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Road and Rail Infrastructure II

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INNOVATIVE MATERIALS FOR SUSTAINABLE RAILWAY TRACKS – ECOTRACK

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Abstract

In the past decade, railway infrastructure experienced significant expansion. In order to assure 'green' transportation, all across the world investments in railway infrastructure are present. Significant industrialization, and accordingly development of the transportation infrastructure caused serious atmospheric pollution and irretrievable degradation of living conditions. In order to stop this constantly raising pollution, most of current investments are focused on development of high speed railways as a way of sustainable transportation. Construction of such engineering structures requires special care during selection of applied materials due to presence of heavy dynamic loads and aggressive exposure conditions.
At the moment the market provides track systems specially designed for high speed railways, but application of inadequate materials caused insufficient durability of these structures. In order to improve existing solutions, scientists from University of Zagreb developed innovative concrete ballastless track prototype called ECOTRACK. In its nutshell, ECOTRACK is a concrete based solution that incorporates waste materials obtained during mechanical recycling of waste tyres. Incorporation of named materials assures ECOTRACK-s alignment with all relevant EU Directives in the field of waste management on one side, and on the other improvement of toughness and post-cracking behaviour desirable for the described ballastless track systems.

1 Introduction

The aspiration of the modern European society is to create acceptable and sustainable living conditions for the wellbeing of the whole ecosystem. The impact of the transport infrastructure on the ecosystem is considerable and in most cases negative. The development of railway infrastructure has enabled that the European land traffic be resolved favourably from the aspect of decrement of pollution caused by the burning of fossil fuels, energy disposal decrement, cheaper and faster transfer of goods and passengers as well as the economic growth. Railway traffic along with cabotage represents the main link in combined transportation in Europe. In Croatia, up until now the main focus was on just one segment of the transportation infrastructure – highways, while other means of transport were given little or no attention. It is clear, in the light of Croatia turning towards EU and sustainable development, that the segment of "green" transportation most grow stronger.
Although most of today's railways still use the classic track systems, demands for modern railways (increasing traffic capacity and the speed of modern trains, ect.) open up space for development and increasing implementation of new construction solutions such as ballastless railway tracks. In case of a ballastless railway track, the sleepers and ballast bed as the constructive elements have been replaced with other more stabile materials such as concrete or

asphalt slabs; hence in this segment of railway infrastructure an opportunity for usage of new innovative materials appeared. In the framework of the 'Concrete track systems – ECOTRACK' project, funded by the BICRO agency (Business innovation centre of Croatia), University of Zagreb Faculty of Civil Engineering developed an innovative technological solution which can significantly contribute to the strengthening of domestic manufacture of competitive and recognizable products. ECOTRACK is an eco-innovative product of a modern high speed railway structure(Figure 1) [1]. Solution is made of two-part concrete sleepers built in the concrete slab, together making a ballastless concrete track system. Although, similar solutions are already present on the market ECOTRACK incorporates by-products from mechanical recycling of waste tyres as a replacement for usual natural raw materials.

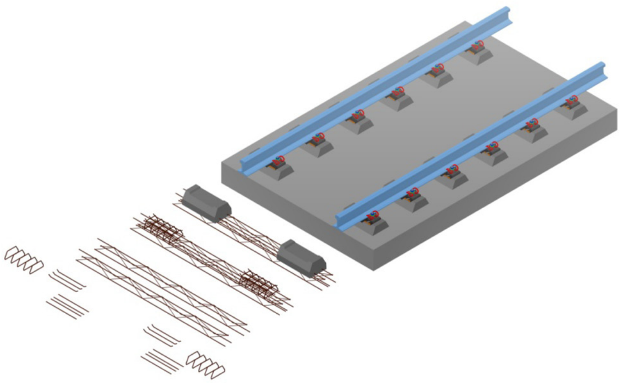

Figure 1 A conceptual prototype of the ECOTRACK railway track [1]

2 Methodology of the project implementation

The development of an innovative, ecologically acceptable material demands a series of tests of all the properties crucial for the material usage in a certain exposure conditions. Relevant standards for concrete railway tracks define criteria for the concrete used for the construction. The set criteria includes: compressive strength (minimum C 45/55), resistance to freezing (exposure class XF3 - decrease of dynamic modulus less than 15%), capillary absorption (good quality concrete; < 0.6 kg/m²√h) and resistance to wear (exposure class XM3 – loss of material < 18 cm³/50 cm²).

