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FROM IDEA TO NEW TECHNOLOGY IN ROAD NOISE PROTECTION

In the past 20 years, Croatia has experienced an intensive development of its transport infrastructure. If referring to road infrastructure, then the region is considered, and Croatia leads in the quantity of constructed highways, as confirmed by data from the European Commission. For any modernization to be successful, it must be closely linked with research and development performed by the scientific community. The Faculty of Civil Engineering – University of Zagreb has been actively involved in all such projects, not only in the process of their creation, but also in the application of innovative solutions and technologies. This paper present successful environmental and innovative product that the Faculty of Civil Engineering - University of Zagreb, in cooperation with its industrial partners, has applied successfully in regular engineering practice. The quality of this product has been recognised by the European Commission through co-financing of environmental programs and innovative products by the EU that have increased European added value and also by the international associations in the field of transport infrastructure, like International Road Federation.

Keywords: transport infrastructure, innovation, new technologies, noise protection, RUCONBAR

1. INTRODUCTION

Today, we live in a world of digital communications and digital networks. However, life today would be unthinkable without the transport infrastructure, i.e. roads and railways. The changes that are now occurring in this area are happening very quickly, and the reason for this is the increasing use of innovation, new technologies and materials. Selecting certain technologies and innovative solutions leads to a more efficient and faster construction of transport infrastructure, and subsequently of course better quality management. Naturally, these changes are inconceivable without innovative engineers, because only they are able to create something new or make something better. Future social and economic trends will impose new challenges for civil engineers. The role and importance of civil engineers in creating

something new is well described in the following view: "It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege." Herbert Hoover, President of the United States.

When observing the creation of something new, attention should be given to the important fact that there are no innovations and new technologies without cooperation and dissemination of knowledge. Innovation is not only based on the individual knowledge of researchers in narrow fields, but today it incorporates interdisciplinarity and exchanging knowledge and experience. This fact has been recognised particularly in Europe and consequently, cooperation between universities and industry is increasing encouraged, especially cooperation from small and medium enterprises. Here, big companies are not mentioned since they tend to have their own highly developed laboratories, and very often a department or institute involved in development, which means that they are able to independently commercialise a new product or production process that has been developed. For small companies that also possess a research potential, this becomes much harder to achieve. Nonetheless, cooperation that is scientifically based and which exists in the academic community (universities, institutes), this can be achieved a lot easier since there exists a developed research infrastructure in most countries. Only through such cooperation can a particular sector become competitiveness. However, such cooperation is often difficult to come by in southern and eastern Europe. The reasons can be found in the following:

- Scientists often think that business entities should be the first to approach with their ‘problem’, which requires solved or with their ‘idea’ that needs to be further developed.
- Business entities often have an attitude that universities are mainly engaged in the research which provide impractical and inapplicable results.

These attitudes results in distrust, and therefore quite poor cooperation between industry and universities. The reasons for poor cooperation and the lack of trust can be explained by the fact that a very small number of engineers from industry enrol into postgraduate studies organised at universities. If this number were to increase, there would be a greater convergence of the business sector and the academic community, communication would become easier and greater trust would be acquired leading to better teamwork. This scenario could lead to improvements in certain technologies, technological processes, and to the creation of new technologies, new products and innovations. It is precisely this fact that can greatly help in boosting the competitiveness of business entities, which in today's market is most important.

The application of road traffic noise barriers began more than 50 years ago in both the USA and Europe [1, 2]. The noise wall exploitation behavior, repair, and/or replacement frequency of aged or deteriorated wall panels became an important issue in the last decade. However, despite the long-term experience in the application of noise walls (and research on the sustainability of noise barriers as well as other noise abatement measures [3–7]), when deciding on the panel material to be used in the design phase, designers still encounter numerous uncertainties associated with the exploitation behavior of noise walls constructed with panels made from different materials [8], including their stability, durability, and resistance to fire, impacts, and atmospheric influences. The main question is how the imminent degradation of panels will affect the efficiency of the wall structure, its life-cycle costs, and its long-term sustainability in specific locations and conditions [9].

The Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb has been striving for many years to link the academic community and industry in order to develop innovative products, new materials and technologies in the area of transport infrastructure. When research is conducted, it is necessary to keep in mind that results do happen immediately, but it is often much time-consuming and hard work is required to achieve a specific result and improve a particular process or create a new product. This paper will present an innovative product RUCONBAR - noise protection barriers with recycled rubber added that have been developed under research project RUCONBAR – Rubberised Concrete Noise Barriers funds of the EU CIP ECO-INNOVATION fund.

