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EXPERIMENTAL INVESTIGATION OF DURABILITY OF CONCRETE WITH RUBBER POWDER EXPOSED TO FREEZING TEMPERATURES

Michal Hora

Czech Technical University in Prague, Czech Republic

ABSTRACT

This research is focused on concrete with rubber powder content exposed to low (freezing) temperatures. Rubber powder serves as air-entraining agent and should provide better freeze-thaw protection. On the other hand, rubber powder limits maximum compressive strength of concrete. The main purpose of this research is to find an optimal rubber powder content in order to satisfy needs for the minimal loss in strength of concrete as well as high freezing-thawing resistance. A freeze-thaw test was carried out on five concrete mixes with different contain of several rubber fractions to determine the optimal rubber grading. Specimens with rubber powder were tested on compressive strength, splitting tensile strength, tensile strength and moduli of elasticity.

Keywords: Air-Entrainment, Compressive Strength, Freezing, Rubber Powder, Thawing

I. INTRODUCTION

When temperature of concrete saturated by water drops below zero, the water held in capillary system of concrete freezes and expansion of concrete starts. After re-freeze of concrete, further expansion takes place. That repeated cycles of freezing and thawing has cumulative effect on concrete. There are several options how to make concrete less vulnerable to frost damage. The use of mix with lower water/cement ratio provides small capillaries. Such concrete has a low permeability and does not absorb so much water in wet environment. It also results in less water in pore structure that is likely to freeze. Other possibility on how to prevent severe frost damage to concrete is use of air-entrainment. In order to prevent concrete deterioration rising from freezing and thawing, the pore structure of concrete has to be modified. This ability is determined by amount of air voids within the cement paste. The larger pores filled with air are in concrete mass, the more durable concrete is. Freezing point varies with the size of pore.

Entrained air produces cavities in the cement paste so that no connections for water are formed within and the permeability of concrete should not be increased. The cavities never become filled with the products of hydration of cement as gel can form only in water. Air voids can be created by adding air-entraining agents. However, a few papers show successful attempts with granulated rubber as a new air-entraining agent. This could positively influence freezing/thawing resistance of concrete.

Since the water in large cavities starts to freeze, the formed ice generates surface tension which puts smaller pores into pressure. The pressure is higher the smaller the pore. So that freezing starts in the largest cavities and gradually extends to smaller ones. Gel pores are too small to permit the formation of ice, only there is temperature below -80°C, so that in practice no ice is formed in them. However, the difference of entropy between gel water and ice, the gel water acquires an energy potential enabling it to move into the capillary cavities containing ice. The diffusion of gel water leads to a growth of the ice.

Thus, there are two source of dilating pressure. First one, freezing of water results in increase of volume (of approximately 9 percent) within the pore structure of concrete. The hydraulic pressure developed depending on the resistance to flow, i.e. on the permeability of the cement paste between the freezing cavity and a void which can accommodate the excess water.

The second dilating force in concrete is caused by diffusion of water. This diffusion is caused by osmotic pressure brought about by local increases in solute concentration due to the separation of frozen (pure) water from the solution. For instance, s concrete slab freezing from the top with also water access at the bottom will be seriously damaged since its total moisture content could become greater than before freezing due to osmotic pressure.

There are two material characteristics that this research is trying to optimise when using rubber powder in concrete, the objectives are follows: to provide high freezing and thawing resistance concrete without any great loss in compressive and tensile strength (maximum up to 10%). This can be done by optimum dosage of rubber powder as an additive to concrete mix.

II. MIX DESIGN

A standard C30/37 concrete mix was chosen as the reference. Three different concrete mixes were tested to determine optimal proportion of different rubber fractions. The fine (0-4mm), (4-8mm) and coarse (8-16mm) aggregates were used.

Three size of rubber powder, obtained from mechanical shredding of car tyres, were used. Combination of three different factions of rubber powder were used as an additive to concrete mix : 0-0,4mm; 0,4-0,8mm ; 0,5-1,5mm. The last fraction can be classified more as “rubber sand” then rubber powder.

Rubber powder was considered to be an additive to the designed mix, not a sand replacement. Replacing sand with rubber powder has the effect of reducing the compressive strength and elastic modulus 0.

Every concrete mix has the same batch of rubber powder, only proportion of three used rubber fractions differs in each batch. This paper derives partly from previous research on concrete with rubber content, where optimum rubber content was investigated. The optimum dosage was set at 0,8% of weight of aggregate. The same dosage was used in this research. However, more research on optimal dosage is still needed.

Table 1: The numbers at the column of “Rubber powder content” represent the dosage of rubber fractions by percent (sorted by the size of the fraction).

Mix type	Description	Rubber powder content [%]
Reference	plain	0-0-0
Mix 1	with rubber	10-20-70
Mix 2	with rubber	20-50-30
Mix 3	with rubber	50-40-10
Mix 4	with air entrainment	0-0-0

III. TESTING METHODS – SUMMARY

Standard cube form (150mm) was used for compressive strength test, splitting tensile strength test (after temperature cycling). Beams (100/100/400) were used for moduli of elasticity test (ultra-sonic test), tensile strength test. All specimens were stored, in water tank for minimum 28 days.