To prove the suitability of the developed material, investigation of material properties was conducted in four phases which contain the following: the selection of adequate rubber pretreatment, selection of industrial /recycled steel fibre ratio, determination of the influence of recycled rubber on the properties of hybrid fibre reinforced concrete, choosing the optimal mix, production and testing of the prototype.

Twenty concrete mixtures with the following ratio (%) of industrial and recycled steel fibres: 100:0, 50:50 and 0:100 with or without the addition of recycled rubber (5% by total volume of the aggregate), were prepared and tested [1][2] (Mixture composition1). Used components incorporate: CEM II/BM SV 42.5 N (420kg/m³), combination of crushed and alluvial aggregate, silica fume (21kg/m³), superplasticizer (polycarboxylic ether hyperplasticiser, 0.55%m_c) and air entraining admixture (0.06%m_c) with w/c ratio equal 0.39. Industrial fibres were 35mm long with diameter of 0.55 mm and bent ends, while Croatian factory for mechanical recycling of waste tyres supplied needed amounts of recycled steel fibres (irregular shape and dimension) and rubber granulates (diameter 0.5 – 2mm).

Table 1 Mixture composition

Mixture	Chemical admixture (kg)	Recycled rubber (kg)	Steel fibers (kg)	
			Industrial	Recycled
100I0RA	+	-	30	0
50I50RA	+	-	15	15
0I100RA	+	-	0	30
100I0RAG	+	+	30	0
50I50RAG	+	+	15	15
0I100RAG	+	+	0	30
100I0RG	-	+	30	0
50I50RG	-	+	15	15
0I100RG	-	+	0	30

For named project, more than 1000 samples were prepared in the precast concrete plant TBP Pojatno, Viadukt d.d (Figure 2). At the age of one day, specimens were transported to the laboratory of Department of Materials on Faculty of Civil Engineering University of Zagreb. The initial research of the innovative rubberized hybrid fibre reinforced concrete included a testing of 16 different properties in its fresh and hardened state. Within this paper, only a part of the results from conducted research is presented, while other results and their analysis can be found in a previous paper [2].

Figure 2 Preparing the samples in the precast concrete plant TBP Pojatno, Viadukt d.d. [2]

3 The development of a conceptual prototype

During the first phase of the 'Concrete track system – ECOTRACK' project, tests on the effect of three different rubber pre-treatments on the properties of a hardened composite were done: without previous treatment, treatment with a saturated solution of sodium hydroxide and treatment with the calcium hydroxide saturated solution. Due to the presence of the zinc stearate on rubber surface, good quality bond between the rubber and cement paste is disabled [3]. By removing zinc stearate from rubber surface, the number of hydroxide groups is increased and in that way appropriate level of hydration in the interface zone is achieved [4]. Testing showed that with small rubber content (≤ 5% of the total aggregate volume) previous rubber treatment doesn't present a crucial parameter for achieving the expected concrete properties [2]. This makes the preparation procedure of these concretes easier in industrial conditions. Ecological and economical feasibility of the recycled steel fibre implementation in concrete industry is one of the research triggers (Figure 3). By replacing a part or the whole amount of industrial steel fibres, with the recycled ones, a considerable savings of natural resources and energy can be ensured, as well as better waste management along with savings in economy.

