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CONTRIBUTION TO THE RESEARCH ON THE POSSIBLE APPLICATION OF HEAT ENERGY RECOVERY IN THE AGGREGATE PREPARATION PROCESS IN THE PRODUCTION OF ASPHALT MIXTURES

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Abstract

The production process of asphalt mixtures has not changed in recent years. Still, research continues to identify opportunities to reduce production costs, increase the efficiency of asphalt plants, and mitigate environmental harm. Special research efforts are underway to explore reducing the moisture content of stone and recycled aggregates used in asphalt mixtures. It was established that most of the energy is required precisely for drying and heating the aggregates. One way to save energy is to use the heat in the exhaust gas, which is typically released into the environment through the asphalt plant chimney. The high-temperature exhaust gas can be reused by returning it to the aggregate pre-drying process to reduce moisture content and thereby lower production energy costs. This research aims to determine the influence of different parameters during aggregate drying on the property of moisture loss. The parameters analyzed and observed in different combinations were selected based on the asphalt plant's existing production process: airflow speed, drying temperature, and the time aggregates were exposed to the drying process. In the laboratory dryer model, tests were conducted to determine the moisture loss of the 0/11 fraction RA (Reclaimed Asphalt) relative to natural moisture. The results showed that higher airflow speed and temperature, and longer drying time, led to a greater reduction in aggregate moisture.

Keywords: reclaimed asphalt, aggregate moisture, thermal energy, exhaust gases, asphalt mixtures production

1 Introduction

Asphalt mixtures can be produced as warm (Warm Mix Asphalt - WMA), hot (Hot Mix Asphalt - HMA), or cold (Cold asphalt mixes - CAM). They are composed of stone aggregate, binder, and, if necessary, additives. The temperature of the warm asphalt mixtures produced in asphalt plants ranges from 135°C to 150°C [1, 2]. The temperature of hot asphalt mixtures produced in asphalt plants is above 150°C [1, 2]. It depends on factors such as the distance from the construction site to the asphalt plant, the type of bitumen used, the type of asphalt mixture, and weather conditions. Additives can be added to asphalt mixtures to improve the adhesion of the bitumen binder, increase the bitumen binder's resistance to aging, reduce the sensitivity of asphalt mixtures to water, lower the production and paving temperatures, or prevent the bitumen binder from flowing away from the aggregate grains. In the production of asphalt mixtures, whether warm or hot asphalt mixtures, various energy sources (gas, fuel oil) are used for various purposes: for heating and maintaining the temperature of the bitumen, drying and heating the stone aggregate, operation of the dust removal system, operation of the plant, and the control mechanism from the control room. During operation, a significant amount of thermal energy is released through the asphalt plant's chimney. The exhaust gases contain chemical compounds such as carbon dioxide CO_2 and carbon monoxide CO, sulfur compounds SO_2 and SO_3, and water vapor [3].

Due to numerous ecological, economic, and technical advantages, reclaimed asphalt (RA) produced by removing the old asphalt layer is increasingly used in asphalt mixture production. Depending on individual countries' regulations, the use of RA is possible today in the construction of all road layers and for various road traffic loads. When reclaimed asphalt is added to the asphalt mixture production process, the energy required increases. The share of RA in the average composition of asphalt mixtures ranges from a minimum of 5% to over 90%. Calabi-Floody et al. reported a 5% - 13% reduction in energy consumption during the production of WMA using RA [4]. Carpani and Venturini showed that using more RA can, on the one hand, lead to significant environmental savings (reduction of CO_{2eq} by up to 44%) and energy savings (reduction of energy consumption by up to 78%). On the other hand, lowering production temperatures reduces CO_{2eq} and energy use by up to 7% and 6%, respectively, regardless of the percentage of recycled material used [5]. Measurements have shown that 57% of energy consumption is used for the production of raw materials, 38% for the production of asphalt mixtures, and 5% for transporting the produced mix [6].

