Oil Shale, 2010, Vol. 27, No. 4, pp. 321–330 ISSN 0208-189X
doi: 10.3176/oil.2010.4.05

UTILIZATION OF WASTE ROCK FROM OIL SHALE MINING

T. TOHVER*

Eesti Energia Kaevandused Ltd
41533 Jõhvi, 10 Jaama Str. Estonia

The paper deals with utilization of oil shale mining waste rock in Estonia. Crushed waste rock is utilized as an aggregate in civil engineering in frost-free environmental conditions and in road building in unbound mixtures where required resistance to fragmentation LA ≤ 35%. This study determines areas of utilization of waste rock and shows that waste rock aggregate produced using selective mining or selective crushing technology is usable in civil engineering in partially saturated conditions and in unbound mixtures where aggregates require resistance to fragmentation LA ≤ 30%. Waste rock is usable for backfilling the already mined areas.

Introduction

The Estonia oil shale deposit stretches from the Russian border at the Narva River 130 km west along the Gulf of Finland. Oil shale is a yellowish-brown, relatively soft sedimentary rock of low density that contains a significant amount of organic matter and carbonate fossils. The productive oil shale stratum contains oil shale (layers A, B, C, D, E, F_1), limestone layers (A/B, B/C, C/D, D/E, E/F_1) and limestone concretions (Fig. 1). The thickness of the oil shale seam, without partings, ranges between 1.7 m and 2.3 m. The compressive strength of oil shale is 15 MPa to 40 MPa compared to 40 MPa to 80 MPa for limestone. The density of oil shale is between 1400 kg/m^3 and 1800 kg/m^3, and that of limestone is between 2200 kg/m^3 and 2600 kg/m^3 [1].

Annually *circa* 15 million tonnes of oil shale are extracted, 50% is mined in underground mines and 50% in surface mines. Oil shale waste rock (limestone, marlstone or dolostone) is produced during extraction as reject material from separation plant and material from crushing and sizing operations in aggregate production. Major part of waste rock from opencast mine is used for mining site restoration. Waste rock from underground mine

* Corresponding author: e-mail *tarmo.tohver@energia.ee*

is piled up in waste rock dumps near to mines, and the deposited amount is about 5 million tonnes per year. In some cases dumps have been designed for recreational purposes. The total amount of already deposited waste rock is over 100 million tonnes. Crushed waste rock from separation plant produced in classes 25/100 and 100/300 mm [2] is utilized as a fill soil and for construction of embankment in road building. Aggregate produced from waste rock is utilized in road building and in civil engineering.

Extraction taxes for mining right and discharge of waste in Estonia are continually increasing. Charge for the extraction of low-quality limestone belonging to the state in 2006 was 0.45 € per m^3, but in 2015 it will be 1.25 € per m^3 [3], and charge rate for oil shale waste rock disposal in 2006 was 0.38 € per tonne, but in 2011 it will be 0.76 € per tonne [4]. So there is demand to exploit natural resources of construction materials in more rational ways and to utilize already mined and deposited waste rock in economic activities.

Worldwide experience shows that solid waste including mineral processing waste and quarry by-products can be utilized for different purposes, also in civil engineering and road building [5–7].

