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Research Article

Experimental Study on the Mechanical Properties of the Songhua River Ice

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Abstract: River ice is an important branch of ice problems. However, the mechanical properties of the river ice are still unclear because of the large variation of ice problems. In the present study, over 160 specimens of river ice taken from Songhua River of China have been investigated using the MTS machine to measure the compressive strength and the elastic modules at various test temperature and strain rate. The test temperature is set at three different point (-10, -15, -20°C, respectively), the strain rate is set at the range from 5.0E-5/S to 1.0E-2/S. The test results show that the compressive strength of river ice is strongly depending on the temperature and strain rate. It increases with the decreasing test temperature. The compressive strength of ice firstly increases and then decreases with the increasing strain rate. There is one peak turning point of strain rate. The turning point value of strain rate is about 1.0E-3. The test results also show that the river ice has the typical dual mechanical characteristics of ductile and brittle behavior. When the strain rate is greater than 1E-3/S, the ice specimen exhibits obviously brittle behavior. When the strain rate is below 5.0E-4/S, the ice exhibits ductile behavior. The range of transition from ductile to brittle is about 5.0E-4/S~1E-3/S. Under compressive loading condition, the initial elastic modules of Songhua River ice are about 0.528~0.671 GPa. And the modules of River ice increases with the decreasing test temperature slightly.

Keywords: Compressive strength, elastic modules, river ice, strain rate, temperature

INTRODUCTION

Rive ice problems can be discovered in the most countries and regions where are located at the northern hemisphere of the earth. The rivers are covered with thick ice layer in winter and the thickness of ice layer can be up to 1~2 m or more. When spring is coming and the weather gets warm, the ice layer will melt slowly and split into huge ice blocks. These huge ice blocks drift down in the river driven by wave and wind.

The drifting huge ice blocks are the great threaten to the safety of the structures (bridge pier, *et al*.,) in the water because they would conflict with the structures. Many documents have reported the case of structure damage even collapse which are conflicted by drifting huge ice blocks. The ice layer in the river also brings many other problems such as ice pressure load to the bridge structures in the rivers. Consequently, many attempts are being made to find efficient methods to reduce the interaction force between the ice and bridges, to design anti-ice structures and to understand the mechanism of action of the ice and structures.

In all of these studies, the mechanical properties of river ice are important and the knowledge of ice behavior under loading conditions is indispensable. In this study, an attempt has been made to measure the compressive strength and initial elastic modules of river ice taken from Songhua River which is the third largest river in China.

Since the ice properties are highly variable depending upon the material's environment, the mechanical behavior has large difference for various types' ice. A number of type's ice properties are discussed in passing. These include rives ice, sea ice, atmospheric ice, *et al*., Some documents (Gold, 1977) investigated the compressive strength of freshwater ice at various temperatures. The relationship between compressive strength and the test temperature was given out in their research. The lake ice's microstructure and the mechanical behavior were also studied (Daniel and Ian, 2007). They pointed out that there is much variation for the ice in the different location in the same lake. The compressive strength of river ice was also investigated in the past (Yu and Yuan, 2008). The flexure behavior of river ice affected by the oncoming wave was studied by François *et al*. (2009).

In short, the mechanical behavior of ice have been studied widely, however, the variation of ice is great for different type and different location ice. The present study aims to the compressive strength and initial elastic modules of river ice taken from Songhua River of China.

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Fig. 1: Songhua river ice blocks

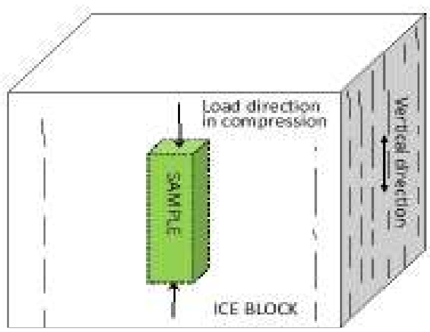


Fig. 2: Schematic illustrating specimen position in ice block and loading direction during test

