DEVELOPMENT OF TEST METHOD FOR CONTINUOS BENDING FRACTURE OF ICE USING UNIVERSAL TESTING MACHINE

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ABSTRACT

In the present study, loading history for ice specimen which is made of fresh water was measured by conducting an ice bending test. In general, ice breaking mechanism in the arctic generates continuous failure. Ice tests were performed using a universal testing machine with three load sensors. The load sensors are used to measure a peak force during the impacts between an inclined plane (jig) and ice specimen. The tests were classified according to the thickness of ice specimen and loading rate. The test scenario was designed by considering the actual interacting situation between an arctic ship and level ice. Three different load cells are fixed to inclined plane of bow structure. In addition, strain rates and ice thickness are considered in order to analyze the mechanical behavior of fresh water ice.

INTRODUCTION

Since industry of oil and gas resources showed an interest in Arctic regions, the study of the ice material has been lasting constantly. There are many factors that affect the material nonlinearities of ice such as loads, strain rate, temperature, impurities contents, grain boundaries size and crystalline orientation.

Ice is one of the most complex materials in nature because it has various amounts and sizes of grain boundaries. According to previous research, a typical and important feature of the mechanical behavior of ice is the transition between ductile and brittle failure in the case of the time-variant failure problem (Batto and Schulson, 1993).

Many different failure mechanisms of ice have been observed. An ice can fail, for example, locally by microcracking or flaking and globally by bending or buckling. The failure mode is affected by both the structure and the ice, so it is important to consider them properly and thoroughly (Daley, Tuhkuri and Riska, 1998).

Zhou, et al. (2013) reported experiments on level ice loading on an icebreaker tanker. The study includes results for the measurements of ice rubble loads against the model hull on the horizontal plane. Phenomena such as ice failure modes and ice rubble accumulation on the upstream side of the hull beneath the ice sheet were observed in some tests. The length of the broken ice and the dimensions of ice rubble were analysed. These results are relevant to the modeling of ice loading on hulls and the design of dynamic positioned structures for operation in ice-covered waters. This is because of the need to understand the ice-failure mode, which is determined by impact velocity, bow shape, stem angle and ice thickness.

Riska (1987) demonstrated that an assumed ice loads can be determined as a function of time with knowledge of the geometry of the bow, ice edge, and ship motion. Although local ice pressure from real icebreakers or ships had been estimated, laboratory-scale ice model tests were employed due to the various difficulties encountered in full-scale testing. There are many constraints such as weather, accuracy, and repetition.

Medium-scale tests provide a good way to study ice failure and local forces in quasi-static condition and to setup the experiments for describing ice breaking. There are many studies on the ice-offshore structure interaction. On the other hand, there are very few relevant studies on ice-ship interaction and part of stem tests.

The primary goal of the present study is to measure the local ice load on the inclined plane and to investigate the corresponding phenomena when arctic ships are in operation such as ice breaking in the continuous mode. The results from study show the time-dependant ice loads estimated by load sensors that were installed on the designed jig.

The tests were conducted by using fresh water ice and were found in the tendency of the results for ice local loads. It is noted that freshwater ice was used in ice behavior test as a preliminary study for the evaluation of the sea ice load. The tests have been considered for the stem angle as a significant parameter when the icebreaker is crushing the ice floe. Laboratory tests of the interaction between ship bow and ice floe were conducted as scenario tests.

EXPERIMENTAL SET-UP

When icebreakers make a voyage in arctic, bending moment is the most dominant behavior generally. In order that the failure of the ice occurs by a bending force, arctic ships are using the hull weight as efficiently as possible. For this reason, stem angle is the most important factor of the ice breaking capability. Recently, spoon shape of bow is applied to the design satisfying much wider contact surface between ice and vessel.

Varsta and Riska (1977) reported the failure was viewed as a combination of crushing, shearing and flexural failure. They assumed a constant crushing pressure and the contact force was increasing with increasing contact area until the force was large enough to cause a shear fracture or a bending fracture. And the model was used to illustrate why the ice loads contained several local peaks and lasted longer than a simple crushing model would predict.