Waste rock utilization in Estonia has started in 1957 when the base for the road between the towns of Jõhvi and Kohtla-Järve was build using the rock from underground mine Kukruse. Studies on utilization of aggregate produced from the oil shale mining waste rock started in 1989 under direction of Prof. Emer. Alo Adamson. For aggregate producing there were used waste rock from different separation technologies and from seam E/C (Fig. 1) from opencasts Aidu and Narva. The conclusion was made that it is possible to use the aggregate in road building for base construction where traffic volume is low and in concrete with compressive strength M300 in accordance with GOST 10268 and with frost resistance F100-F200 in accordance with GOST 10060 [8]. The first crushing and screening plant equipped with two-stage impact crushers was installed in opencast Aidu [9]. In 2001/02 aggregate was produced from waste rock from underground mine Estonia and opencast Aidu at this plant. The tests showed that aggregate from waste rock has resistance to fragmentation LA = 30–35% and resistance to freezing and thawing F = 4–14%. The conclusion was made that in order to increase the resistance of aggregate a third impact crusher should be installed to crush additionally 20-mm particles retained on screen. In 2006, a three stage crushing plant with impact crushers was installed in opencast Aidu (Fig. 2). In 2009 about 1 million tonnes of waste rock and 0.3 million tonnes of waste rock aggregate were utilized in road building. Aggregate produced in natural limestone quarries in Estonia can have resistance to fragmentation LA = 20–30% and resistance to freezing and thawing 1–2% and is used in road constructions where traffic volume is high [10] and in civil engineering in partially saturated conditions [11]. Waste rock aggregates have usually resistance to fragmentation $LA \leq 30\%$ and resistance to freezing and thawing $F \leq 2\%$, and therefore can be utilized in road building where traffic volume is low and in concrete in frost free conditions.