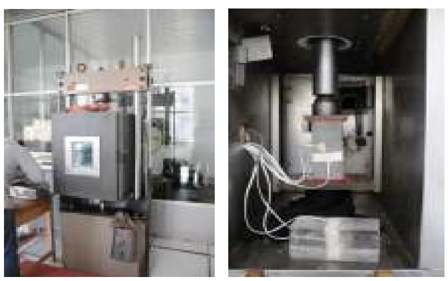


Fig. 3: Test set-up for this investigation

EXPERIMENTAL PROCEDURE AND TEST CONDITIONS

Ice blocks and specimens: The test ice was collected in the Songhua River nearby the Harbin City highway bridge which located at 126° 32' east longitude and 45° 45' north latitude approximately. In January, the thickness of the ice was up to 1.5 m. Using the chain saw to get the ice block, the atmosphere temperature of worksite was about -20°C. The good quality blocks were transported to laboratory and stored in a cold room at -10°C. Figure 1 shows the Songhua River ice blocks which was gotten out from the river.

According to the IAHR guidelines for tests on freshwater ice, the compressive ice specimen should be use right cylindrical. The diameter of specimen is approximately between 7~10 cm and the ratio of length to width are about 3:1. However, the ice is very brittle; the strength is low and easily influenced by temperature. It can't be processed by machine but by handmade. Therefore, many researchers use the cube-shaped specimen to test the compressive strength. In the present work, the author use the cuboid shape specimen, its' size is 7.5×7.5×17.5 cm. The specimen position and loading direction are showed in Fig. 2.

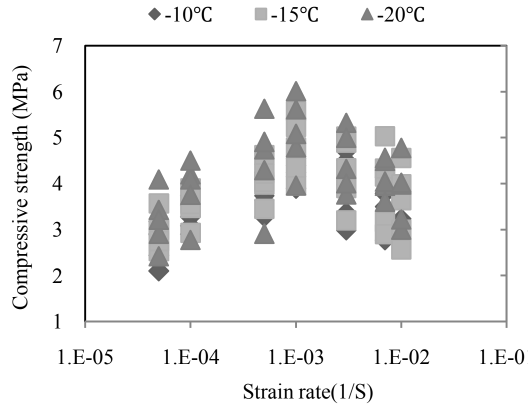


Fig. 4: Compressive strength as a function of strain rate

Test frame: The test frame Fig. 3 was used in this study is MTS 810 with a cold box which can keeps the temperature at the test requirement. One central computer controls the MTS loading rate and the temperature automatically. In this study, the author uses the displacement control method to control the loading rate. The computer records all the load and displacement data in the whole test automatically.

Temperature: As many document shows, the compressive strength of ice is relate to the ice temperature. To get the temperature dependence, three target temperatures are selected for this test: (1) -10°C, (2) -15°C and (3) -20°C. These target temperatures are set using the digital cooling box thermostat. Before test, the specimens are put in a digital freezer for enough times to have the heat conductor. When the temperature of specimens meets the test requirement the specimen are moved out and installed in MTS and begin to load.

Loading rate: According to many previous study results, the compressive strength of ice is strongly dependent on the strain rate. There is a range (about 10^{-4}/s~10^{-2}/s) of strain rate which the ice mechanical behavior transits from brittle to ductile. When the strain rate is low (less than 10^{-4}/S), the ice exhibits ductile behavior. However when the strain rate is height, the ice exhibits brittle behavior.

Considering the speed of floating ice sheet conflicting with the ice apron, in this study the load was applied at the strain rate range between 5.0E-5/S to 1.0E-2/S.

TEST RESULTS AND DISCUSSION

Results of uniaxial compression tests: Table 1 shows the results of uniaxial compression tests of Songhua River ice tested at various temperatures. All the results data are plotted in Fig. 4. As many researchers

Table 1: Results of compression tests of Songhua River ice tested at various temperatures

