THE USAGE OF UNCONVENTIONAL MATERIALS IN SUSTAINABLE ROAD DESIGN AND CONSTRUCTION PRACTICE

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ABSTRACT

Croatia is a country with lot of natural resources which are extensively used in domestic road construction. On the other hand, Croatia is tourist country and nature conservation is of national interest. Compared with other branches of civil engineering, road construction is biggest consumer of natural resources and it has huge influence on water, air and soil pollution as on the plant, animal and human lives.

Ways of environmental and energy savings and most of all founds savings by usage of new materials and techniques will be presented as a great opportunity for Croatian road construction and maintenance of existing road network. Current researches and applications of unconventional materials (steel slag, construction and demolition waste, fly ash, reclaimed asphalt and waste tires) in domestic road construction, which are in accordance to sustainable development, will be also presented.

1. INTRODUCTION

Road construction, compared with other branches of civil engineering is one of the biggest consumers of natural resources. By constructing miles of roads and highways, the influence of road transportation on water, air, soil, plant and animal life, and human itself, is in progress. Due to that, modern road construction is attempting to increase usage of unconventional materials, such as steel slag or fly ash as a way of accomplishing energy savings necessary for processing standard road construction materials and a contribution to environment savings.

In the last tenth years the development of road construction in Republic of Croatia has been very intensive due to the reconstruction and modernization of the existing road network, as well as faster inclusion in the European networks. But, this intensive road construction has increased the need for natural materials, which have been traditionally used in Croatian road construction practice.

Many quantities of stone, gravel or sand have been used in road construction for embankments, pavement or base courses. This dangerous devastation of natural wealth and exhaustion of natural stocks can be prevented by the use of unconventional materials like waste materials and industrial by-products.

The usage of those materials contributes to a more rational spending of stocks of a good quality aggregate, and also has a positive impact on the resolving of environmental problems which arise from disposal of waste material.

2. UNCONVENTIONAL MATERIALS IN CROATIAN ROAD CONSTRUCTION

2.1. Steel slag

Production of steel from melted iron is carried out according to one of the three procedures known so far: basic oxygen furnace, electric arc furnace and nowadays mainly abandoned procedure in open-hearth furnace. Thru this processes, steel slag is generated as a by-product. Depending on the steel making process there are various names of slag (Figure 1), but very frequently all types of slag are simply called steel slag [1]. Like the name, the composition of this material also depends on the procedure in which it was generated, composition of steel additives and the type of steel being produced and the cooling speed.

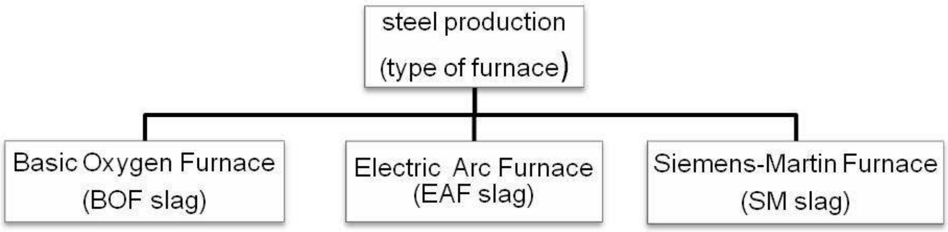

Figure 1 - Names of steel slag based on production procedure [2]

Common feature of all types of steel slag as road building material is a significant share of free calcium and magnesium oxides [3]. This characteristic is considered to be responsible for the biggest lack of this material, expansivity (volume instability) which limits its usage in road building. Namely, free oxides of calcium and magnesium under the influence of humidity hydrate and cause large changes of volume as much as 10% [3-4]. The most appropriate method of eliminating this adverse property is weathering in atmospheric conditions. The weathering period varies depending on the application method and the type of slag itself, i.e., the quantity of free calcium and magnesium oxides. Therefore, it sometimes takes only several months of weathering in atmospheric conditions or occasional sprinkling with water [3].

