INVESTIGATION OF THE POSSIBILITIES TO USE RECYCLED CONSTRUCTION WASTE IN ROAD CONSTRUCTION

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ABSTRACT. The environmental protection and the sustainable development are directly dependent on the proper management of waste. Huge amounts of waste are generated in the process of construction, reconstruction and rehabilitation. The road sector is one of the largest generators of construction waste but it is also a sector that offers the opportunity to use such waste in the construction of new roads and in the reconstruction and rehabilitation of roads. The study of the possibilities to use recycled construction waste in the construction of new roads is an important step towards the environmental protection by reducing the amount of landfilled waste and the volume of natural resources that have been used.

Keywords: road construction, recycled material, utilisation

ИЗСЛЕДВАНЕ НА ВЪЗМОЖНОСТИТЕ ЗА ИЗПОЛЗВАНЕ НА РЕЦИКЛИРАНИ СТРОИТЕЛНИ ОТПАДЪЦИ В ПЪТНОТО СТРОИТЕЛСТВО

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РЕЗЮМЕ. Опазването на околната среда и устойчивото развитие са в пряка зависимост от правилното управление на отпадъците. В процеса на строителство и изграждане на инфраструктура се генерират огромни количества строителни отпадъци, голяма част от които може да се използват повторно в ново строителство, реконструкция и рехабилитация. Пътният сектор е сред най-големите генератори на строителни отпадъци, но е и отрасъл, който предоставя възможности за използване на рециклирани строителни отпадъци, както в строителството на нови трасета, така и при реконструкция и рехабилитация на пътища. Изследване на възможностите за използване на рециклирани строителни отпадъци в пътното строителство е важна стъпка за опазването на околната среда посредством намаляването на количествата депонирани отпадъци и обема на използваните природни ресурси.

Ключови думи: пътно строителство, рециклирани материали, оползотворяване

Introduction

With the development of modern infrastructure, the amount of construction waste generated which is one of the worst and most massive waste streams in the European Union (EU) is increasing. Construction waste is among the priority waste streams and accounts for 25-30% of the total waste generated in the EU. The potential for re-use is high because of the high recyclability of construction waste and the availability of a market for recycled building materials used in the road sector. Despite the high potential and affordable technologies for separating and recovering construction waste, the degree of recycling and input of construction waste materials in the EU varies widely.

In the Republic of Bulgaria, despite the increasing number of persons holding permits (Waste Management Act (WMA), Art. 35, State Gazette (SG), No. 53, 2012, and suppl. SG, No. 1, 2019) and carrying out recycling and recovery activities for construction waste, for 2017 only 26% of the generated waste from the Construction sector was handed over for recovery, while the deposited waste was 46%.

Figure 1 shows quantitative data on construction waste generated, handed over for recovery and disposal.

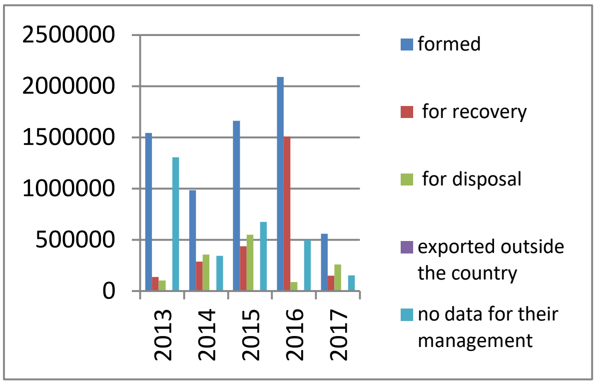

Fig. 1. Construction waste management for the period 2013-2016 (source: NSI)

As shown in the chart, only in 2013 and 2016 the waste handed over for recovery is more than the landfilled, and the difference is more significant in 2016 and consists of 1422339 tonnes. During the remaining years the waste handed over for recovery is significantly less than the disposed.

The exploring of the possibilities of using more recycled construction waste in road construction will increase their demand, which will lead to an increase in the amount of waste utilised. This is an important step in solving the problems of landfilling and waste of mineral resources.