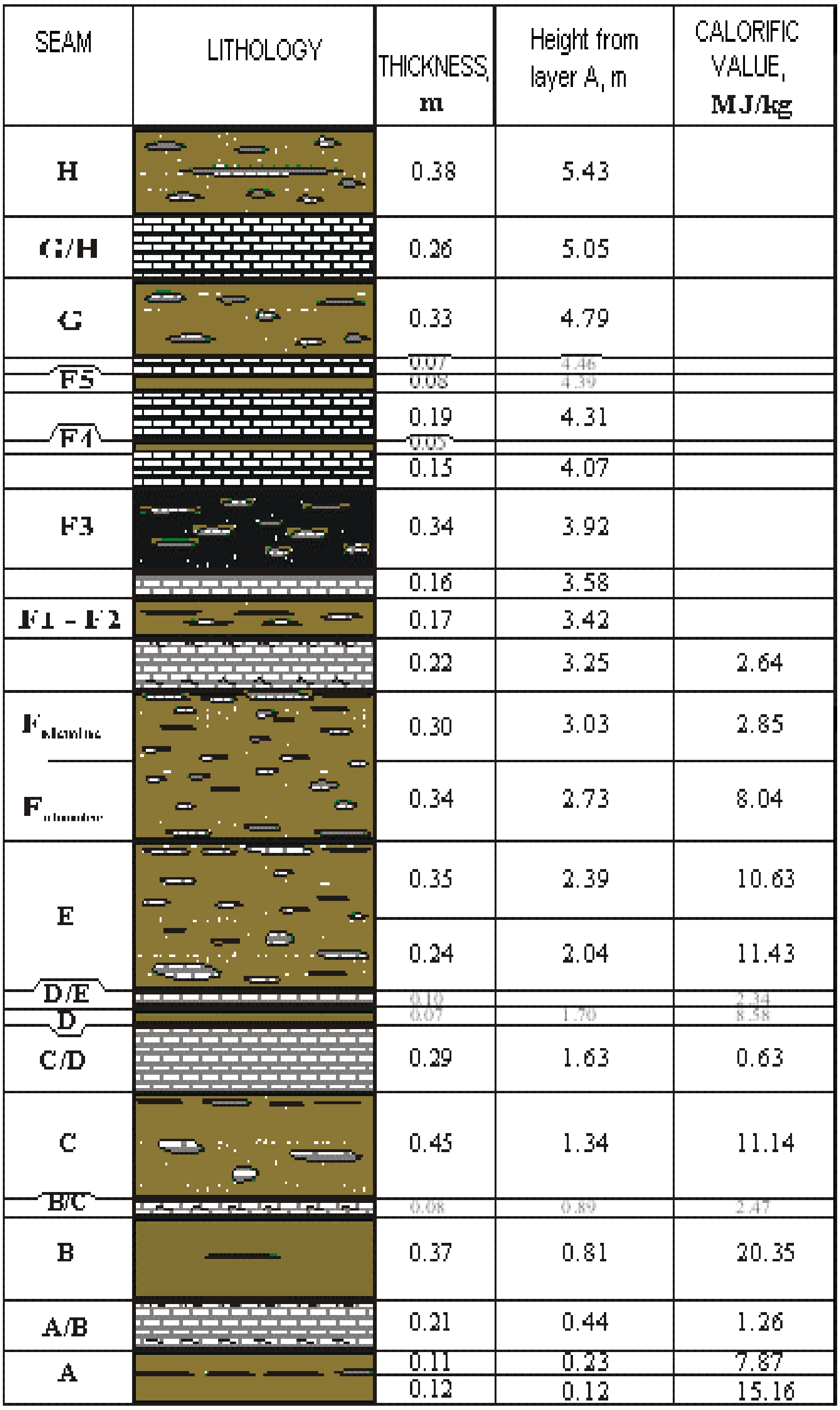

Fig. 1. The oil shale stratum [12].

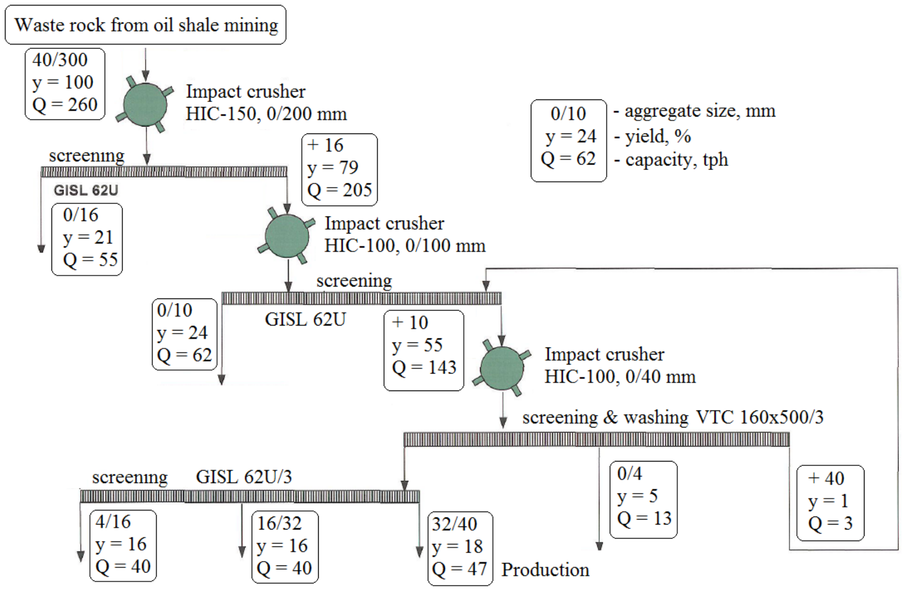

Fig. 2. Three-stage crushing plant in opencast Aidu, Estonia [13].

Methods

In the course of this study data on aggregate properties from 1989 to 2010 were collected, statistically analyzed and compared with requirements for end use utilization. Also tests were made to examine calorific value of aggregate in bomb conditions and resistance to freezing and thawing depending on aggregate particle size after the second stage of impact crusher. The results were compared with calorific value of the aggregate after jaw and impact crusher made in 1989 [14].

Geometrical and physical properties of the aggregate produced from oil shale mining waste rock

There are geometrical, physical and chemical requirements for aggregates. For utilization in road building and in civil engineering requirements are specified in accordance with EVS-EN 13242:2002+A1:2007 "Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction" and in accordance with EVS-EN 12620:2002+AC:2004 "Aggregates for concrete".

Aggregate from oil shale mining waste rock is produced in sizes 4/16, 16/32 and 32/63 mm as an aggregate manufactured using crushing and screening.