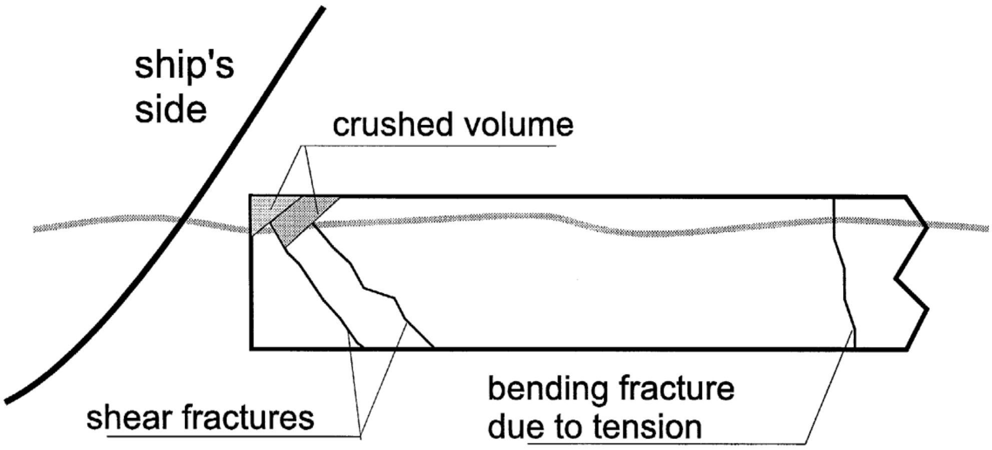


Figure 1. Ice edge failure process on the side of a ship.

Fig. 2 shows that there is a high correlation between ice failure and buttock angle conditions. The buttock angle, which indicates the angle between the ice and the ship’s bow structure, refers to the angle of the buttock line measured from the horizontal at the upper waterline.

Local load is for estimating the bow structural behavior, and it is predicted using the data from the load cells equipped to jig. The experimental factor, the gamma of stem angle (see Fig. 2 (a)), was considered along the bow shape of hull. And using of the jig, triangle shape, can be shown to extend to real scale that has an inclined plane.

Ritch, et al. (2008) showed field test program was carried out with the vessel whose sizes ranged from 20 *t* to 22,000 *t*, at ship speeds from 0.2 to 6.5 *m/s*. As a result, the maximum pressure measured was 11.3 *MPa* on an area of 0.12 m^2 and maximum force of 5 *MN* was measured on the instrumented area during a direct impact. From the pressures measured, pressure-area curves were developed, total forces were calculated and the correlation between various parameters such as velocity and bergy bit mass was analysed.

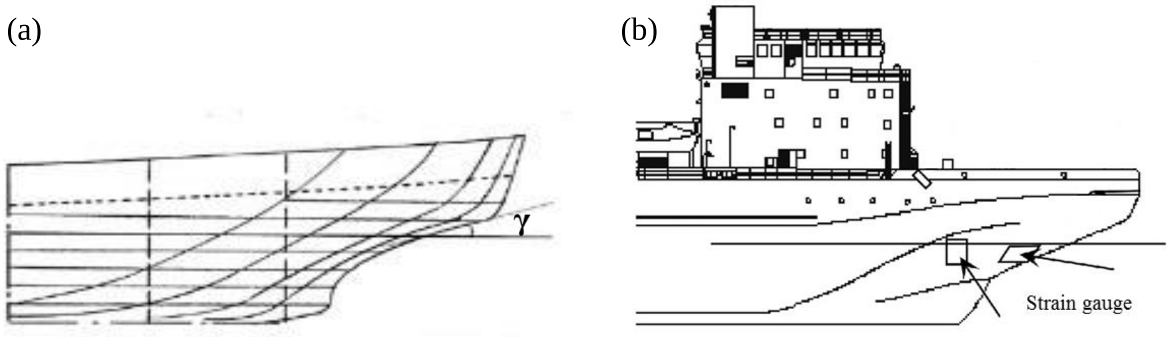


Figure 2. (a) Stem angle of the bow over waterline, (b) Location of the strain gauge panel

It is specified about the stem angle at Russian Maritime Register of Shipping (RS, 2003) ice class rules. The entrance angle for above waterline is to be 22° to 30°, and equipment's design was applied by the RS rules. Jig's breadth is about 25 *mm* and degree is 30°, and the surface shape is a curvature in order to take a concentrated load. There are three load cells, which can be measured up to approximately 100 *kN*, and they're equipped at 50, 130 and 210 *mm* from the edge.

