USE OF INDUSTRIAL WASTE MATERIALS IN ROAD CONSTRUCTION IN POLAND

Dariusz Sybilski (1), Krzysztof Mirski (1), C. Kraszewski (1)

(1) Road and Bridge Research Institute (IBDiM), Poland

Keywords: Poland, waste materials, road construction

Abstract
Protection of environment in Poland has become a very important issue, especially during last years after joining European Union on May 1st, 2004. Strategic motorway construction programme and road network rehabilitation create a field of opportunities for use of waste materials in a large-scale. Although these materials widen range of available road materials, the advantages of their application are not frequently understand. Main problem is that majority of waste materials are not standardized. They may be applied according to technical approvals or individual solutions.

In order to increase use of waste materials in Poland, the Road and Bridge Research Institute undertook to development of the catalog of waste materials for road applications. One of the tasks will be the recognition and recommendation for placing material in road construction. Moreover, both technical and environmental specifications for each product will be given. This study includes industrial waste materials, which are available and practically applied in Poland. These materials are divided into 5 groups: slags, power plant wastes (ash and slag), building construction demolition (crushed concrete), mining waste (clump) and chemical waste materials (refinery deposit and crumb rubber-tires).

This study collects Polish experience in the field of practical use of waste materials in road construction.

1. INTRODUCTION

The road and highway works are usually concerned with displacement of huge amount of soil and it is usually needed to deliver lacking material from outer supply. In this case, road engineers, basing on economic criteria, reach to the closest mineral deposit available. If the deposits are not available, it turns out that usage of waste materials is more economically feasible, if they deposits are located close to construction site. This is the genesis of large scale waste material usage in the road works, in the road fill construction.

The second trend in usage of waste material in road construction appeared in 60’s, and it is concerned with conscious searching for cheaper alternative in basic road construction material.

Third trend in waste material utilization in road construction is relatively fresh; it arouse due to social interest in subject of ecology. The wide agreed statement says that all waste materials should be utilized. There are two ways to reach this goal: by means of encouragement or by means of obligatory. This is the basis of all the newest technical and research works made in Poland in subject of waste material utilization. It is worth mention, that obligatory, non-economical usage of waste materials in road construction is already practised. It is possible thanks to lately extensions of ecological law and increasing activity of
environmental resort, provincial and local environmental divisions and construction industry surveillance divisions.

This paper contains actual data concerning so far polish experience and data summary, which specifies the trends of usage. It leads in comparably small amount of time to large extension of road construction material database. It is particularly useful due to wide scale highway construction project in Poland, which involves large amount of minerals. The possible usage of waste materials would lead to significant economical and ecological benefits.

2. LAW REGULATION

The use of industrial, building and municipal waste materials in road construction is subject to legal, general and specific law regulations. Some aspects can be identified in these regulations, the most important of them being:

- standard and technical aspect;
- constructional aspect; and
- ecological aspect.

The standard and technical law regulations result form the Act on Research and Certification [1] and the Act on Standardization [2]. Under these Acts, each producer, the ‘producer’ of industrial waste materials as well, is obliged to get a certificate of conformity with technical standards which is a necessary condition for a given product to be granted market authorization. Prior to a certificate being given, technical tests of a sample of the product are carried out in order to identify its technical properties, technical usability and to compare these qualities with the requirements of the existing standardization documents.

As regards utilization of waste materials in road construction sector, only eight standards are currently effective in Poland. The other industrial by-products (UPP) used in road structures are not subject to any standardization. At present, the Road and Bridge Research Institute is applying some measures aimed at implementation of the EN standards with respect to road construction. In these actions, the necessity of preparation national annexes to the EN Standards is envisaged in order to incorporate Polish experience that is adapted to the peculiarity of the local waste materials and climatic conditions.

A potentially large group of documents is represented by technical approvals. Under the Act concerning technical approvals [3], it is required that all building materials for which no adequate Polish standard PN has been established should get a technical approval. By way of regulation, the Road and Bridge Research Institute is the body responsible for approving products used in the communication construction industry.