This paper investigates the possibility of reducing RA humidity by exploiting the thermal potential of exhaust gases. The thermal capacity of exhaust gas released into the environment through the chimney can be reused by returning it to the pre-drying process of RA in the production of warm or hot asphalt mixtures. For this research, a laboratory dryer model was designed and built, and tests were conducted on the 0/11 fraction of RA. The 0/11 fraction RA is an aggregate used in the usual production of asphalt mixtures at an asphalt plant. During the research, the basic drying parameters of the hot asphalt mixture production process were monitored: airflow rate, temperature, and drying time to reduce the aggregate's moisture content, and various combinations of these parameters were analyzed.

2 Possibilities of energy saving in the production of asphalt mixtures

The asphalt mixture production process has remained unchanged, but research continues to seek ways to reduce production costs, increase efficiency, and reduce harmful environmental impacts. Research is being conducted in several different directions: (1) research into the possibility of reducing aggregate moisture, (2) improving the technological process of asphalt mixture production, and (3) reducing the temperature of asphalt mixtures. Asphalt plant manufacturers are seeking solutions to improve production efficiency by increasing the size of the drying drum, designing larger burners, and developing complex combustion systems. Atmaja et al. [7] state that changes in production temperature and the length of HMA production time affect diesel fuel consumption. With a longer production time of hot asphalt mixtures and variability in the heating temperature of the aggregates in the drying drum, the required amount of fuel increases. For each ton of hot asphalt mixture produced, diesel fuel consumption is 11.31 liters, and an additional 8.09 liters are required to raise the production temperature by 1°C, for a total energy consumption of 290.16 MJ. Carpani et al. [5] assessed the impact of WMA+RA technology, which enables the recycling of old pavements, reducing CO_{2eq} by 35-50% and energy consumption by 54-80%.

Sayeh et al. [8] analyzed the reuse of RA in asphalt layers, which resulted in a reduction of environmental impact and greenhouse gas emissions through reduced energy consumption and lower costs. Yao et al. [9] state that the use of RA significantly reduces energy and material consumption in the production of asphalt mixtures.

Khanal and Dongol [10] found that using recycled materials, such as reclaimed asphalt from old asphalt layers and ground waste rubber, in asphalt production can significantly reduce pollutant emissions and energy consumption. The authors de Carvalho et al. [11] conducted a study demonstrating significant environmental and economic benefits of incorporating RA into asphalt mixtures. They reported a 24.9% reduction in greenhouse gas emissions compared with standard asphalt mixtures, primarily due to lower production temperatures and reduced consumption of natural raw materials. According to Androjić et al. [12], it is evident that reducing the moisture content in the mineral mixture results in a reduction in energy consumption by 36.3% (winter period) or by 38.5% (summer period). Research has examined the feasibility of preheating stone aggregate, which can reduce the required heating and drying time in the rotary drum and lower costs. The study of the thermal potential of exhaust gases and their return to the production process with the aim of reducing the moisture content of aggregates was conducted by the authors Cimbola and Dolaček-Alduk [13]. By using exhaust gases from the chimneys and redirecting and reusing them, it is possible to reduce energy costs in the production of asphalt mixtures and thus the amount of CO_2 released into the atmosphere. The paper highlights the idea of implementing a belt dryer in which the stone material would lose some of its moisture over a set period as it moves along the conveyor belt. The authors Dolaček-Alduk et al. [14] found that higher air-flow rates led to greater moisture loss. Increasing the inlet temperature during the pre-drying process reduces the aggregate's natural moisture content while simultaneously heating it. It was found that the drying time in the belt dryer affects the reduction in the aggregate's moisture content, thereby conserving energy for drying and heating. Research studies on warm mix asphalt (WMA) are conducted in various directions: from investigating the impact of aggregate moisture and energy saving possibilities [15], the amount of exhaust gas emissions and CO_2 [16, 17], improvements in implementation technologies [18], and the environmental and economic perspectives of warm mix asphalt [19, 20]. In the work of Cimbola et al. [21], the state of Croatian asphalt plants was analyzed, and it was determined that technical and technological innovations are still not used in certain segments of energy conversion and use. The moisture content of aggregates and the lack of regulated and covered storage facilities with minimal slope are problems in almost all asphalt plants in the Republic of Croatia.