One of the first studies conducted in Croatia on the possibilities of application of slag as aggregate in concrete pavement was related to the testing of the ferrochrome slag produced in Dalmacija Ferro-Alloy Factory [5]. Mechanical characteristic of samples with slag aggregates were compared with limestone aggregate samples. The results of this research are shown in table 1.

Table 1 – Properties of concrete made with slag and crushed limestone aggregate [5]

Specific property	Concrete with slag	Concrete with limestone
Compressive strength (MPa)	66.30	52.70
Tensile splitting strength (MPa)	4.80	4.25
Flexural strength (MPa)	13.50	10.20
Los Angeles abrasion resisting (%)	17.70	23.00
Frost resistance, loss of strength (%)	10.00	13.00
Modulus of elasticity (GPa)	39.00	34.00

Based on the higher values of strengths (compressive, tensile splitting and flexural strengths) and modulus of elasticity and lower Los Angeles coefficient for samples with slag aggregate then limestone aggregate, it was concluded that this ferrochrome slag, produced in Dalmacija Ferro-Alloy Factory satisfies conditions posted by Croatian regulations for high strength concrete (C 45/50 and higher). Also the higher frost resistance of concrete with slag aggregate emphasizes the possibility of slag usage in concrete pavements. However, this factory has been closed in the mean time and there are no new quantities of this material so the attention of local researches is now focused on steel slag which is disposed at landfills in Sisak and Split.

Slag from Sisak Ironworks is a combination of blast-furnace and electric arc furnace steel slag. This slag is courently used in local road building as a stabilization layer and in agriculture, where smaller grain size is used as soil improver. On the other hand, electric arc furnace steel slag from Split Ironworks has not been used, and is deposited on the site. The estimated quantities of slag on landfills are approximately 1.8 million tons [2].

Authors Netinger et al. [6-7] have studied the possibilities of slag application from the existing Croatian landfills as aggregate in concrete mixtures. Research has been conducted according to the standard HRN EN 12620/AC: 2006: Aggregates for concrete and obtained results were compared with properties of the usual dolomite aggregate. Since expansive nature of steel slag is considered to be its basic negative feature, this research included testing of bulk stability of aggregate. It was shown that domestic slag has volume increase of 1.6–2.2%. Given the expansiveness of the slag, its usage in concrete pavement can lead to swelling and bump formations on the roadway surface. However, this problem can be solved by proper grain size distribution of slag since the research has shown smaller grain sizes are more susceptible to volume changes [6, 8]. Slag aggregates has also shown superior to the dolomite aggregates in the results of wear resistance and resistance to freezing which is very important characteristic of pavement materials (table 2).

Table 2 - Properties of concrete made with slag and dolomite aggregate [6]

Aggregate	Los Angeles coefficient	Percentage loss of mass using magnesium sulphate	pH value of aggregate filtrates
Slag from Split	24.8	8.3	11.6
Slag from Sisak	21.7	5.7	10.14
dolomite	23.4	10.7	9.26

Since slag can be utilized either as aggregate or cement additive, Rastovcan-Mioc et.al. [9] have studied the properties of steel slag from Sisak landfill. Researching properties of concrete specimens using slag as substitute for cement and samples with CEM I 52.2 they come to conclusion that concrete with 15% of cement being replaced with slag has similar properties as regular concrete specimens (table 3).

Table 3 - Physical and mechanical properties of slag cement [9]

Material	CEM I (52.5)	Sample I	Sample II
Slag share (mass %) (%)	0	15	50
Standard consistency	27.4	27	26.8
Bonding start (min)	115	120	210
Compressive strength (MPa)			
after 2 days	25.7	24.86	-
after 28 days	56.9	44.9	21.4

The usage of slag as cement additive, concrete of better mechanical properties and higher resistance can be achieved. Also, slag can be used in low heat of hydration cement production which is particularly useful in concrete pavement building [10]. Concrete produced with slag cement shows better workability, higher strengths, better resistance to aggressive agents, lower permeability and lighter color then regular concrete [10-11]. It can be concluded that using of slag, saving environment, energy and finances can be achieved by reducing the amount of cement and natural aggregates used in concrete production.

