POAC'13
Espoo, Finland

Proceedings of the 22nd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2013
Espoo, Finland

SEA ICE PROPERTIES OF THE AMUNDSEN SEA, ANTARCTICA

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ABSTRACT

Field trial in ice-covered sea is one of the important tasks in the design of icebreaking ships and offshore structures. To correctly estimate ice load/resistance on ship's hull, it is essential to understand the material properties of sea ice during ice field trials and perform the proper tests for gathering sea ice data. The icebreaking research vessel 'ARAON' had her annual Antarctic voyage in the Amundsen Sea during the summer season of 2012. This paper describes the sea ice properties obtained during ARAON's ice trials which provide necessary information for ship's performance in ice-covered sea. The data gathered from sea ice in the Amundsen Sea includes ice thickness, temperature, density and salinity of sea ice as well as ice strength data. This paper analyses the gathered Antarctic sea ice data compared to the previous data obtained during ARAON's Arctic and Antarctic voyages in 2010.

INTRODUCTION

Due to the effects of recent global warming, the polar sea ice thickness and distribution has changed rapidly. The increasing interest for natural resources in the Polar region has raised issues of designing new structures and icebreaking vessels. After the launching of first Korean icebreaker, IBRV ARAON in late 2009, she made sea ice trials twice in the Antarctic Sea (in 2010 and 2012) and twice in the Arctic Sea (in 2010 and 2011). Detail on the Arctic and Antarctic voyages of ARAON and the analysis of icebreaking performance of ARAON were described in Choi et al.(2011, 2012), Jeong et al.(2011) and in Likhomanov(2010). This paper describes the material properties of sea ice obtained during the ARAON's Antarctic ice trial in February and March 2012, which provides with basic information in the evaluation of ship's performance in an ice-covered sea. The data gathered from the Amundsen Sea includes ice floe thickness and temperature, density and salinity as well as ice strength data.

In our study, sea ice field tests by the ARAON were carried out in the Amundsen Sea, where receding of glacial ice causes dramatic change in oceanic and atmospheric circulation around the Antarctica. Sea ice information obtained through ice field tests can be used for estimation of the resistance of ice-going ships and the design of new offshore structures in Polar waters.

SEA ICE FIELD TESTS

Test Sites

Ice field tests were carried out in the Amundsen Sea as shown in Figure 1, during the summer season (February and March) of 2012. The sea ice in this area consists of pack ice with varying concentration, some hummocks, ice floes and icebergs. Most of sea ice was old ice but there were some first-year ice floes. The field test site for measuring sea ice properties was selected according to the availability of large and flat ice floes for the ice trial of ARAON. Because of warm weather and low visibility it was very difficult to find a large ice floe enough for the ice trial test. With the help of a helicopter pilot and ice navigators onboard, three field test sites were selected (one test site for preliminary exercise and two main test sites).

The first main field test (Feb. 21, 2012; W73° 30' 43", S109° 02' 11") was performed on an first-year ice floe of size 900m × 600m and the mean ice thickness was approximately 1.5m. Total of 19 ice cores were extracted from the ice floe at locations with 100m interval. The second main field test (March 3, 2012; W72° 15' 11", S117° 49' 32") was performed on an ice floe of size 1,100m × 600m. This ice floe was believed to be a multiple-layered first-year ice with hummocks and ridges in the middle of ice floe. Ice thickness was not uniform. Total of 15 ice cores were extracted.

Figure 1 Ice field test sites of the IBRV ARAON (February/March 2012)

Test Procedures and Data

Sea Ice Thickness

Ice thickness is the primary parameter among various ice properties, especially for the evaluation of ship's performance in an ice-covered sea. Sea ice thickness changes greatly year to year depending on prevailing weather condition. An auger connected to an electric motor was used to make a hole and to measure the thickness of sea ice at every 50m distance. Snow accumulation and the freeboard of sea ice were also recorded. Measured sea ice thickness data from two main field tests are given in Figure 2 and Figure3 respectively.

