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UNFROZEN WATER CONTENT IN MULTI-CRYSTAL ICE

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An artificially large crystal ice was smashed and divided into four groups with the grain sizes of >10, 7–3, 3–1, and <1mm, respectively. The unfrozen water content of multi–crystal ice was determined by the nuclear magnetic resonance technique and by calorimeter. Four factors influencing the unfrozen water content in multi–crystal ice, including grain size of ice, interfaces between crystals, freezing speed and air content in water, were investigated. Results show that the unfrozen water content increases with decreasing of grain size of ice. The unfrozen water content between interfaces of ice–water–ice is greater than that of ice–water–air. By using deaerated water and a quick freezing, we can obtain greater multi–crystal of ice than the undeaerated water and a lower unfrozen water content if other conditions are the same.

INTRODUCTION

The basic difference between frozen and unfrozen soils is that ice exists in frozen soils. The ice content and its property in frozen soils are of great significance for physical and mechanical properties of frozen soils. And the ice content and its property depend on the unfrozen water content in ice to a large extent. A lot of previous work has been done on unfrozen water content in frozen soils (M.Anderson et. al.,1974, A.R.Tice et. al.,1978, E.D.Ershov, 1979), but seldom dealt with unfrozen water content in multi–crystal ice. Xu Xiaozu determined the unfrozen water content in ice made by distilled water (1987), but didn't describle the changing regularity of unfrozen water content in multi–crystal ice.

SAMPLE PREPARATION

To obtain multi–crystal ice with different grain sizes, it is necessary to prepare large crystal ice first. Therefore, we pour distilled water into a plexiglass container with the size of 15 cm in diameter and 25 cm high. The temperature at the water surface is kept at zero or slightly below zero degrees centigrade. The side of the container is surrounded by insulation material. Water is gradually frozen from the top downwards. Usually, after one week of freezing the ice thickness may reach to about 10 cm and the diameter of the ice crystal is larger than 10 mm. Taking one sample from this massive ice as the sample with a grain size of larger than 10 mm. After that the massive ice is smashed and sieved and divided into three groups with a grain size of less than 1 mm, 1 to 3 mm and 3 to 7 mm, respectively. Each group of multi–crystal ice is divided into two subgroups. One subgroup is emerged in distilled water of zero degrees centigrade and quick frozen again to create ice–water–ice interfaces between ice crystals, and the other subgroup is kept without distilled water to create ice–water–air interfaces.

To investigate the influence of freezing speed and air content in water on the unfrozen water content in multi–crystal ice, two other samples are prepared. One sample is made with water from the previous determined sample with the grain size of the ice crystal being larger than 10 mm and another sample made from deaerated water and both of them are frozen with a high speed. All of the samples mentioned above are frozen at minus 20 degrees centigrade for 5 hours and are determined by the nuclear magnetic resonance technique in a warming cycle and by a calorimeter.

RESULTS AND ANALYSIS

As a kind of grained material, ice crystals, like soil particles, can absorb a certain amount of unfrozen water under the condition of the temperature being below zero degrees centigade because of the existence of free energy at the surface of particles. Figure 1 shows the curves of unfrozen water content vs. temperature for the ice crystals with the different grain sizes mentioned above. It can be seen from figure 1 that the unfrozen water content increases with decreasing of temperature in the power form. From figur 1–a it can be seen that if the temperature is the same, the unfrozen water content of multi–crystals of ice changes with the grain size of ice crystal and can be divided into three groups: the minimum a grain size is larger than 10 mm, the middle grain size is from 1 to 7 mm and the maximum grain size is less than 1 mm. The difference of frozen water content curves for ice grain size less than 7 mm is not great because of the difference of ice grain size being less after water is filled and being quickly frozen. From figure 1–b it can be seen that under the conditions of ice–water–air interface and quick freezing the changing regularity of unfrozen water content with temperature is the same as shown in figure 1–a, but the maximum of unfrozen water content for the case of IWA is less.

The curves in figure 1 can be expressed by the regressive equations shown in table 1. From table 1 it can be seen that the related coefficients are greater than 0.94.

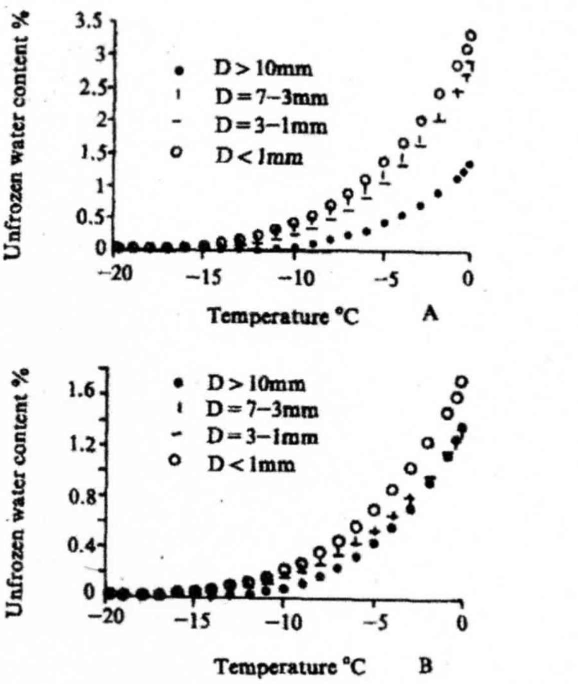

Fig.1 Unfrozen water content in multicrystal ice with different grain sizes vs. temperature (A–for the IWI case and B–for the IWA case)