This paper reviews the possibilities of using recycled construction waste in road construction, the specific requirements for their incorporation in building materials and the technologies used for their recovery. The possibilities for increasing the % content of recycled materials in asphalt mixtures, for the construction of new roads with high and medium loads are considered.

Characteristics of recycled construction waste that can be used in road construction

Rock materials

The main sources of this waste are road and railway construction, as well as the processes of construction and rehabilitation of the technical infrastructure. Theoretically, over 90% of construction waste generated by road and railway construction can be recycled and/or recovered without further processing. The recycling of the rock materials is accomplished only by sieving and, optionally, by further crushing, i.e. by a very simple technology that allows for a high rate of recyclability and utilisation. The percentage of recyclability is directly related to the extent to which waste rock material is homogeneous and clean (unpolluted with soil, petroleum products, etc.).

Rock materials formed by repairs and demolition of buildings may be used as fractional material provided that their physical and chemical properties meet the requirements. However, this is rarely happening, because in most cases, waste is mixed with other materials detrimental to their qualitative performance.

Concrete

The predominant process by which concrete waste is generated is the reconstruction and demolition of buildings and facilities. Very few of them can be reused, i.e. have a limited shelf life but, on the other hand, have a very high recycling potential. They contain rock and cement stone that are inert. The final product of the recycling of concrete waste is fractions of crushed material, similar to crushed stone of natural rock materials (Fig. 2).

Fig. 2. Recycled waste from concrete and reinforced concrete

These recycled fractions can be used for the same purposes as natural materials - from mound materials to asphalt aggregates.

Depending on the treatment processes of construction waste, recycled materials very often meet the requirements as well as the primary materials, i.e. their use in construction should not be restricted. They can be used mainly as filler for drainage works, foundation for road construction (road bed and bottom base layer, soil stabilisation, temporary roads, etc.), car parks, garages, etc.

Asphalt concrete

Asphalt-concrete waste is generated mainly in road construction, repair, rehabilitation and exploitation, as well as in the repair and reconstruction of streets, car parks, storage areas and the like. In the *Guidance for Construction Waste Management on the territory of the Republic of Bulgaria*, asphalt concrete is defined as a material consisting of aggregates (crushed stone and sand) and bituminous binder, with or without mineral and chemical additives. This is a material with a very high potential for recycling and re-use (Fig. 3). With rehabilitation only partially or completely replacing the top layers of the pavement (wear layer and binder), depending on the technology available, it is possible to recycle the old pavement on site using hot or cold recycling. The milling asphalt concrete material can also serve to stabilise the verges by treating it with polymeric materials. In all three cases, the type and quantity of the secondary materials should be complied with the technology. Laboratory tests are conducted on a case-by-case basis to determine the optimal percentage of the milling material in the preparation of the mixtures and determining the optimal quantity of stabilising additives.

Fig. 3. Recycled wastes from asphalt concrete

Requirements for used recycled building materials in road construction

The use of recycled building materials is regulated by Regulation No 305 of the European Parliament and of the Council (EU No 305/2011, 2011). In the Republic of Bulgaria this Directive was introduced by the Ordinance on the Essential Requirements for Construction and Conformity Assessment of Construction Products (OERCCACP, SG, No. 106, 2006, amended SG No. 60, 2014).

Recycled construction waste may be used for stabilising verges, execution of sub-basic, basic and asphalt layers, if they meet the relevant physical and chemical indicators (Technical Specification of the Road Infrastructure Agency (TSRIA, 2014).

Stabilised verges

The implementation of the stabilised verges may be carried out by milling asphalt concrete material and quarry waste or recycled crushed concrete 0.4mm, complying with the physical and chemical characteristics of the requirements set out in Table 1.