Absorbing concrete barriers with the addition of recycled rubber called RUCONBAR, were entirely developed at the Faculty of Civil Engineering, University of Zagreb. The whole idea behind the new product occurred at the Department of Transportation Engineering, but product development was done in close

collaboration with the Department of Materials. Development, from the idea to the new product lasted about one and half years. After conducting all the necessary laboratory tests, the optimal mix for the new product was obtained and then followed transferring the technology to a company's production facilities for the purpose of manufacturing precast elements. The first samples of the product were produced at the factory, which were then subjected to comprehensive testing, confirming that this is a new, innovative, and in this case, the environmentally friendly product, since it produce from recycled products. In order to obtain verification that it indeed is an environmentally friendly and innovative product, and for it to received encouragement to market the product on the international market, the project was registered for the tender 2010 CIP ECO-INNOVATION. Selection of the project for funding from the EU CIP ECO INNOVATION programme, where the annually only approximately 15-20 % of proposals submitted are co-financed, is a confirmation that this is indeed a valuable environmentally friendly and innovative product.

Initiating the research and discovering something new in this area was driven by the state of the economy. During 2006-2007, the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb had already made a similar product for the market (absorbing concrete barriers with expanded clay), which was also a new product in Croatia at the time. The product was then, completely accepted by the profession after only two years, and quickly took approximately 50 % of the market for noise protection barriers, Figure 1. The figure shows the percentage of types of noise protection barriers in use in Croatia after the introduction of absorbing concrete barriers with expanded clay to the market. Prior to this period, this type of barrier did not exist on the Croatian market.

This experience relating to the commercialisation of the product has helped in developing the environmentally friendly and innovative RUCONBAR barrier. The development of the RUCONBAR barriers and its commercialising sought different requirements on the Croatian market for this product, so it was necessary to prepare the product for much wider market acceptance. The construction of road infrastructure in Croatia in 2011 was at an end, with the railway infrastructure sector only beginning to awaken. The situation on the market indicated to us that we had to find an appropriate way to commercialise a completely new product and find a way to make it distinctive and interesting for the market, especially the regional market. This was the development team's goal, to find the appropriate EU fund for branding the product and facilitating its commercialization.

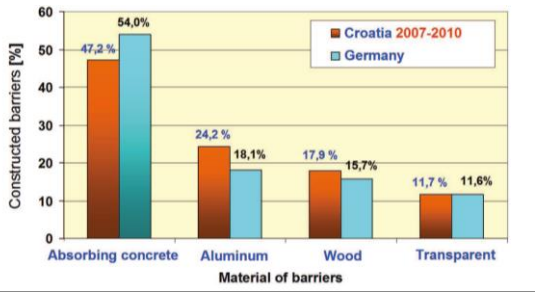

Figure 1. Percentage of the type of particular noise protection barriers on motorways in Croatia after 2007

Since this was an innovative and environmentally friendly product, the decision was made to apply to the CIP ECO-INNOVATION programme. When applying for this EU programme, besides the product being environmentally friendly, innovative, replicative and able to provide European added value, which is the case for the RUCONBAR product, when preparing for the EU project we prepared the material very carefully in order to answers several important facts:

a) Why should the EU Commission allocate funds for co-financing the proposed RUCONBAR product?

b) What makes the RUCONOBAR product stand out and what makes it different?

c) How will the project become recognisable in a large group of projects from many major EU countries?

d) How will the completely new product be commercialised on the international market.

To register at all for the tender against a large number of projects coming from EU member states, the RUCONBAR project had to be different. The next step was systematic preparation of the tender documentation in order to obtain a well defined, clear, interesting, easy to understand project possessing a good vision and purpose. With the vision defined, the required path was determined: obtaining finance from the EU funds, improving the quality of the manufacturing plant and systematic work on the market. This implies a good market analysis, identification of any problems and obstacles that can occur when commercialising new products, answering the question of why would the market want this new product, analysing how to confront a competitive product(s) , in what ways is our product better and more competitive. When looking at the product RUCONBAR, 21 countries

are already interested in the stated product, providing proof that you can create a distinctive EU product. It is important to keep in mind one thing when referring to product innovation and new technologies: innovation without application in business is useless.

As noted previously, the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb in 2006/2007 with industrial partner, developed absorbent noise protection concrete barriers. This product, which was then a completely brand new product in Croatia, had the absorbing barrier layer made from expanded clay (Fig. 2).

