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REHABILITATION OF BUILDINGS IN WINTER CONDITIONS *

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Abstract. *Various factors are taken as the criteria for determining the susceptibility of materials to frost, such as: porosity and water absorption, volume changes, the number of freezing and thawing cycles. Mortars as a mixture of binder, water and sand, after placing and undergoing bonding and solidification processes, represent extremely porous materials, and the same holds for concrete. When the water turns into ice, it changes its volume measure unit from (Vω) into Vt = 1.09 Vω. If the concrete that has not completed bonding is exposed to frost, the process is likely to be suspended, and later when the warming starts, followed by the thawing of concrete, it will need the repeated vibrating in order to bind again and harden up without the detrimental effects on its strength. However, there are cases of devastating effects of frost on the hardened concrete. All the mentioned strategies should be kept in mind when performing remediation.*

Key words: *building, rehabilitation, frost, porosity, strength*

1. INTRODUCTION

Discussing rehabilitation of the building structure in winter conditions means actually discussing behaviour of the primary building materials (concrete, mortar, brick etc.) at the frost action. Low temperatures and frost are not only detrimental to the appearance of buildings, but often put at risk their reliability. At low temperatures, building materials may peal off, crumble, crack and disintegrate, i.e. frost and ice render the materials unstable in these conditions. It has been proven in practice that porous cavernous materials (stone, brick, mortar, roof tile, concrete and all the prefabricated materials) can be stable but also unstable at low temperatures, depending on the composition and structure and their environment. Various factors are taken as the criteria for determining whether a ma-

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terial is susceptible to frost or not, some considering porosity and water absorption, other volumetric changes, some other the number of freezing and thawing cycles endured by the material, etc.

Porosity and cavernousness of building materials depends on their composition and origin. They depend on the structure of the solid material and may be very big. Porosity of materials is divided into overall or total (volume and caverns of all the pores in a volumetric unit), open porosity which can be determined after water absorption and closed porosity.

Porosity of fired clay materials depends on the type and composition of the raw material and then on the method of processing. It depends on the type of clay (fat, lean, calcareous…) quantity and type of filler (sand, fireclay powder…) processing method (pressing, extrusion, hand making) quantity of water used for preparation of clay putty, drying method and finally of the method and temperature of firing. The total porosity of our products is: for normal solid brick 30-40%, and for the façade solid brick – 19-35%.

Mortars as a mixture of binder, water and sand, after placing and undergoing bonding and solidification processes, represent extremely porous materials, but the porosity can be modified. By an engineered composition of ingredients and of processing and placing method, the mortar porosity can be either increased or reduced, but cavities and pores cannot be eliminated. Each grain of cement, regardless of its small dimensions, is porous to lesser or greater extent, as any other material. Several grains, a certain volume (V) of cement consists not only of the volume of cavities (V_1) of grains themselves, but also of the volume of cavities (V_2) which are positioned between the individual grains of cement and the (v_0) volume of solid matter of cement, that is

$$V = V_0 + V_1 + V_2 \quad (1)$$

Soon after good mixing of cement and water, with hydration of cement, large changes in mixture will occur, and a new material will be obtained, a "cement rock" with porosity of 25-40%.

The same facts hold for the concrete porosity and mortar porosity. It should be emphasized that he cement-concrete porosity may vary in a very wide range, given that very different types of concrete are prepared and used, starting from compact concretes of high mechanical strengths and low porosity 2-15%, to the low mechanical strengths and very high overall porosity, up to 90%. Porosity of structural concretes depends primarily on the cement rock and cement mortar, and then on the type of coarse aggregate and the quantity of water used for mixing of concrete and finally on the placing technique. The saturation coefficient (*Ku*) is defined as a ratio of the quantity of absorbed water by a total immersion method (*U*) and the quantity of absorbed water under pressure (*Ur*), and it will be stable at frost if the condition $KU \leq 0{,}92$ is satisfied. However, for the practical purposes, stone, brick and roof tiles will be stable at frost if $KU \leq 0{,}80$.