Grading of aggregate is performed in accordance with EVS-EN 933-1:1997+A1:2005.

Shape of coarse aggregate is determined in terms of the flakiness index in accordance with EVS-EN 933-3:1997+A1:2003. Waste rock aggregate is produced with impact crushers. Crushers installed consecutively produce cubical or spherical aggregate with minimal content of thin particles. Flakiness index of the produced aggregate *Fl* = 0–35% and that depends on crushers type and number of crushing stages. Required flakiness index depends on traffic volume and varies from 25 to 35% [10].

Content of fines (particle size smaller than 0.063 mm) is determined in accordance with EVS-EN 933-1:1997+A1:2005. It depends on screening technology, and produced aggregate is characterized by content f = 1.5–4%. The required content of fines is 3 or 4% and therefore washing of aggregate can be needed [10].

Resistance to fragmentation shows the strength of aggregate and how easily it breaks apart. Resistance to fragmentation is determined in accordance with EVS-EN 1097-2:1998+A1:2006. The test method for the Los Angeles Coefficient involves a test aggregate sample with particles between 10 mm and 14 mm in size. The sample is rotated in a steel drum, which contains a projecting shelf inside, with a specified quantity of steel balls, at a speed of 31 to 33 revolutions per minute for 500 revolutions. The Los Angeles Coefficient is calculated from the proportion of the sample reduced to less than 1.6 mm in size. The lower the coefficient, the higher the resistance of aggregates to fragmentation. The result is expressed as a category, such as *LA* = 30%, where the number represents the maximum value of the coefficient for the sample [15]. Tests have shown that resistance to fragmentation of aggregate retained on screen is better than resistance of aggregate after the previous crushing stage. Softer particles are sieved out after every stage and harder material retained on screen is crushed again. Tests have shown that resistance to fragmentation of the aggregate produced from oil shale mining waste rock *LA* = 26 to 42%, and it depends on mining and separation technology. Resistance required to fragmentation in unbound mixtures depends on traffic volume and varies from 25 to 35% [10].

Water absorption is used to determine the amount of water absorbed under specified conditions in accordance with EVS-EN 1097-6:2000+AC: 2002+A1:2005. For aggregates of the size 31.5-63 mm a method that requires the use of a wire basket is specified, and for aggregate of the size 4–31.5 mm a method that uses a pyknometer is used. Water absorption of a sample is the increase in mass of an oven dry sample when it is immersed in water. The greater the volume of open voids in the sample, the easier it is for water to penetrate it and the higher the water absorption [16]. Tests have shown that crushing increases the amount of microcracks in aggregate. Therefore water absorption of aggregate is also increasing after crushing. Water absorption WA of aggregate produced from waste rock is 2 to 6%, and it depends on the number of crushing stages. According to EVS-EN 12620 “Aggregates for concrete” the aggregate can be considered resistant to freeze-thaw attack when the water absorption of the aggregate is not greater than 1% [11].

Resistance to freezing and thawing of the aggregate is determined by subjecting it to the cyclic action of freezing and thawing. Test portions of single sized aggregates, having been soaked in pure water at atmospheric pressure for 24 h, are subjected to 10 freeze-thaw cycles. This involves cooling to –17.5 °C under water followed by thawing to 20 °C. The freeze-thaw resistance of aggregate, as measured by the proportion of undersize passing the ½ size sieve as sieved from the test portion, is considered separately for each portion and then expressed as a mean % by mass [17]. The resistance to freezing and thawing is determined in accordance with EVS-EN 1367-1:2007. The frost resistance of the aggregate for construction works in partially saturated conditions has to be lower than 2% [11]. Resistance to freezing and thawing of aggregate produced from oil shale mining waste rock $F = 1–18\%$, and it depends on mining and separation technology. Fine aggregate contains more oil shale and its frost resistance is lower than that of coarse aggregate (Fig. 3). In order to increase the frost resistance of aggregate it is necessary to separate fine oil shale particles.