Besides its use in concrete pavement, steel slag has also been investigated as aggregate in bituminous mixtures. Mikoc and Markovic [12] have investigated properties of asphalt concrete samples prepared with steel slag from the steel production in Split and the results are compared with asphalt concrete mixtures prepared with natural stone aggregate. Steel slag has been used as a replacement for fraction of aggregates of 4-8 mm and 8-11 mm. Based on the results it was concluded that steel slag from Split landfill used as aggregate in asphalt mixture increases the density and stability of the mixture. Consequently, steel slag can replace aggregate for asphalt mixture resulting in natural resources preservation and providing sustainable development of Croatian road construction.

From all mentioned research it can be concluded that steel slag from Croatian landfills meet the requirements according to Croatian regulations [13-14] and can be used in road building achieving preservation of natural materials and environment, energy savings in cement production and finance savings thru utilization of waste material.

2.2. Construction and demolition waste

Construction and demolition wastes are materials arising from the construction and demolition of buildings, runways and roads. Types of material contained in construction and demolition waste is presented in table 4.

Table 4 - Types of material contained in construction and demolition waste [15]

Excavation	Road building	Building construction	Mixed construction waste
soil sand, gravel clay stone	bitumen (asphalt) cement bound material sand, gravel crushed stone	concrete brick limestone mortar gypsum ceramics natural stone	wood plastic paper metal rubble

Construction and demolition waste occupies a large proportion of the overall solid waste. For example, only in the European Union 500 kg annual per capita construction waste is generated [16]. Some European countries such as Germany, Sweden, Denmark, Great Britain, and the Netherlands have years of (positive) experience in the application of various alternative materials and recycled construction waste in those countries accounts for more than 80% of produced construction waste. Croatia, on the other hand recycles 7% of the total produced quantities of construction waste, which is approximately 2 million tons per annum.

Construction waste has very high usability in road building. Approximately 80% of the material from construction waste may be re-used in all pavement layers. In flexible pavements it can be used for unbound and stabilized base courses or as aggregates in asphalt mixtures. It can be also used in rigid pavement as aggregates in concrete pavements or as aggregates in manufacturing of various concrete elements for slab paving. Also it can be used as drainage material or as the basic or added material in the construction of embankments.

Because of the natural aggregate contained in construction and demolition waste, it belongs to the category of recycled aggregates which can be re-used. Depending on its origin and composition, there are two recycling technologies [15]. The first concerns the separation of material at its source and the direct transportation of classified fractions in the processing plant or place of use. The second one handles separation mixed constructed and demolition waste in central processing facility or in facility for material renewal. In Croatia there is only one fixed facility for exclusive construction waste processing and it is located within Jakusevac landfill in Zagreb.

The idea of recycling of demolition waste usually occurs when demolition of buildings is undertaken to free space for new construction or use of a specific space for other purposes. This may be motivated by economic, technical, safety, or environmental reasons.

For purposes of investors, buildings at the Sopnica-Jelkovec site in Sesvete and buildings on the premises of military barracks in Spansko-Oranice in Zagreb were demolished in order to free up the existing surfaces for new purposes [17].

At the location of the former pig farm at the Sopnica-Jelkovec site there were a total of 65 facilities divided in two functional units (two sectors) with the total surface size of 72,900 m^2 that needed to be removed. All the facilities were removed together with flooring panels and foundations so as the access roads, plateaus and paths as well as the greenery. According to the Removal design, material originating from demolition was systematically collected and recycled in the place of origin so it can be used again later on.

The closure of the military barracks at the Spansko-Oranice site created a possibility for this exceptionally valuable space to be included mostly into residential area. The site included 54 building structures foreseen for removal with the total gross surface size of 26,000 m² and access roads, plateaus, and paths which were also foreseen for removal.

After performing the works of removal of existing buildings, the material originating from removal was recovered and incorporated into blanket courses of the future temporary roads.