2. Water as Liquid and Water as Ice

Water as liquid and water as ice greatly affects durability of building materials in general, and particularly the durability of cavernous and porous materials, because by alternate moisturizing and dehydration causes great changes in the structure of the material. Under the changes, the material saturated by water for a prolonged period is prone to crumbling, pealing, cracking and total decomposition, particularly in frost conditions. The quantity of water (*V*ω), whose specific gravity is equal to one, at 0°C freezes and solidifies into ice, whose specific gravity is 0,9175, which in turn changes the water volume thus becoming *Vt* = 1,09Vω, which means that after freezing the volume increases for 9%, if it can freely expand. If any volume of water would be cooled to -*t*°C (figure 1, point R) it would freely increase the volume. If this expansion of ice is prevented, it would not only sustain pressure, but would turn into water (figure 1, point R). If the pressure is further increased, and the temperature remained still at t°C, not only would the volume change, but water would turn into ice again (fig.1, point S) whose specific gravity is no loner 0,9175 but higher than 1. Ice, like water is very complex material (fig. 1.) [1].

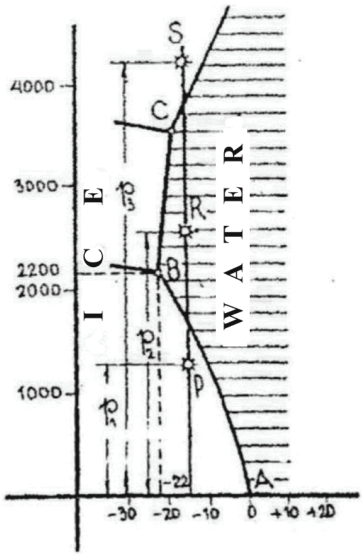

Fig. 1. Diagram of dependency of

In this diagram it can be seen that the ice of interest to us between the AB line and the ordinate axis, can cause a maximum pressure of 2200 kp/cm^2 when water, that is, ice, is cooled to -22°C. The material degradation mechanism due to frost action appears relatively simple, though the mentioned changes occur approximately in a following way:

- cavernous and porous material is saturated by water and at temperatures below zero, ice is created;
- frozen water – ice increases its volume and an increased pressure occurs causing stress in the materials and with the further lowering of temperature the pressures rise, which may bring about the "yield" of material" and its degradation. When the ice pressure becomes so high that the tensile stresses building up in the material are exceeded, the material must crack and eventually disintegrate. Even though this interpretation of the material damage causes under the action of frost appears to be simple and acceptable, it depends on a number of different factors.

Building materials such as: stone, brick, mortars, concrete and the similar materials, increase their volume by being in water for a prolonged period. At the moment of water freezing in a material and by further lowering of temperature, new volumetric changes occur, in two directions: due to the temperature drop the material is shrinking while the water transformed to ice expands, so from the diagram (Fig. 3) "contraction temperature" during frost, conclusions could be made about stability or instability of materials exposed to frost. The coefficient of linear expansion of ice is 51×10^6 while for the brick and concrete it is 4,5 to 11 times smaller. Professor Leman [1] has displayed in Fig. 2 behaviour of ceramic material stable at frost, and in the Fig. 3, of the material unstable at frost.

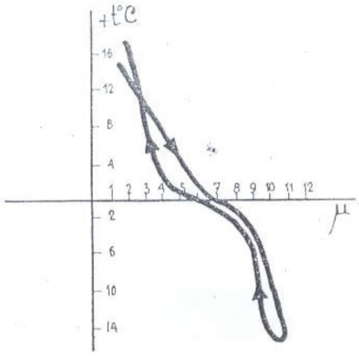

Fig. 2. Ceramic material behaviour stable at frost

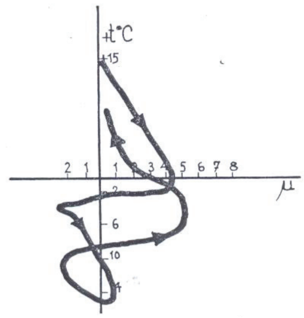

Fig. 3. Ceramic material behavior unstable at frost

The same phenomenon is perceived in concrete structures. Namely, it has been established that mortars and concretes that are not stable at frost conditions, in the event of a protracted exposure to frost, exhibit expanding tendency, whereas those which are stable at frost do not increase volume, but on the contrary, contract.