		T = -10°C			T = -15°C			T = -20°C		
Row	Strain rate	Com. strength (MPa)	Ave. (MPa)	S.D. (MPa)	Com. strength (MPa)	Ave. (MPa)	S.D. (MPa)	Com. strength (MPa)	Ave. (MPa)	S.D. (MPa)
1	5.00E-05	2.887	2.700	0.428	2.532	2.972	0.388	2.421	3.211	0.620
2	5.00E-05	3.171			2.988			4.090		
3	5.00E-05	2.098			3.571			3.430		
4	5.00E-05	2.906			3.017			2.905		
5	5.00E-05	2.438			2.752			3.210		
6	1.00E-04	2.903	3.306	0.335	3.471	3.532	0.379	4.203	3.864	0.665
7	1.00E-04	3.737			3.893			2.775		
8	1.00E-04	3.277			2.931			4.090		
9	1.00E-04	3.082			3.557			3.753		
10	1.00E-04	3.530			3.810			4.500		
11	5.00E-04	4.052	3.789	0.377	3.451	4.062	0.424	4.742	4.495	1.010
12	5.00E-04	3.737			4.621			4.901		
13	5.00E-04	3.277			3.983			4.294		
14	5.00E-04	4.247			4.036			2.906		
15	5.00E-04	3.634			4.221			5.631		
16	1.00E-03	4.545	4.196	0.294	3.957	4.780	0.654	6.012	5.089	0.790
17	1.00E-03	4.399			5.582			3.959		
18	1.00E-03	3.901			4.347			4.783		
19	1.00E-03	4.242			5.231			5.075		
20	1.00E-03	3.891			4.783			5.615		
21	3.00E-03	3.969	3.908	0.728	4.337	4.271	0.746	5.323	4.483	0.658
22	3.00E-03	4.504			5.020			4.993		
23	3.00E-03	3.376			3.907			3.765		
24	3.00E-03	4.704			4.891			4.322		
25	3.00E-03	2.987			3.201			4.010		
26	7.00E-03	3.793	3.597	0.514	4.153	3.917	0.875	4.493	4.128	0.398
27	7.00E-03	4.137			3.170			3.952		
28	7.00E-03	2.770			5.032			4.038		
29	7.00E-03	3.501			4.330			3.600		
30	7.00E-03	3.782			2.900			4.555		
31	1.00E-02	3.853	3.210	0.409	3.641	3.549	0.787	3.000	3.798	0.707
32	1.00E-02	3.153			2.995			3.220		
33	1.00E-02	3.084			4.556			4.770		
34	1.00E-02	2.724			3.983			3.980		
35	1.00E-02	3.237			2.570			4.021		

S.D.: Standard deviation

have reported and made clear in Fig. 4, the strength results of ice are much more discrete. As shown in Table 1, the maximal standard deviation is 1.01 MPa. But even that, the average of test results still give out how the strength is changing at different strain rate and test temperatures. That is, the strength of ice is depended on the temperature and strain rate as showing in Fig. 5.

Figure 5 shows that the compressive strength of Songhua River ice increases with the decreasing test temperature. The test temperature is lower, the strength is higher. This is agreed with the results reported by many researchers. Another conclusion can be draw that the strength of River ice increases firstly and then decreases with the increasing of strain rate. That is to say, there is one peak turning point for strain rate. From the present test, the turning point value of strain rate is about 1.0E-3. When the strain rate is less than 1.0E-3, the strength of ice increases with the increasing of strain rate, when the strain rate is greater than 1.0E-3, it decreases with the increasing of strain rate. From the present test, the maximum of compressive strength of Songhua Rive ice tested at -10, -15 and -20°C is 4.196, 4.78 and 5.089 MPa, respectively.

Figure 6 shows the comparison of strength data from the present test with the results from previous studies. These previous work also used the fresh water ice as the test object (Jones, 1982; Hawkes and Mellor, 1972; Schulson and Canon, 1984; Yu and Yuan, 2008).

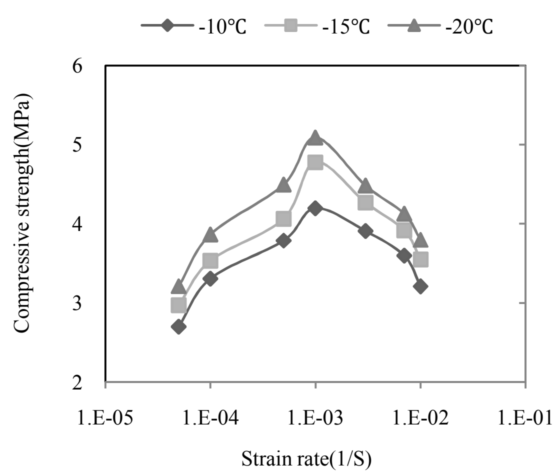


Fig. 5: Compressive strength of Songhua river ice tested at different temperature and stain rate

Obviously, there is some difference between the previous results with the present studies. As mentioned before, the strength of ice is much more discrete. Many factors will influence the test result such as the air content, ice density and load direction and the test specimen size. In spite of the differences between the data shown by other researchers and the present data, the trend of increasing strength with strain rate up to 1×10^{-3}/S is evident in most of all the data.

