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Research Paper

Usage of solar aggregate stockpiles in the production of hot mix asphalt

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HIGHLIGHTS

- Low energy storage mineral mixtures.
- The impact of models thermal insulation on the temperature of aggregate.
- Effect of periods with no solar radiation on the aggregate accumulated heat.
- Low energy storage saves energy for preheating mineral mixtures.

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ABSTRACT

The production process of hot mix asphalt (HMA) requires a considerable demand for thermal energy which is fed into the process of drying and heating of mineral mixture. An overview of solar aggregate stockpiles designed in order to reduce energy consumption is given. Solar stockpiles were designed with the primary goal of achieving as much accumulation of thermal energy obtained from solar radiation as possible during the exposure period. Models of solar stockpiles were made with a constant volume capacity, variable thermal insulation thickness in the range of 2, 5 and 10 cm, and a glass ceiling surface to allow the realisation of high solar transmission into the interior of a stockpile. Temperature measurement of the mineral mixture deposited in the solar models and of those exposed to external environmental conditions was conducted during the period from May to November, 2015. The results achieved indicate to the facts that there comes to the constant growth in warmth of mineral mixtures in insulated stockpiles for the duration of their exposure to solar radiation, that an increase in thermal insulation thickness leads to the quadratic functional dependence between the referred thickness and mixture temperature and, ultimately, that there comes to the exponential loss of an accumulated thermal energy in insulated models in the period with no effect of solar radiation.

1. Introduction

Hot mix asphalt contains (HMA) a stone mixture with a weight ratio of over 90% stone dust, bitumen as a binding agent and possibly some additions. HMA production is performed at plants in continuous or cyclic work mode regimes. According to the European Asphalt Pavement Association (EAPA, 2013), an average production of warm and hot mix asphalt in the European Union, consisting of 28 Member States, for the period of 2008–2013 amounted to 307.1 million tons, ranging from 276.4 to 338 million tons [1]. According to the same source, the average production in the United States of America for the same period amounted to 344.5 million tons. The production range was slightly higher than in the European Union (including Russia), ranging from 318.1 to 440 million tons of asphalt [1]. The average power consumption in the production of 1 t of hot mix asphalt amounts to 85 kW h [2,3], which is a significant amount when considering the total volume of the world's production of asphalt mixtures. According to Jullien et al. [4], HMA production consumes up to 97% of the total energy demand in the process of drying and heating of the mineral mixture in a rotating drum [4]. Currently, the reduction of energy consumption is one of the primary objectives of EU countries, with the aim of reducing annual energy consumption by 20% by 2020 [5].

According to previous studies, energy consumption in a rotary drum is significantly affected by the moisture in the mineral mixture (Table 1) [6–9], work continuity [10], and the temperature of the produced asphalt [11–19]. The authors [11–19], in their studies, come to a conclusion that the usage of warm mix asphalt results in reduced emissions, reduced laydown and production temperatures, lower energy costs, reduced age hardening response

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Table 1
Energy requirements in the removal of moisture.

Explanation	Authors	Savings
Reducing the moisture content for 3%	Ang et al. (1993)	55–60%
Reduction in the moisture content for 2%	Jenny (2009)	Savings in fuel consumption for 1.5 kg/t of asphalt mixture
Initial moisture content of 6%	Grabowski and Janowski (2010)	4 L of fuel are needed to dry 1 t of mineral mixture
Removing 1% of moisture	Peinado et al.	8.21 kW h

of mix and other. The occurrence of moisture in the mineral mixture is due to its exposure to the same external weather conditions as well as to the technological process of production. Table 1 shows the energy requirements in the process of removing moisture from mineral mixtures according to certain authors.

Assuming that the average moisture in the mineral mixture amounts to 4%, it can be concluded that it is necessary to invest 3 kg of fuel or more than 30 kW h of energy per ton of asphalt mix for its removal. In addition to the moisture of the mineral mixture, which has a decisive impact on the energy demand, the production process is also affected by the temperature from which and to which the mixture is heated. The current work regime of existing asphalt plants entails the reduced utilisation of production capacities, substantial energy consumption caused by the oscillator production of asphalt mixtures and the use of stone fractions, which are exposed to external influences. The lowest energy consumption is achieved in the periods of high air temperatures and low precipitation. This is the period in which the need for heating a mineral mixture to the projected temperature is the lowest. In colder time periods, it is necessary to invest more thermal energy to heat the mineral mixture to the required temperature for the production of hot mix asphalt. Based upon studies so far, it has been evident that energy consumption in the HMA production is most affected by the depositing conditions of mineral mixture which is present over 90% in the asphalt mix. The depositing conditions are directly related to the external weather conditions, thus affecting the input temperature and moisture in mineral mixture. These findings prompted the realisation of depositing the mineral mixture with the aim of