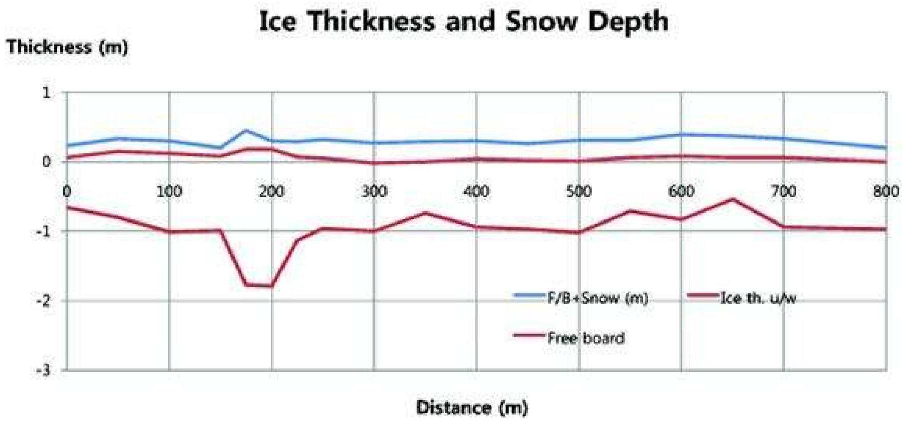

Figure 2 Ice thickness and snow depth measured in the ice floe #1

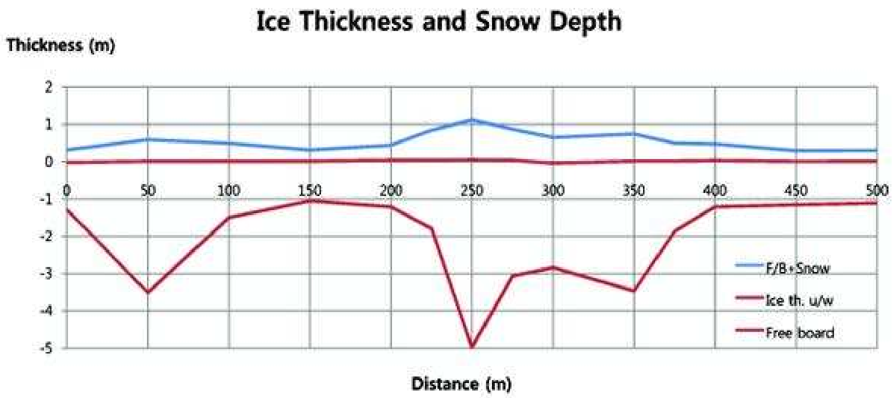

Figure 3 Ice thickness and snow depth measured in the ice floe #2

Temperature, Density and Salinity

Core samples were extracted from the sea ice and a probe-type thermometer was used in measuring temperatures from the top surface to the bottom. The ice core was cut into a 19cm long specimen for compression test. Before a compression test, ice density was calculated by measuring the weight and the volume of each ice specimen. Ice specimen after a compression test was put into a small plastic box and stored to melt under a room temperature. Days later the ice salinity can be measured. Mean values of ice temperatures, salinity and density data measured from each ice core are shown in Table 1 and Table 2. The air temperature while doing measurements was recorded as -3°C~-5°C for the first and the second main field tests.

Table 1 Material Properties of sea ice in the Amundsen Sea (ice floe #1)

Coring Position	Temperature [°C]	Density [kg/m³]	Salinity [‰]	Compressive Strength [MPa]	Flexural Strength [kPa]
100m	-1.45	915.3	3.8	1.30	205
200m	-1.72	843.5	3.8	1.41	292
300m	-1.67	855.8	4.4	1.643	239
400m	-1.68	850.9	4.3	1.247	240
500m	-1.82	824.5	3.8	1.35	302
600m	-1.72	852.1	4.0	1.725	281
700m	-1.77	792.2	4.4	N/A	267
Mean	-1.72	842.6	4.0	1.445	274

Table 1 Material Properties of sea ice in the Amundsen Sea (ice floe #2)

Coring Position	Temperature [°C]	Density [kg/m³]	Salinity [‰]	Compressive Strength [MPa]	Flexural Strength [kPa]
0m	-1.43	864.6	4.0	0.28	214
100m	-1.79	842.4	3.7	0.67	310
200m	-1.74	895.4	3.1	0.68	312
300m	-1.45	891.6	3.5	1.40	256
400m	-1.48	891.0	3.7	2.26	235
Mean	-1.55	875.4	3.6	1.32	266

Compressive and Flexural Strengths

Ice strengths are also very important factors in consideration of ice load and ice resistance on a ship's hull. Compressive strength of sea ice was measured using a compression tester in a laboratory onboard the ARAON. Well-prepared ice specimens were used in the measurement of ice compressive strengths. The temperature of ice samples during the compression tests is slightly below 0ºC. Flexural strength of sea ice can be estimated using Timco and O'Brien(1994)'s empirical formula such as in Equation (1). The compressive strength data and the flexural strength estimation are summarized also in Table 1 and Table 2.