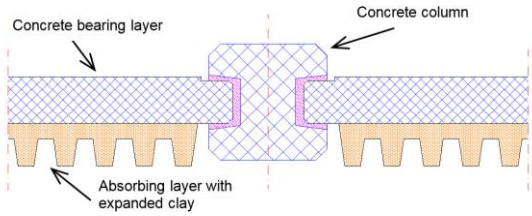

Figure 2. Cross-section of the absorbing concrete panel and bearing column

After the first use of the product on the test section and complete laboratory and field tests, market penetration began. In the beginning, this was very difficult. Since most infrastructure projects were in areas exposed to strong hurricane gusts, the proposed concrete barrier due to their greater weight and stability, proved to be the optimal solution. It was also aided by the fact that it was an entirely domestic product. Figure 3 shows the first absorbing concrete barrier in Croatia.

Figure 3. Absorbing concrete barrier at the entry to the City of Zadar (2007), [10]

By obtaining a stable barrier with the necessary absorptive properties, the product was ensured a rapid success on the market and already next year (2008) it was fully in use on the Split-Ploče motorway and the Šestanovac-Zagvozd and Zagvozd-Ravča sections. The corresponding sections had a total of approximately 15,000 m2 of noise protection barriers installed, ensuring the product's primacy on the market, as shown in Figure 1. Very quickly, other designers began fully implementation of the noise protection solutions by applying absorbent concrete barriers.

Excavation of clay | Thermal treatment

Granules of expanded clay | Environment following excavation of clay

Figure 4. Process of producing expanded clay

Forest cutting | Sawing

Wood fibres | Forest after cutting

Figure 5. Process of producing wood fibres

The important element in absorbent concrete barrier is primarily the absorbent layer made of a porous lightweight concrete. The first products that were marketed, as shown in Figure 2, were made of lightweight concrete with expanded clay granules that were imported. Since two Croatian companies had already adopted the production of these barriers, the desire was to produce the stated part of barriers from local materials. Today, manufacturers of absorbing noise protection concrete barrier use two materials, expanded clay and wood fibres. Were the production of these materials commenced in Croatia, it would not be in line with sustainable development. Namely, the production of expanded clay requires the excavation of clay in

the environment, followed by thermal treatment to form the required granules for the production of lightweight concrete. Besides the irrecoverable consumption of natural resources for the production of expanded clay granules, it creates a stripped and devastated environment (Figure 4). Another material used for the production of porous lightweight concrete is wood fibres. The lack of such barriers is also an exploitation of natural resources, forests, for the purpose of producing the absorbent layer, Figure 5.

Due to these shortcomings in existing solutions for concrete barriers, the Faculty of Civil Engineering at the University of Zagreb continued its research into the field of noise protection for developing solutions compliant with sustainable development. The goal was to find a material for the production of lightweight concrete, which would have the appropriate absorption properties. The new material posed a number of requirements for its production and use in a new product [10-12]:

a) That it be produced from recycled waste

b) That the waste to be recycled is found on roadways

c) That it contributes to waste management

d) That its application produces an environmentally friendly product,

e) That sustainable production is achievable,

f) That work be done on innovative products

e) That a completely domestic product be obtained.

To respond to such demands placed at the start of developing new products is not simple. The development of the barrier RUCONBAR commenced from the first presumptions, and that is, that the absorbing lightweight concrete be produced from materials obtained from recycling waste found on roadways. The analysis of transport equipment and transport infrastructure confirmed the assumption that the recycling of used tires can provide granules for the production of lightweight concrete, Figure 6.

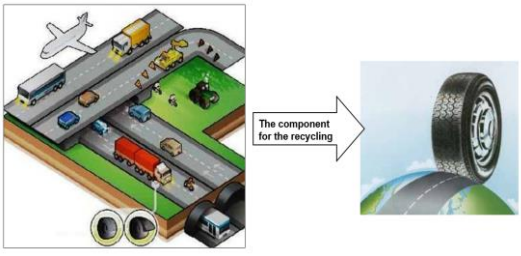

Figure 6. Transport resources and transport infrastructure – seeking suitable components for recycling following its lifetime of use

The use of tires in concrete was done before. There are studies that have dealt with the application of rubber in concrete, but from the point of view of improving the mechanical properties. Data and information on the use of recycled rubber for the production of concrete mixes for achieving absorption properties was not previously investigated. This fact prompted the development team at the Faculty of Civil Engineering in Zagreb to focus research into these new materials in this direction. A test program was defined in order to obtain an optimum mixture that would fully meet the set requirement, i.e. to obtain a lightweight concrete with the addition of recycled rubber that has absorptive properties. In addition to absorption properties, also investigated were other mechanical properties such as strength, fire resistance, freezing/thawing, compressive strength, tensile, impact resistance.

