Aggregates from mineral wastes

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Abstract. The problem concerning the growing demand for natural aggregates and the need to limit costs, including transportation from remote deposits, cause the increase in growth of interest in aggregates from mineral wastes as well as in technologies of their production and recovery. The paper presents the issue related to the group of aggregates other than natural. A common name is proposed for such material: "alternative aggregates". The name seems to be fully justified due to adequacy of this term because of this raw materials origin and role, in comparison to the meaning of natural aggregates based on gravel and sand as well as crushed stones. The paper presents characteristics of the market and basic application of aggregates produced from mineral wastes, generated in the mining, power and metallurgical industries as well as material from demolished objects.

1 Introduction

Limited resources of mineral raw materials and competitive methods of utilization of areas where they are deposited (e.g. environment protection, cities, etc.) cause that more attention is paid to rational management of natural resources and optimization of secondary raw materials utilization. The EU raw material policy assumes maximum utilization of secondary raw materials for production of goods of quality not worse in comparison to goods made of natural resources, as one of the major goals [1]. Also national regulations [2], recommend utilization of all raw materials, including secondary and waste raw materials. The paper presents the condition of production and application of aggregates other than natural, included in the common group of alternative aggregates.

2 Classification of aggregates

Natural aggregates (gravel and sand as well as ground material) represent ca. 1/3 of raw materials utilized in the world and in terms of volume, this is the largest group of mined minerals. World's production of aggregates is estimated at 20–40 milliard Mg (no detailed data). Both gravel and sand as well as ground aggregates are used mostly in the construction industry, for the production of concrete, roads and other applications: asphalt, cements and glues, prefabricated products, land macro-levelling, sporting infrastructure, mining backfills, embankments, etc. Fine sands of high silica content, are used almost in all contemporary electronics (mobile phones, PCs, TVs, solar panels, etc.), in technical

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engineering, and lately for the construction and maintenance of golf course, for gas and oil mining using hydraulic fracturing method from shale deposits, etc. The wide range of application of natural aggregates, especially in many Arabic countries and other highly industrialized areas with very high constructions and specialist engineering building industry make that in some countries there are significant shortages of natural aggregates and the necessity to import them from remote deposits. Prices of imported aggregates in those countries are high (50–100 USD/Mg), i.e. exceed current hard coal prices. Problems concerning covering current demand for natural aggregates cause the increase of interest in alternative raw materials and technologies of their production in order to satisfy the demand and limit costs, especially costs of transport from remote deposits.

Standards concerning aggregates, harmonized with European standards, beside the requirements, set the following division of aggregates together with their definitions. The following types of aggregates can be distinguished:

- natural aggregates - aggregates from natural sources (deposits), which, except mechanical processing, are not subjected to any other processing. Natural aggregates can be divided into ground as well as gravel and sand
- artificial aggregates - mineral origin aggregates, obtained as a result of industrial process, covering thermal or other modification
- recycled aggregates - aggregates produced as a result of processing inorganic material previously applied in the construction industry.

However, the above mentioned classification adopted according to the PN-EN standard is not unequivocal and raises many reservations, mostly due to a large group of aggregates produced of waste, accompanying and by-product raw materials, which beside the mechanical processing (crushing, sieving) are not subjected to any other modification. Can these aggregates be included to the artificial aggregates group?

Within 2010–2011 in the European Union, except narrowing the aggregates classification, also normative Annex A has been enclosed, which includes a list of raw materials and their origin, which can be the base for aggregates production. Due to the type and origin of raw materials for aggregates production, one can proposed a division to primary raw materials for production of natural aggregates and secondary raw materials for production of artificial and recycled aggregates.

Primary raw materials cover all petrographic types of rocks (magmatic, sedimentary, metamorphic) included in the PN EN 932-3 standard. However, the following is the source of secondary raw materials: construction industry and recycling, combustion of solid municipal waste, energy industry, metallurgy, non-ferrous metals industry, founding, coal and rock mining, dredging works and other [3].

In the construction industry, except for artificial and recycled aggregates, separate group of aggregates can be noticed - "waste aggregates" which include mineral origin aggregates from any technological process, subjected only to mechanical processing. This group includes, among other, aggregates produced from metallurgical and power plant slag as well as self-burnt coal associated shales.

Considering the above, it is proposed to adopt the classification of aggregates to two large groups of aggregates, i.e. natural and alternative aggregates. Similar division is also adopted in the case of fuels: fossil fuels (natural) and alternative fuels. The scope of application of all alternative aggregates is set in the PN-EN standard and it is identical for natural aggregates, thus the basic criterion of aggregates application is their properties.

Aggregates are manufactured mostly from various kinds of waste raw material, generated in the metallurgical, mining, power and other industries. Raw material origin has a significant influence on physical and mechanical parameters of produced aggregates.