In the recent years, the ecological aspect of business activity has been acquiring more and more importance in the construction sector, and in road construction in particular. A legal base for this aspect constitutes a rapidly developing set of regulations called in short the ecological law. Almost all of such regulations relate to the construction sector, including road building. As regards the application of industrial waste materials in highway engineering, the basic provisions result from the Act on the Environmental Protection Law [4].

The General Head Office for National Roads and Motorways successively commissions and approves individual sections (installments) of “Principles of Environmental Protection in Designing, Construction and Maintenance of Roads” to be implemented [e.g.:5,6] that adopt a universal approach to all the ecological aspects which might appear in the road construction sector.
3. BASIC TYPES OF INDUSTRIAL WASTE MATERIALS THAT CAN BE USED IN ROAD CONSTRUCTION

The systematic of industrial by-products has been made as divided by branches of economy and industry where they are generated [7]. Types of waste materials are shown according to their origin, e.g.: from the industry of construction and building construction materials, from the power industry and the metallurgical industry, etc.

Of special interest are the materials that are to be found on a mass scale, which have had a proven track in engineering practice and which represented a valuable substitute material for traditional raw materials. These materials may be admitted to be applied in individual technical solutions and for technical approvals. While making allowance for the foregoing assumptions, the following five groups of waste materials, by the branches of economy, have been distinguished: metallurgical waste materials, mining waste materials, combined heat and power waste materials and chemical waste materials.

On the basis of an analysis carried out, the basic industrial waste materials have been chosen which may be used in the road construction and characteristics of which have been shown below.

3.1 Metallurgical waste materials

Metallurgical waste materials are waste materials that come directly from the production process of iron, steel and non-ferrous metals. In general, aggregates obtained from such materials correspond, more or less, to the range of properties specified in PN-B-11112:1996 [8].

Individual sub-groups of metallurgical waste materials are characteristic of specific properties that have been included in their technical specification. For some sub-groups, PN Standards are available.

Applications of all the sub-groups of metallurgical waste materials have been referred to some selected elements of a road construction: asphalt courses, subbase, slops and embankments. General characteristics of the waste materials as a product and their potential applications in road construction have been presented below.

3.1.1 General characteristics of the types of building waste materials adequate for road construction

Blast furnace slag is generated in the process of pig iron melting from iron ore and mineral additives with slow cooling (split up slag) or quick cooling in water (granular slag). The following are the features of slag that make it different from natural aggregate: aggregate size distribution (split up), bulk density when shaken down (both types), constancy of volume – disaggregating (split up) and alkaline hydrogen ion concentration (split up). Standard PN-88/B-23004 [9] defines, to some extent, the specific qualities of aggregate made of blast furnace slag split up, whereas there is no standard to describe requirements with respect to blast furnace slag split up.

Steel-making slag is a by-product of the process of pig iron melting from iron ore in a converter furnace of electric furnace. One can distinguish slag form a process in a LD (Linz-Donawitz) (BOF) converter furnace or an electric arc furnace (EAF). The following qualities make the steel-making slag different from natural aggregate: abrasion homogeneity, bulk density when shaken down constancy of volume, swelling and alkaline hydrogen iron concentration. PN-B-11115:1998 Standard [10] defines, to some extent, the specific qualities of the aggregate from steel-making slag.

Non-ferrous metal slag is a by-product of the metallurgical process of melting copper, nickel, zinc and lead. In Poland, post-cupric slag is of special importance. The Polish copper mining and metallurgical complex, KGHM Polska Miedź S.A. is the sixth largest producer of...
copper in the world. The following qualities make the slag different from natural aggregate: aggregate size distribution (both), bulk density when shaken down constancy of volume – disaggregating and swelling, components of water extract (copper, zinc, lead, hydrogen ions) and radioactivity. There is no standard to specify requirements with respect to such aggregates.

3.1.2 Potential and practical applications

As a commercial product, the slag is available in variety of assortments in accordance with PN-B-11112:1996 Standard [8] and, depending on the needs of the aggregate consumer (the granular slag has the aggregate size distribution of 0/5 (0/6.3) millimetre. In practice, it is a product to be used in: slops, embankments, for the purposes of ground levelling, road subbase mechanically stabilised, subgrade, binder and wearing asphalt courses (split up only). In future, some requirements with respect to specific applications and built-in technologies should be established. With respect to the post-lead and post-zinc slag, some methods or technologies of amelioration should be developed.

