EVALUAREA EFECTULUI ANTRENOR DE AER A PULBERII DE CAUCIUC ȘI INFLUENȚA ACESTEIA ASUPRA REZISTENȚEI LA ÎNGHEȚ-DEZGHEȚ A BETONULUI

ASSESSMENT OF THE AIR-ENTRAINING EFFECT OF RUBBER POWDER AND ITS INFLUENCE ON THE FROST RESISTANCE OF CONCRETE

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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. The specimens with rubber content were tested at laboratory temperature as well as at freezing temperatures. Influence of rubber addition was assessed on the base of original and residual values of studied properties after freeze-thaw loading. Resistance to frost damaged was determined by splitting tensile strength test and tensile strength test. Non-destructive methodology was predominantly used to monitor gradual deterioration during freeze-thaw cycling.

Keywords: *freezing, thawing, rubber powder, compressive strength, air-entrainment*

1. Introduction

When the 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 the amount of air voids within the cement paste. The larger pores filled with air are in concrete mass, the more durable concrete is [1]. 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 [2-4] with granulated rubber as a new air-entraining agent. This could positively influence freezing/thawing resistance of concrete.

This paper is mainly focused on the effect of granulated rubber as an admixture which can serve as an air-entraining agent. The effect of air-entraining can be explained by the following mechanism: since the water in large cavities starts to freeze, the formed ice generates surface tension which exerts pressure on the smaller pores. The pressure is higher the smaller the pore is. In this way freezing starts in the largest cavities and gradually extends to smaller ones. Gel pores (average sizes of 0.5 – 2.5 nm) are too small to permit the formation of ice, 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 sources of dilating pressure. First one, freezing of water results in increase of volume (of approximately 9 %) 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

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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, a 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.

The idea to utilize waste rubber in the concrete production is not very novel, mentioned technology was extensively researched by number of laboratories [5-7]. The main attention was paid for predominantly mechanical properties. The sufficient durability properties of such designed concrete are necessary for wide industrial utilisation. The frost resistance of concrete ranks to the dominant durability factors describing resistance to environment [8]. Air-entraining effect of rubber particle was confirmed and studied in [10], where the increase of the frost resistance index after 200 load cycles was observed.

There are two material characteristics that we try to optimize in this research when using rubber powder in concrete i.e. to provide high freezing and thawing resistance of concrete without any great loss in compressive and tensile strength (maximum up to 9%).

2. Experimental program

2.1. Mix Design

A standard C30/37 concrete mix was chosen as the reference. The fine (0-4mm), (4-8mm) and coarse (8-16mm) aggregates were used. Mix proportions of studied concrete mixtures are presented in Table 1. Natural siliceous sand and crushed aggregate of two grading were used as the main part of concrete filler. Rubber powder (Fig. 1) was used as partial replacement of natural aggregate of 0.80 % by weight [2]. It was considered to be an admixture to the designed mix, not a sand replacement. Replacing sand with rubber powder has the effect of reducing the compressive strength and elastic modulus [3]. Three different concrete mixtures were tested to determine optimal proportion of different rubber fractions. Every concrete mix has the same batch of rubber powder, only proportion of three used rubber fractions differs in each batch, these are presented in Table 2. Three different grading curves of rubber powder were used. The rubber powder was obtained from mechanical shredding of car tyres. Combination of three different factions of rubber powder was used as an admixture 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. Cumulative passing of these rubber fractions are in Figure 2. Other components of designed concrete mixtures were plasticiser Sika 1035 (based on polycarboxylate ether) and air entraining agent, which was used for comparison of air-entraining effect of studied rubber. Water/cement ratio was set as a 0.49 in all cases of studied mixtures.

2.2. Rubber powder as an admixture

Rubber particles could provide space for forming ice within the cement paste voids in order to prevent concrete mass deterioration. Moreover, rubber particles are hydrophobic thus more air is included to concrete mix. Therefore, rubber

Table 1

Concrete mixture composition.