Figure 3. Equipment for the ice tests; Load cell (left) and jig of triangle shape (right).

Fig. 4 shows the universal testing machine and experimental procedure used in this study. The experimental condition can be generated with crosshead speed of up to 70 *mm/min*. During the laboratory tests, ice loads were estimated from the results from universal testing machine (U.T.M.) main body and local load cells. The ice load which obtained from the U.T.M. globally shows the ice fracture behavior. On the other hand, the other which obtained from the load cells shows concentrated load and serves the comparison between total and local force while the U.T.M. was in operation.

There are many laboratory tests about material characteristics using a universal testing machine, but there is a little test, which was related to ice breaking in the continuous mode. In the present study, experimental loading condition was a flexural test and boundary condition was equivalent to cantilever-beam in order to consider the phase of ice breaking (see Fig. 1 and Fig. 6)

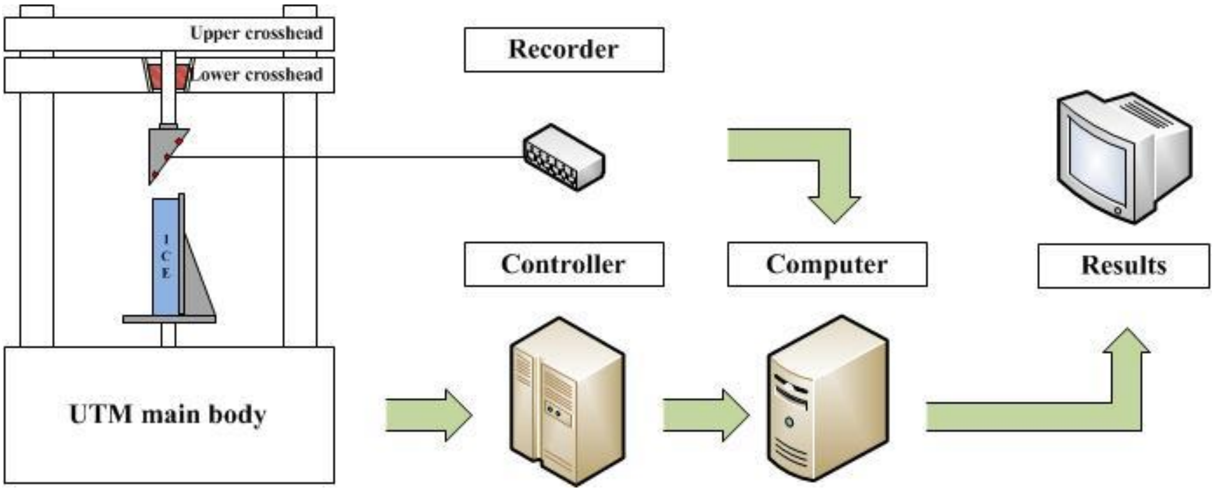


Figure 4. Schematic view of the experimental procedure and setup.

When continuous breaking operated on ice, the flexural test is the dominant factor about failure of ice. Considering the failure mode, loading condition is a vertical load and this is causing a bending fracture. The cantilever, which is a beam anchored at only one end, applied to the boundary condition such as the conditions of level ice.
Considering the feature of level ice, which has a longer than any other types of ice, it was so hard to implement the conditions of field tests in medium scale tests. In spite of the constraints, to satisfy the abovementioned conditions, length of the ice specimen has to be long.
As a practical method for preventing change in the crystallinity of ice, it is recommended that a temperature of -15 *℃* be considered as the optimum condition. In this study, although an investigation of the crystallinity of ice was not conducted for the specimens used in this study, the test specimens were stored at -15 *℃* prior to bending testing to prevent any change in the ice crystalline structure.
The bottom of the equipment was fixed to U.T.M. at every direction and rotation. Then, bracket, which is fastened in order to support structure, was added to the installation. As aforementioned, in order to create the breaking condition of the ship's bow structure and ice, U.T.M. was used according to the test scenario (crosshead speed: 30 *mm/min* and 60 *mm/min*).