3.2 Mining waste materials

In the process of production of hard coal, there is a lot of waste materials generated as a result of the preparatory work as well as mining and processing connected with the production of coal. Economic utilisation of mining waste materials, especially in the extensively urbanised Silesian agglomeration is a serious problem in Poland, since the mines have practically exhausted their possibilities of further placing the materials on dumps. At present, the quantity of waste materials collected on dumps exceeds significantly 1.5 billion tons per year, and the annual growth amounts to 70÷80 million tons.

The following products that are suitable to be used in road construction have been selected: carbon shale and disintegrated rock from the dumps. Classification of these waste materials and their general characteristics has been presented below.

3.2.1 Division and general characteristics of waste materials from the hard coal mining

The post-coal waste materials include various types of rocky grounds and non-rocky grounds such as: shale, mudstones, carbon shale, sandstones and chippings of hard coal. The laminar structure, which is frequently found in them, makes the weathering rocky chippings form plates and thin sheets.

The division and classification of the waste materials may depend of the criteria adopted such as the way they were formed or usability to some selected applications as resulting from technical properties of the waste materials. While making allowance for the direct or indirect usability of mining waste materials, some types of carbon shale may be distinguished.

The features that identify individual types as well as conditions and the extension to which the post-coal waste materials can be used depend on many factors and mainly on: petrography, mineral and chemical composition as well as geotechnical properties (physical and mechanical). The basic physical and mechanical properties of the post-mining waste materials that are used as a substitute of natural soils or crushed stone aggregates are determined in accordance with the existing standards. Mostly, these materials lie useless on the dumps; they are mixed with one another and that is why the best method of recovering them is to segregate them before storing. Sometimes, they require initial treatment before they are applied in the road structure. Also, you should take into consideration the fact that their parameters tend to change over time, e.g. weathering of not-burnt colliery shale or the reverse process – lumping of burnt colliery shale.

Tests of some selected properties of waste materials and changes that take place in them resulting from thickening, soaking in water and after cyclic freezing and defrosting of the materials have been made for many years by the IBDiM [e.g. 11]. The tests carried out refer
to various types representing ‘soft’ materials or those more resistant (‘hard’) to degradation of the aggregate size distribution.

3.2.2 Potential and practical applications

To use post-mining waste materials for the purpose of constructing communication embankments is the simplest way of the utilisation of such materials in big quantities since earthwork is characteristic of high material consumption index. Here, all the types of post-mining waste materials may be employed, provided they are used in an adequate way. General evaluation of the usefulness of waste materials for the individual parts of the road body (embankment) is specified in PN-S-02205:1998 Standard [12]. A good example of this is the construction of A-4 motorway within the area of Chorzów city, where crude and red shale was employed, in the total amount of approximately 250 thousand cubic metres. For the capping layer and subbase of an auxiliary road pavement, one should use materials that comprise mainly hard solid rock or well-burnt shale. In practice, to make the capping layer of the pavement, e.g. of the Katowice-Gliwice Road Cross-Town Route, burnt shale or raw materials from secondary mechanical processing (i.e. the process of decarburisation) from the seasoned dumps attached to mines were successively used. In order to obtain the disintegrated material required, a specially selected set of equipment was used which was operated in accordance with the strictly established methods and conditions defined at trial sections. In order to identify possible extension of the scope of the utilisation of individual types of post-mining waste materials, some supplementary tests with the use of adequate ‘improving agents’ which improve the properties of the post-mining waste materials should be carried out.

3.3 Building construction waste materials

Building construction waste materials are those that are generated in the process of demolition of buildings. We call demolition materials various products of which not all can be converted into aggregate used to road construction, that is why they require selective sorting. Special attention should be focused on materials contaminated with asbestos to be removed. The properties of road materials produced from building waste materials depend first of all on the raw material (the source material) used for the production. Three main groups of sources of raw materials can be distinguished here: old concrete road and airfield pavements, concrete and reinforced concrete engineering structures as well as debris of different materials from demolition of engineering structures or road structures. From these sources, two types of materials useful in road construction can be obtained: concrete aggregate and building debris.