Figure 3 a) Industrial steel fibres (Dramix RC 65/35 BN); b) Recycled steel fibres (Gumiimpex GRP)

During the second phase of the project the positive synergy between industrial and recycled steel fibre was demonstrated through increased energy absorption capacity, as well as post-cracking behaviour and resistance to impact compared to the fibre reinforced concrete with only recycled steel fibres. The fibres ability of energy absorption at different crack widths – recycled steel fibres during the development of micro cracks; industrial fibres with damage increment, macro cracks – provides the load transfer from damaged to undamaged cross section in this way ensuring improved concrete ductility [2].
Diminished ability of energy absorption of recycled fibres in comparison with industrial fibres can additionally be improved with the implementation of a small rubber content (<5% of total aggregate volume). Previous research [5–7] shows a positive synergy of the industrial steel fibres and rubber, as the rubber serves as the absorber of the produced energy without decreasing the fibre's ability to ensure the load transfer from the damaged to the undamaged cross-section. During the third phase positive synergy of hybrid fibre reinforced concrete and recycled fibres was demonstrated.
By incorporating rubber in the concrete a certain decrease of named property can be observed. However, this decrease is not substantial and still enables preparation of high strength concretes. All of the shown mixtures can be categorised in the compressive strength class C45/55 (Figure 4). Decrement of compressive strength is a consequence of a lower rubber elastic modulus. Lower elastic module values indicate a higher composite flexibility under loading, which in cases of constructions exposed to the cyclical loadings such as railway tracks, is considered as a positive material property. [2] The change of industrial and recycled steel fibre ratio has no effect on the described values.

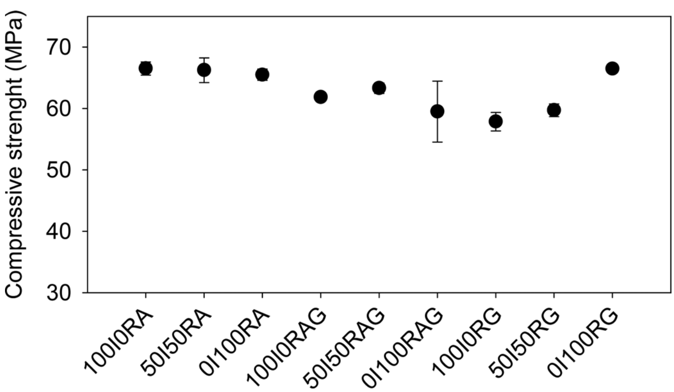

Figure 4 The effect of a chemical admixture and recycled rubber on the compressive strength of the concrete

Durability properties are of essence for reaching the proposed service life, especially in the aggressive environments in which the first Croatian high speed railway will operate. Although, different durability properties were tested within this research [2], only values prescribed with legal directives will be shown here.

By adding recycled rubber to the composite a minute improvement of concrete's resistance to wear was created, although all the prepared composites can be put in the same wear resistance class XM3. In the same way, in accordance with the values of capillary absorption, independent on the fibre ratio and presence of recycled rubber, all the prepared mixtures present the average quality concrete (Figure 5).

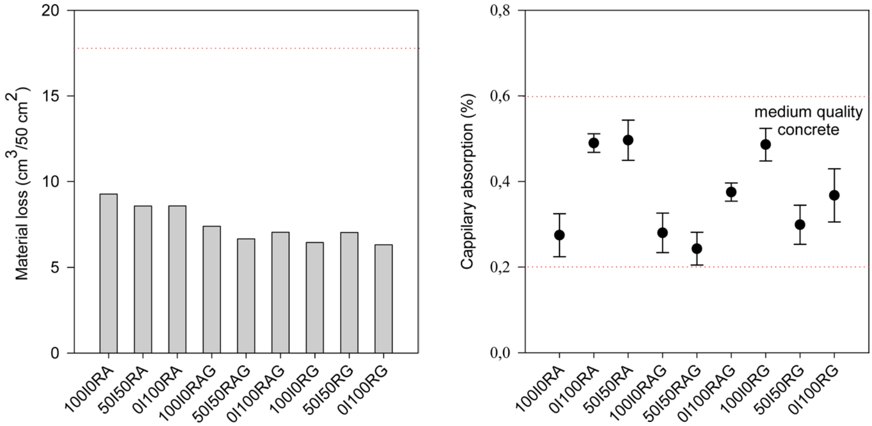

Figure 5 The effect of chemical admixture, fibre ratio change and recycled rubber on: a) resistance to wear, b) capillary absorption coefficient

According to the standards, railway track system as horizontal surface exposed to the freezing without salt is set in the exposure class XF3. In this type of environment, concrete is presumed to be resistant when the decrement of dynamic elasticity module is not higher than 15% in relation to the starting values after 56 freeze-thaw cycles (Figure 6).
The research results imply that the resistance of mixtures that contain a chemical admixture is satisfying, while the other mixtures do not satisfy the acknowledged criteria. Mixtures containing exclusively recycled rubber without chemical admixture kept the required level of resistance only by the 28th cycle, after which a more serious degradation of material occurred.