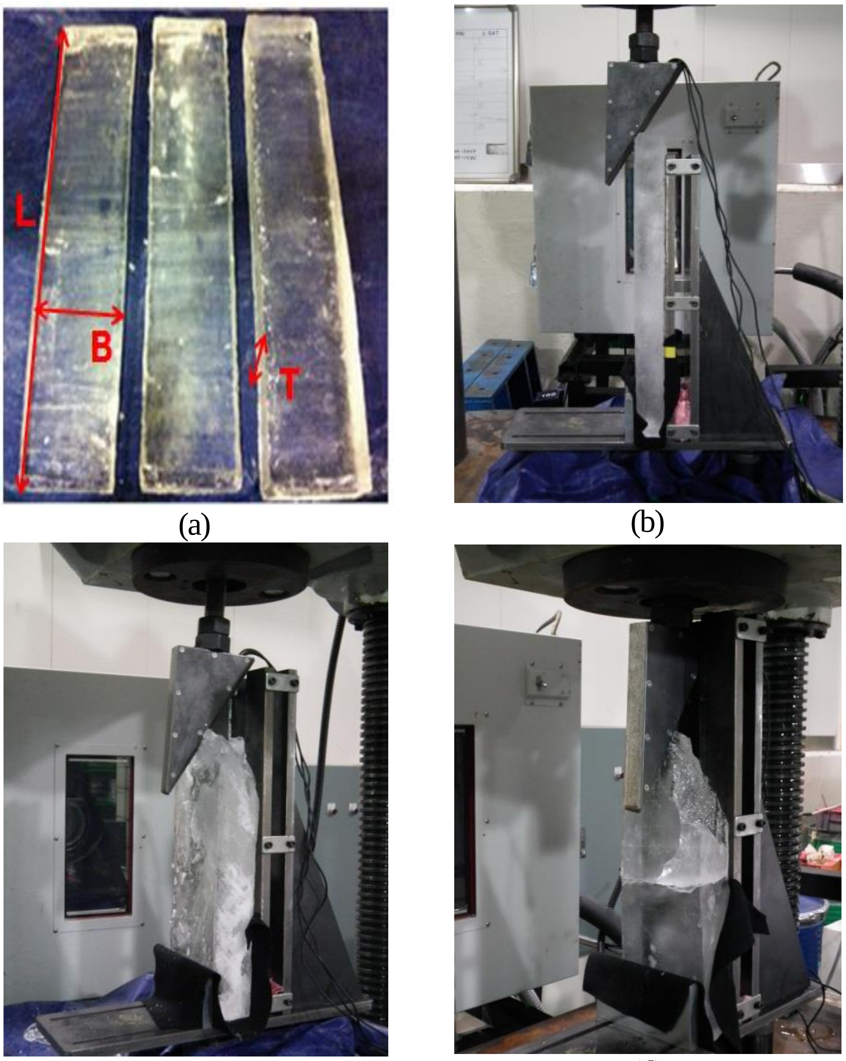

(a) (b) (c)

Figure 5. (a) Universal testing machine with cryogenic chamber. (b) and (c) Photograph of experimental equipment (front & oblique view).

Table 1. Conditions for the ice-bending test.

Case	**Loading Rate (*mm/min*)**	**Thickness of specimen (*mm*)**
R30_T40	30	40
R30_T70		70
R60_T40	60	40
R60_T70		70

Table 1 summarizes the test scenarios. In this study, there are two variables, which are loading rate and thickness of ice specimen. In conclusion, four types of scenarios have been conducted. For example, R30_T40 means that loading rate is 30 *mm/min* and thickness of ice specimen is 40 *mm*. Each of the cases was conducted three times. The sizes of ice specimen are as follows. It has a length of 550 *mm* and a breadth of 120 *mm*. As seen Table 1, thickness of the specimen is 40 *mm* and 70 *mm*.