3.3.1 General characteristics of the types of building waste materials adequate for road construction

Concrete aggregate contains crushed concrete with proper fractions or mixtures of fractions. Aggregate that comes from recycling of concrete represents material in 100% crushed and its grains are characteristic of very much sharp-edged shapes. Processed material shows a course surface texture, lower density and higher absorbability than conventional natural aggregate. Its production consists in sorting and crushing and then crushing the material in order to obtain a proper fraction. Standard installations, the same as in case of mineral aggregates, are employed for the purpose of concrete aggregate production. The aggregate may be used in embankments, in subbase stabilised mechanically and with the use of a hydraulic binding agent and as aggregates to concrete mixes, including those for new roads made of cement concrete.

Building debris contains a mixture in the form of the following waste materials: mineral, concrete, brick, roofing-tile, mortar, etc. This material is usually available in small quantities, and it is characterised by low resistance and great variability of its composition. For this
reason, it is used as material to construct the body of road embankments and when adequately segregated, to prepare the subgrade for constructional courses of road pavements.

3.3.2 Examples of building construction waste materials being used in practice and their practical applications

Concrete aggregate coming from airfield pavement was used for road subgrade in the pavement structures in Warsaw. The aggregate was used in the stabilisation with cement as a road base. Concrete breakstone from recycling is to be found in numerous applications. Subbases made on the basis of an optimal mixture with the use of such breakstone have been constructed in Poland for ten years; the recent examples include the complex repair work of several streets and squares in Warsaw. Building debris has not been used so far for the purpose of road construction in Poland.

3.5 Power plant waste materials

Combined heat and power waste materials generated from burning of coal have been for many years a source of significant amounts of alternative materials, in particular with respect to construction of embankments and capping layers and subbases. They may be used as substitute filler for mineral and asphalt mixtures. They loose, however, their mechanical properties. These represent conventional ashes and slag formed from burning of both hard and brown coal. The annual production of such waste materials in Poland is estimated at about 15 million tons. The utilisation of power plant ashes and slag is rather well standardised with respect to road construction in Poland. Most standards were established or revised in 1997 and 1998. They allow for wide utilisation of ashes in road construction. There exist many technical approvals as well. They refer in particular to earthwork, capping layer and stabilisation of subgrade or components of mineral mixtures having stronger resistance with admixture of concrete. A short characteristic of the waste materials has been presented below.

Ashes form a very fine grey powder with the predominant quantity of grains smaller than 0.075 mm. These include mineral parts coming from burning of coal and precipitated from the exhaust gases in a mechanic or electrostatic way. Also, active fly ashes are generated from brown coal or mixture fly ashes and solid wastes from the calcium methods of desulphurisation of exhaust gases.

Slag represents mineral parts with predominant proportion of the sand and gravel fraction coming from burning of coal and precipitated in the lower part of the boiler, usually with a wet method employed.

Ash and slag mixtures comprise mineral parts coming form burning of coal and they are drained to the storage area with the use of a wet method.

3.5.1 Examples of practical applications

In Warsaw, in order to build embankments, significant quantities of ash and slag mixtures generated in the CHP Żerań have been applied. These mixtures composed of various fractions and easy to build in. Coarse fraction mixtures have been used, e.g. in the high embankments along the Toruńska Expressway. Similar applications took place in other areas.

One of the most important application of fly ashes was construction of roads for heavy trucks in the woodland complex of Kuźnia Raciborska. Fly ashes have been also used for construction of cycle tracks connecting the housing estates of the city of Rybnik with the recreational grounds. Another example of the implementation is that of the construction the sections of housing estate roads in Zwonowice near Rybnik. Using the ash and slag mixture, the subbases of parking lots at the airfield of the local Aeroclub and a shopping centre in Sosnowiec of the area of 33,000 m² have been built.

These technologies are becoming more and more popular, due to the technical approvals being developed. For example, in the neighbourhood of Rybnik, from June to September
2003, 20 thousand tons of concrete made of ash and slag mixture to be used for road construction were produced, sold and built in.