Mean values of sea ice strength were obtained as 1.445MPa for compressive strength and 274kPa for flexural strength (ice floe #1). Also 1.32MPa and 266kPa were obtained for mean compressive and flexural strengths respectively for ice floe #2. This calculated values of flexural strength are slightly smaller than the values presented in ice trials of ARAON in 2010 AARI report (Table 3). In order to compare the properties of Arctic sea ice to those of Antarctic sea ice, temperature, salinity, density data measured during ARAON's Antarctic voyages are shown in Table 3.

$$\sigma_f = 1.76e^{-5.88\sqrt{\gamma_b}} \quad (1)$$

where σ_f : Flexural strength of sea ice (MPa)

$\gamma_b = \rho S_i / F_i(T_i)$: Non-dimensional brine volume

ρ : Density of sea ice (g/cm^3)

S_i : Salinity if sea ice (‰)

$F_i = -4.732 - 22.45\ T_i - 0.6397\ T_i^2 - 0.01074\ T_i^3$ (-2.0 ºC > T_i > -22.9 ºC)

Table 3 Physical-mechanical properties of sea ice measured from various locations

Test Site and Season	Feb./Mar. 2012 Amundsen Sea (Antarctic)	Jan. 2010 Ross Sea (Antarctic)	Aug. 2011 Chukchi Sea (Arctic)	Aug. 2010 Beaufort Sea (Arctic)
Total No. of Sea Ice Cores	34	17	6	9
Total No. of Sea Ice Specimen	136	-	18	140
Sea Ice Temperature (ºC)	-2.3 ~ -1.0 (Mean: -1.58)	-0.9 ~ -3.7 (Mean: -1.95)	-1.7 ~ 0.2 (Mean: -0.71)	-1.7 ~ 0.0 (Mean: -0.84)
Sea Ice Density (kg/m^3)	580 ~ 960 (Mean: 856)	670 ~ 940 (Mean: 840)	740 ~ 930 (Mean: 866)	750 ~ 980 (Mean: 913)
Sea Ice Salinity (‰)	1.15 ~ 5.90 (Mean: 3.84)	1.2 ~8.6 (Mean: 4.19)	0.1 ~ 2.6 (Mean: 1.01)	0.1 ~ 5.0 (Mean: 2.18)
Compressive Strength (MPa)	0.52 ~ 3.57 (Mean: 1.398)			0.69 ~ 3.70 (Mean: 1.830)
Flexural Strength (kPa)	125 ~ 443 (Mean: 272)	190 ~ 490 (Mean: 299)	244 ~ 554 (Mean: 351)	10 ~ 660 (Mean: 190)
References	Choi et al. (2012)	Likhomanov (2010)	Jeong et al. (2011)	Choi et al. (2011)

DISCUSSION

The measured compressive strength in the present study can be compared to previous researches for compressive strength as summarized in Mellor(1983). Since temperature and crystalline structures are different, direct comparison is difficult. But the range of compressive strength presented in Table 3 (0.52~3.57MPa) and the uni-axial compression tester's strain-rate range (0.5~1.0x10^{-4}/s) indicate that our data falls in the shaded area in Figure 4. Timco and Frederking(1990) proposed an empirical formula for estimation of compressive strength of sea ice, and they presented Exxon's 1980-1981 measurement data for Arctic sea ice (large-scale test). Strain-rates from 0.92x10^{-5}/s to 7.5x10^{-4}/s produced the measured compressive strength range of 1.0~3.53MPa. In the present study, the compressive strength was slightly smaller than the Exxon's data for the similar range of strain-rate, while considering the scale effect and temperature difference.