	R [kg/m^3]	VZ [kg/m^3]	1 [kg/m^3]	2 [kg/m^3]	3 [kg/m^3]
Cement CEM I 42.5 R	410	410	410	410	410
Water	200	200	200	200	200
Sand 0-4 mm	840	840	840	840	840
Grit 4-8 mm	340	340	340	340	340
Grit 8-16 mm	620	620	620	620	620
Rubber 0-0.4 mm	0	0	1.44	2.88	7.2
Rubber 0.4-0.8 mm	0	0	2.88	7.2	5.76
Rubber 0.5-1.5 mm	0	0	10.08	4.32	1.44
Plasticizer	0.82	0.82	0.82	0.82	0.82
Air-entrainment	0	0.82	0	0	0
w/c	0.49	0.49	0.49	0.49	0.49

Table 2

Properties of fresh concrete

Mix designation	Mix type	Slump [mm]	Air content[%]
R	Reference	50mm	4.2%
1	Mix 1 (10-20-70)	140mm	5.8%
2	Mix 2 (20-50-30)	170mm	6.0%
3	Mix 3 (10-20-70)	160mm	5.8%
VZ	Mix 4 (air-entraining)	200mm	5.8%

Fig. **1 -** Rubber powder

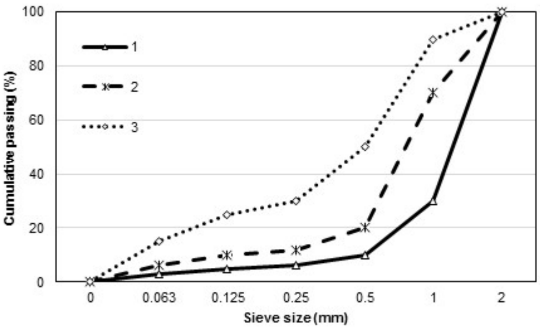

Fig. 2 - Grading curves of used rubber filler. 0-0.4mm (3); 0.4-0.8mm (2) ; 0.5-1.5mm (1).

Fig. 3 **-** Specimen without rubber powder (right), with rubber powder (left)

powder has similar effect as air-entraining agents. The higher air content can be seen in the picture Figure 3. Rubber particles have rough surface which has ability to entrap air due to their non-polar nature. Air-entrainment is an extremely complex process, which is affected by many factors, including the mixing process, material mixture proportioning, physical and chemical properties of cement, water amount, dosage and properties of air-entraining agent and a range of other parameters [5].

Series of tests aimed on freezing/thawing resistance which results from disintegration of the concrete mass were conducted with mix proportion with rubber powder as an admixture. The Czech manufacturer (GUMOEKO [9]) obtained rubber powder from mechanical shredding of old tyres. This particular type is claimed to be high quality recycled since it's without any steel fibres or any chemical pollution (chlorides, sulphur).

Entrained air pockets provide a relief system for internal ice pressure by providing internal voids to accommodate the volume expansion caused by freezing water, see Figure 4. 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

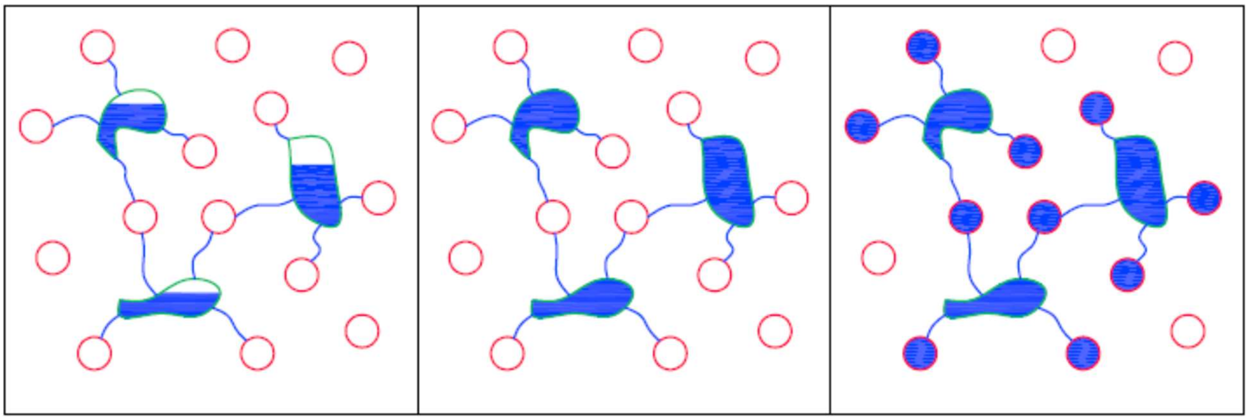

Fig.4 - Basic scheme of air-entraining principle in concrete.

have severe effects on strength and durability of concrete. The goal is to develop a system of uniformly dispersed air voids throughout the concrete.