3.6 Chemical waste materials

These include products formed during manufacturing based on many-stage chemical processes. The following two groups of waste materials have been distinguished that may be used for road construction: post-refinery deposits and rubber wastes.

3.6.1 Post-refinery deposits

Increasingly bigger amounts of waste materials are produced by the petroleum industry, and due to the contents of oil-derived residues and heavy metals, the not-solidified petrochemical deposits are qualified as noxious and hazardous waste materials. Therefore, before they are applied they should be converted – solidified. A solidified petrochemical deposit may have various forms, from granulated product of small contents of lime to a powder with bigger contents of lime. A powder with the minimal contents of lime of 25% is suitable for ground stabilisation. The contents of small fractions that go through a 0,075 mm sieve is between 82%-92%. This product shows some bonding characteristics that manifest itself in small ultimate compressive strength.

3.6.1.1 Applications

Post-refinery products processed have been applied as a binder to stabilise ground along three trial sections. It is a short section of roads with a dusty subbase in an agricultural area. The Town Market Place located in the Piaseczno and a part of embankment 1.0 metre high on the premises of the CHP Siekierki. The results of tests carried out so far have proved that the impact of the deposits on the properties of dusty soils is positive.

3.6.2 Rubber wastes materials

Rubber is a product commonly used in our every day life. The following two groups of rubber wastes can be divided: 70% of the total amount of waste materials represent worn out car tyres, 30% - industrial waste materials and conveyer belts. In this paper, our attention is focused on the utilisation of tyre rubber waste in road construction. Approximately 120 000 tons of worn out car tyres are produced each year in Poland and the amount is likely to increase in future. These wastes may be used as a crumb to be added to mineral and asphalt mixtures or in their non-processed form as tyres to stabilise embankments and slopes. The experience with respect to the utilisation of rubber crumb in Poland is presented below.

3.6.2.1 Characteristics and applications of rubber crumb

The properties and usefulness of rubber after being disintegrated depend on many factors, among others: the type of rubber, disintegration method, size and shape of particles, size of specific surface, cross-linking density and modification method. The classification of rubber crumb is based on a fraction. According to the IBDiM’s classification, the following four fractions can be divided: dust, fines, granulated product and grit having the diameter between 0 and 10 millimetres. Another division of these products has been established by the STOMIL Rubber Industry Institute based in the town of Piastów: fines, granulated products, grit and cuttings of the diameter from 0 millimetre up to and 300 millimetres.

In practice, under the IBDiM’s projects, two trail sections have been made in the neighbourhood of the town of Piła. One of the sections has been constructed with ‘a wet’ method using a mixture of SMA12.8 mm type with rubber granular of the aggregate size of 0.1 millimetre and binder D70 Am = 4.8%. The section constructed is 300 metres long and 6 metre wide, and the coarse 4 centimetre thick. The other trial section, constructed with ‘a dry’ method, is a fragment of a cycle track. Mixture of a discontinuous aggregate size distribution
MNU6 mm with rubber crumb of 2/7 mm and binder D70 Am=6.5% was used to construct it. The section is 1,760 metres long, 2.5 metre wide; the thickness of the asphalt course is 3 centimetres, and it is placed on a mineral and asphalt subbase. In November 2003, yet another two sections were made with the use of a mixture with addition of rubber crumb. The mixture of a discontinuous aggregate size distribution MNU 0/6 mm with 3% of rubber crumb of the fraction of 5/8 mm and with polymer fibres was constructed. The first section has the area of 2,200 sq. metres, the other has the area of 1,923 sq. metres. Both sections were constructed with a thin 3 centimetre thick layer placed on a very much worn pavement. The pavement of such a type prevents reflecting cracks and improves the acoustic qualities of the pavements.

On the basis of the tests and analyses of the trial sections carried out, one can state unequivocally that it is possible to apply rubber crumb for the purpose of road construction with good results when adequate technologies are implemented.