In the diagram in Fig. 1 or the diagram in Fig. 4. which is only a part of the diagram in figure 1. it can be seen that the pressures exerted by ice on the obstacles in its way of expanding can be far higher than the strengths of solid capillary structure materials used in engineering, thus the material is not capable of withstanding the pressures, resulting in degradation of material due to the action of ice.

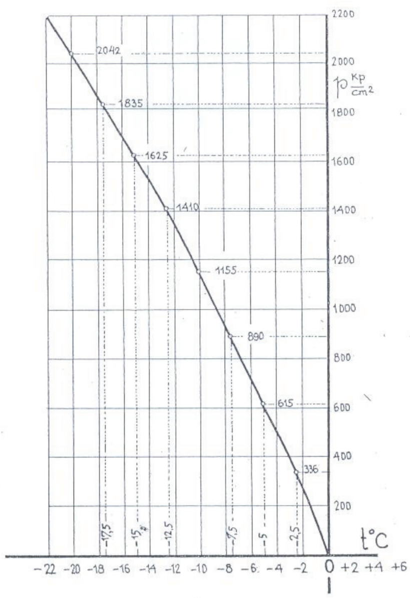

Fig. 4. Diagram of dependency of pressure on the ice temperature (part of the diagram in figure 1)

Therefore, for each material, depending on its structure, there will be a certain amount of water, "critical quantity of water" which will cause material degradation at a certain freezing temperature. To what extent different materials will resist the destructive action of frozen water depends, undoubtedly, on the mechanical properties of the material. Tensile strength (βz) and compressive strength (βp), as well as the elasticity modulus (*E*), can indicate whether the changes occurred in the structure of the material or not. The materials should demonstrate even less strength after the cycles of freezing and thawing, thus in the evaluation of stability of a material very frequently a coefficient of resistance to frost is used, which is determined by the ratio of the material compressive strength in dry state (βρ) and the same strength after the freezing and thawing cycles (βρ").

Methods applied for determining the stability of materials at frost action, are very long, and the results obtained do not correspond the best with the phenomena encountered in engineering practice [1].

3. Influence of Ice on Concrete

3.1. Influence of fresh ice on concrete

Before the detrimental effects of freezing and thawing on hardened concrete are discussed, and which give rise to the major stability problems, the action of frost on fresh concrete will be considered. If the concrete that has not completed bonding is exposed to frost, an effect will take place, that is somewhat similar to that when the water-saturated soil is frozen and thus is swelling, as water will increase its volume as it transforms into ice, as has already been said. But, apart from that, when water is frozen, it cannot partake in the chemical reactions, which retards and delays the binding and hardening processes in concrete. This implies that if concrete is frozen immediately after it has been produced and placed, it will not be bound, thus there will be no paste which will sustain destruction due to frost action. For as long as the frost is continuing the bonding process of cement will be suspended, and later when the warming starts, followed by the thawing of concrete, it will need the repeated vibrating in order to bind again and harden up without the detrimental effects on its strength. In the event the concrete is not vibrated after the thawing, it would bind and harden in its present state, and since ice has larger volume than water, the concrete would be full of pores, which would have very poor effects on its strength. Repeated vibrating after the concrete thawing completely rectifies this potential flaw, and perfectly good concrete is obtained. If the concrete has frozen after the binding has been finished, and still has not acquired the adequate strength, expansion due to ice build up can result in its damage, and in the irretrievable loss of strength. If concrete has acquired the permissible strength prior to freezing, it can resist the freezing effects, not only by being able to sustain the ice pressure, but because at the time the quantity of free water will be greatly reduced, as its considerable portion will be in the concrete hydration process, and because a great deal will have already been distributed in the gel pores, where its freezing is prevented. However, it is difficult to determine when such state will be achieved. Generally speaking, risk of frost damage to concrete lowers with the progress of hydration, and with the strength of concrete at the moment of freezing from 5 to 14 MN/m^2). A considerable decrease in the rate of swelling is noted as early as after 24 hours, so it is very advisable to protect concrete from frost at least in this initial period (Fig. 5.).