Table 1. *Characteristics of unfractionated rock material used for the lower layer in the implementation of stabilised verges*

№	Parameters	Normative test documents	Value based on traffic category (%)	
			Very light, light, medium	Heavy and very heavy
1.	Coefficient of Sundry grains	BSS EN 13242 + A1/NA	≥ 10	≥ 10
2.	Freeze-thaw resistance after 5 cycles of treatment with MgSO4, permissible mass loss of material, %	BSS EN 1367-2	declared value	≥ 35
3.	Resistance of degradation by Los Angelis coefficient, %	BSS EN 1097-2	≤ 50	≤ 40
4.	Content of fine fraction (particles < 0,063 mm), %	BSS EN 933-1	≤ 12	≤ 7
5.	Flat grains coefficient, %	BSS EN 933-3	≤ 50	≤ 40
6.	Shape factor, %	BSS EN 933-4	≤ 55	≤ 40
7.	Content of crushed or broken grains, %	BSS EN 933-5	-	≥ 50
8.	Content of fully rounded grains, %	BSS EN 933-5	≤ 50	≤ 30
9.	Sand equivalent, %	BSS EN 933-8	≥ 25	≥ 30
10.	Indicator of plasticity Plasticity indicator, %	Annex 17[1]	≤ 6	≤ 4
11.	California Bearing Ratio (CBR)	BSS EN 13286-47	≥ 50	≥ 80
12.	Content of total sulphur aggregates different than air-cooled blast furnace slag, %	BSS EN 1744-1	≤ 1	≤ 1

When performing the stabilisation in each particular case, laboratory tests are held to determine the optimal percentage ratio of the milling material and the new rock material and to determine the optimal amount of stabilising additives.

Underlay layer

An underlying layer is performed when the earth bed of the pavement consists of associated soils (mixtures of soils and grain materials), fine sand. Sand, gravel, ballast, crushed stone and inert materials from recycled waste conforming to BSS EN 13242 + A1/NA, which have strong and frost-resistant grains and meet the requirements set out in *Table* 2, are used for its construction. The grain size of the material should be less than or equal to one second of the thickness of the applied layer.

Base layers of rock materials, unprocessed with binders

Recycled rock materials used to build base layers unprocessed with binders must comply with the requirements of BSS EN 13242 + A1/NA. The basic requirement is that the material is clean and free from organic impurities, clay, binding particles and other inappropriate materials. According to the *Technical Specification*, the use of recycled rock materials in the construction of highway and 1st class roads is prohibited. For the construction of the remaining second class, third class and temporary roads, recycled rock materials are used that meet the requirements set out in Table 3.

Table 2. *Characteristics of building materials used for the underlying layer*

№	Parameters	Normative test documents	Value based on traffic category (%)	
			Very light, light, medium	Heavy and very heavy
1.	Maximum grain size (mm)	BSS EN 933-1	≤ 80	≤ 80
2.	Content of fine fraction (particles < 0,063 mm), %	BSS EN 933-1	declared value	≤ 12
3.	Plasticity indicator, %	"Road design standards", Annex № 17	≤ 6	≤ 6
4.	Freeze-thaw resistance after 5 cycles of treatment with MgSO4 Permissible mass loss of material, %l	BSS EN 1367-2	declared value	≤ 35
5.	Content of fully rounded grains, %	BSS EN 933-5	≤ 70	≤ 50
6.	California Bearing Ratio (CBR)	BSS EN 13286-47	≥ 20	≥ 30
7.	Content of total sulphur aggregates different than air-cooled blast furnace slag, %	BSS EN 1744-1	≤ 1	≤ 1
	- Air-cooled blast-furnace slag, %		≤ 2	≤ 2
8.	Content of water-soluble sulphates in recycled rock materials%	BSS EN 1744-1	-	≤ 1.3
9.	Coefficient of filtration for compacted material, for a drainage layer m/h	BSS 8497	≥ 2 m/ 24 h	≥ 2 m/ 24 h

Asphalt layers

Nowadays, asphalt is the main building material in road construction. The asphalt mixture consists of sand, rock materials and binder.

For asphalt mixtures intended for a wearing layer for heavy and very heavy traffic, the use of recycled asphalt is not allowed.

For asphalt mixtures intended for a wearing layer for medium, light and very light traffic, it is allowed to include recycled asphalt in their composition, but not more than 10%.