### 3.7 Environmental impact

Some harmless waste materials can adversely affect the landscape only, however, most of them have a harmful impact, to some extent, due to the substances emitted. In most cases, environmental impact of such a material is evaluated through examination of water extract (in future, the procedure of examination of water extract should be improved so that it is adopted to the conditions to be found in the road construction sector). All waste materials are subject to the classification with respect to their impact on the environment, and their code reflects their harmfulness. Some materials should be processed, intermixed, etc. so that, with certain conditions being maintained, they can be applied and then they do not constitute any threat to environment and health of the population. Then, they represent a full value raw material for road and industrial construction as well as for other applications not related to a direct impact on a human body within long periods of time.

### 4 CONCLUSIONS

This paper has described Polish experiences in practical use of industrial, building and municipal waste materials in road construction. Waste materials can be placed in the road construction with good results when adequate technologies are implemented. Use of waste materials in a large-scale solves serious problem of the impact on the environment of these materials, also it would lead to economical benefits. At this moment the low regulations aren’t sufficient for needs, but new standards, technical approvals and guidelines are developed. Table 1 presents current and potential use of waste materials, which are available and applied in Poland in road constriction.
### Table 1 Use of waste materials in road construction

<table>
<thead>
<tr>
<th>Type of waste material</th>
<th>Use in road construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wearing course</td>
</tr>
<tr>
<td>Metallurgical waste materials</td>
<td></td>
</tr>
<tr>
<td>Blast furnace slag (air cooled)</td>
<td></td>
</tr>
<tr>
<td>Blast furnace slag (water cooled)</td>
<td>+</td>
</tr>
<tr>
<td>Steel slag</td>
<td>+</td>
</tr>
<tr>
<td>Post - cupric slag</td>
<td>+</td>
</tr>
<tr>
<td>Post - nickel slag</td>
<td>+</td>
</tr>
<tr>
<td>Post - zinc and lead slag</td>
<td></td>
</tr>
<tr>
<td>Mining waste materials</td>
<td></td>
</tr>
<tr>
<td>Not burnt colliery shale</td>
<td></td>
</tr>
<tr>
<td>Burnt colliery shale</td>
<td>+^1^</td>
</tr>
<tr>
<td>Crumble rock of heap</td>
<td>+^1^</td>
</tr>
<tr>
<td>Building construction waste materials</td>
<td></td>
</tr>
<tr>
<td>Crushed concrete aggregate</td>
<td></td>
</tr>
<tr>
<td>Building construction demolition aggregate</td>
<td></td>
</tr>
<tr>
<td>Power plant waste materials</td>
<td></td>
</tr>
<tr>
<td>Fly ash</td>
<td>+</td>
</tr>
<tr>
<td>Mix of fly ash and the slag (traditional)</td>
<td>+</td>
</tr>
<tr>
<td>Mix of fly ash and slag (fluid combustion)</td>
<td>+^2^</td>
</tr>
<tr>
<td>Fly and slag with products of desulphurisation</td>
<td>+</td>
</tr>
<tr>
<td>Chemical waste materials</td>
<td></td>
</tr>
<tr>
<td>Refinery deposit</td>
<td></td>
</tr>
<tr>
<td>Crumb rubber-tires</td>
<td>+^3^</td>
</tr>
</tbody>
</table>

^1^ lover layers (non-asphalt), ^2^ as hydraulic binder or part of it, ^3^ in asphalt layers
References

1 The Act of 3 April 1993 on Research and Certification (Official Journal No. 55, Item 250), Warsaw, 1993
3 Decree of the minister of the interior and the administration of 5 August 1998 on case of technical approval and technical criterions and unit use of construction products. (Official Journal No. 107, Item 679) with revisions, Warsaw, 1998
4 The Act of 27 April 2001 on the Environmental Protection Law (Official Journal No. 62, Item 627) with revisions, Warsaw, 2003
5 Principles of Environmental Protection during designing, constructing and maintenance of the road, General Part, Section 00, Transprojekt, Warsaw, 1984
6 Principles of Environmental Protection during designing, constructing and maintenance of the road, Road noise protection, Section 01, Transprojekt, Warsaw, 1984
7 J. Pachowski, R. Puchalski, P. Wileński - Use of industrial and municipal waste materials in road construction; IBDiM works no 4, Warsaw, 1987
11 Wileński P. Assessment of usefulness of the shale from KWK Gottwald to construction of road: - Drogowej Trasy Średnicowej GOP, IBDiM, Warsaw, 1986