(a) (b) (c) (d)

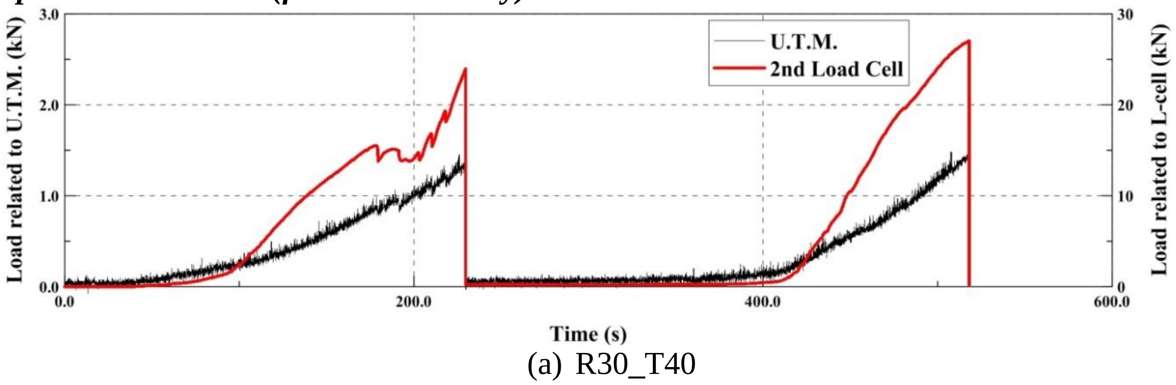
Figure 6. (a) Photograph of ice specimen. (b), (c) and (d) Photograph of the ice bending test in continuous mode (Case R60_T70).

In the present study, we investigated the ice breaking phenomena related to the loading rate and thickness. Failure of ice occurred to direction of breadth, because the tensile strength of ice weaker than compressive while the bending force is in operation all over the specimen.
The test of this research is as following the process. First, specimen of ice is fixed at the edge using a supporting jig and vertical jig. The vertical jig has a large hole, so it looks like a letter the alphabet ‘U’, and the ice specimen is leaning against this. Second, we let the inclined wedge which is triangular shape down by U.T.M., and then there is a contact between the wedge and the specimen. The inclined jig heads consistently down and pushes the ice specimen. At this moment, the jig of triangular shape and ‘U’ shape are engaging with each other, and fracture of the ice occurs. An area of the failure is divided into two kinds according to the thickness of the ice and the loading rate. The one appears at the contact area, and the other appears at the part which is approximately 22 percent of a total length of the ice specimen in the tests. In other words, the second one is caused by bending force. After a crack initiation and propagation, the ice fracture can be operated.

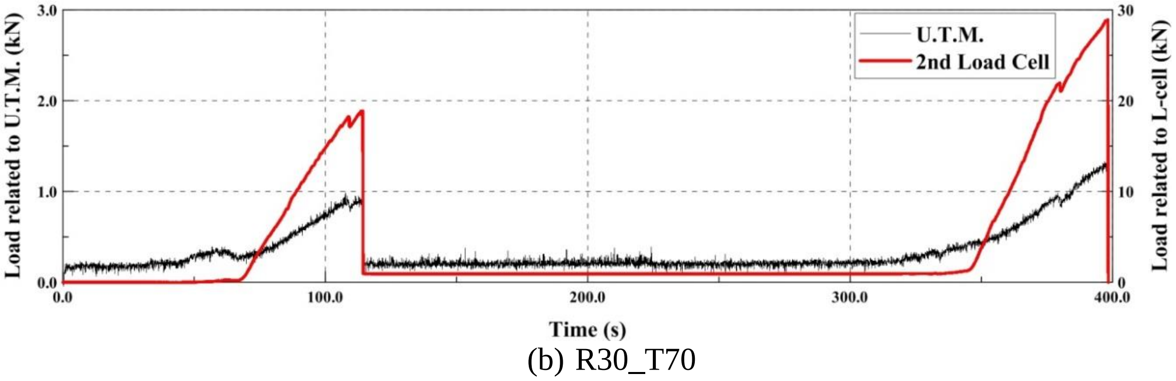
EXPERIMENTAL RESULTS AND DISCUSSION

During ice breaking operation, the results from the data show a time history of ice loads. Laboratory tests of ice breaking in continuous mode were conducted with variables, such as loading rate and thickness of specimen.
Result from the obtained U.T.M has a value of force, and it is smaller than one from the 2^{nd} load cell. Because of the concentrated loads, the force was highly measured.
The load cells, except the 2^{nd}, don’t significantly affect the failure of ice because ice was not big enough to cover the ice all over. It couldn’t be available for the experiments so they were not included in results. The results from each of cases were introduced such as follows (see Table 1). Y-axis on left side is related to U.T.M. and the other on the right side is related to 2^{nd} load cell. In this study, the maximum load of ice tests is 52.24 *kN* from the at case R60_T70. In general, ice load from the 2^{nd} load cell bigger than U.T.M.