Figure 7. The process of producing rubber granules – from a polluted to a clean environment

During research, most of the attention was given to the fact whether it was possible to improve or reduce certain mechanical properties of concrete, which contains in its composition a certain percentage of rubber granules. Another important piece of information that was to be kept in mind was that if satisfactory properties of lightweight concrete were obtained, and whether there are enough of used tires on the market from which to obtain the necessary raw materials. If taking into consideration the used tires sector, then about 12% of used tires are used for the retreading purposes, 54% are recycled in the form of rubber granules, and the remaining are used for burning in cement making facilities and recycled in the form of rubber thread, rubber

powder and some other specially requested products [13]. Furthermore, this innovative product does not only allow noise protection, but contributes to the disposal and management of waste tires in an appropriate, effective, innovative and economically efficient manner - with the development of new products. if we consider the barriers RUCONBAR in terms of sustainable development, then this widely used product is environmentally acceptable since waste tires creates a value added product, and also contribute to a cleaner environment (Figure 7).

RUCONBAR contains in the structure of its absorbent layer 40 % rubber granules (Figure 8), obtained by recycling waste tyres and as such represents an innovative solution to the production of noise protection barriers. A patent has been taken out for the product at the State Intellectual Property Office of the Republic of Croatian (P20100483A) and the trademark (Figure 9).

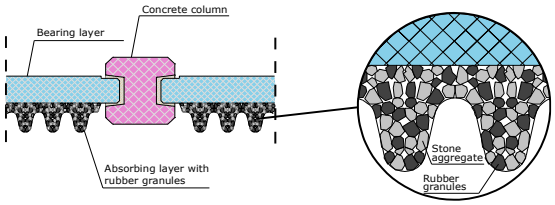

Figure 8. Cross-section of the innovative solution – RUCONBAR noise protection barrier

RUCONBAR
Rubberised Concrete Noise Barriers

Figure 9. Visual mark for the product RUCONBAR, [14]

According to data [12, 15], only 5 % of waste tires are uncontrollably disposed of in Western Europe, whereas in the area of the new member states and candidate countries 29 % of the resulting waste tires about 450 000 t, or about 42.5 million units) are uncontrollably disposed of, Figure 10. According to Directive 1999/31/EC as of 2006, any kind of disposal of waste tires in the environment is completely prohibited; hence, this decision has brought about an increase in the available quantity of waste tires used for recycling. This is the answer to the question of whether we have a sufficient amount of this type of waste for the production of rubber granules and what is the potential market for these barriers. These facts are rightly the reason for the high interest in this product. Two environmental components are related, noise protection, which is achieved with the product and the manufacturing of products with recycled material, whereby we have prevented its unauthorized disposal into the environment. A great interest in barrier RUCONBAR is currently expressed in the following countries: Bosnia and Herzegovina, Slovenia, Serbia, Romania, Lithuania, Bulgaria, Australia, Canada, Switzerland, India, Ukraine, Qatar, Turkey, France, Iran, Russia, USA, Canada, Germany, Hungary. Agreements on the transfer of technology with some companies are in the phase of being signed.

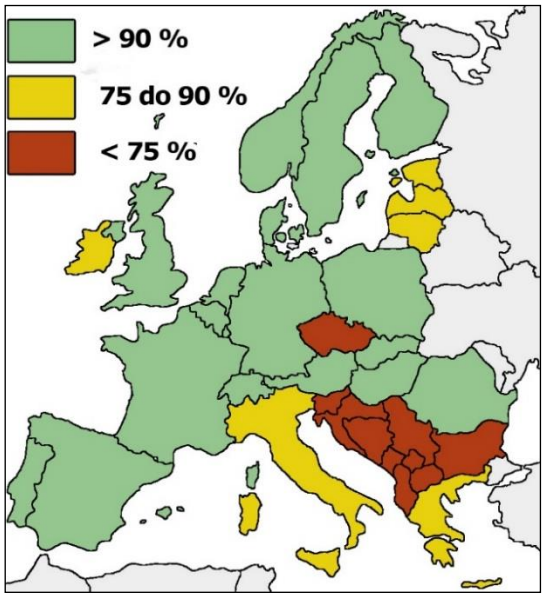

Figure 10. Percentage of recycling waste tyres in the area of Europe [3, 4]

