcomings of UR S6.2&3

3.1. It was not intended for polar ships

Sections *S6.2 - Structures exposed to low air temperatures* and *S6.3 Design temperature* t_D were added to IACS UR S6 as Revision 2 in 1996 (rev. 1 was in 1980). These sections are addressed to any hull structures exposed to low ambient air temperatures but do not mention the ice-strengthened structures and do not distinguish ice classes of ships. No technical background or explanations for adoption of Revision 2 were produced at the time of adoption and none have been found yet. The apparently intended absence of any reference to ice class or ice strengthening implies that S6.2&3 was deliberately not intended for ships navigating in ice but only for hypothetical ships exposed to air temperatures below –20°C to as cold as –55°C. However, it is virtually impossible to find a sea area subjected to sustained air temperatures below –20°C where no sea ice forms and grows to a level that would require ice strengthening, especially in polar waters.

3.2. Steel grade selection is governed only by air temperature, ignoring ice class

The design temperature defined in S6.3 as "*the lowest mean daily average air temperature*" is inherently site-specific but ships are designed to operate in any polar waters as far as **ice conditions** (not air temperatures) permit. Air temperatures may vary greatly from site to site within a geographical area regardless of ice conditions. Within every geographical region the severest ice conditions take place a few months after the period of the coldest air temperatures. And the severest ice conditions do not necessarily take place in the coldest areas, e.g. ice conditions within Arctic archipelagos and river bays with restricted ice cover dynamics and limited access for in-coming m-y ice floes are not as severe as in open Arctic seas where air temperatures may be not as cold as within large archipelagos and continental bays. Thus, using S6.2&3 may result in a ship of a higher ice class designed to a lower material standard as compared with another ship of a lower ice class designed to a higher material standard. This also illustrates that S6.2&3 give room and motivation for manipulating the standard by selecting more favorable temperatures. The approach of S6.2&3 would also imply including individual operational areas as a part of vessel's ice class. It should also be noted, that there are no official (or commonly recognized) worldwide air temperature statistics, especially for polar waters. Therefore, one of the most complete and advanced data bases - the NOAA's* provides only the raw records of daily min, max and mean temperatures for all those points worldwide where any records are available but it does not provide statistical characteristics. As a result, air temperature statistics (daily mean, monthly mean, etc.) obtained from different sources can slightly differ

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* visit *http://www.ncdc.noaa.gov/onlineprod/gsod/climvis/gsod.html*

from each other by up to a few degrees due to different data bases and processing techniques used. But the requirements of three Tables 4 in S6.2 are designed so that a minor change in the temperature border lines (-20°C, -25°C, -35°C, -45°C) may result in a change by one steel grade, thus giving temptation and a room for manipulating the rules and using a sub-standard steel or requiring an over-conservative grade.

Thus, in summary, the controversy of S6.2&3 is due to the site-specific nature of temperature, the absence of an official worldwide data base which might be referred to in the rules, the absence or insufficient data for many polar areas, ambiguity in selecting the data and in their statistical processing, ambiguity in translating the air temperature statistics into the design temperature of steel, and so on.

3.3. The specifics of ice loading are ignored

Low temperature is a very important but not the only factor contributing to brittle fractures. Other factors of major importance include impact loading, stress level and state, and structural restrains of the member in question. These factors together with the importance of the structural member for general integrity and safety of ship are commonly considered in classification rules via material class assigned to every structural member - the approach adopted in IACS UR S6.1 for general hull structures but surprisingly ignoring the ice-affected members. As a result, according to second paragraph of S6.2 and Table 1 of S.6.1, the bow plating of an Antarctic RV intended for summer operations may be built of grade A steel regardless of its thickness. Another example: the submerged bow shell plating of an Arctic icebreaker may be made of grade A steel regardless of thickness - solutions which are hardly acceptable for a responsible designer.

3.4. Conclusion

These shortcomings demonstrate that the current UR S6.2&3, adopted without due consideration of navigation in ice, cannot be used for polar ships as well as for any ice-strengthened ship. They should be replaced by new material requirements for polar ships. The new rules should incorporate polar ice class as a primary factor in selecting the steel grades, assign appropriate material classes to ice-affected members, and unambiguously address the controversial issue of ambient air temperature effect. Moreover, and most importantly, the new rules should be based as much as possible on the accumulated worldwide experience of using steel grades in polar ships. The new rules should be compared, as a reference point, with the decades old existing <u>polar</u> rules of classification societies and CASPPR with many <u>polar</u> ship in class, but not with the recently enacted UR S6.2&3.

4. Basic concepts in developing the proposed IACS rules

Steel grades are the final product of the new requirements. No scientifically based formulas or proven empirical relationships exist for selecting the appropriate steel grades as a function of steel temperatures, loading rates and stress-strain parameters. After Japanese studies started in the late 1970's [Yajima&Tada, 1981 and others], a remarkable progress has been recently made in this field [e.g. Sumpter et al., 1995, Malik et al., 1997] making it possible to probabilistically predict some fracture toughness characteristics as a function of many factors including probabilities of various material defects. However, this progress didn't translate yet in commonly agreed scientific criteria for selecting the grades. The selection is mainly based on empirical rule requirements verified or not verified by practical experience.

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Rules of major classification societies provide generally adequate steel grades for polar ships with varying and often unspecified degree of conservatism. But the rules differ considerably between each other in details and procedures. Since the UR S6.2&3 does not address the nature of ice operations at all, the development of the unified rules for polar ships was based on the following concepts.