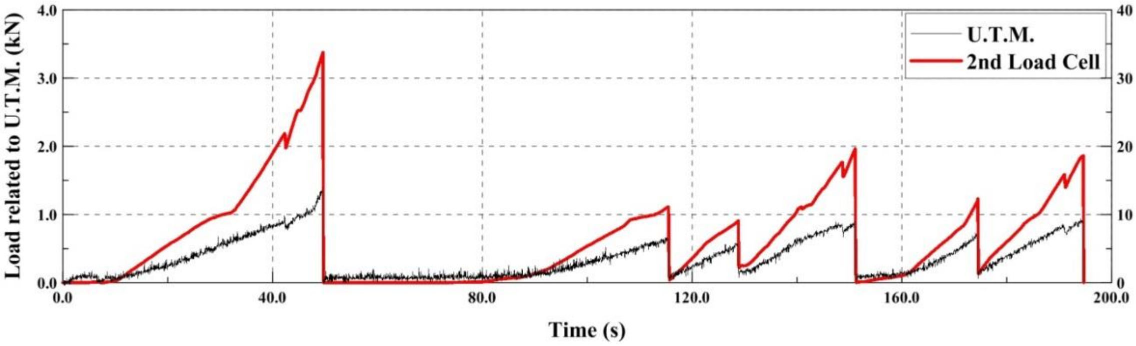
Experimental Results (force-time history)