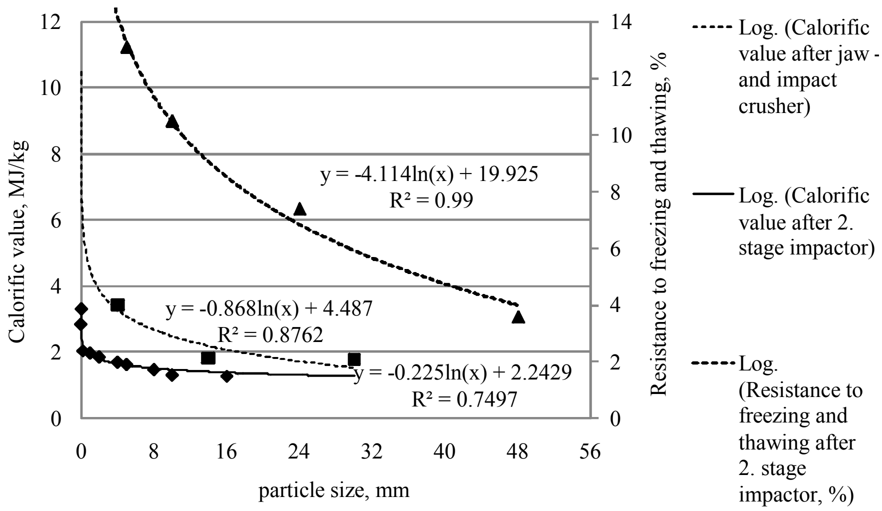

Fig. 3. Calorific value (MJ/kg) and resistance to freezing and thawing (%) depending on particle size.

Calorific value

There are two significant properties of aggregate, resistance to fragmentation and resistance to freezing and thawing which are depending on oil shale content of aggregate, and therefore it is essential to find solutions to minimize the content of oil shale or find ways to prevent oil shale occurrence in aggregate. Determination of calorific value is a rapid way to estimate the content of oil shale in waste rock and in aggregate produced from waste rock. The calorific value of a substance is the amount of heat released during combustion of a specified amount of it. Calorific value Q^d_b is determined in bomb conditions in accordance with GOST 147-95 or ISO 1928-76. Net calorific values of oil shale used for power generation and chemical processing must be at least 8.5 MJ/kg [2]. Calorific value of mining waste rock separated from oil shale is different and depends on enrichment technology and varies from 1.8 to 3.5 MJ/kg (Fig. 4) [14]. Figure 4 includes also closed underground mines Tammiku, Ahtme and Sompa, because deposited waste rock is still usable for aggregate production.

Calorific value of the aggregate produced from oil shale mining waste rock depends on mining and crushing and screening technology. Fine aggregate contains more oil shale, and its resistance to freezing and thawing is lower than that of coarse aggregate. Calorific value of the aggregate retained on screen will be lower after every stage of crushing. Tests showed that frost resistance of aggregate *F* is lower than 4%, if the calorific value of aggregate in bomb conditions is lower than 1.4 MJ/kg (Fig. 3). Aggregate with resistance to freezing and thawing F ≤ 4% is usable for road construction [10].