3 Production and application of alternative aggregates

3.1 Aggregates from waste raw material from mining and metallurgical industry

Aggregates are acquired from waste or accompanying raw materials from current production or kept on stockpiles. Volumes of stored waste (over 1.6 milliard Mg - mostly from mining industry), which are annually announced by the Central Statistical Office, should not be perceived as the volumes of available resource base.

In the case of coal waste (deposited), red shale (burnt) is the most desirable for production of aggregates, the "operating volumes" of which on all dumps or reclamation area amounts ca. 20–25 million Mg, which is not even 5% of waste in this group. In turn, in the case of the copper ore mining wastes, their application is not possible at this moment (e.g. for production of mining bentonites, heavy concrete, cement, porous aggregates, cellular concrete, glass powder - component of bituminous compounds) because they are used as construction (embankment) material and to seal the object used for rendering harmless the waste deposited in the Zelazny Most area. Infringement of this construction stability would be a serious environmental hazard due to the type of waste being rendered harmless. About 25-30% of the waste present in this object could be potentially used, maintaining the structure and current function [4].

In case of aggregates produced of waste stored in metallurgical and open-heart furnace dump yards, the main problem is the depleting resources or their complete utilization (in case of some objects) for the production of aggregates. In 2004, the amount of stored gravels from melting processes was ca. 22 million Mg, in 2013 it was ca. 4 million Mg [5, 6]. Similar problems apply to aggregates produced from waste collected on non-ferrous metals metallurgy waste yards (copper and zinc). Some minor quantities of copper derivative gravels are available in Legnica Steelworks, and gravels deposited in Glogow Steelworks have been fully utilized.

At the moment, the ongoing production provides resource basis. Production of waste from current operations is closely related to standing of a given sector, and its volume is correlated with the size of production (mining). In the case of [4]:

- hard coal mining waste - the volume is ca. 35–40% of the coal mining volume,
- copper ores mining waste - the volume is ca. 90% of the ore mining volume,
- metallurgical and open heart furnace gravels – the volume is ca. 30% of steel production.
- copper ores gravels – the volume is ca. 190% of copper production.

From the mentioned data it results that current production provides about 30 million Mg of coal derivative waste, ca. 2.5 million Mg of metallurgical and furnace gravels and about 1 million Mg of gravel from copper metallurgy. In relation to gravels from steel and copper metallurgy, one can say about their total depletion from aggregates production. However, in case of coal derivative waste, only a small part is used for economic purposes. The example could be technological line for aggregates production in the Katowicki Holding Weglowy (Wujek Mine). This mine started production of aggregates from waste raw materials used in the road industry and other engineering works.

Aggregates are produces from waste raw materials and depending on their quality and origin they can be used in numerous construction applications:

- aggregate for concrete,
- aggregate for soil gradation improvement,
- backfill of engineering objects consisting of stone and coarse grain soil,
- filling and / or stabilizing material for auxiliary base course,
- construction of embankments (below the ground freezing zone, in the freezing zone, in dry locations or when isolated from water or represent backfill for stone and coarse grain soil),
- freeze resistant layer, draining layers,
- backfill of:
  - engineering objects,

  - excavations for installations,
  - abutments and supporting structures,
- land macro-levelling,
- land reclamation,
- construction of flood banks,
- reinforcement of unsurfaced roads,
- maintenance of roads during winter (grip improvement aggregate).

Due to low quality of aggregates produced from hard coal mining waste, their application is limited to simple engineering works.

3.2 Aggregates from energy industry waste raw material

Despite relatively large volumes of ashes and slag produced by power plants and CHPs (ca. 20 million Mg/year), two companies are engaged in the production and distribution of waste based aggregates in the energy sector: EDF Ekoserwis Sp. z o.o. from Wroclaw and Epore Sp. z o.o. from Bogatynia. Aggregates are produced mostly basing on the furnace slag which is a by-product generated during combustion of hard and brown coal in the furnace.

The slag based aggregate is not homogeneous and its bulk density is 700–1100 kg/m^3. Low quality of aggregates for concrete production purposes and cases of defective elements made of slag-concrete are the grounds to limit the application of slag based aggregates for reinforced elements as well as medium and large structural non-reinforced elements. At the moment, aggregates are mainly applied for:

- base and auxiliary courses of roads,
- drainage layers of roads,
- base courses for yards and walkways,
- levelling backfill for cobblestone,
- sanitary and sewerage construction, backfill of cables and systems,

The second group is aggregates generated during thermal treatment of ashes in energy and heating sector. At the moment, the only company offering such aggregate is LSA Sp. z o.o. from Bialystok. The main orientations of the aggregate application are:

- production of light structural concrete as well as structural and insulation concrete,
- production of abrasive elements (products), ceiling elements, stack materials, insulation materials and products for small architecture,
- production of thermal insulating mortars,
- acoustic and thermal insulation,
- geo-technology (reduction of buildings settlement, reduction of horizontal thrust and transfer of structure loads, stabilization of foundations, replacement of the base),
- road industry (road base courses),
- gardening (drainage layers under crops or a component for hoeing of soil, controlling penetration of water and air),
- construction and road filtering and draining layers,
- filtering and water accumulation layers under green (green roofs) and sporting areas,
- engineering construction,
- reinforcement of unsurfaced and forest roads,
- formation of road embankments,
- land levelling,
- soil stabilization,
- ceramic product manufacturing,
- aggregate for light concrete,

- reclamation and macro-levelling of degraded elements.