For asphalt mixtures intended for the lower layer of the pavement and the base layer it is allowed to include in their composition recycled asphalt, but not more than 20%.

Recycled asphalt must comply with the requirements of BSS EN 13108-8-1:2006 and all materials must be tested in laboratory conditions and approved prior to their use for the production of asphalt mixtures.

For preparing an asphalt mixture, depending on its purpose, a working recipe is developed, which specifies the physical and chemical characteristics of the mineral materials and the binder, as well as their ratio. The recipe contains the particle size curve showing the single percentage of each sieve, the percentage of each material used in the mixture, and the mixing and compaction temperature.

[1] Annex 17 of Ordinance No RD-02-20-2, 2018. Roads Design

Table 3. *Characteristics of recycled rock materials not treated with binders used for base layers*

№	Parameters	Normative test documents	Value based on traffic category (%)	
			Very light, light, medium	Very light, light, medium
1.	Freeze-thaw resistance after 5 cycles of treatment with MgSO4, permissible mass loss of material, %	BSS EN 1367-2	≤ 35	≤ 25
2.	Resistance of Degradation by Los Angelis coefficient, %	BSS EN 1097-2	≤ 50	≤ 45
3.	Content of fine fraction (particles < 0,063 mm), %	BSS EN 933-1	≤ 16	≤ 10
4.	Flat grains coefficient, %	BSS EN 933- 3	≤ 50	≤ 40
5.	Shape factor, %	BSS EN 933-4	≤ 55	≤ 40
6.	Content of crushed or broken grains, %	BSS EN 933-5	-	≥ 50
7.	Content of fully rounded grains, %	BSS EN 933-5	≤ 50	≤ 30
8.	Sand equivalent,, %	BSS EN 933-8	≥ 25	≥ 30
9.	Plasticity indicator, %	Annex 17[2]	≤ 6	≤ 6
10.	California Bearing Ratio (CBR)	BSS EN 13286-47	≥ 50	≥ 80
11.	Content of total sulphur aggregates different than air-cooled blast furnace slag, %	BSS EN 1744-1	≤ 1	≤ 1
	Air-cooled blast-furnace slag		≤ 2	≤ 2
12.	Content of water-soluble sulphates in recycled rock materials, %	BSS EN 1744-1	-	≤ 1.3

Cold and hot asphalt recycling technologies

Traditional methods of rehabilitation of roads are costly and their implementation time is prolonged and to a great extent dependent on weather conditions. They most often include complete milling of the damaged pavement or intersections thereof, and the milling material must then be removed and transported to waste recycling sites for construction waste landfill. He delivery and installation of new materials for the restoration of the roadway is the next stage.

The alternative solution is the use of cold and hot recycling technologies that allow the removed asphalt layer to be recycled and placed on-site.

Cold on-site recycling

Cold recycling is a road rehabilitation method that allows 100% use of the layers of existing damaged road pavement, making it a major building material. With appropriate mechanisation, the unsuitable asphalt concrete layer is involved in the construction of a reliable high-strength base for the new pavement without further heat processing.

This type of repair technology is appropriate and economically feasible to extend the service life of the road construction.

Specialised machines (recyclers) designed to process structural layers of certain thicknesses are used. For one working cycle, only a part of the road is closed, which is a great advantage for the transport traffic.

Depending on the type and thickness of the processed layer, cold recycling can be divided into three types: deep, thin and recycling of roads with surface layers not processed with binders.

To improve the grain size of the mixture, new materials (within 2-10%) and stabilisers (hydraulic binders /3-6%/, bitumen emulsion / 3-6% / or penobitumen 2-5%/) are added.

Before the cold recycling is done, an analysis of the state of the existing pavement is carried out, which requires preliminary research to determine the depth at which the recycling will take place, the type of material to be added to improve the grain size as well as the type of stabilisers and their quantity.

Activities related to cold recycling on-site technology include:

1) milling of the material from the layers of the existing road surface that are to be recycled;

2) changing the grain size of the recycled material by adding a new mineral material (sand or quarry waste sterile, most often 0.5 or 0.10 mm);

3) mixing the milled material with the required amount of water and stabilisers until complete homogenisation;

4) profiling and compaction of the mixture until a new layer of pavement is obtained.