- The resulting grades should be basically in line with existing regulations for polar ships with some adjustments where it is justified by operational experience.
- Steel grade selection should be based on a minimum number of unambiguous criteria characterizing the cold environment, the dynamic nature of ice loads, the role of the structural element in question in ship safety, and the steel thickness. These basic criteria for steel grade selection can be reduced to only three parameters, namely:
  - polar ice class which characterizes generally the coldest ambient air temperatures of polar ship operations worldwide,
  - material class of the structural member in question, which characterizes the level and impact intensity of ice-induced stresses and the importance of the member for structural integrity and safety of the ship,
  - thickness of the structural member in question, which is a primary factor of brittle failure probability of the steel grade under stress at cold temperatures.

Temperature per se is undoubtedly a very important factor in selecting steel grades. However, the direct use of temperature for steel grade selection was considered inconvenient due to the ambiguity in quantifying the temperature effect on ships operating within vast geographical areas, and consequently due to potential for manipulating the rules. Polar ice class was taken in place of it as the appropriate criterion. According to the definitions of polar classes and the operational experience with the existing ships, which are believed to be a kind of prototypes for polar class divisions, the polar classes PC1-5 operate in polar waters for a considerably long time during the coldest winter months. Although the severity of critical ice conditions varies dramatically from PC1 to PC5, temperature-wise they are all exposed to virtually the same freeze level. Suffice to say that December-January temperature lows in Siberian and Canadian Arctic river bays and archipelagos can exceed those in the Beaufort or Chukchi Seas or in the Central Arctic, while the ice conditions in these bays/archipelagos can allow PC5 ships to operate there, at least during early (and coldest!) winter months. Therefore, the polar classes PC1 through PC5 are treated similarly with respect to their polar class though some exceptions can be made for PC5. This similarity doesn’t mean that the resulting steel grades would be the same for the same structural members of PC1 and PC4 or PC5, since the thickness of those plates may differ considerably from PC1 to PC5.

In the rules of many classification societies structural members that can be affected by ice contacts are grouped in two material classes. Of these ice-loaded members, Material Class II is assigned only to shell plating of the bow and intermediate areas, stem/stern frames and important appendages. All other ice-loaded members, as well as all supporting and stiffening members attached to the ice-loaded shell plating are rated as Material Class I. Material Class II is also assigned to the air and sea exposed hull girder members within 0.2L from FP categorized by UR S6.1 as “SPECIAL”. Other weather and sea exposed structural members categorized by UR S6.1 as “PRIMARY” and “SECONDARY” are rated as Material Class I. Thus, the proposed rules assign material classes for all structural members exposed both to the weather and to the sea. When the material class of the proposed polar rules is different from that of UR S6.1, the higher material class is to be applied.

As in all other rules, thickness of steel plates is recognized as a factor of primary importance and the required grades in the proposed rules are specified for plates up to 50 mm in with 5-mm intervals.

The resulting steel grades for all weather-exposed plating (from ice belt to upper decks) are to be taken from Table SG2 of the proposed rules. Steel grades for plating members, other than weather-exposed plating, are to be taken from UR S6.1 with the material class taken from the proposed rules or from S6.1 whichever is greater. Steel grades for supporting and stiffening structural members attached to weather-exposed plating are specified in the proposed rules depending on polar class and thickness only.

5. Operational experience

5.1. Brittle fractures

Based on the historical experience gained in the 1950's from widespread brittle failures in the great fleet of the WW2-era ships and subsequent studies, special steels manufactured and tested to provide sufficient fracture toughness at low temperatures have been used for the icebreakers and Arctic ships built in the 1960's and on. A major bulk of polar experience has been accumulated in the Russian Arctic where many tens (in some years up to two hundreds) of ice-strengthened ships and icebreakers operated for three decades, including year round navigation along the Western part of Northern Sea Route (NSR) in the late 1970's – 1980's. A summary of the conclusions learned from that experience on preventing brittle fractures in Arctic ships was published by Boitsov et al. [1989]. This study as well as the experience accumulated by leading Russian institutions such as AARI, CNIIMF, Krylov Institute and RR refers to numerous brittle fractures in cargo ships with sub-standard steels operating extensively in the Arctic water. At the same token, a great majority of Russian icebreakers (both Russian and Finnish built) and ULA cargo vessels built from the late 1950's and on have been made mostly of grade E or equivalent steels. They experienced virtually no brittle fractures. These findings were used by the Russian Register in developing its material requirements, which had been rated by Russian experts as being ambivalent and sometimes inadequate in the 1960'-70's, then rather conservative after changes in the early 1980's and sufficiently adequate in the late 1980's after some relaxation and adjustment.

Considerable experience has steadily been growing in the North American Arctic from the 1970's. Purpose icebreakers built almost entirely of grade E steels experienced no brittle fractures while cargo ships of relatively low or no ice classes built of grade A steels experienced a considerable number of brittle failures. This experience led from no requirements in CASPPR to developing rather conservative material requirements in the current Canadian Equivalent Standards [Tomin, 1990]. Much less, if anything new, was learned on steel performance in the Antarctic waters.

As a result of using the high-grade steels, the number of brittle fractures in Arctic ships reported in the 1970's had dramatically declined. In fact, virtually no brittle fractures were found in damaged ship structures made of high-grade steels, while the structures made of grade A and sub-standard steels have experienced brittle fractures with little or no plastic deformations. No brittle fractures have ever been reported for ice-affected structures of high ice class polar icebreakers and icebreaking cargo vessels. This is because all of them, regardless of then-existing rules, were made mainly of high (mostly E) grade steels or their equivalents.