3 Experimental research

Introductory part of the paper highlights the possibility of using the thermal potential of exhaust gases to reduce the moisture content of aggregates in the production of asphalt mixtures. One of the possible solutions considered in this paper is the process of pre-drying aggregates with hot exhaust gases in a so-called belt dryer. The dryer can be placed on an inclined endless belt in front of the rotary drum for drying aggregates. The inclined endless belt collects all stone fractions that are dosed via a pre-doser. To determine the influence of temperature and air flow speed, and drying time on the reduction of aggregate moisture, a laboratory model of the dryer was designed and built (figure 1).

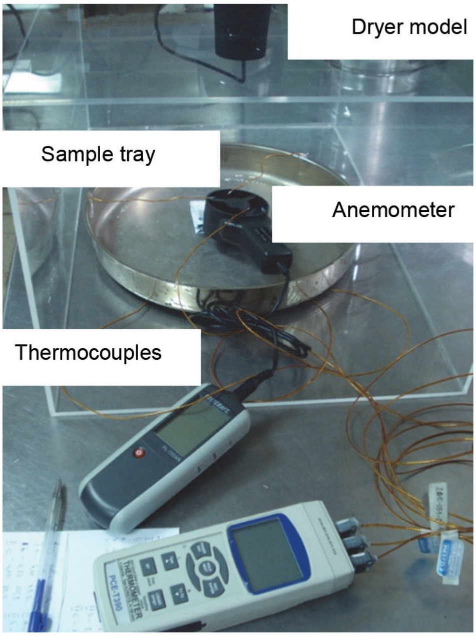

Figure 1 Laboratory model of dryer (Source: authors)

Moisture loss tests were conducted on the 0/11 fraction RA in relation to its natural moisture content. The tests were conducted in the premises of the Motičnjak laboratory of the company COLAS Hrvatska d.d. in Varaždin. Samples of reclaimed asphalt were taken from an uncovered landfill in the storage area of the Motičnjak asphalt plant of the company COLAS Hrvatska d.d. in Varaždin. The test samples were sampled on the same day from the same landfill. The 0/11 RA samples were delivered to the laboratory with a natural moisture content of 5.09% at the time of sampling. The laboratory tests were conducted to determine the percentage reduction in moisture relative to the fraction's natural moisture content (5.09%). The determination of material moisture content is defined in HRN EN 1097-5:2008, Tests for mechanical and physical properties of aggregates - Part 5: Determination of the water content by drying in a ventilated oven [22]. Samples of the 0/11 fraction RA, approximately the same mass, were taken from different locations at different levels throughout the landfill. When choosing the place and number of individual samples, the way the landfill was formed (shape) and the possibility of segregation were considered. To enable sampling from inside the landfill, a loader was used that sampled RA from the formed landfill in a certain number of operations, after which individual samples were taken with a shovel from randomly selected locations according to the HRN EN 932-1:2003 Tests for general properties of aggregates - Part 1: Methods for sampling [23]. For the purpose of testing aggregate reduction, a laboratory model of a belt dryer (chamber with a lid) was designed and built (figure 1). During drying, the airflow speed can be controlled from 3.86 m/s to 6.32 m/s, and the temperature can be set from 33°C to 110°C.

4 Results

For defined temperatures (33.1 to 94.0°C), drying times (30, 45, and 90 s), and different air flow rates (3.86, 4.53, and 5.94 m/s), the results of the moisture loss of fraction 0/11 RA were obtained. The reduced moisture values were compared with the fraction's natural moisture, which was 5.09%. The results of the moisture loss due to different durations, drying temperature, and air flow rate for the reclaimed asphalt fraction 0/11 are shown in figure 2.

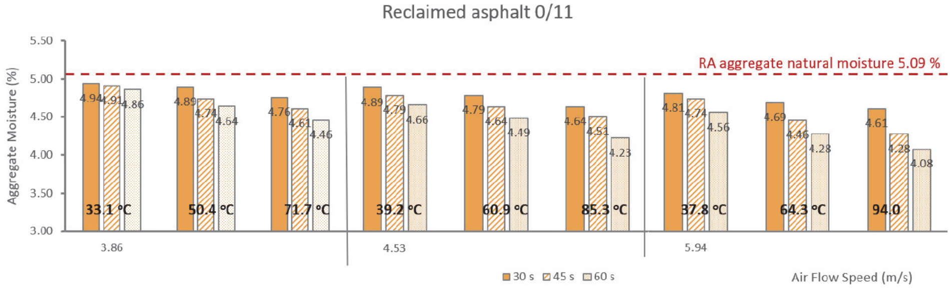

Figure 2 Reduced humidity values of reclaimed asphalt 0/11 for different temperatures, drying times, and different air flow speeds