Table 2: Summary table of tests

Test	Test Method	Specimen	Curing	Number of specimens
Compressive strength	ČSN EN 12390-3	Cube	Curing under water (28 days)	3
Splitting tensile strength	ČSN EN 12390-6	Cube	Curing under water (28 days)	3
Freeze/thaw test	ČSN 731322 ČSN EN 12390-6	Cube, Beam	Curing under water (28 days)	3
Moduli of elasticity (sonic method) + tensile strength test	ČSN EN 12504-4 ČSN EN 12390-6	Beam	Curing under water (28 days)	3
Air content	ČSN EN 12350-7	-	-	-
Slump test	ČSN EN 12350-2	-	-	-

IV. AIR CONTENT AND SLUMP TEST

Entrained air pockets provide a relief system for internal ice pressure by providing internal voids to accommodate the volume expansion caused by freezing water.

At this point, it is important to note that entrained air is not the same as entrapped air. Entrapped air voids are created during improper mixing, consolidating and placement of the concrete. These kinds of voids have severe effects on strength and durability of concrete.

The goal is to develop a system of uniformly dispersed air voids throughout the concrete.

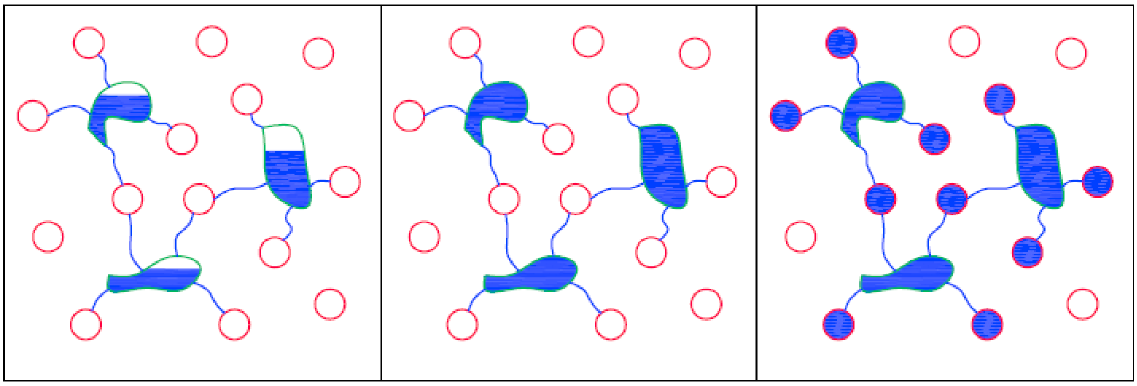

Figure 1: Basic scheme of air-entraining principle in concrete

Measuring of air content was done by pressure type air meter. Slump test was executed by ČSN EN 12350-2 standard. Mix proportions and the effect on the workability and air content of concrete are shown in Table 3.

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The result of the slump test indicates that fresh concrete with rubber powder content achieved a reduced slump, so the workability of fresh concrete rises. The results obtained from air content test also point at the fact that rubber content brings more air to the mix.

The reason for the improvement of workability by entrained air is probably that air bubbles act as a fine aggregate of very low surface friction.

Table 3: Table of specimens for slump test

Mix type	Slump [mm]	Air content [%]
Reference	50 mm	4,2 %
Mix1 (10-20-70)	140 mm	5,8 %
Mix2 (20-50-30)	170 mm	6,0 %
Mix3 (10-20-70)	160 mm	5,8 %
Mix4 (air-entraining)	200 mm	5,8 %

a) Reference Mix **b) Mix 1**

Figure 2: Slump test (ČSN EN 12350-2)

V. RESULTS

All tests are still running so only preliminary results are available at the moment of writing this paper. Only a few specimens have been tested so far. Especially tests with temperature cycling take more time (for determination of freezing/thawing resistance, 200 temperature cycles were settled). However, cube strength test are presented in **Error! Reference source not found.**.

Table 4: Preliminary results of cube strength test and dynamic modulus of elasticity (values are related to the reference specimens)

Mix type		Splitting tensile strength	Compressive strength
Reference mix	100 %	100 %	100 %
Mix1 (10-20-70)	98 %	85 %	82 %
Mix2 (20-50-30)	98 %	71 %	77 %
Mix3 (10-20-70)	97 %	71 %	84 %
Mix4 (air-entraining)	96 %	62 %	81 %

The reduction in overall density indicates the presence of internal voids in concrete. Compressive strength of specimens with rubber powder was reduced approximately about 17% for specimens with rubber powder. Very similar results are obtained for specimen with air-entraining agent. The reduction again pointing at influence of air-entering which rubber powder brings.

Splitting tensile strength of specimens with rubber powder was higher than with specimens with air-entrainment. It was shown (see **Error! Reference source not found.**) that amount of air in both mixes is very similar. Yet, the loss in tensile strength is lower with rubber powder. That's a good advantage for rubber powder as a possible entraining agent.

Dynamic modulus of elasticity wasn't practically changed. These results will serve for the oncoming comparison with values of dynamic modulus after temperature cycling.

VI. CONCLUSION

This paper has shown that there is a potential for using rubber powder as entraining agent as well as freeze/thaw resisting agent in concrete. The use of rubber powder in concrete has sustainable credentials in that it uses a waste product to enhance the performance of concrete.

All tests are still running so only preliminary results were presented. The data of freezing/thawing resistance of concrete with rubber powder and air-entraining agent, which will provide ongoing research, are crucial for the next research. The results showed in this paper confirmed that rubber powder can be used as an air-entraining agent which can bring similar amount of air to the concrete mix as commonly used air-entraining agents.

VII. ACKNOWLEDGEMENT

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