Study by Wells-Keinonen-Revill [1993], focused on ice damages to ASPPR Type vessels in the Canadian Arctic, summarizes many hull damage incidents and outlines a considerable number of brittle fractures in submerged bow structures made of grade A steel. The authors emphasize the principal difference in operation of the Baltic ice class vessels in the Canadian Arctic waters versus the winter Baltic. They demonstrate, that contrary to the winter Baltic where damages are distributed over the vessel's length and are caused mainly by ice compressions [Kujala, 1991], the damages to the Type ships in Canadian Arctic **in summer** (including numerous brittle fractures) are mainly concentrated in the bow area due to impacts against multi-year (as well as first year) ice floes. Moreover, they found that many brittle fractures occur within the submerged bow areas, including below the ice belt where the steel temperature is close to zero but the stress level and loading rate are high.

The principal difference in distribution of ice-induced damage to hull structures of IA/IAS ships in Baltic and Arctic waters is very well corroborated with the study by Tsoy & Karavanov [1992] based on surveying the hull damages to tens of vessels including many RR L1. According to this study, up to 80% of all damage to cargo vessels in the Arctic occurs within the fore part of the hull, which demonstrates the high role of impact ice/hull interaction in Arctic as opposed to static interaction in the Baltic. The virtual absence of brittle fractures in Tsoy's report is due to high-grade steels used in the Russian ships as was required by RR Rules. And the presence of brittle fractures in the Wells' report is due to wide use of grade A steel allowed by the then-existing Baltic rules.

A brief note presented by CNIIMF [Tsoy, 1998] on the brittle fractures surveyed during the 1970's on the Soviet icebreakers and Arctic cargo vessels operating on their NSR shows that a small number of brittle fractures have occurred only in the weather-exposed upper decks, forecastle decks and superstructures during December-January. A few of the fractures have been reported in the upper deck of the Arctic/Antarctic supply vessel *Ob* (RR ULA) made of a steel which was supposedly equivalent at least to grade D.

A search for brittle fracture records during 1977-1997 in more than 300 LR-classed ships of IA and IAS Baltic classes [E-mail by L. Karaminas] revealed only four cases of brittle fractures in various structures (long. bhd, side shell, deck plating, bottom plating) made of grade A steel. However, the LR records provide no information attributing these fractures to ice actions or cold weather and whether the ships have ever been operating in the Arctic.

5.2. Steel grades used in the existing polar ships

Experience with the steel grades installed on ships with considerable history of operations in polar waters is an important component in developing and calibrating the new standard. In recognition of the role of such experience, data on the existing polar ships have been provided by the SWG members for more than three dozens of ships as shown in Tables 3A & B. Some entries in these tables refer only to the first of a series of many sister ships (e.g. 15 sister ships in SA-15 series). It is also interesting to compare the grades used with the grades that would be required by existing standards. As agreed by the SWG, only two standards have been selected for comparison: Canadian Equivalent Standard and Russian Register rules. This is due to the fact that a great majority of the existing polar ships have been built to either of the two. The grades resulting from the proposed requirements are included in the table, as well as the grades resulting from UR S6.2&3.

When applying a standard to a ship built to another standard, certain assumptions have to be made. They are as follows.

- In interpreting the Canadian standard, all Canadian Class ships are assumed to be CAC ships. Of the ships built to other standards, all icebreakers and ULA ships are treated as CAC ships, other ships are treated as Type ships.
- In applying RR rules, all ships in Table 3A are treated as LL1-LL4 icebreakers or ULA, while those in Table 3B are assumed to be UL and L1.
- In applying S6.2&3 the design temperature of –40°C is assumed for ships in Table 3A (i.e. for PC1-5). For ships in Table 3B (i.e. for PC6&7) temperatures of -26°C and -25°C are used to demonstrate the sensitivity of S6.2&3 to a minor temperature variation.

Some of the ships are placed both in Table 3A and 3B since their equivalency to either PC5 or PC6 seemed disputable.

It should be noted that the comparison between the grades installed and required contains a considerable degree of ambivalence because a majority of the existing ships were built to old versions of the rules with different or no requirements for materials. As the tables show, in many cases, especially for low polar classes, the designers preferred a conservative selection of steel grades for major ice-affected structures regardless of the then-existing regulations.

Tables 3A&B: Comparison of as-built and required steel grades for the existing ships

Notes to the tables. In assessing the steel grades, the following assumptions were made:

- **CASPPR**: Non-Canadian ships listed in Table 3A are treated as CAC ships and in Table 3B as Type ships;
- **RR:** Non-Russian Register's ships are treated as LL1-LL4 & ULA in Table 3A, and as UL and L1 in Table 3B;
- **UR S6**: Design temperature of -40°C is assumed for ships in Tables 3A and -26°C & -25°C for ships in Table 3B.

Table 3A. Comparison for the existing ships considered as being equivalent to PC1-PC5

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6
1	I/B *Arktika+4* LL1, RR	Side plating within bow area at LWL	44.5	EH eq	E	E	E	E
		Side plating at midship at LWL	32	EH eq	E	D	D	E
2	I/B *Taymyr+1* LL2, RR	Side plating within bow area at LWL	42	EH eq	E	E	E	E
		Side plating at midship at LWL	34	EH eq	E	D	D	E
		Deck stringer at ~0.15L from FP	15	EH eq	DH	D	D	E
3	I/B *Ermak+2* LL2, RR	Side plating within bow area at LWL	45/40	EH eq	E	E	E	E
		Side plating at midship at LWL	40/35	E26	E	D	D	E
4	I/B *Moskva+4* LL3, RR	Side plating within bow area at LWL	48	E30	E	E	E	E
		Side plating at midship at LWL	40/35	E30	E	D	D	E
		Side plating at stern at LWL	45	E30	E	E	E	E
5	LASH *Sevmorput* ULA, RR	Side plating within bow area at LWL	32	E36	E	E	E	E
		Side plating in midship/stern at LWL	26/28	E36	E	D	D	E
		Deck stringer at ~0.15L from FP	20	E36	DH	E	D	E
		Deck stringer 0.4L midship	26	E36	E	E	E	F
6	I/B *Oden* Polar20, DNV	Side plating within bow area at LWL	48	E49	E	E	E	E
		Side plating at midship at LWL	34	E49	E	D	D	E
7	MV *Arctic* CAC4 LR	Side plating within bow area at LWL	56/47/36	E	E	E	E	E
		Side plating at midship at LWL	32	E36	E	D	D	E
		Side plating at stern at LWL	23, 25	B, A	E	B	D	D
		Deck plating 0.4L midship	27	D	EH	E	E	E
		Deck stringer 0.4L midship	27	D	EH	F	E	F
		Sheerstrake 0.4L midship	27	E	F	F	E	F
		Deck plating at 0.1L	22, 16, 22	B, A, D	DH	D	D	D
		Side frames	28, 32,	DH	E	D	D	A
		Deck longitudinals	27	A	EH	E	D	A
		Stern frames	12.5,16	A	E	B	B	A
8	I/B RV *Polarstern* Arc2, GL	Side plating within bow area at LWL	43.5	E36	E	E	E	E
		Side plating at midship at LWL	34.5	E36	E	D	D	E
		Deck stringer at ~0.15L from FP	13/11	E	DH	D	D	D