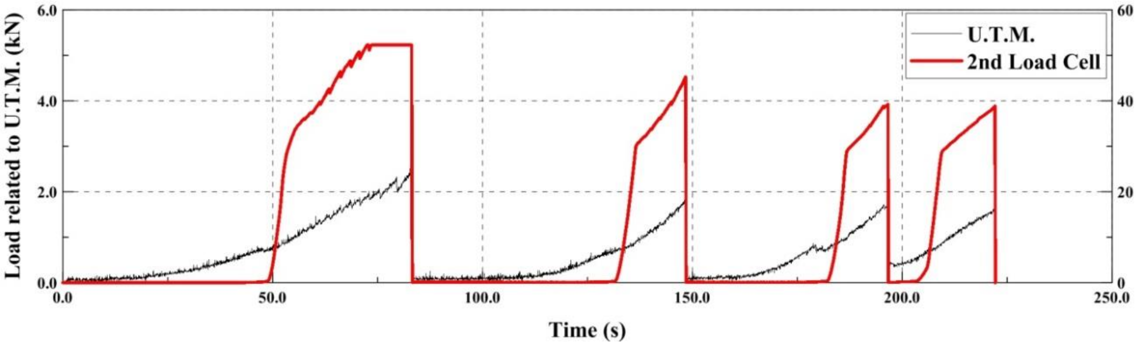
(a) R30_T40



(b) R30_T70



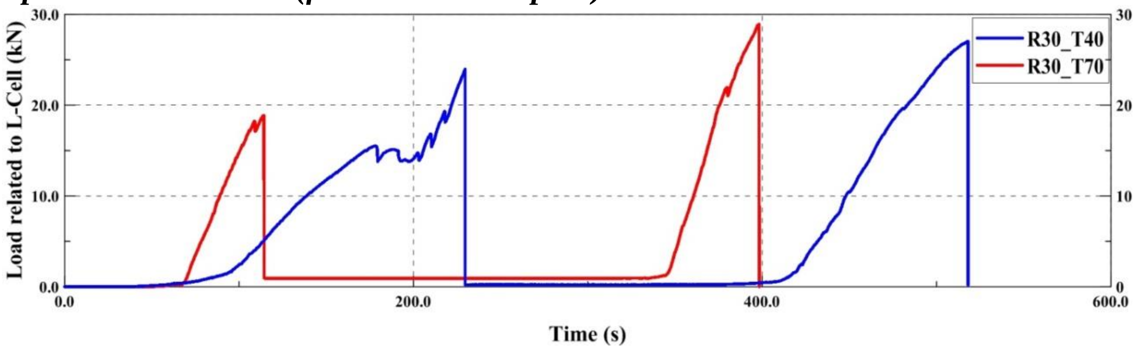
(c) R60_T40



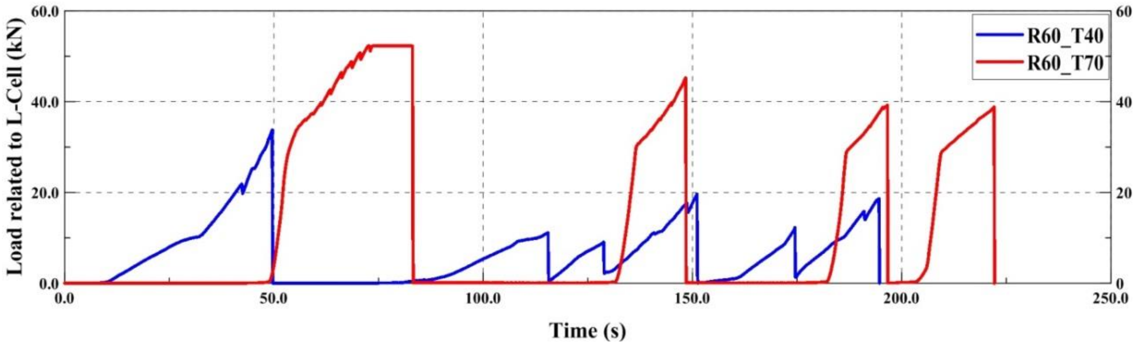
(d) R60_T70

Figure 7. Time history of ice load in comparison with U.T.M and 2nd Load Cell.
(where L-cell means load cell.)

Compare with Thickness (fixed crosshead speed)



(a) R30_T40 and R30_T70

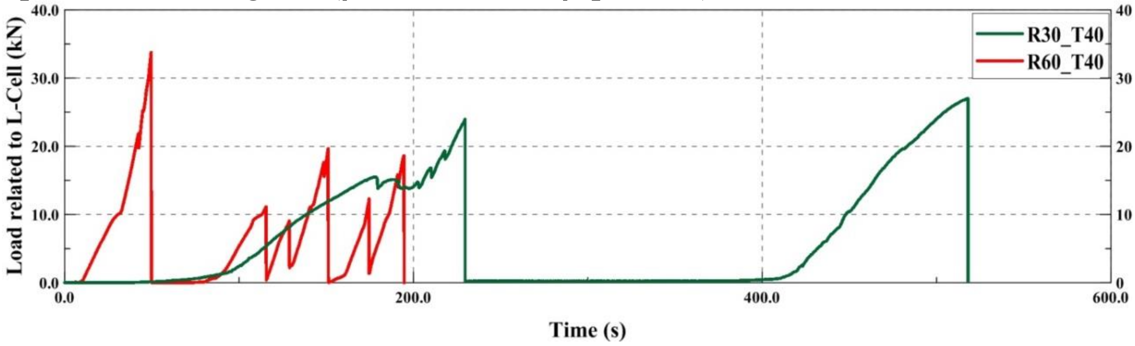


(b) R60_T40 and R60_T70

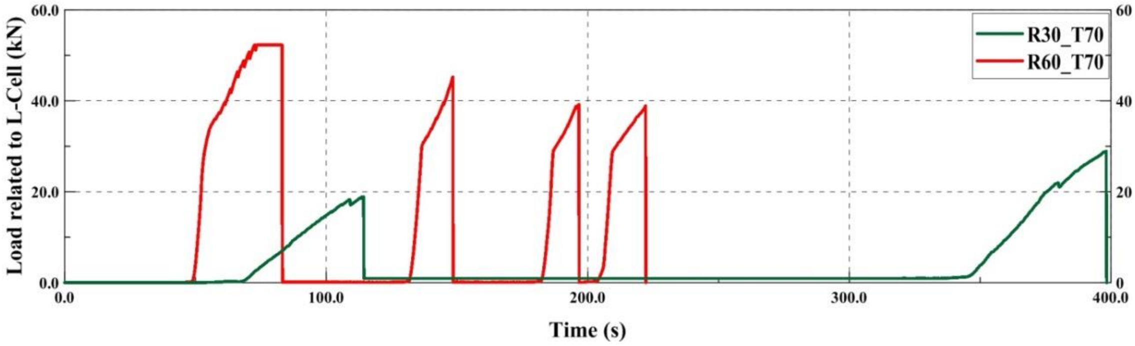
Figure 8. Time history of ice load compared with thickness of specimen.