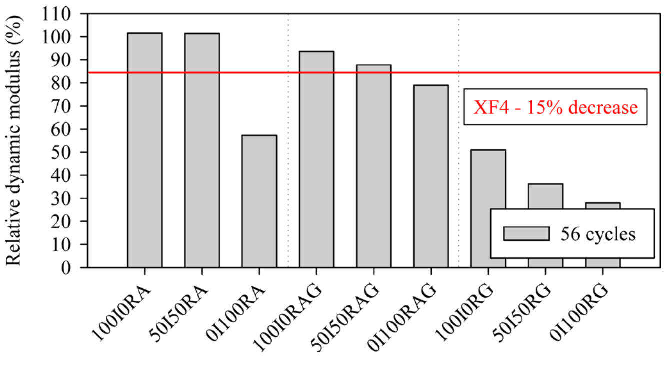

Figure 6 Resistance of concrete to freeze-thaw cycles without salt

Taking into account the prescribed criteria which concrete for construction of railway systems must fulfil, the stipulated properties were the basic parameter during the fourth phase of the project while an optimal mixture for the prototype construction was selected. The basic goal of the research is to use the maximum quantity of waste materials in order to decrease the use of non renewable resources and obtain higher sustainability of the concrete industry. However, except for the ecological parameters, the economical parameter is for sure one of the triggers

for this research. And by using recycled steel fibres instead of the industrial ones decrease of 13 to 33 % of the concrete price per m³ can be obtained. By choosing the mixture containing both industrial and recycled steel fibres, chemical admixture and recycled rubber and taking into account the length of the Zagreb-Rijeka railroad (121km), the total savings with implementation of this material could reach 1,2 million kunas only for construction of sleepers [2].
Despite series of research on the behaviour of prepared composites, final evaluation is impossible without detailed static and dynamic prototype testing. Since the prototype research demands certain resources, up until now only a research on one prototype sample has been conducted with the goal of defining basic characteristics of a referent material under the mentioned conditions [2]. A scheme of samples for the mentioned testing is shown in Figure 7.

Figure 7 A track prototype on a concrete surface – ECOTRACK [2]

4 Conclusion

The usage of rubberized hybrid fibre reinforced concrete elements assures an adequate resistance ability of the structure under various strain conditions. Furthermore, the appearance of first cracks on concrete surface is prolonged and thus a higher durability of such construction elements is achieved. Preliminary testing of ECOTRACK prototype, whose sleepers were prepared with RHFRC, showed promising results. For the acknowledgment of the results gathered by preliminary testing, further research on a bigger number of samples is needed.
Taking into account all the advantages (Croatian production, innovation, ecological acceptability, lower price) of the ECOTRACK compared to the competitive solutions on the market, it is obvious that this product will in the future achieve a strong market up take. The results of the initial testing satisfy, and it is considered that with additional optimization of the systems components it is possible to expect, in a very brief period of time, the commercialization of the ECOTRACK. The time needed for the placement of the product on the market will depend on the disposable resources needed for the research update.
In accordance with the starting expectations, the initial testing of the ECOTRACK confirmed the possibility of the application of ecologically acceptable resources (recycling products) for the production of high performance concrete for special application. Comparing the achieved results with the criteria set up in relevant standards for concrete railway tracks, it has been confirmed that concrete with specific ratio of recycled products satisfies the mentioned conditions.
The project showed that with strong support of all included parties (science community and industry) it is possible to develop a new and innovative product, which can be produced in whole in domestic factories, providing future competiveness of domestic companies in the field of railroad infrastructure.

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