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6
		Sheer strake at midship	12.5	E	E	E	E	E
9	CCG I/B *L. S. St.Laurent* (New Bow) CAC2	Side plating within bow area at LWL	50/41	EH36	E	E	E	E
		Side plating at midship at LWL	50.8/44.5	EH36	E	E	E	E
		Deck stringer at midship	9.5	A	E	D	E	E
		Deck stringer within bow area	9.5, 8	A; B	DH	B	B	D
		Sheer strake at midship	15.9	D	E	E	E	E
		Submerged bow side plating	43	EH36	DH	D	E	A
		Bottom plating in forward area	43	EH36	B	B	D	A
10	CCG **Pierre Radisson** **Sir John Franklin** **CAC3**	Side plating within bow area at LWL	43	E	E	E	E	E
		Side plating at midship & aft at LWL	43/38	E	E	E/D	E/D	E
		Deck stringer 0.5L midship	11.9	A?	E	E	E	E
		Deck stringer in forward area	12.7	A?	DH	D	D	D
		Upper deck plating 0.4L midship	8.7	A	E	D	B	D
		Sheer strake at midship	12.7	D	E	D	E	E
		Submerged bow side plating	43	EH36	DH	D	E	A
		Bottom plating in forward area	32	E	B	B	B	A
11	CCG **Henry Larsen** **CAC4**	Side plating within bow area at LWL	35/38	EH36	E	D/E	E	E
		Side plating at midship at LWL	35	EH36	E	D	D	E
		Deck stringer at midship area	18, 19	EH36	E	F	E	E
		Deck stringer from 0.15L to FP	20	EH36	DH	E	D	E
		Sheer strake at midship	25/22	EH36	E	F	E	F
		Submerged bow side plating	38	EH36	DH	D	D	A
		Bottom plating in forward area	38, 25	EH36, A	B	B	B	A
12	I/B **Terry Fox** **Kalvik** **CAC4**	Side plating within bow area at LWL	38, 41	EH36	E	E	E	E
		Side plating at midship & aft at LWL	38	EH36	E	D	D	E
		Deck stringer at midship	19	EH36	E	F	E	E
		Deck stringer from 0.25L to FP	14	EH36	DH	E	D	E
		Sheer strake at midship	27	EH36	F	F	E	F
		Submerged bow side plating	41	EH36	DH	D	E	A
		Bottom plating in forward area	20	E	B	A	B	A
13	I/B & RV *Nathanie Palmer* A2, ABS	Side plating within bow area at LWL	40	EH36	E	E	E	E
		Side plating at midship at LWL	32	EH36	E	D	D	E
		Deck stringer at ~0.15L from FP	10	EH36	DH	D	B	D
14	I/B *Fennica+1* Polar10, DNV	Side plating within bow area at LWL	38	EH49	E	E	E	E
		Side plating at midship at LWL	23	EH49	E	D	D	D
15	CCG I/B *J.E. Bernier*	Side plating within bow area at LWL	32, 25.4	E	E	D	E	E
		Side plating at midship at LWL	22.1, 20.6	E	E	B	D	D
		Sheerstrake at midship	22.1, 20.6	E	E	F	E	F
		Upper deck plating 0.4L midship	10.9, 7.9	A	E	D	D	E/D
		Submerged bow side plating	32	E	DH	B	D	A
		Bottom plating in forward area	25.4, 19	E	B	A	A	A
16	CCG I/B *Martha L. Black* CAC4	Side plating within bow area at LWL	31.5	EH36	E	D	E	E
		Side plating at midship at LWL	24	EH36	E	B	D	D
		Sheerstrake at midship	24, 18.5	E	E	F	E	F/E
		Submerged bow side plating	31.5	EH36	DH	B	D	A
		Bottom plating in forward area	31.5	E	B	B	B	A
21	Multi-Purpose *SA-15* **Norilsk** & 18 sister	Side plating within bow area at LWL	36, 34-33	E32	E	E	E	E
		Side plating at midship at LWL	24.5	E32	E	D	D	D
		Side plating within stern area	28-30	E32	E	E	D	E
		Shearstrake0.4L midship	25	E32	E	E	E	E
		Deck stringer 0.4L midship	15	E32	E	E	E	E