Figure 2 - Disposition of Recycled Material on the Sopnica-Jelkovec Site [17]

The volume of material incorporated into the pavement base course which was obtained by recycling of demolition waste was 19,000 m^3 on the Sopnica-Jelkovec site, and on the Spansko-Oranice site its volume was 11,000 m^3 [17].

Quality control of the built pavement layers containing recycled material were conducted by measurement of the modulus of compressibility by means of a circular plate Φ300mm. The minimum required modulus, according to project documentation was M_s=50MN/m^2. During the first test, the values of the modulus of compressibility attained were lower than minimum required so the additional site establishment and rolling of the layer was performed. Repeated tests showed satisfactory results of modulus of compressibility which were M_s=51 MN/m^2 to M_s=88 MN/m^2.

2.3. Fly ash

Fly ash is a by-product produced during the process of coal combustion in power plants. In boiler furnaces, at a temperature of 1000-1600°C, volatile substances and organic particles are combusted, while mineral impurities from the coal (e.g. quartz and clay) appear as incombustible residue. This residue is quickly transported to a lower temperature zone where it solidifies as fine powdery material which is known as fly ash. Given the production method, properties and quality of fly primarily depends of used coal, its grade, chemical and mineral composition and the conditions of the combustion process.

The use of fly ash is intensified after the introduction of stricter environmental regulations, specifically those dealing with air pollution by power plants which had to install various devices for collecting fine particles that were previously discharged into the environment. Since this type of energy production is very widespread, the problem of ash disposal appeared since the quantities of ash produced were rapidly increasing and piling up on the dumping sites.

Fly ash is one of the rare waste materials which can be used in construction industry without any reprocessing or content change. It can be utilized in two ways: as a binding component, because of its pozzolanic properties or as filler, when the physical properties of mixtures need to be improved by increasing the percentage of fine particles.

Fly ash in Croatia is “produced” in only one thermo-electric power plant “Plomin”. Until the year 2000, this power plant used coal from domestic coal mines but since produced fly ash had significant radioactivity level, all testing of its possible usage were abandoned. After the year 2000, they switch to new operation technology and starts using imported coal for combustion, with a low sulfur level from South Africa, Australia, Columbia and Indonesia. Today, all quantity of produced fly ash is used as an additive material in cement production at nearby cement factory “Koromacno”. So, due to long-standing inadequate quality of and its contemporary appropriate management, Croatian fly ash was not used in construction industry nor had there been research undertaken on its possible application and use. But, there is some experience of fly ash utilization in road construction based on the research of “foreign” fly ash.

At the Faculty of Civil Engineering Osijek in 1996 there were conducted initial researches on stabilizing mixtures with a percentage of fly ash in the binder and sand from river Drava as local material [18]. Since domestic fly ash proved to be inconvenient for this purpose, fly ash for this research was supplied from the thermo-electric power plant in Pécs, from the neighboring Hungary. The basic purpose of this research was to determine the influence of the proportion of fly ash in binder on changes in compressive strength of stabilized mixtures. It was concluded that the increase in quantity of binder results in an increase in compression strength for all mixtures. On the other hand, compressive strengths for mixtures containing fly ash was find to be decreasing whit the increase in the portion of fly ash in binder. The drop in the compressive strengths was decreasing with the increase in total binder in the mixture.

This research have been expanded and continued in 2004 [19], and here also, fly ash from the Pécs power plant was used. Research included testing of mechanical and elastic properties: compressive and indirect tensile strength, the dynamic modulus of elasticity, dynamic shear modulus and the Poisson coefficient. The impacts of changes in the treatment conditions on the compressive and tensile strength were also considered. Based on the results it was concluded that stabilization mixtures cured at lover temperature have higher and more “regular” increase in compressive strength. For the indirect tensile strength, samples cured at lower temperature have lower initial strength. However, with time the strength of samples cured at lower temperatures gets higher than the strength of samples cured at higher temperature.