- accumulating higher quantities of solar thermal energy during the exposure period;

and reducing losses of accumulated thermal energy to the surroundings during the period of decreasing ambient temperature. To achieve the set requirements, the conducted studies analysed the possible use of passive solar stockpiles for meeting the industrial needs of storing mineral mixtures.

1.1. Passive and other energy buildings

Solar energy spreads into space in the form of light and thermal energy, and only its small portion reaches the soil. The amount of such radiated energy is determined by sunlight intensity, as well as by the length of sunshine period over the year. On a sunny day, solar energy to the amount of 1000 W on average reaches each 1 m^2 of the soil sunlit surface, whereas on the territory of the Republic of Croatia the referred radiation amounts to 1200–1600 kW h/m^2 on a yearly basis [20]. The basic principle of the passive exploitation of solar energy refers to the exposure of a building to solar radiation where, in periods of reduced radiation, energy loss to the surroundings should be prevented. Thermal energy accumulation is the capacity of a construction material to absorb the released energy, accumulate it, and release it back to the environment when this cools down. The thermal energy amount which construction material is able to accumulate per unit area, for the unit difference between the incoming and outgoing air temperature and after the stationary condition has been reached, shall be calculated by the following equation [21]:

$$W = U[d_1G_1c_1(1/\alpha_e + d_1/2\lambda_1) + d_2G_2c_2(1/\alpha_e + d_1/\lambda_1 + d_2/2\lambda_2) + \cdots d_nG_nc_n(1/\alpha_e + d_1/\lambda_1 + d_2/\lambda_2 \cdots + d_n/2\lambda_n)]\ (\text{kJ/m}^2\text{K}), \quad (1)$$

where W is heat accumulation coefficient (kJ/m^2 K), U is the overall heat transfer coefficient (W/m^2 K), $\propto$ is heat convection coefficient (W/m^2 K), d is thickness of a particular element (m), G is specific weight (kg/m^3), c is specific heat capacity (J/kg K), and λ is thermal conductivity coefficient (W/m K). The experiences of building low-energy and nearly zero-energy residential houses and low-energy office buildings are described in many publications [22–26]. In booklet from the IEE project NorthPas present examples of Very Low-Energy Houses in Denmark, Finland, Norway, Sweden, Estonia, Latvia, Lithuania and Poland. Vladykova et al. (2012) presents the experience gained from a low-energy house in Sisimiut, Greenland, over the 5 years of operation since its inauguration in April 2005. In 2010 the annual energy consumption for heating the house was 90 kW h/m^2. Flodberg et al. (2012) presented few examples of low-energy office buildings in Sweden. Mlecnik (2012) and Torcellini et al. (2006) in their papers examine what nearly zero-energy terms can be expected to be adopted in Belgium and the Netherlands. At the moment, the basic elements of passive and other low-energy buildings are not used to improve the storing quality of the mineral mixture in the industrial production of hot mix asphalt. Storage is performed by applying simple measures, such as covering and arranging the surfaces of aggregate stockpiles. Many studies suggest that it is necessary to strive to reduce the moisture content in the mixture during its storage, deposit the mixture on covered and arranged surfaces, as this improves the quality of the produced asphalt, and reduce energy consumption [27–32]. Among others, Thijsssen et al. (2011) states that considerable time is required to reduce the moisture content from 7% to approximately 4.5% (approximately sixty days) for recycled asphalt with maximum grain sizes of 3.5 and 10.5 mm [33].

1.2. Research goals

The aim of the research was to determine the effect of storage conditions of mineral mixture on the temperature of deposited mineral mixture. The research was conducted during the period from May to November, 2015, when mineral mixture was deposited into the storage models with a thermally insulated external shell of different thermal insulation thickness, as well as in an uninsulated, external storage area. The following factors were examined by the research:

- to what extent thermal insulation thickness of the covered and thermally insulated area for storing mineral mixture affects the temperature of deposited mineral mixture;
- how much amounts the loss of an accumulated thermal energy from a covered, thermally insulated storage area in the period when there is no effect of solar radiation;