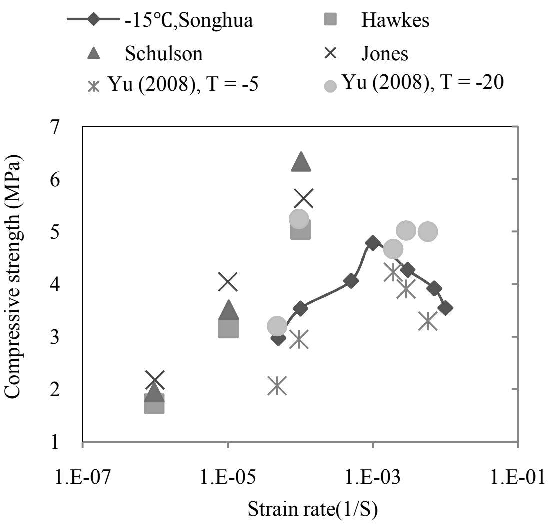
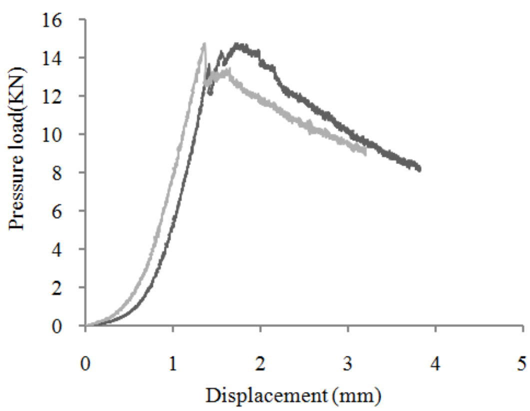
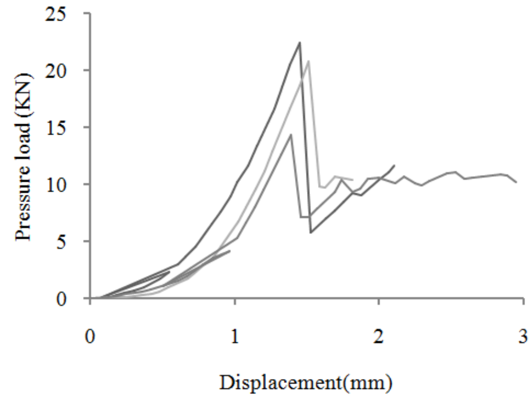


Fig. 6: Comparison of strength data from the present test with the results from other studies



(a) Load-displacement curve at the lower strain rate (1×10^{-4}/S): ductile



(b) Load-displacement curve at the higher strain rate (3×10^{-3}/S): brittle

Fig. 7: Typical load-displacement curve at the lower and higher strain rate

Failure models: As many researchers mentioned, ice exhibits two kinds of inelastic behavior under compress. At lower strain rate, the ice material is ductile. Its strain-stress relation curve has ascending and descending branches. At the initial loading stage, the ice began to crack but not collapse until a kind of percolation threshold is reached. Thus, the deformation can be very large and have the descending stage. However, when the strain rate is higher, the material exhibits brittle behavior. Under these conditions, its strain-stress relation curve only has ascending branch and failure occurs quickly. According to many documents, the turning point of strain rate is about $10^{-4}\sim10^{-3}$/S. Before the turning point, the ice exhibits ductile behavior. If strain rate greater than the turning point, the ice is brittle.

The similar conclusions are drawn in the present study for River ices. When the strain rate is below 5.0×10^{-4}/S, the ice exhibits ductile behavior. The ice specimens began to crack at the initial loading stage, with the load increases, the numbers and the length of crack grows step by step. The test lasts long time and has no suddenly crush. When the strain rate is greater

Table 2: The result of the initial elastic modules of Songhua River ice tested on the various temperatures

