Requirement for Cold Weather Concreting to Overcome the Extremely Severe Mongolian Winter

ABSTRACT：Mongolia is ranked 19th in the world by the size of its territory. The total population of Mongolia in 2022 was 3,457.5 thousand. Mongolia has an average elevation of 1580 meters above sea level. Mongolia has an extreme continental climate and four seasons with short summers and long, cold winters. The average temperature drops to −20ºC during the winter season. The total duration of sub-zero temperature lies between 133 to 211 days in a year depending on the weather conditions. As a result, a very short period is available for concrete works. Therefore, there are many negative consequences such as seasonal unemployment due to the harsh climate conditions of Mongolia.

Recently, construction companies have begun to strive for continuous construction work during winter seasons in Mongolia. It is common for concrete works to be done even in the winter without prior planning. As a result, controlling the quality of concrete becomes difficult without revising the existing norms and regulations, especially for buildings constructed during the cold seasons. Currently, Mongolia lacks specific guidelines dedicated to cold weather concreting. The current Mongolian norms and regulations for cast-in situ reinforced concrete structures (BNbD52-02-05) describe not only the cold weather concreting, but also many other subjects for the cast-in-place concrete and reinforced concrete structures. Therefore, current construction norms do not fully cover the country's long cold seasons since important specifications and definitions are not adequate. In this research, there were reviewed 4 guidelines, 4 standards, and one norm from 8 different countries. Most of them contain similar main topics such as the definition of the cold period, application of maturity calculation, minimum required compressive strength, requirements of materials, concrete temperatures, curing and protection methods, and quality control. However, some requirements were not applicable for extremely severe Mongolian winters due to the temperature limitation.

Based on the above background, the purpose of this research was to develop a suitable concreting method for extremely severe Mongolian winter, even considering climate difference between east to west, and north to south. The significance of this research is that it will help to establish Mongolian new guideline for the cold weather concreting based on the scientific evidence. Figure 1 shows the thesis's graphical abstract, which indicates the two main sections. Chapters 2, 3, and 4 were focused on understanding the current Mongolian situation for the cold weather concreting. Chapters 5 and 6 proposed appropriate concrete methods to prevent early-age freezing at construction sites.

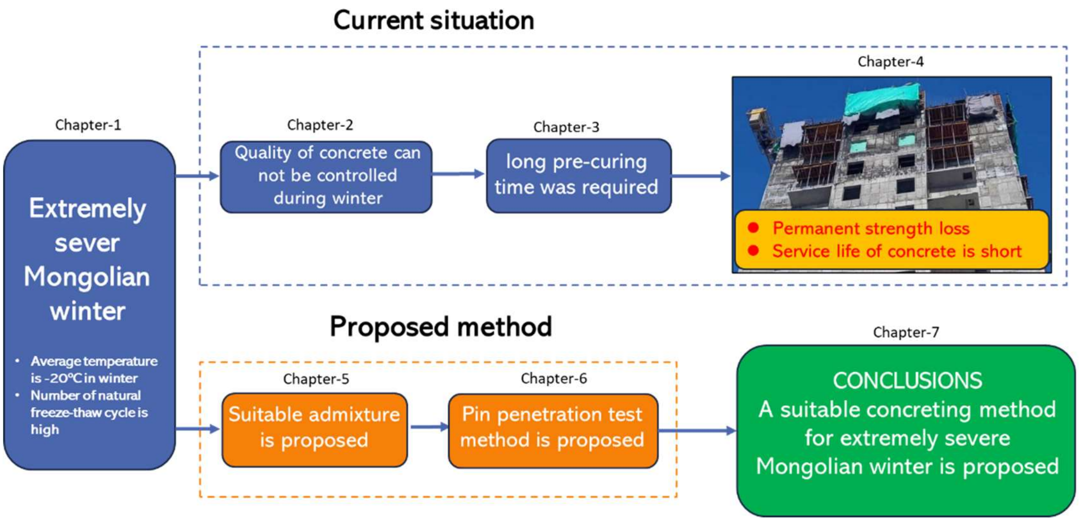

Figure 1. Graphical abstract of thesis

In Chapter 2, A questionnaire survey accompanied with interviews on cold weather concreting in Ulaanbaatar, in 2020. Seventeen responses were collected from specialists, general engineers, and directors who have experience with cold weather concreting. The respondents are employees of construction companies, ready-mixed concrete companies, precast concrete companies, consultants, and governmental entities. As a result, all respondents insisted that the insufficiency of consensual Mongolian norms for cold weather concreting due to lack of detailed methodological guidelines and rules in the existing norms. In total, 71% of respondents answered that they execute concrete works during the winter season, even ambient air temperature is between −10 °C and −20 °C. However, 53% of them thought that current Mongolian norms are not sufficient for the cold weather concreting.

In Chapter 3, it was investigated that the minimum required time span of pre-curing in order to achieve the potential strength at 28 days before being exposed to extremely low temperatures (−20 °C). A different pre-curing times are planned to simulate actual Mongolian condition before exposed to freezing (−20 ºC) condition. Hence, concrete will obtain different accumulated temperature depend on pre-curing times. As a result, it was confirmed that the concrete strength will not increase at the extremely low temperature (−20 ºC) and permanent strength loss will occur if concrete is exposed to early-age freezing. Moreover, this study added the research value of conducting experiments at −20 ºC. It confirmed that the maturity function proposed by AIJ was applicable for extremely severe Mongolian winter (−20 ºC).

