RUBBERIZED HYBRID FIBRE REINFORCED CONCRETE

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Abstract
The aim of this paper is to demonstrate that by using industrial and recycled steel fibres together with recycled rubber, high quality rubberized hybrid fibre reinforced concrete (RHFRC) can be prepared. In such way, environmental and economic savings are provided without significant influence on mechanical and durability properties of concrete.

Nine concrete mixtures were prepared and compressive strength, capillary absorption, water permeability, chloride diffusion, gas permeability and resistance to freezing and thawing were tested. Mixtures were prepared with different steel fibre ratios (only industrially fibres, combination of industrially and recycled fibres, only recycled fibres) and 5% fine rubber aggregate replacement. Special focus of this research is the possibility of utilization of recycled rubber as an admixture responsible for improvement of concrete resistance to freezing and thawing cycles.

1 INTRODUCTION

Today sustainability represents one of the major concerns of concrete industry. With the use of million tons of natural resources per year, concrete industry settles between major environment pollutants. In order to reduce consumption of natural resources and provide preservation of the environment, incorporation of different waste materials in concrete is explored.

One of today’s largest environmental problems are waste tyres; left in the environment they represent great danger due to their long decomposition and high risk of durable fires. On contrary when they are mechanically recycled no additional waste substances and gas emissions are left behind. Furthermore, performed studies confirmed that products from mechanical recycling of waste tyres (rubber, steel and textile fibres) can easily be used in preparation of concrete.

In further period, Croatia is planning major reconstruction of existing railway infrastructure so intention of this research is to prepared innovative and ecologically acceptable solution for this special application. Research presented in this paper is part of larger research project “Concrete track system – ECOTRACK” which encompassed preparation of 20 concrete mixtures and specimens required for conducting 16 different tests. The main aim of the project is to produce innovative and ecologically acceptable concrete for the application on high-speed railways. Previous experience in material design for such systems showed that usually applied materials have certain disadvantages and require significant optimisation to satisfy prescribed mechanical and durability properties of concrete. Although fibre reinforced concrete (FRC) has adequate properties for named application, such as improved post cracking behaviour, due to the high price of industrially produced steel fibres their application is not present.

During this research, influence of simultaneous use of industrial and recycled steel fibres, as well as possibility of using only recycled steel fibres was investigated together with substitution of 5% of total volume of aggregate by rubber particles. By using recycled materials, besides ecological, enormous economic savings can be achieved especially taking into account continuous price rising of steel due to steel deficiency. Currently the price of industrial steel fibres is 10 times higher that of recycled ones.
2 EXPERIMENTAL DESIGN

Specimens were due to limited conditions in laboratory, prepared in precast concrete plant (TBP Pojatno, Viadukt dd) which in one way restrained possibility to control all parameters (Figure 1). In order to minimise influences caused by robustness of the technologies used in precast concrete plant, all components were manually added in mixer. For the same purpose, aggregate was taken from silo and left in the closed space to obtain saturated surface dry state. During the concreting all components were incorporated in mixture in the same amount and no correction of water amount due to aggregate humidity was done.

Figure 1 a) Rubber pre-treatment; b) Casting of concrete specimens

Specimens were at the age of one day transported to University of Zagreb Faculty of Civil Engineering in Laboratory of Department of Materials and were further cured according to the relevant standards (Table 1) until the age of testing. All tests were performed on three specimens.

Table 1 Performed testing and belonging procedures

<table>
<thead>
<tr>
<th>Testing of fresh concrete:</th>
<th>Testing of hardened concrete:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air content (EN 12350-7:2009)</td>
<td>Water permeability (EN 12390-8:2009)</td>
</tr>
<tr>
<td></td>
<td>Freeze-thaw resistance (CEN/TR 15177)</td>
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<td>Chloride diffusion (NT BUILD 492)</td>
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2.1 MATERIALS AND MIXTURE COMPOSITION

Components for mixture preparation included cement (CEM II/BM SV 42,5N), combination of crushed and natural aggregate, silica fume (5% on mass of cement), superplasticizer (carboxylic ether polymer with long lateral chains) and air entraining admixture (Table 2).

Figure 2 a) Industrial steel fibres; b) Recycled steel fibres

Used industrial steel fibres were 35 mm long and with diameter of 0.55 mm (Figure 2a), while due to irregular shape and size of recycled steel fibres overall dimension is impossible to determine (Figure 2b).
For the purpose of this investigation, fine rubber granules (0.5 – 2 mm) were used as supplement of air entraining agent in some mixtures. Since rubber particles due to presence of zinc stearat [1] cannot easily accomplish good quality bond on the rubber/cement paste interface, rubber was initially pre-treated. Particles were immersed in saturated calcium hydroxide solution for 15 minutes, then washed with potable water before their incorporation in concrete (Figure 1a).