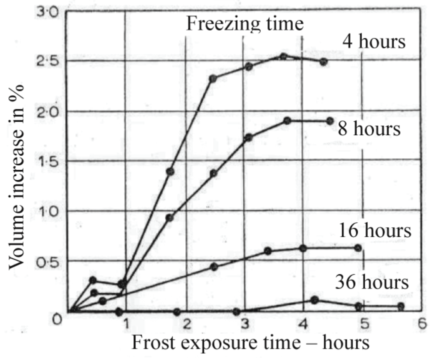

Fig. 5. Concrete volume increase rate during long-term cold period as a function of time when freezing started

It is important when the first cycle of freezing began, but the action of cyclic freezing –thawing is much more destructive than the action of long-term frost – without thawing, so several cycles can destroy concrete kept before that at the temperature of 20°C (Fig.6.). In order to avoid the unfavourable consequences of frost action on a fresh concrete, certain precautions must be taken.

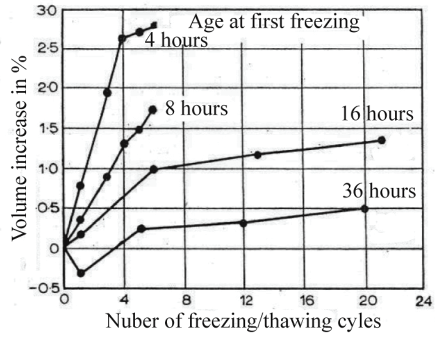

Fig. 6. Concrete volume increase rate during alternate freezing and thawing as a function of time when freezing started

Primarily, water should be warmed to 60-80°C, providing that any contact between cement and hot water is prevented. If water warming cannot produce sufficient temperature of concrete mixture, then the aggregate is warmed up to 52°C. The temperature of finished concrete must be calculated in advance, because if the mixture turned out excessively hot, it would have adverse effects on concrete strength. Certain acceleration admixtures can be used (for instance potassium chloride). The most favourable temperatures for concrete binding are 7-21°C, and it is important that its temperature does not drop below 10°C in the course of three days upon placing. The most favourable temperatures are those up to 21°C, and that the adequate temperature (depending on the type of cement) is present as long as possible. If the concrete completed binding prior to the onset of frost, and gained certain strength, hydration will proceed in the non-frozen cavities as low as to -4°C, and perhaps below that [3].

In practice many precautions should be taken when concrete is placed at frost, and concrete should not be cast into the formwork having the ice crust. Concrete is maintained after it has been placed by covering over, in order to protect it from the cold atmosphere, and if possible the space around concrete is enclosed and, if possible, heated. Action of frost is aggravated in high or icy winds, whereas snow acts as thermal insulation, and constitutes a protective layer over concrete.

3.2. Destructive effects of frost on hardened concrete

Freezing is a gradual process, partially because frost gradually penetrates into the depth of concrete mass, and in part because the percentage of dissoluble alkali in still unfrozen water rises, and eventually, because the freezing point depends on dimensions of water-filled cavities. The question is what the critical limit of concrete water saturation is? A closed vessel, filled up to 91,7% of its capacity with water, and left to frost, will be completely filled with ice and brought on the brink of bursting due to pressure. This, however, is not the case with a porous body, where critical saturation depends on the size of the body, its homogeneity and the rate of freezing, where it does not have a critical point of saturation.