2. FIRST APPLICATION OF THE RUCONBAR NOISE PROTECTION BARRIER

Given that the developed barrier meets the requirements relating to the reduction of noise levels set governed regulations and standards, each innovative solution seeks also a first application. Selecting the first application for any product is always the hardest. Since the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb conducted a large number of surveys, and a large number of main and detailed design projects on noise protection, finding the first applications was somewhat easier. The settlement of Scott was chosen for the first noise protection application, near the toll station on the Krk Bridge. The stated application will be co-financed from the EU RUCONBAR project. To facilitate selection of a visual solution for the stated barriers, and its position illustrated in space, the first application of RUCONBAR noise barriers (Figure 11).

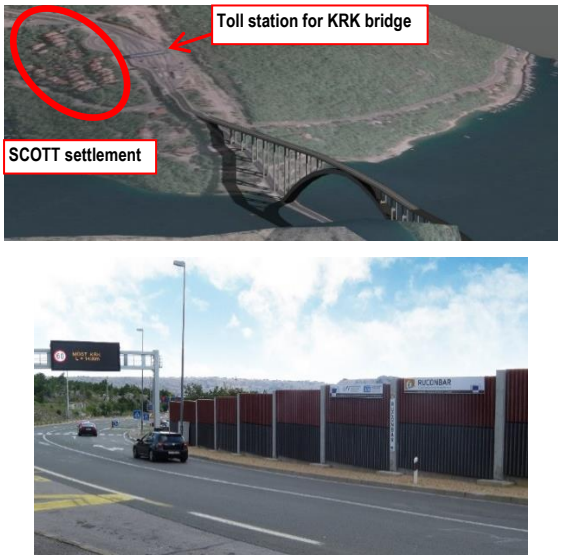

Figure 11. First application of RUCONBAR noise barriers on road section (noise road protection of the settlement Scott)

The first application of this novel innovative noise protection barrier was made on a road section near toll booths for Krk Bridge in Croatia. Following this example, RUCONBAR walls are being constructed on different road and railway sections.

Application of the RUCONBAR barriers was also realized at the Croatian Railways network. The first application of this innovative noise protection barrier was made on Perušić-Gračac railway line, Figure 12. Application of the RUCONBAR barrier on a railway line is interesting since this is a first noise protection implemented along a railway line in Croatia and on account of announced major investments in the future of this sector in the Republic of Croatia, [15].

Figure 12. First application of RUCONBAR noise barriers on railways line (noise protection of the settlement near railways station Gospić)

3. INTERNATIONAL RECOGNITION OF THE INNOVATIVE PRODUCT RUCONBAR

The simple design makes absorbent concrete barriers a very practical application not only for new roadways (road or railway lines) but also along existing roads. It is actually the area of existing roads that the issue of noise protection is being increasingly investigated. If we consider current practice in Croatia, then noise protection is applied only to new highway sections. However, existing motorways should not be forgotten. In fact, many sections of motorways in Croatia were constructed 30 years ago or more, and in some parts of these roads there are frequent complaints from the local population relating to increased noise due to an increase in the number of vehicles. A particular application of this kind of barrier can be found in urban areas, where its ease and speed of construction but also very simple possibility architecture make it appealing. Application of the RUCONBAR noise protection barrier is very practical for aesthetic, economic and architectural reasons. Using a product made from recycled type waste in the absorption layer helps protect the environment by solving the problem of disposing of tyre waste, the consumption of natural resources, and compared with similar solutions reduces CO2 emissions and the actual price of ready-made barriers. These benefits were anticipated by the EACI Commission (European Agency for Competitiveness and Innovation) which accepted the project RUCONBAR for financing through EU funds based on the 2010 ECO-INNOVATION tender. Project RUCONBAR and its final product – the noise barrier – have been widely recognized as an excellent example of academic-professional cooperation to tackle major environmental challenges. This has been acknowledged by:

ARCA 2012, 10th International innovation exhibition - Grand prix (Zagreb, Croatia, 2012)

GREENOVATION Award for best technology of Croatian green business (Croatia, 2012)

CEMEX – Building award 2015 (Sustainable building) - Noise protection of settlement Scott near toll stop for Krk Island (Croatia, 2015)