Table 2 Mixture composition

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Cement (kg)</th>
<th>Water (l)</th>
<th>Aggregate (kg)</th>
<th>Chemical admixture (kg)</th>
<th>Mineral admixture (kg)</th>
<th>By-products (kg)</th>
<th>Indus. steel fibres (kg)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Superplasticizer</td>
<td>Air entraining admixture</td>
<td>Silica fume</td>
<td>Rubber</td>
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<tr>
<td>100I0RA</td>
<td>420</td>
<td>170</td>
<td>1743</td>
<td>2,31</td>
<td>0,25</td>
<td>21</td>
<td>0</td>
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<td>420</td>
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Abbreviation: I=industrial fibres; R=recycled fibres; G= rubber granulates; A=air entraining admixture; R=rubber particles
100I0RAG: 100% industrial fibres + 0% recycled fibres + air entraining admixture + rubber granulates

3 EXPERIMENTAL RESULTS AND DISCUSSION

According to the special application of these concretes main focus of the research was to satisfy requirements set in standard relevant for railway structures [2]. Prescribed requirements include: minimum required compressive strength, adequate wear and freeze-thaw resistance, as well as capillary absorption.

3.1 Air content and slump

Air entrainment is primarily recommended to improve the freeze-thaw resistance of hardened concrete [3]. Taking into account that one of the main tasks is to prepare freeze-thaw resistant concrete, air-entraining admixture was incorporated. On the other hand, due to capability of rubber particles to entrap air on their jagged surfaces [4] they were used for the same.

![Figure 3 Comparison of air entraining admixture and rubber particles influence on: a) air content; b) slump](image-url)
From the Figure 3a it is obvious that presence of only rubber did not assure adequate air content, while simultaneous use of air entraining admixture and rubber obtained the same air content as mixtures containing only air entraining admixture. Incorporation of rubber in mixtures containing air entraining admixture assures additional increase in air content [4][5], although here presented results imply that 5% rubber aggregate replacement is too small amount to assure such effect.

Various consistency classes are consequence of different moisture levels of the aggregate (Figure 3b) caused by previously explained conditions (see Experimental design). Named differences should be taken into account during further evaluation of results.

3.2 Compressive strength

Mix design encompassed selection of components in prescribed amounts for acquiring compressive strength class specified in relevant standard [2], C 45/55. Decrease of compressive strength with addition of rubber particles is already demonstrated in previous investigations, in which dependency with the amount of used rubber is also proven [6] [7] [8]. According to the conducted research by using 5% of rubber particles as replacement of the aggregate or cement obtained decrease was around 10%. Compressive strength decrease can be even lower when mineral admixtures such as silica fume are incorporated. By achieving better homogeneity and decreased number of larger pores in cement paste, presence of silica fume leads to higher strengths and can be presented as alternative way to improve properties of rubberized concretes [9]. From results follows that although rubber/cement paste interface has lower quality than aggregate/cement paste interface, small amount of fine rubber particles has almost negligible effect on concrete microstructure and is possible to achieve specified strength class (Figure 4). During compressive strength analysis, slump values were considered since water correction due to different aggregate humidity was not conducted during concreting.

![Figure 4 Comparison of air entraining agent and rubber particles influence on compressive strength](image)

According to the results, with exclusive use of recycled steel fibres no reduction in compressive strength can be determined (Figure 5). Therefore, is possible to conclude recycled steel fibres can be used as viable alternative to industrial fibres.

![Figure 5 Comparison of recycled steel fibres influence on compressive strength](image)
3.3 Capillary absorption and water penetrability depth

Literature data indicates that increased amount of rubber particles in composites causes parallel decrease of capillary absorption mostly due to rubber capability to repel water [3]. This decrease is attributed to the non-sorptive nature of rubber causing the change in absorbed water flow, which is eager to bypass rubber particles in order to propagate within the cement paste.

![Figure 5 Influence of different fibre ratios on compressive strength](image)

Ganjian et al. [7] concluded that obtained decrease in capillary absorption is caused by reduced concrete porosity, when powder rubber is used. Namely, fine rubber particles are able to fill present voids in concrete microstructure. Air entraining admixture acts similar as rubber particles with its ability to entrap closed air pores. Therefore is expected that no significant difference between test results of three groups will be obtained (Figure 6a).

