Examination of the utilization of aluminum dross in road construction

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Abstract. Aluminum dross is a recyclable by-product of the aluminum manufacturing process. Since the use of aluminum alloys increased in large quantities, which cause a significant amount of aluminum dross produced, therefore, the need for alternative solutions are also increased. The goal of this study is to investigate the utilization possibility of dross as an alternative asphalt filler. During the research aluminum dross and limestone (as reference material), which is well-known filler in asphalt technology, were investigated. Different tests were done on the samples: specific gravity, particle size distribution, BET specific surface area and Rigden voids were determined on the fillers. Scanning electron microscope was used to characterize the morphological features of fillers. To reveal the affinity of fillers to bitumen hydrophilic/hydrophobic properties and oil adsorption ability were also investigated. These examinations help to better to understand the interaction between fillers and binder material. With the use of fillers asphalt mixtures and specimens were also prepared for stiffness tests and asphalt cracking temperature tests. The results show a good correlation between dross and limestone fillers, therefore aluminum dross may be an alternative to partly substitute limestone filler.

1. Introduction

In this research work aluminum dross, which is a by-product of aluminum manufacturing process was investigated. Handling of this material causes a large problem not only in Hungary, but all over the world. Storaging in landfills is not a proper solution, therefore the industrial utilization of dross is environmentally and economically important. Road construction may be a potential area on utilizing, but it has been used in other areas [1].

Aluminum dross can be classified into two different types (white and black dross), which are depend on the aluminum content. The white (or non salt-containing) dross contains more aluminum, than the black (or salt-containing) dross [2, 3, 4, 5, 6, 7].

During the research limestone powder was used as a reference material, because of its current usage in asphalt technology. Different tests were made on the fillers in order to determine their physical properties: specific gravity, particle size distribution, BET specific surface area, Rigden voids, morphological test by SEM, and hydrophilic coefficient. By the use of fillers standard asphalt specimens were prepared, on which stiffness and asphalt cracking temperature were determined.
2. Experimental

2.1 Sample preparation

The as-received form of aluminum dross was a solid material, which needed to crush by hammer. Smaller pieces of dross was comminuted by planetary ball mill to. Limestone was in a bulk state as received from the manufacturer. According to the standard (ÚT 2-3.602 (e-ÚT 05.01.13):2008) [8] the required particle size (d<0.063 mm) was prepared using standard sieves. Samples were dried for weight-constancy in a laboratory drying chamber.

2.2 Preparation of asphalt samples

Two types of standard asphalt samples (Marshall specimens and beams) were prepared for stiffness tests and low temperature cracking (LTC) tests, respectively. The following mineral aggregates and fillers were used in this study:

- fillers (aluminum dross and limestone, d<0.063 mm)
- dolomite 0/2,
- basalt 2/4,
- basalt 4/8,
- basalt 8/11.

The binder used in the mixtures was a standard 25/55-65 bitumen. A special additive material, called Viatop Premium was also used in the mixture. It is a natural fibre additive material, which provides fast and complete dispersion in the asphalt mix [9].

Marshall specimens were prepared (Fig. 1.) for stiffness test. Raw materials were dried on 180°C for 2 hours and then bitumen was heated up to 180°C. As bitumen is a viscoelastic material, and its rheological properties are important [10, 11], therefore it was necessary to reach this temperature. Raw materials and bitumen were mixed together by laboratory mixer. After mixing 1200 g of hot asphalt was poured into a preheated mold and was compacted by 50 blows in both sides.

Specimens for LTC tests were prepared using the following method: after mixing the hot asphalt mixture was poured into a steel mold and was compacted using a compactor apparatus. After cooling down, the required geometrical sizes of specimens were obtained by cutting.

2.3 Testing methods

Specific gravity of fillers was determined using a standard pycnometer [12]. Particle size distribution was measured using Malvern Mastersizer X instrument using an air dispersion unit. For morphological tests Carl Zeiss EVO MA10 scanning electron microscope (SEM) was used. High resolution electron micrographs were taken in different magnifications for further observation. Specific surface area (SSA)
of the powders (by BET-method) were determined by TriStar 3000 instrument (manufactured by Micromeritics). The method of this instrument based on physical absorption and capillary condensation, and it works in volumetric mode. The fine powder samples were prepared with the use of SMARTPREP instrument. Rigden Void was determined using a standard Rigden apparatus [13]. Hydrophilic coefficient of powders was determined by sedimentation method. 5 grams of fine materials were weighed and put in a 25 ml measuring cylinder. Parallel 10 ml of water and 10 ml of paraffin were poured into the cylinder. Powders and liquids were thoroughly mixed together then the cylinders were filled with more liquid and were closed by plugs. Volume of powders were determined after 72 hours of sedimentation.