The results from the compare with thickness showed that there are peak loads two times at the case of R30, but there are the loads two more times at the case of R60 (see Fig. 8). This means that the length of the broken ice is managed by the loading rate. At this comparison, it was hard to find features related with thickness of ice specimen.

Compare with Loading rate (fixed thickness of specimen)



(a) R30_T40 and R60_T40



(b) R30_T70 and R60_T70

Figure 9. Time history of ice load compared with loading rate.

The results from the compare with loading rate showed that there is difference of a duration time. As see the Fig. 9, the more loading rate is low, the more the duration time is long. At this comparison, it was hard to find features related with thickness of ice specimen.

CONCLUDING REMARKS

In the present study, the laboratory ice bending tests conducted with freshwater ice. The tests provide information about continuous breaking on ice using universal testing machine. During the tests, ice load varies widely according to the conditions related with angel of stem, temperature, loading rate and size of specimen. The test was carried out according to the loading rate; *30 and 60 mm/min* and the thickness of ice specimen; *40 and 70 mm*.
The results from the tests are explained by the conclusions summarized below.

- The present study developed an experimental equipment and method about ice breaking.
- Ice loads are more dependent on crosshead speed than thickness of specimen. In lower speed, thickness of specimen doesn’t have an effect on the failure of ice (see Fig. 8 (a) and (b)).
- In this study, When the loading rate is 60 *mm/min,* the maximum load of the tests is 52.24 *kN* (from 2^{nd} load cell) at case R60_T70. It means that the ice loads increase as the velocity would be faster.
- In this study, there is a little characteristic between the ice breaking and the ice thickness, but it is a big deal to consider the thickness in actual. As see the case R60_T70, the maximum load of the tests was estimated.

Therefore, further studies on a variety of scenario should be carried out to extend the results of this study. The scenario of the laboratory test should be considered with the factors, such as sea-ice, crystallinity, strength, density, temperature and salinity. Consequently, we expect that method of continuous breaking on ice can be developed, as significant factors are analyzed and the force-time history can be used to construct the data.

ACKNOWLEDGEMENTS
Research funds provided by the Ministry of Knowledge and Economy, Korea, through the Industrial Strategic Technology Development Program (Grant No.10033640) are acknowledged and greatly appreciated. This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) through GCRC-SOP (Grant No.2011-0030667).

REFERENCES
Batto, R.A. and Schulson, E.M., 1993. On the ductile-to-brittle transition in ice under compression. *Acta Metallurgica et Materialia*, 2219-2225 pp.

Daley, C., Tuhkuri, J. and Riska, K., 1998. The role of discrete failures in local ice loads. *Cold Regions Science and Technology*, 197-211 pp.

Riska, K., 1987. *On the mechanics of ramming interaction between a ship and a massive ice floe*. Thesis for degree of doctor of technology, technical research center of Finland, publication 43, Espoo.

Ritch, R., Frederking, R., Johnston, M., Robin Browne and Freeman Ralph, 2008. Local ice pressures measured on a strain gauge panel during the CCGS Terry Fox bergy bit impact study. *Cold Regions Science and Technology*, 29-49 pp.

Russian Maritime Register of Shipping, 2003. *Rules for The classification and construction of sea-going ships, edition 2003*. St. Petersburg: RS

Varsta, P. and Riska, K., 1977. Failure process of ice edge caused by impact with a ship’s side. *Ice, Ships and Winter Navigation Symposium*, 235 p.

Zhou, L., Riska, K., Moana, T. and Sua, B., 2013. Numerical modeling of ice loads on an icebreaking tanker: Comparing simulations with model tests. *Cold Regions Science and Technology*, 33-46 pp.