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6
	ships ULA, RR	Deck stringer at ~0.15L from FP	20	E32	DH	E	D	E
22	Antarc. Supply *Vitus Bering+4* ULA, RR	Side plating within bow area at LWL	25	E40	E	E	D	D
		Side plating at midship at LWL	18	E40eq	E	D	D	D
		Deck stringer at ~0.15L from FP	14	E40eq	DH	D	D	E
23	RV *Mikhail Somov* UL, RR	Side plating within bow area at LWL	28	E40eq	E	D	E	E
		Side plating at midship at LWL	18	E40eq	E	B	D	D
		Deck stringer at ~0.15L from FP	14	E40eq	DH	D	D	E
24	*Samotlor+13* UL, RR	Side plating within bow area at LWL	28/23	E30	E	D	E/D	E/D
		Side plating at midship at LWL	21	E32	E	B	D	D
25	Tanker *Ventspils* & 9 sister ships UL, RR	Side plating within bow area at LWL	18	E32	E	B	D	D
		Side plating at midship at LWL	14	E32	E	B	B	D
		Deck stringer at ~0.15L from FP	10	E	DH	D	B	D
		Shearstrake 0.4 midship	10.5	E	E	E	E	E
26	BulkCarrier *Dmitriy Donskoi* & 12 sister ships UL, RR	Side plating within bow area at LWL	27/25/22	D32eq	E	D	E*/D/D	E/D/D
		Side plating at midship at LWL	20	B30	E	B	D	D
		Shearstrake at midship	24	E	E	E	E	F
		Deck plating at midship	28	D32eq	EH	E	E	E
27	Timber carrier *Pr. 151* UL, RR	Side plating within bow area at LWL	22	E	E	D	D	D
		Side plating at midship at LWL	18	E	E	B	D	D
		Deck stringer at ~0.15L from FP	13	D	DH	D	D	E
28	Tanker *Pr. 756* UL, RR	Side plating within bow area at LWL	22	E32	E	D	D	D
		Side plating at midship at LWL	17.5	E32	E	A	D	D
		Deck stringer at ~0.15L from FP	13	E	DH	D	D	E
29	Timber carrier *Pr. 749* UL, RR	Side plating within bow area at LWL	20	D32	E	B	D	D
		Side plating at midship at LWL	15	D32	E	A	B	D
		Deck stringer at ~0.15L from FP	15	B	DH	D	D	E
30	RV *L.M.Gould* A1, ABS	Side plating within bow area at LWL	25	E36	E	D	D	D
		Side plating at midship at LWL	18	E36	E	B	D	D
		Deck stringer at ~0.15L from FP	9.5	E36	DH	D	B	D
31	Tanker *Lunni+3* 1AS; DNV	Side plating within bow area at LWL	24	A	E	D	D	D
		Side plating at midship at LWL	17	A	E	B	D	D
32	Gen. Cargo *Amguema +2* ULA, RR	Side plating within bow area at LWL	28	EH40eq	E	D	E*/D/D	E/D/D
		Side plating within midship at LWL	20	EH40eq	E	B	D	D
		Side plating within stern area at LWL	24	EH40eq	E	B	E	F
		Shearstrake 0.4L midship	16	EH40eq	E	E	E	E

* D for the lower strake

Table 3B. Comparison for the existing ships considered as being equivalent to PC6-PC7

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6 -26/-25
20a	Tanker *Samotlor* UL, RR	Side plating within bow area at LWL	28/23	E30		D	D/B	D
		Side plating at midship at LWL	21	E32		B	B	D

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6 -26/-25
21a	Tanker *Ventspils* UL, RR	Side plating within bow area at LWL	18	E32		B	B	D / B
		Side plating at midship at LWL	14	E32		B	B	D / B
		Deck stringer at ~0.15L from FP	10	E		D	B	D / B
		Shearstrake 0.4 midship	10.5	E	E	E	E	E / D
22a	Bulk carrier *Dmitriy Donskoi* UL, RR	Side plating within bow area at LWL	27/25/22	D32eq		D	D/B/B	D
		Side plating at midship at LWL	20	B30		B	B	D / B
		Shearstrake at midship	24	E		E	D	E
		Deck plating at midship	28	D32eq		E	D	E / D
23a	Timber carrier *Pr. 151* UL, RR	Side plating within bow area at LWL	22	E		D	B	D
		Side plating at midship at LWL	18	E		B	B	D / B
		Deck stringer at ~0.15L from FP	13	D		D	B	D
24a	Tanker *Pr. 756* UL, RR	Side plating within bow area at LWL	22	E32		D	B	D
		Side plating at midship at LWL	17.5	E32		A	B	D / B
		Deck stringer at ~0.15L from FP	13	E		D	B	D
25a	Timber carrier *Pr. 749* UL, RR	Side plating within bow area at LWL	20	D32		B	B	D / B
		Side plating at midship at LWL	15	D32		A	B	D / B
		Deck stringer at ~0.15L from FP	15	B		D	B	D
27a	Tankers *Lunni* 1AS; DNV	Side plating within bow area at LWL	24	A		D	B	D
		Side plating at midship at LWL	17	A		B	B	D / B
41	**Pr. 15750** L1 RR	Side plating within bow area at LWL	20	D32		B	B	D / B
		Side plating at midship at LWL	14	D32		A	B	D / B
		Deck stringer at ~0.15L from FP	10	D32		B	B	D / B
42	*Pr. 16540* L1 RR	Side plating within bow area at LWL	14	D40		B	B	D / B
		Side plating at midship at LWL	14	D40		A	B	D / B
		Deck stringer at ~0.15L from FP	13	B		B	B	D
43	Timber carri. **Petrozavodsk+19 L1, RR**	Side plating within bow area at LWL	20	A32		B	B	D / B
		Side plating at midship at LWL	15	A32		A	B	D / B
		Deck stringer at ~0.15L from FP	15	A32		D	B	D
44	Bulk carrier *Federal Franklin* **Federal Baffin** **1A, DNV**	Side plating within bow area at LWL	34	AH32		D	D	D
		Side plating at midship at LWL	26	AH		B	B	D
		Shell plating within stern area	24,25, 26	AH32		B	B	D
		Sheerstrake 0.4L midship	19.5	AH32		E	D	E / D
		Deck stringer 0.4L midship	19.5	AH32		E	D	E / D
		Deck plating 0.4L midship	19.5	AH32		D	B	D
		Deck plating forward 0.1L	13	A, AH		B	B	D
		Side frames within bow & other areas	17,13, 12	AH32		A	B	A
		Deck longitudinals 0.4L midship	13	AH32		B	B	A
45	Bulk carrier *Federal Polaris* **Federal Fuji** **Federal Agno** **1A, LR**	Side plating within bow area at LWL	23-24.5, 25	A, AH32		B	B	D
		Side plating at midship at LWL	17.5	AH32		A	B	D / B
		Shell plating within stern area	16.5	AH32		A	B	D / B
		Sheerstrake 0.4L midship	21.5	AH32		E	D	E
		Deck stringer 0.4L midship	19.5	AH32		E	D	E / D
		Deck plating 0.4L midship	19.5	AH32		D	B	D
		Deck plating forward 0.1L	11	AH32		B	B	D
		Side frames within bow & midship	13, 12	AH32		A	B	A
		Deck longitudinals 0.4L midship	10	AH32		B	B	A
46	Bulk carrier E3 (1A), GL	Side plating within bow area at LWL	18	D32		B	B	D / B
		Side plating at midship at LWL	14	D32		A	B	D / B
		Deck stringer at ~0.15L from FP	14	D32		D	B	D
		Sheer strake at midship	14	D32		D	D	E / D
47	Ro-Ro E4 (1A S) GL	Side plating within bow area at LWL	28/23	D		D/B	D/B	D
		Side plating at midship at LWL	20	D		B	B	D / B
		Deck stringer at ~0.15L from FP	16	A		D?B	B	D
		Sheer strake at midship	12	A		D	D	E / D