3.3 Recycled aggregates

Recycled aggregates are produced as a result of construction works such as: demolition works, repairs, modernizations. Quality of recycled aggregates depends on the quality of recycled materials (concrete, brick, asphalt). There are two methods of producing recycled aggregate: "in situ" at the site of demolition, construction, modernization, repair and "ex situ" at the disposal plants. Significant savings, on transportation costs, can be achieved in case of in situ production of aggregates. Turnover with these raw materials is very difficult to register. Based on historical data, share of construction materials in total volume of waste from demolition, construction and repair works is ca. 30% (40% scrap, 30% soil and earth), in turn, the degree of recovery of waste is at the level of ca. 80% [7]. Assuming the increase of recovery index to 90% as well as the option to recycle waste of code 10 12 08 (rejected ceramic waste, brick, tiles and construction ceramics) and 10 13 82 (rejected products), one can say that practical level of recycled aggregates production may be at the level of ca. 2.0 to 3.0 million Mg. This value should be increased by aggregates from asphalt recycling, the volume of which is estimated at the level of ca. 5 million Mg per year.

Places of recycled aggregates production and at the same time their economic utilization should be linked mostly to large urban agglomerations, where most of demolition works are focused. Main directions of utilization are related to land levelling, ballast (lower layers) under cobblestone pavement, backfilling of foundations in building construction industry, replacement of soil, lower level of road base courses (concrete aggregates).

4 Summary

Poland is a major producer and user of natural aggregates. Current production is at the level of ca. 210–240 million Mg/year, i.e. ca. 5.5–6.3 Mg/year per citizen. Over 70% of the production of natural aggregates is related to gravel and sand aggregates located within the whole country and mined in all Provinces (leaders in this list are Podlasie, Warminsko-Mazurskie, Malopolskie – year 2014 data) and the remaining part applies to aggregates, produced of solid rocks, which are located mostly in Southern Poland, Dolnoslaskie Province (ca. 44%), Swietokrzyskie Province (ca. 34%), Malopolskie Province (over 11%) and Silesian Province (ca. 5%).

The production of natural aggregates is complemented by alternative aggregates, produced mostly from mineral wastes. Production of alternative aggregates matches the message concerning basic goals and principles of waste management, i.e.: reduction of waste to minimum, minimization of their impact on the environment, recovery in accordance with the environment protection. The name "alternative aggregates" seems to be fully justified due to adequacy of this term for the origin and roles of these raw materials in comparison to natural aggregates.

Alternative aggregates are used in building construction industry and in horizontal structures. Intensification of interest in these aggregates is observed when major constructions are located near the area of resource base for their production. Projects requiring significant volumes of construction works (geotechnical applications), alternative aggregates, especially light ones, due to three-times less bulk density, in some cases, have the edge over natural aggregates. Their application may reduce the cost of construction investment, including transport costs.

In developed countries, with vast ecological awareness, production of alternative aggregates represent significant share in the total production of aggregates. These are Great Britain (68 million Mg) and the Netherlands (18 million Mg) where the share of alternative aggregates is ca. 25% of total production. Share of over 15% in total production can be noticed in Belgium (16 million Mg), Germany (the largest production, almost 100 million Mg). Average share of artificial aggregates for 28 EU states is 10%.

In Poland, according to the UEPG data [8], production of alternative aggregates in 2013 amounted 30 million Mg, which is 11.7% of the total production. Within the closest future, one can expect reduction of alternative aggregates production (mostly secondary raw materials) due to depletion of the resource base. Complementation of lost capabilities can be provided by utilization of recycled aggregates as well as common utilization of mining waste from current production and production of light aggregates from new raw materials such as sewage sediment, bottom sediments. Mining aggregates and some recycled aggregates, in relation to metallurgical aggregates can be characterized by worse utility parameters, thus they cannot fully substitute them.

The last specific group of natural waste aggregates is small fractions of gravel-sand aggregates (sands) as well as ground aggregates (sand generated during production of grit). In relation to large production capacities of mines, less demand in relation to 2010–2012 and low prices of aggregates, some fractions of aggregates (especially fine ones) are at the moment difficult or even impossible to sell. At the same time, the quality of gravel and sand deposits deteriorates. For example, within 8 years 2007–2015, the share of industrial resources of gravels in Poland was reduced from 8.8 to 4.2% and in the share of sands (fraction below 2 mm) increased from 25.7% to 37.4%. The most significant deterioration of deposits quality was in the northern and central part of Poland. Very often, these aggregates are returned to pits as useless waste, even though, after re-qualification and enrichment, they could be a valuable raw materials applied outside road industry.

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