The technology can be applied for rehabilitation of all roads, including highways. Any material that complies with the technical specification can be used as a building material for the relevant layer.

Hot on-site recycling

If recycling of the asphalt concrete surface layers is required, hot recycling technology can be used as an alternative to the cold recycling. The principle is similar to cold recycling, but it is important to note some specifications. In the case of hot recycling of asphalt pavements, the bituminous properties of the bitumen are largely preserved in the asphalt concrete composition, even though in the operation of the roads it is in solid state. This allows re-heating of the existing asphalt concrete pavement and with small additional quantities of new bitumen, to achieve indicators of recycled asphalt concrete similar to newly produced one.

Prior to performing hot recycling, an analysis of the condition of the existing asphalt pavement is done, which requires preliminary research.

The results of this research determine the depth at which the hot recycling will take place, the type of mineral material to be added to improve the grain size and physical and mechanical characteristics of the mixture, as well as the quantity of binder and/or the fresh asphalt mixture.

The particle size composition of the hot-recycled mixture must comply with the requirements of BSS EN 13108-1/NA for the type of asphalt mixture with which the old layer is implemented.

The hot on-site recycling process consists of four steps:

1) Softening the road surface by heating;
2) Mechanical loosening of the material in the upper layer;
3) Mixing the material with a binder and/or a mineral substance and/or a fresh asphalt mixture;
4) Laying the recycled mixture as a new road pavement.

[2] Annex 17 of Ordinance No RD-02-20-2, 2018, Roads Design

Road bitumen category B 50-70 or polymer modified bitumen category PmB 45-85/65 is used as a binder in the process of hot on-site recycling.

The technology allows restoration of the surface characteristics of the road pavement and improvement of the physical and mechanical properties of the material from the upper asphalt layer.

Traditional hot asphalt mixes are produced at a temperature of about 170°C, whereas hot asphalt mix technologies allow the production temperature to be around 100°C.This reduces to some extent the energy and transport costs.

Also, with the use of the material from the existing damaged top asphalt layer, savings in building material and savings in transport costs are achieved.

Opportunities to increase % content of recycled material in asphalt mixtures

According to recent information there are numerous examples on the use of recycled construction materials in road construction in different countries in Europe and the USA (Abukhettala, 2016; Freire et al., 2013; Schimmoller et al., 2000). There are restrictions on the use of recycled materials in the construction of the main, lower and wearable road layers for the high-load roads in Bulgaria.

To increase the percentage of recycled content in the preparation of asphalt mixtures, an investigation and evaluation of the economic resources and the costs required for the construction of 1 km of the main surface and bottom layer of the pavement was carried out. Table 4 calculates the average amount of asphalt mixtures needed for the construction of 1 km of pavement on a highway, first-class and second-class roads. Quantitative accounts for determining the amount of asphalt mixtures for each layer and type of roads are made in accordance with the requirements and specifications for road design (Ordinance RD-02-20-2, 2018).

Table 4. *Resource and economic costs needed for the construction of 1 km of pavement of main and bottom layer of the coating (bender)*

№	Parameters	**Construction of 1 km highway**		**Construction of 1 km first-class road**		**Construction of 1 km second-class road**	
		Main layer 8 cm	Bottom layer 6 cm	Main layer 6 cm	Bottom layer 6 cm	Main layer 5 cm	Bottom layer 5 cm
1	Average amount of asphalt mixes (t)	3870	2967	2025	2070	1102	1127
2	Conventional asphalt mixtures, average price (BGN)	390870	344172	204525	240120	111302	130732
3	Asphalt mixtures with 20% content of recycled materials, average price (BGN)	367650	281865	192375	196650	104690	107065
4	Difference (3 - 4) in BGN	23220	62307	12150	43470	6612	23667

The average quantity of asphalt mixtures (A) needed for 1 km of pavement is determined using the formula:

$$A = V * P \quad (1)$$

where P is the volume weight of the asphalt mixture intended for the respective layer. For asphalt mixtures intended for the lower layer it is 2.3 g/cm^3, while for the main layer it consists of 2.25 g/cm^3. *V* is the volume of the mixture to be determined by the formula:

$$V = a * b * h \quad (2)$$

where *a* - the length of the intersection, *b* - the width of the lane, *h* - the thickness of the layer.