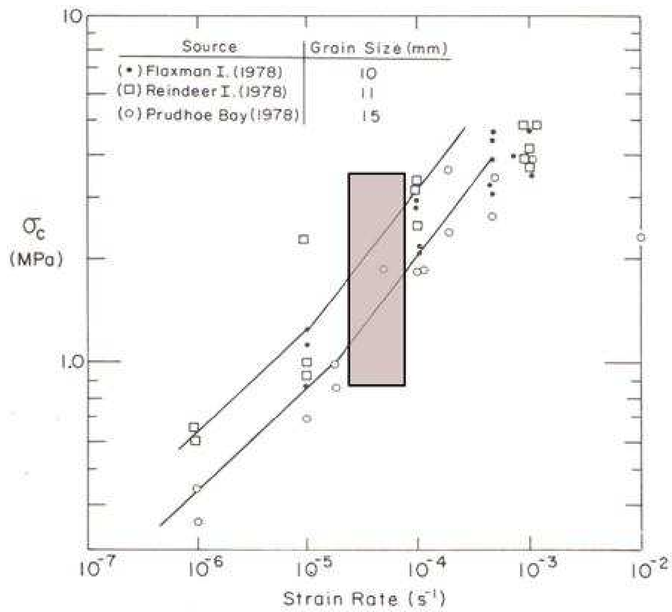

Figure 4 Variation of compressive strength with strain-rate in first-year sea ice at -10℃. Present data falls in the shaded region. The graph is modified from Mellor(1983) and data was prepared by Wang(1979).

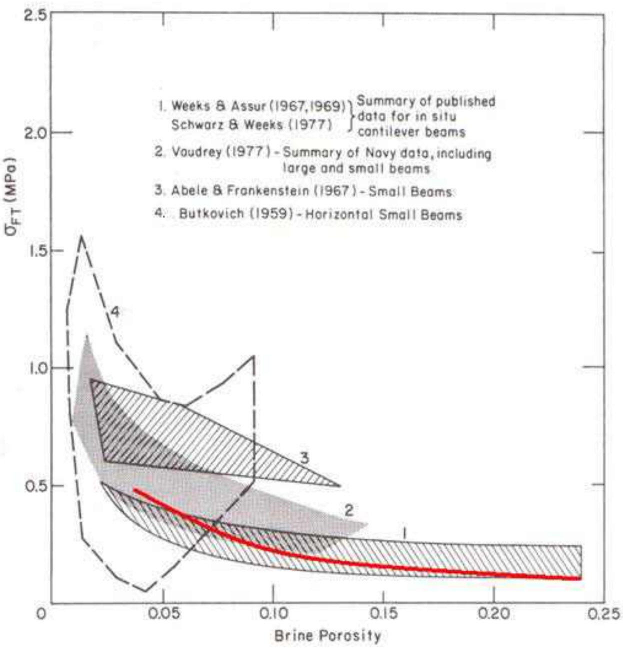

Figure 5 Variation of flexural strength as a function of brine porosity. Graph is modified from Mellor(1983). Present flexural strength data is drawn with a solid line.

Figure 5 shows the calculated flexural strength as a function of brine volume. As in Figure 5, present flexural strength data shown by a solid line was compared to those of other researchers. As the Equation (1) indicates, our estimation of flexural strength of sea ice shows similar trend that the strength decreases as the salinity increases.

As shown in Table 1 and Table 2, the temperature measured inside the sea ice was -1.71℃, -1.55℃ which were very close to the melting point of sea ice. The measurements were performed at relatively warm conditions and this causes problems to find flexural strength of sea ice using Equation (1).

CONCLUSION

The Korean icebreaking research vessel ARAON had several ice trials in the Amundsen Sea, Antarctica, during the summer season of 2012. In this paper sea ice properties obtained during ARAON's ice trials and the test procedures to obtain sea ice properties which provide basic information to ship's performance in ice-covered sea have been discussed. The data gathered from sea ice includes ice thickness, temperature, density and salinity of sea ice as well as ice strength.

There was a difficulty to find a suitable size of ice floes for the test to run the icebreaker and it was not easy to explore the proper ice conditions because weather condition was not favorable compared to the exploration of the Arctic sea ice in 2010. The ice was generally weaker than expected due to warm temperature. The measured temperature and salinity data showed minor difference to the value measured by the Russian research team in 2010 in the Antarctic.

Because it was a survey in a limited area, the ice filed tests of the ARAON in the Amundsen Sea this time is not the general information about the properties of the material strength of Antarctic sea ice. However it was possible to create a guideline for the test procedure of ice field trials and to set up a significant achievement through the study.

Especially when using empirical formulas for calculating flexural strength or compressive strength, we should be more careful in adopting temperature range of sea ice. Since the Equation (1) is very sensitive to temperature/density variation, especially in ranges close to melting point of sea ice, the calculated flexural strength may produce unrealistic results.

ACKNOWLEDGEMENT

Research fund provided by the Ministry of Knowledge and Economy, Korea, through the Industrial Strategic Technology Development Program (Grant No. 10033640) is greatly acknowledged.

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