	Polar ship and ice class	Structural member and its location	As-built steel		Grade as required by:			
			t, mm	grade	CASPPR	RR	Proposed	UR S6 -26/-25
48	Bulk Carrier 1A S LR	Side plating within bow area at LWL	15.5	AH36		B	B	D / B
		Side plating at midship at LWL	12	AH36		B	B	D / B
		Submerged bow side plating	15.5	AH36		B	B	A
		Deck plating 0.4L midship	25	A		D	B	D

For all ships in Tables 3 no brittle fractures have been reported by the sources who provided these data either because the ships experienced no brittle fracture or because operational data on brittle fractures were unavailable. Tables 3 do not show a dramatic difference between the rules but show a considerable difference between any of the rules and the as-built grades. This is again due to the time gap as mentioned above. Tables 3 give pictures of many individual cases but for outlining general situation the information can be rearranged to summarize what is available for each thickness range of each material class, as shown in Tables 4. Here, the ship numbers from Tables 3 are entered as subscripts at steel grades used in polar ships, e.g., for thicknesses from 20 to 25 mm of Material Class II, grade A steel was successfully used in ship 31 (*Lunni* & 3 sister ships), grade D in ship 26 (*Dm. Donskoi* & 12 sister ships), and grade E for ships 22, 24, etc. while the proposed UR would require grade D for these members. That means that grade D required by the proposed rules has been directly confirmed in only one *Dm. Donskoi* series of 13 ships in Table 3A and grade A was successfully used in another series of 4 ships. Are these samples enough to justify the required grade D? There is no definite answer to this question, but it looks likely that the experience of these two series of ships with their bow plating made of D and A gives a certain level of confidence in allowing grade D for this thickness range of Material Class II.

Table 4A. Operational Experience versus Proposed Rules for **PC1-5**

Thickness, mm	Material Class I Grades used *[Proposed]*	Material Class II Grades used *[Proposed]*	Material Class III Grades used *[Proposed]*
≤10	N/A *[B]*	$A_{9,10,15}$, $B_{9?}$, E_{25}, *[B]*	$A_{9?}$, $E_{13,30}$, *[E]*
10<t≤15	E_{25}, D_{29}, *[B]*	$A_{10?,15}$,B_{29},$D_{9,27}$, $E_{2,8,12,22,23,28,32}$, *[D]*	$A_{10?}$, D_{28}, $E_{8,21,25}$, *[E]*
15<t≤20	A_{31}, $B_{7,26}$,$E_{12,21,22,23,27,28,32}$, *[D]*	D_{29}, $E_{5,11,25,32}$, *[D]*	$D_{9,10?}$, $E_{11,12,16,30}$, *[E]*
20<t≤25	B_7, D_7, $E_{11?,14,15,16,21,24,32}$, *[D]*	A_{31}, D_{26}, $E_{22,24,27,28,30,}$ *[D]*	$E_{11,15,16,26}$, *[E]*
25<t≤30	$E_{5,21}$, *[D]*	$D_{7,26}$, E_{15}, *[E]*^{2}	D_7, $E_{7,12,28}$, *[E]*
30<t≤35	$E_{1,2,3,4,6,7,8,10,11,13,16}$, *[D]*	$E_{5,15,21,23,24}$, *[E]*	N/A *[E]*
35<t≤40	$E_{3,4,10,11,12,15}$, *[D]*	$E_{3,7,12,13,14,16,21}$, *[E]*	N/A *[F]**
40<t≤45	$E_{9,10,12}$, *[E]*	$E_{1,2,3,8,9,10,12}$, *[E]*	N/A *[F]**
45<t≤50	E_9, *[E]*	$E_{4,6,7,9}$, *[E]*	N/A *[F]*