Inventions Geneva 2016 – Golden medal with the congratulations of the jury (Geneva, Switzerland, 2016)

Innova 2016 - Golden medal with the congratulations of the jury (Brussels, Belgium, 2016)

Silicon Valley International Invention Festival 2018 – Silver medal (Santa Clara, USA, 2018)

IRF Global Road Achievement Award 2018 in category “Research” (Las Vegas, USA, 2018), Figure 13

RailTech 2019 Innovation Award in category “Infrastructure” (Utrecht, Netherlands, 2019), Figure 14

The Awards are recognized as a prestigious industry accolade in their own right, but they also serve to remind a much wider audience that the mobility everyone takes for granted would not be possible without the talent and commitment of our industry. Faculty of Civil Engineering University of Zagreb now joins an elite group of scientific institutions whose exemplary projects have been recognized by their peers for their excellence, innovation, and societal impacts [16]. This project and innovation will continue serving as a model and inspiration for others in the road and transport sector.

Figure 13. Crystal Globe for RUCONBAR in category “Research”, IRF Global Road Achievement Award 2018

Figure 14. RailTech 2019 Innovation Award for RUCONBAR in category “Infrastructure”

4. CONCLUSION

The economic development of a country is inconceivable without a properly developed transport infrastructure. In Croatia, intensive work on the construction of road infrastructure was carried out in the previous period, while very little attention was given to railway infrastructure. Today, all attention of builders is focused on the construction and modernisation of the railway infrastructure. Industry activities in both sectors of the Department of Transportation Engineering have been successfully monitoring this and through participation in a number of preliminary, main and detailed design projects and supervision of construction and testing of materials. A significant step forward has been made in developing new products and technologies which are recognised by the profession and which are increasingly find their place in daily engineering practice. The reason for this is the fact that most of the innovative products developed in collaboration with industry certainly facilitate market penetration. The direction in which today new trends move in the field of transport infrastructure is certainly the use of new products and technologies that contain a certain proportion of recycled material and in turn contribute positively to waste management, and thereby protection of the environment.

The innovative product RUCONBAR is designed to be replicable on any market in need of end-of-life tire recycling and quality noise protection on road and railway infrastructure. Technology transfer has been ensured through prepared procedures for production plant assembly and staff training documentation.

RUCONBAR concept is an economical, easy to implement, and environmentally sound noise protection solution. For orientation, 46.4 t of recycled rubber granules, obtained by recycling 7.800 waste car tires, can be used for manufacturing 1 kilometer of noise barriers 3 m in height (3,000 square meters of barriers). Major environmental benefits of using RUCONBAR are:

- 31% reduction in GHG emissions compared to similar solutions available on the market [11],
- reduced consumption of non-renewable resources (gravel or crushed stones, natural clay and tree felling),
- protection of natural environment against uncontrolled clay excavation and tree felling practices,
- recycling end-of-life car tires.

Desired sound absorption properties can be achieved by varying the thickness and shape of absorbing layer of the noise protection panel. Absorption properties have been tested according to HRN EN ISO 354 and HRN EN 1793-1. Class of A2 and A3 is expected for standard applications of RUCONBAR. Class A1 can be achieved for special purpose applications. Aside from noise mitigation properties, product certification and compliance has been established through rigorous testing

resulting in CE label (Conformite Europenne) issued by Notified Body in 2014.

Innovative and environmentally friendly concept of Ruconbar is applicable in all EU and beyond but it is most applicable in those countries that have need for waste tyres management and demand for noise protection barriers due to underdeveloped traffic infrastructure. With the introduction of EU Directive in SEE, which bans landfilling of whole (July 2003) and shredded (July 2006) tyres, it is clear that there is need to increase recycling capacities and develop markets for utilising recycled tyres. Ruconbar provides an opportunity to accelerate transit and adoption period of SEE countries and reduce the gap between them and other EU countries in the field of noise pollution and waste tyres management, [14]. Ruconbar production in each country of these contributes jointly to the implementation of the Waste Management which yields significant ecological benefits in reduction of noise pollution and waste tyres disposal.

AUTHOR'S NOTE

This paper is based on the manuscript prepared for the chapter in the book Future Trends in Civil Engineering (eds. Cerić, A., Lakušić, S.), Zagreb, 2014. Due to the importance of the topic covered, chapter in the book was for the purpose shorted and connected with the research performed at the Faculty of Civil Engineering University of Zagreb.

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