Row	Test temperature	Loading increment (KN)	Stress increment (KPa)	Strain increment (με)	E (GPa)	Ave. (GPa)	S.D. (GPa)
1	T = -10°C	1.000	177.778	354	0.502	0.528	0.051
2		1.000	177.778	327	0.544		
3		1.000	177.778	388	0.458		
4		1.000	177.778	331	0.537		
5		1.000	177.778	298	0.597		
1	T = -15°C	1.000	177.778	319	0.557	0.612	0.035
2		1.000	177.778	284	0.626		
3		1.000	177.778	287	0.619		
4		1.000	177.778	273	0.651		
5		1.000	177.778	293	0.607		
1	T = -15°C	1.000	177.778	255	0.697	0.671	0.056
2		1.000	177.778	278	0.639		
3		1.000	177.778	241	0.738		
4		1.000	177.778	258	0.689		
5		1.000	177.778	300	0.593		

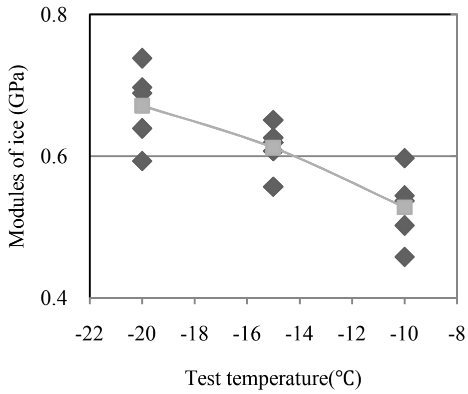


Fig. 8: Compressive modules of ice vs test temperature

than 1×10^{-3}/S, the ice specimen exhibits obviously brittle behavior. In this case, the test specimen splits off quickly through vertical direction, crushed and lost its load capacity. Figure 7 gives out the typical load-displacement curve under lower and higher strain rates, all of these are gotten from the present studies.

Modules of ice: In the present research, the initial elastic compressive modules of river ice are also studied. Seeing Fig. 3, the strain sheets are pasted on the surface of ice test specimen. Using the strain data acquisition system to record the ice strain change value during the loading. The loading step is 1 KN and the strain rate is 3×10^{-4}/S, the test temperature is -10, -15, -20°C, respectively. The initial elastic modules of ice can be calculated by using the nominal stress divides the strain. The entire test is done in MTS.

Table 2 shows the result of the initial elastic modules of Songhua River ice tested on the various temperatures. The value of modules is between 0.528~0.671 GPa. As the Fig. 8 made clearly, the Modules of river ice increases with the decreasing test temperature.

CONCLUSION

The compressive strength and the initial elastic modules of Songhua River ice are investigated comprehensively. More than 160 ice specimens have been tested on the MTS. The results can be summarized as the following:

- The compressive strength of river ice is strongly depending on the temperature and strain rate. It increases with the decreasing test temperature. However, the compressive strength of ice firstly increases and then decreases with the increasing strain rate. There is one peak turning point of strain rate. The turning point value of strain rate is about 1.0E-3/S. At the turning point, the compressive strength is maximum. To Songhua River ice, the compressive strength range is about 2.7~5.089 MPa.
- The test results show that the river ice has the typical dual mechanical characteristics of ductile and brittle behavior. When the strain rate is greater than 1E-3/S, the ice specimen exhibits obviously brittle behavior. When the strain rate is below 5.0E-4/S, the ice exhibits ductile behavior. The range of transition from ductile to brittle is about 5.0E-4/S~1E-3/S.
- Under compressive loading condition, the initial elastic module of Songhua River ice is about 0.528~0.671 GPa. And the modules of River ice increases with the decreasing test temperature slightly.

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REFERENCES

Daniel, I. and B. Ian, 2007. The structure and mechanical properties of river and lack ice. Cold Reg. Sci. Technol., 48: 202-217.

François, N., M. Brian and Q.T. Tung, 2009. River ice cover flexure by an incoming wave. Cold Reg. Sci. Technol., 55(2): 230-237.

Gold, L.W., 1977. Engineering properties of fresh water ice. J. Glaciol., 19: 197-212.

Hawkes, I. and M. Mellor, 1972. Deformation and fracture of ice under uniaxial stress. J. Glaciol., 11(61): 103-131.

Jones, S.J., 1982. The confined compressive strength of polycrystalline ice. J. Glaciol., 28(98): 171-177.

Schulson, E.M. and N.P. Canon, 1984. The effect of grain size on the compressive strength of ice. IAHR Ice Symposium, Hamburg, pp: 109-117.

Yu, T. and Z. Yuan, 2008. Experimental research on mechanical behavior of river ice. Proceedings of the19th international Symposium on Ice, Canada, 1: 519-530.