Note: * E for PC4&5

Table 4B. Operational Experience versus Proposed Rules for **PC6-7**

Thickness, mm	Material Class I Grades used *[Proposed]*	Material Class II Grades used *[Proposed]*	Material Class III Grades used *[Proposed]*
≤10	D_{42}, E_{25a}, *[B]*	$D_{41,42}$, *[B]*	A_9, *[B]*
10<t≤15	$B_{43,44,45,48}$, E_{25a}, $D_{29a,41,46}$, *[B]*	$B_{29a,42,43}$, E_{28a}, $D_{27a,46}$, *[B]*	A_{47}, $D_{28a,46}$, E_{25}, *[D]*
15<t≤20	A_{31}, $B_{26a,45,48}$, D_{47}, $E_{27a,28a}$, *B]*	A_{47},$B_{43,44,45,48}$, E_{25a}, $D_{29a,41,46}$, *[B]*	$B_{44,45}$, *[D]*
20<t≤25	B_{44}, E_{24a}, *[B]*	$A_{31a,45,48}$,B_{45},$E_{24a,27a,28a,}$$D_{26a,47}$, *[B]*	B_{45}, E_{26a}, *[D]*
25<t≤30	B_{44}, *[B]*	$D_{26a,47}$, E_{24a}, *[D]*	E_{28a}, *[E]*
30<t≤35	N/A *[B]*	B_{44}, *[D]*	N/A *[E]*
35<t≤40	N/A *[D]*	N/A *[D]*	N/A *[E]*
40<t≤45	N/A *[D]*	N/A *[D]*	N/A *[E]*
45<t≤50	N/A *[D]*	N/A *[D]*	N/A *[E]*

Table 4C. Operational Experience versus Proposed Rules for framing members

Thickness, mm	PC1-5	PC6-7

≤20	A_{7}, *[B]*	$B_{44,45}$, *[B]*
20<t≤35	A_{7}, D_{7}, *[D]*	N/A *[B]*
35<t≤45	N/A *[D]*	N/A *[D]*
45<t≤50	N/A *[E]*	N/A *[D]*

In Tables 4 all kinds of structural members of the same material class are placed together, e.g. column “Material Class II” includes both the shell plating within bow/intermediate areas, deck plating within 0.4L midship and shearstrake in bow area. In Table 5 these groups of material classes are placed separately what provides another view on the data on used and required grades.

Table 5A Steel grades used and required for **PC1-5**

Thickness, mm	Grades used	Proposed	CASPPR	RR	S6
Material Class I - Shell plating within midbody and stern areas					
≤10		B	E	A	D
10<t≤15	D_{29}, E_{25},	B	E	A	D
15<t≤20	A_{31}, B_{26}, $E_{22,23,27,28,30,32}$,	D	E	B,A	D
20<t≤25	A_{7}, B_{7}, $E_{15,16,21,24}$,	D	E	B	D
25<t≤30	$E_{5,21}$,	D	E	B	E
30<t≤35	$E_{1,2,3,4,6,7,11,13}$,	D	E	D, B	E
35<t≤40	$E_{3,4,8,10,12}$,	D	E	D	E
40<t≤45	$E_{4,9,10}$,	E	E	E	E
45<t≤50	E_{9},	E	E	E	F
Material Class II - Shell plating within the bow/intermediate area					
≤10		B	E	B, A	D
10<t≤15		D	E	B&A	E
15<t≤20	D_{29},	D	E	B	E
20<t≤25	A_{31}, D_{26}, $E_{22,24,27,28,30}$,	D	E	D	E
25<t≤30	D_{26}, $E_{15,23,24,32}$,	E	E	D	E
30<t≤35	$E_{5,11,15,16,17}$,	E	E	D	F
35<t≤40	$E_{3,7,11,12,13,14,17}$,	E	E	D,E	F
40<t≤45	$E_{1,2,3,8,9,10,12}$,	E	E	E	F
45<t≤50	$E_{4,6,7,9}$,	E	E	E,F	F
Material Class II – Deck plating within 0.4L midship; Deck stringer at 0.15L from FP					
≤10	$A_{9,10,15}$, B_{9}, $E_{13,25,30}$,	B	E	D,B	D
10<t≤15	$A_{10?,15}$, B_{29}, D_{27}, $E_{2,8,12,22,23,28}$,	D	E	D	E
15<t≤20	A_{7}, $E_{5,11,21}$,	D	E	E,D	E
20<t≤25	B_{7}, D_{7}, E_{16},	D	E	E	E
25<t≤30	$D_{7,28}$,	E	E	E	E
30<t≤35		E	E	EH	F
35<t≤40		E	E	F, EH	F
40<t≤45		E	E	F	F
45<t≤50		E	E	F	F
Material Class III - Deck stringer and shearstrake within 0.4L midship					
≤10	$A_{9?}$,	E	E	D	E
10<t≤15	A_{10}, D_{10}, $E_{8,21,25}$,	E	E	DH, E	E
15<t≤20	D_{9}, $E_{11,12,16,32}$,	E	E	F, EH	E
20<t≤25	$E_{11,15,16,21,26}$,	E	E	F, E40	F
25<t≤30	$E_{5,7,12}$,	E	F	F	F
30<t≤35		E	F	F	F
35<t≤40		F*	F	F	F
40<t≤45		F*	F	F	F
45<t≤50		F	F	F	F