3. Results and discussion

Table 1. summarizes the results of tests.

| Parameter                        | Unit    | Limestone | Aluminum dross |
|----------------------------------|---------|-----------|----------------|
| Specific gravity, $\rho$ [7]     | g/cm³   | 2.82      | 2.90           |
| Average particle size, $d_{50}$  | $\mu$m  | 13.77     | 15.62          |
| Specific surface area, SSA       | m²/g    | 1.55      | 1.26           |
| Rigden Void, RV [8]              | vol%    | 47.90     | 43.90          |
| Hydrophilic coefficient, $\eta$  | -       | 0.57      | 0.74           |

Values of the specific gravity shows that limestone has a lower density, than aluminum dross, but the difference is not significant. The reason of the difference is that dross contains elements with higher density (for example Al, Mg). Particle size distribution is very important in asphalt technology, because the size and distribution of fine aggregates affects the stiffness of the asphalt pavement. Table 1. illustrates the average particle sizes of fillers. Based on it limestone has a 50% of the particles below 14 $\mu$m, while average particle size of dross is around 16 $\mu$m. During the research it was needed to determined the BET specific surface area, because the materials with high specific surface area are require bitumen surplus, which can reduce the strength of asphalt pavement. Specific surface area of the dross is lower, than the limestone. The reason of this is due to the particle size, because dross consists coarser particles. Rigden void test is used to evaluate the stiffening effect of fillers on asphalt mixtures. Table 1. clearly shows that limestone powder has a higher Rigden voids, than dross. The value of Rigden void depends on the particle size distribution, particles size, shape and specific gravity of filler. It was concluded, that those material, which has higher specific surface area, has a higher Rigden voids. According to the hydrophilic coefficient test both fillers are hydrophobic, therefore fillers can generate a good relation with the binder. During the research scanning electron micrographs were taken to observe the microstructure and the surface features of fillers. It is important that the raw material need convenient geometrical features, because it affects the function of mineral skeleton and bearing capacity of the asphalt pavement. Fig. 2. show the electronmicrographs, which were taken on the fillers.
3.1 Indirect tensile test (IT-CY)
Research of asphalt technology focuses on the stiffness of asphalt as based on the sizing of the traffic load on asphalt pavements.

One of the most important properties of asphalt mixture is stiffness, which depends on the composition of mixture, temperature and loading time. The measurements were carried out according to the method described in MSZ EN 12697-26-2005 [10]. During the test one of the diameters of the sample is loaded, while transverse elongation of the specimen was measured. Stiffness modulus of the material is the function between the loading force and elongation [14, 15, 16, 17, 18]. During the research stiffness was determined at different temperatures (5°C, 20°C and 50°C). Fig. 3. shows the results of stiffness tests.

![Figure 3. Result of stiffness test](image)

Based on the results, it can be stated that with the increasing of temperature stiffness modulus are decreases. As the temperature rises, the difference between the two fillers is smaller.

3.2 Low temperature cracking (LTC)
In the late autumn, winter and early spring period, as a result of rapid cooling, thermal tensile stresses are generated in the asphalt pavement, whose values can achieve the tensile strength of the asphalt, so it can cause cracks in the asphalt layer. The cracks will appear first in the wearing course and as a results of water penetration and the reduction of the cross-section of the asphalt pavement it will spread into the lower layers of the asphalt. As a result, the bearing capacity of the asphalt pavement will reduced.
Both the cross and longitudinal cracks may appear on the wearing course, therefore mosaic-like ruptures and potholes will generate.

In this paper low temperature cracking values of asphalt specimens were determined. The formation of fracture is depend on the cooling rate. A uniform cooling rate was applied on beam specimens (50x50x250 mm), which prevents the longitudinal shrinkage caused by the cooling. During the test, the longitudinal reduction was continuously measured, which always reinstate by the control pull, so it can prevent the shrinkage of the longitudinal dimension. Decrease of the temperature asphalt cracks were occurred at a certain temperature, which is called low temperature cracking (Fig. 4.)[17, 18].

![Cracking of the asphalt specimen](image)

**Figure 4.** Cracking of the asphalt specimen

![Results of LTC tests](image)

**Figure 5.** Results of LTC tests

The mixture, which contains limestone has an average cracking temperature at $T=-26,1 \, ^\circ C$, while the mixture contains aluminum dross has an average cracking temperature at $T=-28 ^\circ C$. It can be stated that the mixture with aluminum dross has a better cracking property, therefore its behaviour in the lower temperature region is better, than the reference mixture.

### 4. Conclusion

Test results show that aluminum dross behaves very similar to limestone powder as a filler. The results of stiffness tests indicate, that stiffness of both asphalt mixtures decreases as temperature rises. Asphalt cracking temperature of the mixture made with aluminum dross is more resistant to low temperatures. It can be concluded, that dross may be a potential asphalt filler to (partly) substitute limestone powder. However, further investigations and more standard asphalt tests are needed to determine the exact amount of dross in asphalt mixtures.

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