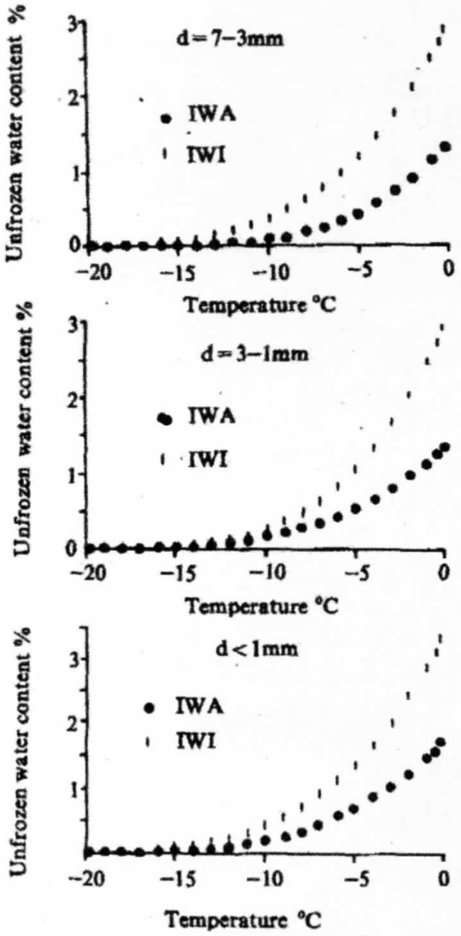

Fig.2 Unfrozen water content of multicrystal ice with different interfaces

Figure 2 shows the curves of unfrozen water content vs. temperature for multi–crystal ice with grain size less than 7 mm and interface of ice–water–ice and ice–water–air respectively. From figure 2 it can be seen that if temperature is the same, the unfrozen water content of multi–crystalice with interface of ice–water–ice is higher than that with interface of ice–water–air. There is no much difference for different grain sizes.

Figure 3 shows the curves of unfrozen water content vs. temperature for samples of grain size larger than 10 mm and deaerated and undeaerated distilled water being quickly frozen. From figure 3 it can be seen that if the temperature is the same, the unfrozen water content of the sample made by undeaerated distilled water being quickly frozen is much greater than that of the sample with grain sizez greater than 10 mm. It indicates the freezing rate has a great influence on the unfrozen water content. Microscope observation on the thin section indicates that the freezing rate infleuces the grain size of ice crystals. The higher the freezing rate, the less the ice crystals is and the less the ice cryatal, the higher the unfrozen water content. Compared with the unfrozen water content of the deaerated sample, the unfrozen water content of the undeaerated sample is higher even if the freezing condition is the same. Microscope observation indicates that the grain size of the deaerated sample is greater than that of the undeaerated sample.

Table 1 Regressive equation of unfrozen water content of multi–crystal ice

grain size,mm	regressive equation	coefficient A	B	related coefficient	Number of point
>10		−0.05498	1.0895	0.9418	11
3–7		−0.04259	1.0723	0.9772	14
3–7 *		−0.05224	1.3045	0.9965	15
1–3		−0.04568	1.0838	0.9837	11
1–3 *	$Y=(AX+B)^4$	−0.05967	1.3170	0.9989	14
<1		−0.04675	1.1505	0.9976	15
< 1 *		−0.05445	1.3582	0.9989	14
refreeze		−0.05503	1.3725	0.9995	15
vacuum		−0.05565	1.3696	0.9989	12

Where Y – unfrozen water content,%; X – absolute value of temperature, °C; A and B– constants; * – ice–water–ice interface.

CONCLUSIONS

The unfrozen water content of multi–crystal ice is controlled by the grain size and the interface between ice crystals. If other

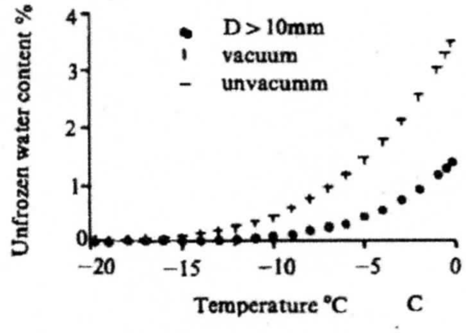

Fig.3 Unfrozen water content in multicrystal ice with deaerated and undeaerated water quickly frozen

conditions are the same, the unfrozen water content of multi–crystal ice increases with decreasing grain size and with increasing ice content.

The freezing rate and air content in the sample are the important factos for the grain size of ice crystal formation. If other conditions are the same, grain size of ice crystals decreases with an increase in the freezing rate and air content.

The maximum of unfrozen water content for IWI and IWA interface is less than 3.5 and 1.5 %, respectively.

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