Average prices of conventional asphalt mixes for building the respective layers are calculated using the formula:

$$C_к=A*c_1 \text{ and } C_p=A*c_2 \quad (3)$$

where *A* is the average quantity of asphalt mixtures,

c_1 – the average price of conventional asphalt mixes for building a base layer is BGN 101/ ton;

c_2 – the average price of conventional asphalt mixes for building a lower layer of coating (bender) is BGN 116/ton;

Average prices when using asphalt mixtures with 20% content of recycled materials are calculated using the formula:

$$C_p=A*c_3 \quad (4)$$

where *A* is the average amount of asphalt mixtures, and c_3 – the average price asphalt mixes with 20% recycled materials for the main and bottom layer of the coating is BGN 95/ton.

As a source for the prices of asphalt mixtures, price quotes from inquiries sent to companies, which recycle and produce building materials that wished to remain anonymous, were used.

Cost analysis has shown that the use of 20% recycled materials in asphalt mixtures for the construction of main and lower layers saves more than BGN 85000 for highways, BGN 55000 for first class roads and BGN 30000 for second class roads.

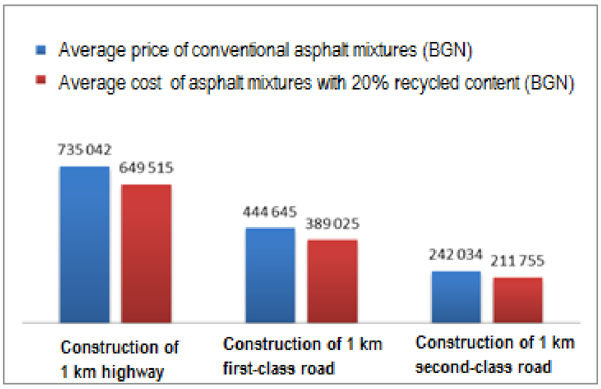

Fig. 4. Comparative analysis of material costs for construction of 1 km main and bottom layer using conventional asphalt mixtures and mixtures with 20% content of recycled materials

Restriction of used recycled materials in the construction of new road pavements is dictated by their physical and chemical properties, influencing the quality indicators of the materials. One of the factors restricting their use is their contamination with other substances. Pollutants reduce quality indicators, may react with some of the impurities, or alter the grain size of the materials. This in turn affects the potential of their re-use.

To solve this problem, it is important to apply selective demolition /deconstruction/ and separate collection and storage of the construction waste. This is the first and most important requirement for obtaining high quality of the waste fractions and for increasing the percentage content of recycled construction materials incorporated in asphalt mixtures for the construction of new roads. This increase will positively affect the financial factors by reducing the cost of materials and environmental factors, by reducing the amounts of landfilled waste and the amount of natural resources used.

Conclusions

In summary, reuse, recycling and recovery of construction waste is an ideal opportunity to reduce the mineral and energy resources used in the conditions of developing road infrastructure on the territory of the Republic of Bulgaria.

Road construction offers great opportunities for re-use and utilisation of recycled construction waste, both in the construction of new routes and in the reconstruction and rehabilitation of existing ones. Applying the technologies discussed in the article allows for reduced transport, energy and resource costs. Trends in temperature reduction in the production of asphalt mixes for road rehabilitation have shown new possibilities for its use and an increase in the number of technological solutions for the production of asphalt mixtures from recycled construction materials available on the market.

In conclusion, it is important to note that selective demolition and separate collection of construction waste can lead to an increase in the % content of recycled construction materials in the production of asphalt mixtures for building of new road pavements. This in turn will have a positive impact on both the financial side, reducing the cost of building materials and waste disposal, as well as the environment by reducing the amount of landfilled waste and natural resources used.

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