2.4. Reclaimed asphalt

Until recently, the attention of road construction engineers was occupied with the problems of road building. Today, Croatian road network is almost completely built and the existing roads are getting deteriorated so the attention of professionals is being shifted from road building to the issue of road maintenance. Since pavement structure is the most expensive part of the road its rational maintenance requires special attention.

In Croatia, almost all road network (state, county and local roads) in total length of 28 000 km are built with asphalt surfacing. Until recently, maintenance was restricted to construction of “asphalt mat” (thin asphalt overlay of special particle size distribution) or construction of levelling course of bitumenized stone material with surfacing asphalt concrete layer. However, raising cost of stone material transport and energy coasts in quarries as well as requirements for preservation of the environment resulted in increasing rate of natural aggregate and impose the need for selecting the most efficient and cost effective methods and materials for asphalt pavement maintenance. One of those methods is recycling of the decrepit asphalt pavement.

Recycling of asphalt pavement includes procedures to re-build materials from the existing pavement structure. These methods can be divided into two groups: the production process in plant and in place. Within each group it can be deferred hot or cold recycling.
In Croatia, design and construction of pavement by applying the methods of recycling started only few years ago. Only two methods of cold in place recycling are currently in use. As a binder in the first method is used foamed bitumen, cement and water. First design of recycling by this method was proposed in the Road Rehabilitation Project Betterment II and so far only the state road D55 Vinkovci-Zupanja the total length of 17.5 km is completely rehabilitated using this method. Three more sections of state road D1total length of 31.1km are designed to by rehabilitated by this method and the start of works has been planned for the end of 2009.

For the second method cement with the so-called geocret as additive are used as a binder combined with water. Using this method, rehabilitation of state, county and local roads in total length of 9.65 km are constructed until now. Rehabilitation of 30.4 km of state roads are also planned to be rehabilitated using this method.

2.5. Waste tires

Estimated quantity of waste tires in Croatia are in range of 20 000-30 000 tons per year with increasing tendency. In 2005 the total amount of tires disposed on landfills was estimated to around 50 000 tones. It is estimated that around 80 000 and 200 000 used and waste tires have been disposed on the Croatian territory which substantially burden environment. In fact, because of its specific size and shape they occupy a large space in landfill and disposed in beds endanger people’s health as a good foundation for the breeding of mosquitoes and other insects. In addition, tire landfill can be a fire hazard and burning tires are very difficult to extinguish.
In developed countries, waste automotive tires are processed in many ways and used as secondary raw material. But in Croatia only 3.5% is recycled and the rest is disposed in

landfills, mainly illegal ones [20]. Because of that, problem of waste tires is a burning issue in Croatia, which has to be solved, possibly by finding some new ways for their reuse.

The most common application of used tires is as an energy source. Namely, the energy value of rubber is similar to high grade coal, that is one tone of rubber can generate energy as much as 0.7 tonnes of oil [20]. As a fuel, tires are used in power plants, waste incinerators and cement industry.

The first rotary kiln with possibility of waste tires incineration in Croatia were opened in 1999 in cement factory “Koromacno”. This factory has the capacity of incineration of 20 tonnes of waste tires per day (nearly 7000 t/year). But, due to waste tires storing problems, until 2001, only 8000 tonnes of waste tires were subjected to heat treatment. Cement factories “Nasice” and “Split” also has possibilities of using waste tires as fuel. The main problem of this kind of waste disposal is that it is not environmentally friendly since only one ton of incinerated tires produce 647 kg of CO_2.

More acceptable method of dealing with this waste problem is mechanical recycling. According to the Croatian Regulation on management of waste tires, recycling is preferred to use as energy source and thus recycling must include at least 70% of the amount of waste tires defined on the basis of data on the quantity of imported new tires in the previous year. The first plant for recycling of waste tires into rubber granules in Croatia is opened in late 2005. Annual capacity of this plant is recycling more then 15 000 tonnes of tires which are almost all quantities of waste tires produced in Croatia annually.