2.3. Testing Methods – fresh concrete

Fresh concrete mixtures were prepared in the horizontal laboratory mixer. Slump test (Figure 5) according to [11] was carried out approximately five minutes after mixing, simultaneously was measured air content in fresh concrete mixture using the pressure method [12]. The rest of fresh concrete was used to sample production. 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.

Measuring of air content was done by pressure type air meter. Mix proportions and the effect on the workability and air content of concrete are shown in Table 3.

Table 3

Table of specimens for slump test

Mix type	Slump [mm]	Air content[%]
Reference	50mm	4.2%
Mix1 (10-20-70)	140mm	5.8%
Mix2 (20-50-30)	170mm	6.0%
Mix3 (10-20-70)	160mm	5.8%
Mix4 (air-entraining)	200mm	5.8%

2.4. Testing Methods – hardened concrete

Bulk density of studied concrete mixtures was investigated on the base of the actual weight and accurate dimensions of specimens. Compressive f_{cm} and split strength f_{sp}

a) Reference mix

b) Mix 1 (with rubber)

Fig. 5 - Slump test (CSN EN 12350-2).

determination were carried out according to [13] and[14], respectively on the cubic specimens of 150 mm edge. The cubes were oriented perpendicularly to the compaction direction during measurement.

Flexural strength f_{tm} measurement was executed as a three point test with supports distance of 300 mm in term of [15] and was calculated by help of the maximum reached force.

Determination of frost resistance was realized according to [16] by using prismatic specimens of dimensions of 100x100x400 mm. Testing was consisting of cycle temperature loading of saturated samples. Load cycle starts with frosting phase down to -18 °C lasting for four hours and then continues by defrosting period up to 20°C for another two hours. Defrosting is realized by flooding of climatic chamber by water of 20°C. Before frosting is chamber automatically drained what ensures full saturation of the specimens. Figure 6 clearly describes the process of temperature loading. Non-destructive measurement, as well as visual evaluation, is usually performed after each 25 or 50 cycles. Frost resistance is often expressed by ratio of final and original investigated values.

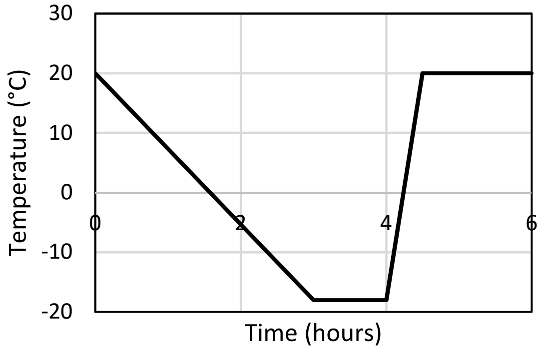

Fig. 6 - Illustration of the course of freeze-thaw cycling.

The Proceq PunditLab+ ultrasonic velocity test instrument has been used to determine the ultrasound speed v_L by 54 kHz transducer. Ultrasonic direct transmission is the most frequently used because in this arrangement, pulse amplitude reaching the receiving transducer is the highest.

$$E_{dyn} = v_1^2 \cdot \rho_v \cdot \frac{1}{k^2} \cdot 10^{-6}. \qquad (1)$$

E_{dyn} - dynamic modulus of elasticity [GPa],
v_L – velocity of the impulse [m/s],
k – coefficient of sample sizing [-],
ρ_v – bulk density [kg/m^3].

3. Results

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 Table 3) 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.

Detailed results of bulk density and mechanical properties are summarized in Table 4 at the age of 28 days. The highest value of bulk density exhibited logically reference mixture. Obtained values of bulk density well document ability of used rubber to bond air bubbles in the fresh mixture. However, the total replacement is constant; values of bulk density are changing accordingly to the content of the finest fractions of the rubber powder. Graphical interpretation of detailed results of measurement is shown on Figures 7-9.

Generally, cycle loading causes gradual deterioration of the material. It is due to internal pressure of originated frost in the pore system. Increase of the ice volume is just about 9%. That is why the concrete with frost resistance requirements is targeted air-entrained what ensures the space for ice expansion. Gradual reduction is well documented on the results the dynamic modulus

Table 4

Results of bulk density and mechanical properties after 28 days

	R	VZ	1	2	3
Bulk density [kg/m3]	2296	2209	2255	2250	2232
Split strength [MPa]	3.4	2.1	2.9	2.4	2.4
Flexural strength [MPa]	6.0	5.1	5.1	4.8	4.8
Compressive strength [MPa]	46.7	37.7	38.1	35.8	39.0
Dynamic modulus of elasticity [GPa]	38.8	39.8	36.6	39.6	35.5