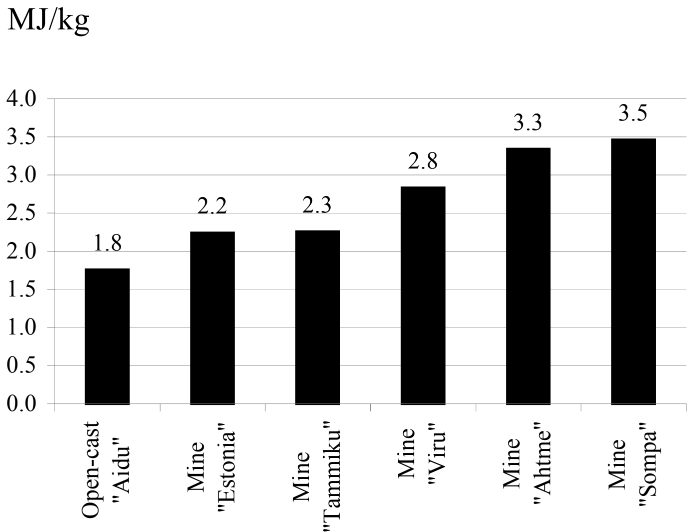

Fig. 4. Calorific value (MJ/kg) of oil shale mining waste rock, 1989 [14].

Mining and crushing technology

The commercial oil shale bed (F/A) is extracted unselectively (bulk extraction) using a drilling and blasting method in underground and opencast mining, selectively of three seams (F/E, E/C and C/B) in opencast using a ripper and excavator and highly selectively in opencast using a Surface Miner Wirtgen 2500SM. Surface Miner can cut more exactly than rippers (2–7 cm) with deviations about one cm [1]. Based on the result of the performed test, calorific value of the aggregate for utilization in road building $Q^b{}_d$ has to be lower than 1.4 MJ/kg. The productive oil shale stratum contains two limestone layers whose calorific value is lower than 1.4 MJ/kg, layer C/D and layer A/B (Fig. 1). Using a highly selective mining method, resistance to freezing and thawing of aggregate produced from layer C/D and layer A/B $F \leq 4\%$. Aggregate produced from other limestone layers with resistance to freezing and thawing $F \leq 4\%$ is not usable for road construction and is usable in frost-free conditions only.

Waste rock from bulk and selective extraction contains fine particles of oil shale. Therefore selective crushing using impact crushers is needed. Impact crushers are characterized by a high reduction ratio and are used for selective crushing, a method that liberates hard limestone from soft oil shale. Grains of aggregate are crushed against crusher parts and against each other, producing a good cube-shaped product. Impact crushers also produce large amounts of fine-grained material. Impact crushers can be used at primary, secondary and tertiary crushing stages. Aggregate retained on screen is crushed until calorific value of the aggregate is lower than 1.4 MJ/kg (Fig. 2).

Discussion

Using highly selective mining or selective crushing method enables to produce oil shale waste rock aggregate with resistance to fragmentation LA < 30% and resistance to freezing and thawing $F < 2\%$. Therefore oil shale waste rock aggregate can replace natural limestone aggregate in road construction. Aggregate with resistance to freezing and thawing $F \leq 2\%$ can be utilized for concrete in partially saturated conditions in civil engineering [11]. In order to meet these requirements, aggregate retained on screen may need to be crushed additionally.

Aggregate with resistance to freezing and thawing $2\% < F \leq 4\%$ is usable in road construction, and the area of utilization is depending on resistance to fragmentation and traffic volume [10].

In case the resistance to freezing and thawing F of aggregate is higher than 4%, the material can be used in no-frost conditions including backfilling the mined areas where the temperature is constantly +6 °C. Laboratory of Civil Engineering of Tallinn University of Technology has tested different backfill mixtures of oil shale waste rock aggregate and ashes from combustion of oil shale. Compressive strength of specimens at an age of 28 days is up to 8 MPa [18]. Compressive strength of artificial pillars 8 MPa allows to support roof and to avoid surface collapses. Fine is also usable for backfilling aggregate from crushing and sizing operations, particle size 0–4 mm [18].

The use of oil shale ash and oil shale mining waste rock as backfilling materials decreases the amount of wastes dangerous to the environment. The effects of backfilling are significant: minimization of surface movement above underground mines, improvement of safety, facilitation of mining operations, and increase of extraction ratio. From the other side, backfilling has been considered an inevitable part of mining technology. For working out new technologies for Estonian oil shale mines it is necessary to perform supplementary investigation on backfilling in underground conditions. Underground utilization of oil shale combustion and oil shale mining waste rock reduces the volume and area required for surface disposal.