It is observed that the moisture content of fraction 0/11 RA ranges from 4.46% to 4.94% for a speed of 3.86 m/ s; 4.23% to 4.63% for a speed of 4.53 m/s, and 4.08% to 4.81% for a speed of 5.94%. As expected, the same trend of behavior is observed for all drying times, from 30 to 60 seconds, regardless of temperature or drying speed - with longer drying time, moisture loss is more intense. The overall results of the percentage of moisture reduction compared to natural humidity are shown in table 1. If the results obtained for the speed of 3.86 m/s and the temperature of 33.1°C are analyzed, it is observed that the percentage of moisture reduction compared to natural humidity is higher for the time of 45 s (-3.9%), i.e., 60 s (-6.5%), compared to the time of 30 s (-2.9%). The percentage reduction in moisture for all analyzed drying speeds and temperatures is similar.

Table 1 Percentage of moisture reduction compared to the natural moisture content of the reclaimed asphalt 0/11 (5.09%)

Air flow speed	Drying temperature	Drying time	Reduction in relation to natural moisture	Air flow speed	Drying temperature	Drying time	Reduction in relation to natural moisture	Air flow speed	Drying temperature	Drying time	Reduction in relation to natural moisture
[m/s]	[°C]	[s]	[%]	[m/s]	[°C]	[s]	[%]	[m/s]	[°C]	[s]	[%]
3.86	33.1	30	-2.95	4.53	39.2	30	-3.93	5.94	37.8	30	-5.50
		45	-3.93			45	-5.89			45	-7.86
		60	-6.48			60	-8.84			60	-9.43
	50.4	30	-3.54		60.9	30	-5.89		64.3	30	-6.88
		45	-6.88			45	-8.84			45	-12.38
		60	-9.43			60	-11.39			60	-15.91
	71.7	30	-4.52		85.3	30	-8.45		94.0	30	-10.41
		45	-8.84			45	-11.79			45	-15.91
		60	-12.38			60	-16.90			60	-19.84

5 Conclusion

In this study, the aim was to determine the influence of different drying parameters on the moisture loss of reclaimed asphalt used in the production of asphalt mixtures. The drying parameters that were analyzed and observed in different combinations were: air flow rate, drying temperature, and aggregate drying time. Based on the results obtained, the following conclusions can be drawn:

- The moisture loss of the fractions is lower at a lower air flow speed (3.86 m/s) than at higher speeds, while the highest aggregate moisture loss was observed at an air flow speed of 5.94 m/s.
- The drying temperature directly affects the reduction of aggregate moisture; the higher it is, the more significant the moisture loss during aggregate drying. If the aggregate is exposed to higher temperatures for a longer period of time, it loses its moisture content more quickly and also assumes a certain temperature gradient, which means that it has a higher initial temperature before the start of drying in the rotary drum.
- For all drying times, regardless of the temperature or speed of drying, it is noticed that as the drying time increases, aggregate moisture is lost more intensively.

Significant results were obtained at a drying temperature of 94°C, where the humidity was reduced by as much as 19.84%. On several occasions, the possibility of using RA in the production of asphalt mixtures was prevented or reduced due to excessive humidity. Depending on the asphalt plant's design, it is possible to use the exhaust-gas temperature to pre-dry the aggregate at different locations. Exhaust gas temperatures range from 105-220°C, which depends on a number of factors. Given the increasingly stringent energy-saving requirements, asphalt mixture manufacturers are forced to systematically invest in new technologies and apply new knowledge in the use of existing resources and energy. Energy consumption increases when producing asphalt mixtures with RA, and the principle of utilizing waste heat energy results in sustainable production, reducing the consumption of energy sources for drying and heating the aggregate in the rotary drum while using existing aggregates. With proper storage of RA as well as other aggregates and with the proposed pre-drying process of aggregates, a multiple energy, ecological, and economic contribution is achieved.

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