In fig. 7 is presented the general effect of water absorbed in concrete on its resistance to freezing and thawing action, and in the Fig. 8 is presented the effect of water/cement factor on its resistance to frost, for the concretes cured in moisture for the first 28 days.

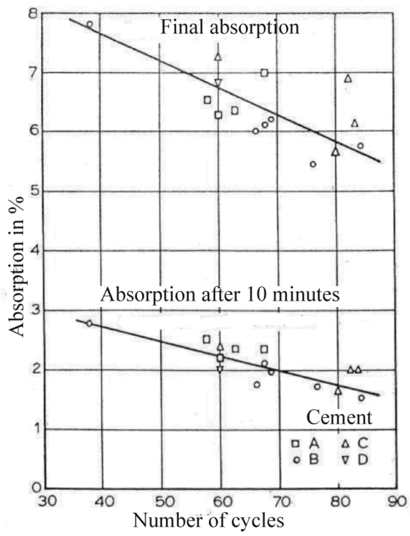

Fig. 7. Ratio between concrete absorption and the number of freezing and thawing cycles, required to accomplish loss of 2% of the original weight of the sample.

In the Fig.8 can be seen that in the concretes with W/C factor below 0,45 the dominant influence is exerted by inadequate hydration, because the concrete which is cured for a shorter period in moisture exhibits lower resistance to frost action.

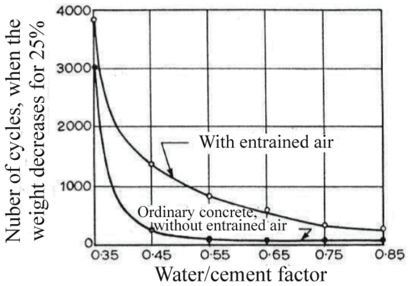

Fig. 8. Influence of water cement factor W/C on the resistance of concrete to frost, cured in moisture for 28 days.

The influence of intensive hydration is exerted by reducing the quantity of water, susceptible to freezing in the tests, as it is displayed in Fig. 9. for the case of concrete with W/C=0,41. Also, in the same figure it can be seen that the freezing temperature decreases with the age of concrete, and that only small portion of water freezes at 0°C, but it is a surface water on the specimen. The temperatures at which freezing of the capillary water begins, have the following order: after three days is -1°C, after 7 days -3°C, and after 28 days -5°C.

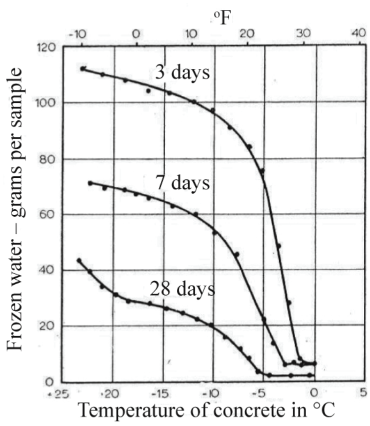

Fig. 9. Influence of age of concrete on the quantity of frozen water, as function of temperature

In order to reduce the danger of destructive action of frost, it is very important that the concrete is well compacted and impermeable, so aggregates which do not guarantee good compaction should be avoided. Susceptibility of concrete to destruction by frost, because of aggregates or cement sand can be determined by testing the sample by cooling, in the range of expected freezing temperatures and by measuring the change of volume. This means that the reliable data can be attained only by testing the concrete resistance to frost, on the specimens or in situ.

4. CONCLUSION

Water as liquid and water as ice greatly affects durability of building materials in general, and particularly the durability of cavernous and porous materials, which is mostly true for the most important building materials. Alternate moistening and drying causes great changes in the structure of the material and promotes crumbling, pealing, cracking and total decomposition, particularly in frost conditions.