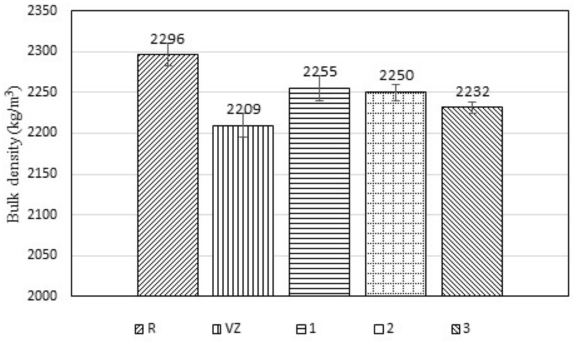

Fig. 7 - Detailed results of bulk density.

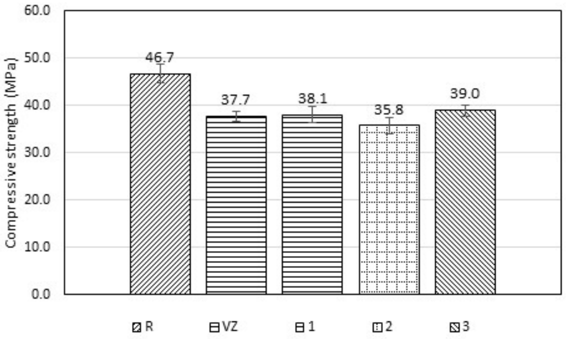

Fig. 9 - Detailed results of compressive strength.

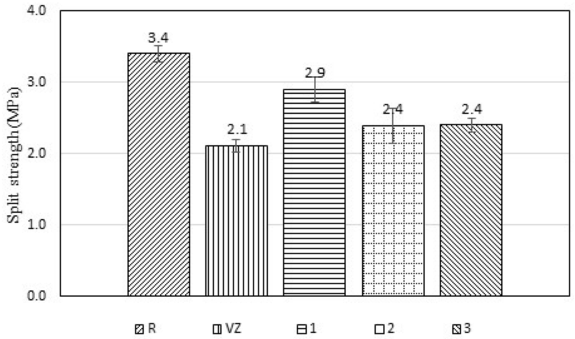

Fig. 8 - Detailed results of split strength.

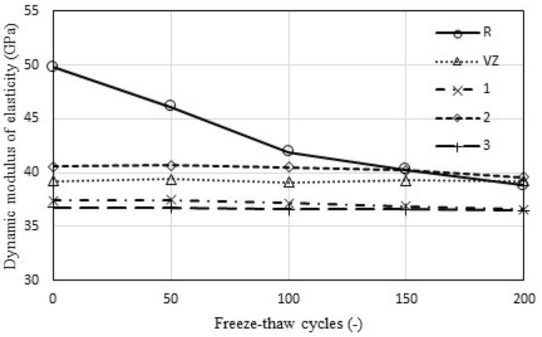

Fig. 10 - Evolution of the dynamic modulus of elasticity due to freeze-thaw cycling.