Water permeability is increased with presence of rubber particles in concrete [7]. This negative influence of rubber particles on water permeability is consequence of physical characteristics of rubber, such as low modulus of elasticity and lower stiffness. During water permeability testing water penetrates into concrete under high pressure which neutralizes initial water repel by rubber. Lack of proper bonding between rubber particles and cement paste, acts as bedding for pressurised water to flow into concrete [10]. Restraining the amount of rubber in mixture on 5% of the total aggregate volume, assures adequate water permeability of concrete (Figure 6b).

3.4 Chloride diffusion and gas permeability

Silica fume has positive effect on both, compressive strength and durability properties. Ultra-fine particles of silica fume reduce permeability of concrete by arranging better filament of concrete microstructure. Presence of silica fume (10% by cement mass) improves resistance of concrete against chloride penetration, irrespective of the amount of rubber used [11]. Although, some researchers point that beneficial effect of silica fume in rubberized concretes is more pronounced with high silica contents (15-20%), due to higher influence on bond between rubber and surrounding cement particles [9]. Other indicate that the beneficial effect of silica fume was more pronounced at low rubber contents (5% by total volume of aggregate) irrespective to the silica content [11].

All tested mixtures are classified as good quality concretes [12] it is therefore possible to conclude that presence of 5% silica fume by the mass of cement was sufficient amount to assure filament of concrete microstructures since only 5% of fine rubber particles by total volume of aggregate was incorporated in mixtures (Figure 7a). Similar behaviour was observed during gas permeability testing (Figure 7b).
3.5 Freeze-thaw resistance

Concrete presented in this paper is prepared for special applications on structures were freeze-thaw resistance together with compressive strength is the most important concrete property. According to the relevant standards [13], prescribed requirement for exposure class XF4 allow 15% decrease of relative dynamic modulus. From literature is known that improvement of concrete resistance to freezing and thawing can be achieved by using air entraining admixture. Purposely, involved air voids act as empty chambers relieving hydraulic pressure and preventing degradation of concrete microstructure [5]. Due to rubber capability to entrap air on their jagged surfaces [4] they were used for the same purpose as an air entraining admixture.

According to the expectations, all mixtures incorporating air entraining admixture satisfy prescribed criteria obtaining decrease of relative dynamic modulus lower than 15%. On the contrary, mixtures incorporating rubber as replacement for air entraining agent did not reach required resistance level. It can also be observed that when only recycled fibres are used (0I100RAG) better freezing resistance is acquired for mixtures incorporating both air entraining admixture and rubber (0I100RA), indicating positive rubber effect on concrete microstructure during aggressive environment exposure. The reason for this is probably elastic behaviour of rubber particles, which serve as accumulators of stresses caused by...
Ice formation in concrete pores [14] who simultaneously with air entraining admixture create durable concrete (Figure 8).

Different steel fibre ratios (only industrially fibres, combination of industrially and recycled fibres, only recycled fibres) have no influence on concrete behaviour during its exposure to freezing and thawing.

![Graph showing relative dynamic modulus (in %) for different fibre ratios.](image)

**Figure 9** Influence of different fibre ratio on freezing and thawing resistance of concrete

## 4 CONCLUSIONS

In further period, Croatia is planning major reconstruction of existing railway infrastructure so intention of this research is to prepared innovative and ecologically acceptable solution for this special application. Since major part of named high-speed railway will be set in harsh environment, exposed to chlorides carried by strong winds from coast as well to cold and long winters, durability properties of presented materials is of major interest. To satisfy requirements prescribed in relevant standards and at the same time contribute to sustainable development, fibre reinforced concrete incorporating by products from mechanical recycling of waste tyres was prepared.

Utilization of recycled rubber as replacement of an air entraining admixture is not justified in this research, since mixtures incorporating only rubber particles (100I0RG, 50I50RG, 0I100RG) did not reach adequate freezing resistance. At the same time, mixtures incorporating both air entraining admixture and rubber (100I0RAG, 50I50RAG, 0I100RAG) obtained minor decrease of compressive strength while other their other presented properties were similar to the ordinary fibre reinforced concrete with air entraining admixture (100I0RA). Accordingly it follows that hybrid fibre reinforced concrete (HFRC) containing 15 kg of industrial and 15 kg of recycled steel fibres together with air entraining admixture, with or without 5% of fine rubber particles, presents reasonable alternative to ordinary FRC for special applications. Further research of its properties is currently undertaken.

## ACKNOWLEDGEMENTS

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## REFERENCES