Concrete as a mixture of aggregate , water and cement, after mixing, placing binding and hardening, represents an extremely porous material in a wide range, given that very different types of concrete are mixed and used. Compact concrete is that of high mechanical strength and low porosity (2÷15%), whereas low-strength concretes have porosity of up to 90%. The same facts hold for the concrete porosity and mortar porosity. The total porosity of our solid bricks is 30-40%, and of the façade solid brick – 19-35%. In the diagram in fig. 1 it can be seen that the ice of interest to us between the AB line and the ordinate axis, can cause a maximum pressure of 2200 kp/cm^2 when water, that is, ice, is cooled to -22°C. When the ice pressure becomes so high that the tensile stresses building up in the material are exceeded, the material must crack and eventually disintegrate, because the coefficient of linear expansion of ice is 51x10^6 whereas for brick and concrete it is 4,5 to 11 times lower. Namely, it has been established that mortars and concretes that are not stable at frost conditions, in the event of a protracted exposure to frost, exhibit expanding tendency, whereas those which are stable at frost do not increase volume, but on the contrary, contract. Therefore, for each material, depending on its structure, there will be a certain amount of water, "critical quantity of water" which will cause material degradation at a certain freezing temperature. To what extent different materials will resist the destructive action of frozen water depends, on the mechanical properties of the material. The methods applied for determining the stability of materials at frost action do not correspond the best with the phenomena encountered in engineering practice [1].

If concrete that has not completed binding is exposed to frost, it will increase its volume. Water that is frozen, cannot partake in the chemical reactions, which retards and delays the binding and hardening processes in concrete. The bonding process of cement will be suspended, and later when the warming starts, followed by the thawing of concrete, it will need the repeated vibrating in order to bind again and harden up without the detrimental effects on its strength. Generally speaking, risk of frost damage to concrete lowers with the progress of hydration, and with the strength of concrete at the moment of freezing (from 5 to 14 MN/m^2). If the concrete completed binding prior to the onset of frost, and gained certain strength, hydration will proceed in the non-frozen cavities as low as to -4°C, and perhaps below that [3]. Freezing is a gradual process and the freezing point depends on the dimensions of the cavity filled with water, so frost can act on the hardened concrete, that is even after 28 days if the temperature is below -5 °C. It should be noted that the volume of water (Vω) is one and the volume of ice is Vt = 1.09 Vω. In order to reduce the danger of destructive action of frost, it is very important that the concrete is well compacted and impermeable, so aggregates which do not guarantee good compaction should be avoided. Susceptibility of concrete to destruction by frost, because of aggregates or cement paste can be determined by testing.

All the mentioned strategies should be kept in mind when performing remediation in winter, that is, frost conditions.

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SANACIJA GRAĐEVINSKIH OBJEKATA U ZIMSKIM USLOVIMA

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Kao kriterijumi za utvrđivanje osetljivosti materjala na dejstvo mraza, uzimaju se različiti faktori kao što su: poroznost i upijanje vode, zapreminske promene, broj mržnjenja i kravljenja. Malteri kao mešavina veziva, vode i peska, posle ugrađivanja, vezivanja i očvršćavanja predstavljaju izuzetno porozan materijal što se može reći i za beton. Kada voda pređe u led njena se zapremina menja od jedinice (Vw) i postaje Vt=1,09Vw. Ako beton koji još nije obavio vezivanje, bude izložen uticaju mraza, proces će verovatno biti obustavljen, a kada kasnije dođe do otopljavanja, pa i kravljenja betona, treba ga ponovo izvibrirati, pa će on vezati, i stvrdnuti se bez štetnih posledica po svoju čvrstoću. Međutim, dolazi i do razornog dejstva mraza i na otvrdnuti beton. Sve dalje rečeno treba imati u vidu prilikom izvođenja sanacije.

Ključne reči: *objekat, sanacija, mraz, poroznost, čvrstoća.*