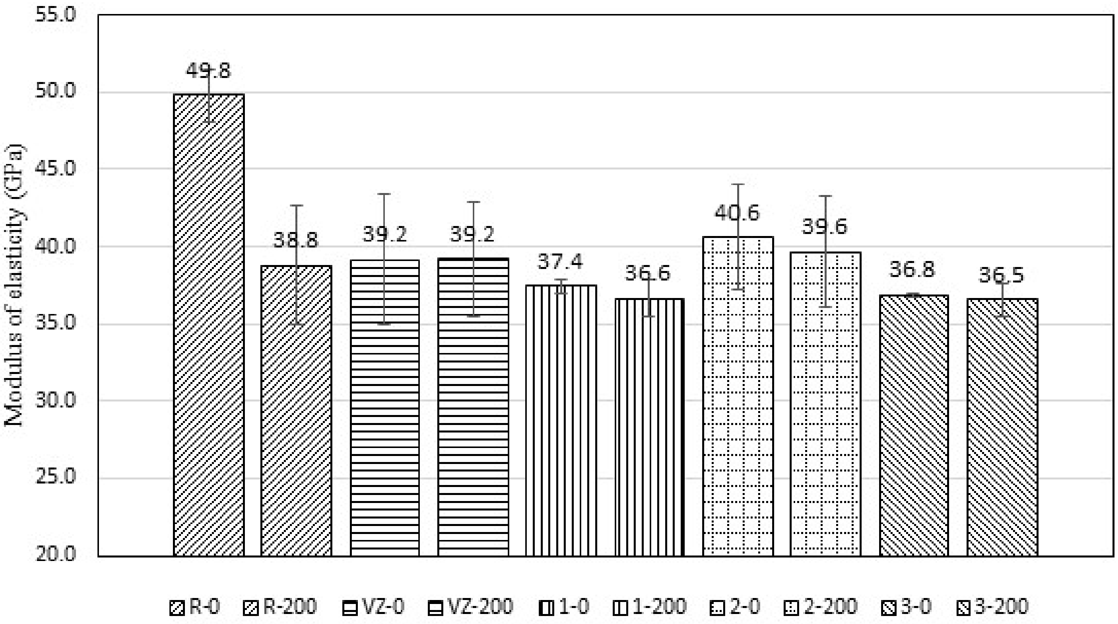

Fig. 11 - Changes of the dynamic modulus of elasticity after 200 freeze-thaw cycles for every tested series of specimens respectively.

of elasticity measurement, Figure 10. Final results of the measurement of the dynamic modulus of elasticity after 200 of load cycles are shown in Figure 11, where are well obvious structural changes in the reference mixture.

It is obvious the decay of the values of reference mixture on the level of 80%. The other studied mixtures did not exhibit a radical decrease. Changes of the flexural strength due to freeze-thaw cycling are shown in Figure 12.

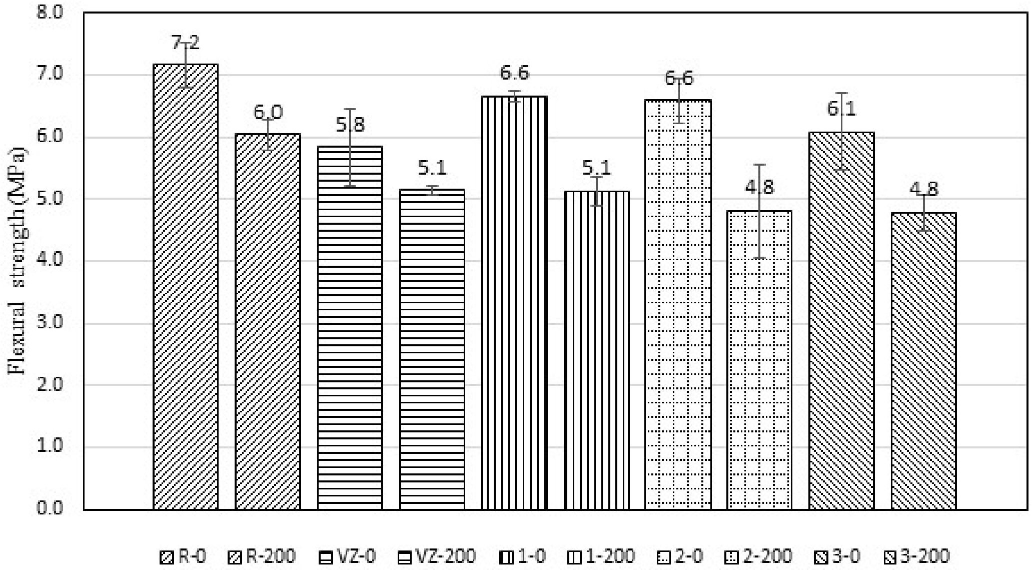

Fig. 12 - Changes of the flexural strength after 200 freeze-thaw cycles for every tested series of specimens respectively.

4. Conclusions

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.

The results presented 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.

Compressive strength of specimens with rubber powder was reduced about 15% (Figure 9). This reduction again pointing at influence of air-entering which rubber powder brings.

Similar results were obtained for freezing/thawing resistance series. However, higher values of flexural strength after temperature cycling are for concrete mix without rubber powder, as shown in Figure 12. The difference between the flexural strength of specimens with and without rubber powder after temperature cycling is higher for specimens with rubber powder content. Thus, better freezing/thawing resistance by adding rubber powder, than by normal air-entraining agent, wasn't proved.

General decrease of the flexural strength is probably caused by the decreased adhesion of rubber filler and the cement matrix. Significant role has surface shape of the rubber aggregates and their low wetting ability affecting the lower contact with the cement paste and also the air-entraining effect.

Practical utilization of waste rubber products could contribute to the increased effectivity of materials usage because of high energy consumption of synthesis during the traditional air- training agents production.

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