Considering its properties (elasticity, strength, durability, resistance to freezing and thawing cycles, improved tightness), rubber granules found wide applications in construction and design of roads. It can be used in the production of wide range of new products such as equipment for road (speed retarder, curb for traffic lanes separation, shock bumps in the form of barriers), gully grates and inspection pits as well as in pavement construction.

Research on concrete mixtures with a percentage of waste rubber in the aggregate was undertaken at the Faculty of Civil Engineering in Zagreb. Figure 3 presents the results of compressive and tensile strength [20].

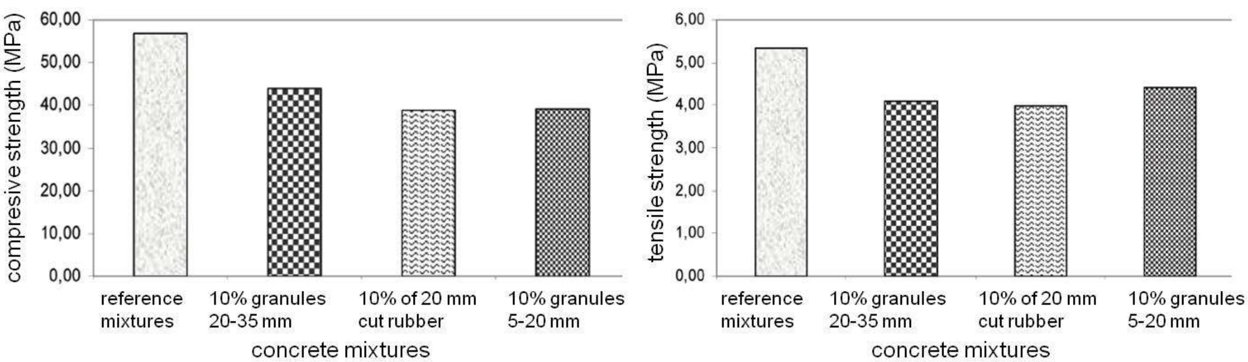

Figure 3 – Compressive and tensile strength of concrete with rubber aggregate [20]

The results show that compressive strength of concrete with replacement of 10% crushed aggregate with rubber decreased by 20 to 30% compared to the strength of concrete with crushed aggregate [20]. Similar to that, tensile strength of concrete containing rubber aggregate also decreased by 15 to 25%.

The same research included determination of density and settlement. From the results it was evident that the greatest reduction in density is in mixtures with cut rubber which is explained by the increased amount of caught air due to the rubber chip shape. The reduction in total slump with the increase in rubber chip size and decrease in workability of concrete mix with the elongated shape of rubber is also noticed.

For pavement materials, resistance to freezing and thawing is very important property. So, the research mentioned before also included investigation of that property. It was concluded that concrete mixtures with rubber granule size 20-35 mm show increase in resistance to freezing-thawing cycles by 60% [20].

In Croatia, usage of rubber asphalt for now is practically non-existing. Very small amount of waste tires are used in production of bituminized sealant masses for the asphalt and concrete pavement. Only three test sections of rubber asphalt have been built, one within the reconstruction of highway and the other in the city of Zagreb. Test results are not yet known.

3. CONCLUSION

Beside of great ecological benefits replayed by reduction in number of dumping sites, greater utilization of waste materials as fly ash or steel slag in concrete reduce necessary amount of cement. By reducing amount of cement, amount of released gasses in the atmosphere in cement production which highly contribute to “greenhouse” effect and global warming is reduced. Moreover, amount of energy necessary for cement production saves nonrenewable sources of energy and reserves of natural materials. Natural aggregate can be preserved by usage of unconventional materials such as reclaimed asphalt, rubber or steel slag by which environment is also preserved and negative impact of road construction on the nature is reduced.

Croatian experience with unconventional materials in road construction has been limited to researches conducted on various universities and only few practical examples. Because Croatia is a tourist country, greater efforts must be invested in conserving natural resources and reduction of pollution. A good road network is foundation for the tourism development and the use of waste materials in their construction is ensures sustainable development.

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