In chapter 4, the service life of concrete under the Mongolian freeze-thaw situation was investigated due to if concrete subjected to early age frost damage, it could cause serious problems such as permanent strength loss and durability deterioration. The relationship between number of freeze-thaw cycle (C_{yn90}) and compressive strength was determined when relative dynamic modulus of elasticity is 90%, and new empirical equation was obtained by experimental results, as shown in Figure 2. ASTM equivalent number of cycles was calculated based on Mongolia's meteorological data. The freezing and thawing cycles $C_{(yASTM\text{-}sp)}$ was between 5 and 10 cycle/year in Mongolia. The service life of concrete was determined depending on the locations of Mongolia and compressive strength of concretes.

In Chapter 5, the delayed time of setting can affect the strength development of concrete in cold weather by increasing the potential for freezing of the concrete before initial set. Therefore, it was proposed to reduce the minimum required pre-curing time to prevent from early age freezing before exposed to extremely low temperatures (−20 ºC) using the accelerating admixture. In this study, two type of accelerating admixtures was investigated such as Nitrite-type non-chlorine special inorganic salt (AC-N) and amorphous calcium aluminate (AC-ACA) which are non-chloride and can effectively increase the early age compressive strength. As a result, it is confirmed that if concrete obtains sufficient accumulated temperature before being exposed to sub-zero temperature, its strength can be matured without loss. Moreover, it was found that 10% of AC-ACA can significantly increase the early age compressive strength of concrete and target

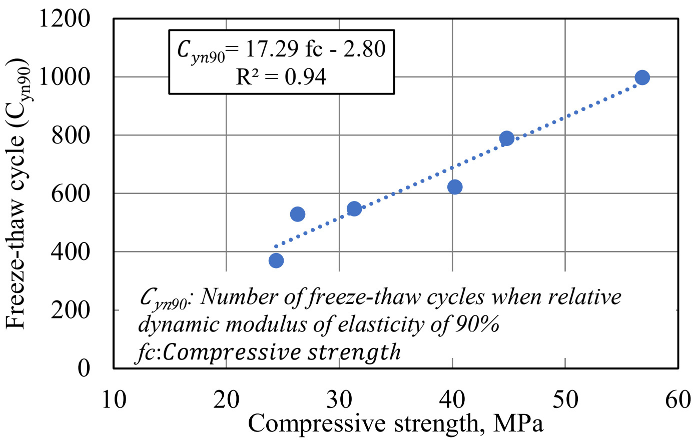

Figure 2. Relationship between number of freeze-thaw cycles and compressive strength when relative dynamic modulus of elasticity is 90%

strength can be obtained after re-curing even if specimen is exposed to −20 ºC just after pouring. The required accumulated temperature to obtain minimum required compressive strength was determined for concrete mixture incorporated with different accelerators. The required accumulated temperature was 33.4 ºD·D for control, 19.4 ºD·D for AC-N and 7.0 ºD·D for AC-ACA, respectively. Based on the above result, the minimum required pre-curing time was determined depending on accelerators and curing temperatures as shown in Table 1. Therefore, the proper curing methods to prevent early age freezing using accelerating admixtures and temperature controlling was proposed to use for extremely severe Mongolian winter.

Table 1. Minimum required precuring time to prevent early-age freezing [hours]

Groups	Accumulated temperature, ºD·D	Curing temperature, ºC			
		20	15	10	5
Control	33.8	24	32	41	54
AC-N	19.4	12	19	23	31
AC-ACA	7.0	3	6	8	11

In Chapter 6, a method to determine early age compressive strength using the pin penetration test before demolding was investigated. According to international norms for cold weather concreting, the require initial curing until the compressive strength exceeds 5 N/mm^2 was recommended in order to avoid initial frost damage. However, there is no suitable method to confirm very early age strength with the remaining mold conditions. This study proposes to use the pin penetration tester as a method that can be directly applied to structural concrete before demolding, which enables strength estimation at the construction site in a non-destructive and much more straightforward manner.

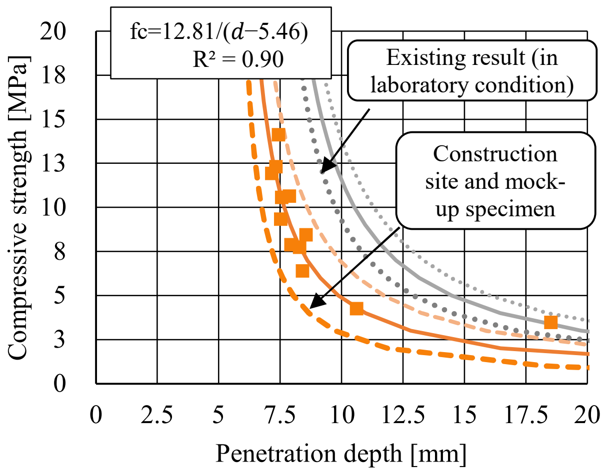

Figure 3. Pin penetration depth and compressive strength of concrete (fc: Compressive strength, *d*: Penetration depth)

Applicability of pin penetration test was confirmed at actual construction site and mockup mold. It was confirmed that the correlation between penetration depth and compressive strength could be expressed by the same approximate equation (Figure 3) even if used different mix proportions and cured at different ambient air temperature.