Conclusions

As a result of this study, the areas of utilization of oil shale waste rock are determined. Waste rock is usable for road construction and in civil engineering under certain circumstances and areas depending on aggregate calorific value, on resistance to freezing and thawing and on resistance to fragmentation. In case the aggregate frost resistance is low ($F \leq 4\%$), aggregate is usable for backfilling the mined areas. Selective mining or selective crushing method guarantee required properties of aggregate.

Acknowledgement

This research was supported by Estonian Science Foundation (Grant No. 7499).

REFERENCES

1. *Lohk, M., Väli, E., Tohver, T., Pastarus, J.-R.* Surface miner technology impact on the environment // 5th International Symposium "Topical problems in the field of electrical and power engineering". Doctoral school of energy and geotechnology / Lahtmets, R. (Ed). Tallinn University of Technology. 2008. P. 44–47.
2. *Väli, E., Valgma, I., Reinsalu, E.* Usage of Estonian oil shale // Oil Shale. 2008. Vol. 25, No. 2S. P. 101–114.
3. Regulation of the Estonian Government, 2005. The rates of the mineral resources extraction charge for the extraction of mineral resources belonging to the state for 2006–2009. RTI 2005, 71, 553 [in Estonian].
4. Environmental Charges Act. RTI 2005, 67, 512 [in Estonian].
5. *Collins, R. J., Miller, R. H.* Utilization of mining and mineral processing wastes in the United States // Environ. Geochem. Hlth. 1979. Vol. 1, No. 1. P. 8–19.

6. *Kassim, T. A., Simoneit, B. R., Williamson, K. J.* Recycling Solid Wastes as Road Construction Materials: An Environmentally Sustainable Approach. – Handb. Environ. Chem. 2005. Vol. 5, Part F, Vol. 1. P. 59–181.
7. *Rai, M.* Mining & Mineral Wastes for the Development of Building Materials. www.ics.trieste.it/media/135657/df3730.pdf.
8. *Adamson, A.* Study on crushing processes of oil shale mining waste rock. Determination of utilization area of the produced aggregate for construction works and data processing for terms of reference of crushing and screening plant. Research report. Contract no 48/89, 1990 [in Russian].
9. *Yurkevich, G.* Researching of industrial wastes, composition and industrial testing of building mixtures recipes for the underground mining. Research report. Study no 508L, 1995 [in Russian].
10. Estonian Asphalt Pavement Association. Asphalt Norms AL-ST 1-02. 2002 [in Estonian].
11. EVS-EN 12620:2002+AC:2004 Aggregates for concrete. 2004.
12. Eesti Energia Kaevandused Ltd. Mine layout of Estonian oil shale deposit (unpubl. manuscript), 2009 [in Estonian].
13. Eesti Energia Kaevandused Ltd. Three stage crushing plant in open cast Aidu (unpubl. manuscript), 2006 [in Russian].
14. *Adamson, A.* Study on utilization possibilities of the aggregate produced from oil shale mining waste products. Research report no 955, 1989 [in Estonian].
15. EVS-EN 1097-2:1998+A1:2006. Tests for mechanical and physical properties of aggregates – Part 2: Methods for the determination of the resistance to fragmentation. 2006.
16. EVS-EN 1097-6:2000+AC:2002+A1:2005. Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption. 2005.
17. EVS-EN 1367-1:2007. Tests for thermal and weathering properties of aggregates – Part 1: Determination of resistance to freezing and thawing. 2007.
18. *Raado, L.-M.* Waste rock from oil shale mining and separation for backfilling mined areas. Tallinn University of Technology Department of Building Production Research and Testing Laboratory of Building Materials. Research report. Contract no 8008 (unpubl. manuscript), 2008 [in Estonian].

Presented by V. Kalm
Received March 18, 2010