* E for PC4-5

Table 5B Steel grades used and required for **PC6&7**

Thickness, mm	Grades used	Proposed	CASPPR	RR	S6.2&3 -26°C / -25°C
Material Class I - Shell plating within midbody and stern areas					
≤10		B		A	B / A
10<t≤15	$B_{43,48}$, $D_{25a,41,42,46}$, E_{21a},	B		A	D / B
15<t≤20	A_{27a}, $B_{22a,45}$, D_{47}, $E_{23a,24a}$,	B		B,A	D / B
20<t≤25	B_{44}, E_{20a},	B		B	D
25<t≤30	B_{44},	B		B	D
30<t≤35		B		D,B	D
35<t≤40		D		D	E / D
40<t≤45		D		E, DH	E / D
45<t≤50		D		E, DH	E
Material Class II - Shell plating within the bow/intermediate area					
≤10		B		A	D / B
10<t≤15	D_{42},	B		B, A	D
15<t≤20	$B_{43,48}$, $D_{25a,41,46}$, E_{21a},	B		B	D
20<t≤25	$A_{24a,45}$, B_{45}, $D_{22a,47}$, $E_{20a,23a,24a}$,	B		D,B	E / D
25<t≤30	$D_{22a,47}$, E_{20a},	D		D	E / D
30<t≤35	B_{44},	D		D	E
35<t≤40		D		E,D	E
40<t≤45		D		E	F / E
45<t≤50		D		F,E	F / E
Material Class II - Deck plating within 0.4L midship; Deck stringer at 0.15L from FP					
≤10	D_{41}, E_{21a},	B		B	D / B
10<t≤15	$B_{25a,42,43,44,45}$, $D_{23a,46}$, E_{24a},	B		D, B	D
15<t≤20	A_{47}, $B_{44,45}$,	B		D	D
20<t≤25	A_{48},	B		D	E / D
25<t≤30	D_{22a},	D		DH, E	E / D
30<t≤35		D		F, E, D40	E
35<t≤40		D		F, E40	E
40<t≤45		D		F, E40	F / E
45<t≤50		D		F	F / E
Material Class III - Deck stringer and shearstrake within 0.4L midship					
≤10		B		D	D
10<t≤15	A_{47}, D_{46},	D		D	E / D
15<t≤20	$B_{44,45}$,	D		E, DH	E / D
20<t≤25	B_{45}, E_{22a},	D		F, E, D40	E
25<t≤30		E		F, EH	E
30<t≤35		E		F, E40	F / E
35<t≤40		E		F	F / E
40<t≤45		E		F	F / E
45<t≤50		E		F	F

5.3. Verification

“Verification” is understood as a situation when the steel grade required by the proposed rules has already been successfully used in polar ships with a sufficiently long history of polar operations. How many ships and how long operational periods are sufficient to verify is an open question. But we assume that the verification is satisfactory if there are at least two polar ships where the grades in question or lower are installed with at least 10 years of successful polar service for each. When there is only one ship or polar service is shorter, the verification might be rated as uncertain (existing but incomplete). And there is no verification when all ships have grades higher than required by the proposed rules. The data presented in Tables 3, though far from being comprehensive, provide a sufficient base for distinguishing the thickness ranges where the proposed rules are satisfactory verified, where there is no certain verification and where verification is not available at all. The latter are basically that marked N/A (not available) in Tables 4.

Thickness ranges where verification is **not available** include structural members of Material Class III as thick as approximately 30-35 mm and more for all polar classes. Material Class III includes mainly shearstrakes, deck stringers, continuous longitudinal hatch coamings and deck strakes at longitudinal bulkheads. For these members one should not expect to find thicknesses in excess of ~35 mm in the existing polar ships, which are relatively small (less than ~65,000 ton in displacement) and do not include container carriers where such thicknesses could probably be found. Also absent in the real polar ships of PC6&7 are thick plates of Material Classes I and II. Bow shell plates are the thickest plates of Material Class II in polar ships. In the existing ships of ~PC6&7 these plates do not exceed ~35 mm. A similar situation is with Material Class I of PC6&7 where icebelt plates in the midship and stern areas do not exceed ~30 mm. And lastly, the framing members in polar ships are considerably thinner than the plating and therefore are rarely more than 30 mm thick.

Thickness ranges of **satisfactory verification** include:

- thicknesses up to 30 mm for Material Class III of PC1-5,
- virtually all thicknesses for Material Class II of PC1-5,
- thicknesses of up to 30 mm and more than 40 mm for Material Class I of PC1-5 (it should be noted that verification for the ranges of 0-15 and 25-30 mm can be taken from the bow shell plating of ships in column for Material Class II)
- thicknesses up to 30 mm for Material Class III of PC6&7,
- thicknesses up to 35 mm for Material Classes II and I of PC6&7 (verification for 30-35 mm thickness of Material Class I follows from this range of Material Class II).
- thicknesses up to 35 mm for framing members of PC1-5 and up to 20 mm for PC6&7.

It should be noted that the thicknesses ≤10 mm for PC6&7, though having no direct verification, can be considered as verified by the next thickness range of 10-15 mm, except for Material Class III.

Thus, the thickness range with **no verification** includes mainly the range of 30-40 mm for Material Class I of PC1-5. All data for this range are from dedicated icebreakers, i.e. corresponding to approximately PC1-3. The existing polar cargo ships do not have such large thicknesses for their side shell plating in the midship and stern areas.

5.4. Conclusion

The only range of thicknesses with no verification (30-40 mm of Material Class I for PC1-5) might be re-examined. It does not necessarily mean that the proposed grade D should be changed. As seen from Table 5A, the Russian Register with their huge experience in this area allows grade D for midship shell plating of that thickness range. Canadian Equivalent Standard, which is also based on vast experience, flatly requires grade E for all thicknesses including those with well-confirmed experience of using lower grades. The ranges of thicknesses where data does not exist may also be re-examined when the proposed rules provide considerable relaxation as compared with both Russian and Canadian Rules. These are mainly the 40-50 mm thickness range for Material Classes II and I of PC6&7 – a range of very unlikely thicknesses for ships in near future. As a possible solution this range for all material classes of PC6&7 can be removed from the proposed rules and left for discretion of individual classification societies.

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