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STUDY CONCERNING THE FORMING OF ASPHALT CRUST DURING TRANSPORT

BY

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Abstract. The study concerning the cooling process of the asphalt, during the transport was realised to analyse the evolution of temperature field at the surface and inside the mass of asphalt during the transportation from the production site to the commissioning site. The study is important because the quality of asphalt pavement and compaction are dramatically affected if crust is formed during transport. The study was conducted by mathematical modelling and is covering a real case situation of asphalt transport with forming of crust.

Key words: asphalt; cooling; transport; modelling.

1. Introduction

Hot mixed asphalt (***HMA***) is used at the construction of more than 90% of the USA roads (Bode, 2012).

Generally, the pavements realised with ***HMA*** are conceived for duration of minimum 15 years or more. Despite this, several times this objective is not achieved due to cracks, graves, local disaggregation and other problems (Phillips, 2008; Bode, 2012).

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In many researches realised by thermography by the universities and by others, it was shown that excessive temperature variation during the construction of pavements are contributing to the forming of areas with different density. This phenomenon is due to the forming of areas with cold material surrounded by areas with higher temperature material (Chadbourn et al., 1996; Willoughby, 2003; Amirkhanian & Putman, 2006; Mathew & Rao, 2006; Song *et al*., 2009; Bode, 2012).

The main cause of forming areas with cold material surrounded by areas with higher temperature material is considered to be the cooling of peripheral surfaces of ***HMA*** during transportation from the manufacturing place to the yard (Bode, 2012).

During transport ***HMA*** are undergoing a process of fast cooling of lateral surfaces. When the material is unloaded (often it is not carefully remix) areas with different behaviour at compacting appear due to different temperatures of asphalt. The rule is that areas with cold material and low density appear currently and repetitive during the casting of asphalt (Bode, 2012).

A study realised at the University of Washington, provide that areas of HMA, colder with 4°C than the rest of the material, presents lower densities after compacting. The same study shows that if asphalt temperature decreases under 80°C it becomes rigid and resistant at compaction so that in those areas results low densities and the material is become subject to premature failure (Willoughby, 2003).

It was also observed. Taking into account the phenomenon of cold crust forming during long time transport and its impact on the asphalt casted on the road, the study by numerical simulation of the behaviour of asphalt during transport is justified.

The goal of this study is to analyse and evaluate the variation of temperature field inside the asphalt during transportation.

2. Material and Method

The study was realised by 3D and 2D numerical simulation in transitory regime.

The initial temperature of asphalt was considered of 175°C, with uniform distribution in the mass of asphalt.

The ambient temperature was considered constant at 28°C.

It was considered two stages of transportation according to an investigated real case scenario, part of a non-disclosure agreement:

− The first stage with 60 km/h for 70 min;

− The second stage with 10 km/h for 30 min.

It was considered that inside the mass of asphalt the heat transfer is realised through conduction and from the asphalt to the ambient the heat transfer is realised through convection and radiation, through the lateral sides of the dump truck and through the surface covered with a tarp.

The heat transfer coefficient for the surrounding sides of the dump truck was calculated in function of the ride speed, being different in the two stages of transport.

For the coefficient of convection (α) corresponding to the lateral sides and to the back, function of the air speed (w), it was used the formula:

$$\alpha = 3.1 + 4.1 \cdot w \tag{1}$$

Thus it was determined the values:

$\alpha_{60km/h} = 71.43$ W/m^{2}K; $\alpha_{10km/h} = 14.49$ W/m^{2}K

For the surface of the dump truck, facing the back of the cabin, the coefficient of convection was decreased by 50% comparing to the coefficient corresponding to the lateral sides:

$\alpha_{60km/h} = 35.72$ W/m^{2}K; $\alpha_{10km/h} = 7.24$ W/m^{2}K

For the coefficient of convection corresponding to the bottom side was determined the values:

$\alpha_{60km/h} = 57.15$ W/m^{2}K; $\alpha_{10km/h} = 11.59$ W/m^{2}K

It was considered that the presence of the tarp over the asphalt on the upper side is reducing the coefficient of convection by 15% leading to the values:

$\alpha_{60km/h} = 60.72$ W/m^{2}K; $\alpha_{10km/h} = 12.32$ W/m^{2}K

The geometry of the transportation dump truck was considered a simplification of the real geometry. The isometric view of the asphalt mass inside the dump truck is presented in Fig. 1.

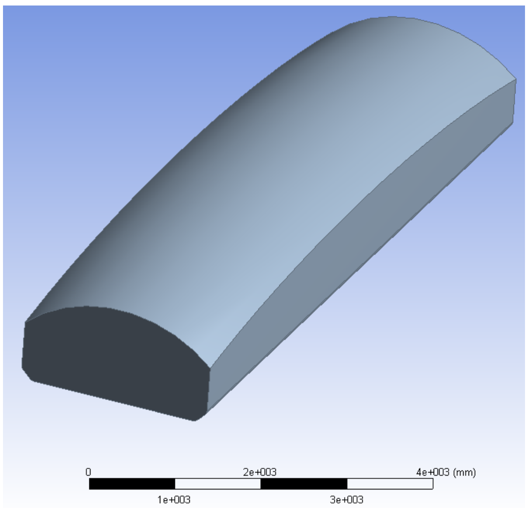

Fig. 1 − The isometric view of the asphalt mass inside the dump truck.

It was considered the following values for the material properties of ***HMA***: density of 2300 kg/m^3 and specific heat of 920 J/kgK.

In the 3D simulation it was studied the influence of thermal conductivity on the cooling process. It was considered two values for the thermal conductivity: (0.75 and 1.5) W/mK, corresponding to different types of asphalt.

In the 2D simulation it was considered only the value of 0.75 W/mK for the thermal conductivity of asphalt.

For the steel of the dump truck was considered the following material properties: density of 8030 kg/m^3, specific heat of 502.48 J/kgK and thermal conductivity of 16.27 W/mK.

A numerical grid of 3.023 million hexahedral elements was generated for the analysed interest domain, to capture with accuracy the asphalt temperature variation. An isometric view of the mesh for the 3D simulation is presented in Fig. 2.

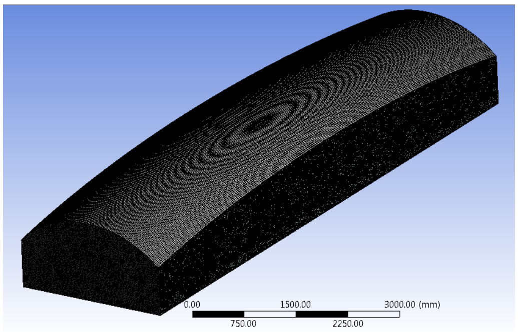

Fig. 2 − The isometric view of the mesh for the 3D simulation.

In the 3D simulation the influence of the dump truck is neglected.

For the 2D simulation the geometry was considered with 300000 elements corresponding to a single plan. A mesh detail of the 2D simulation is presented in Fig. 3.

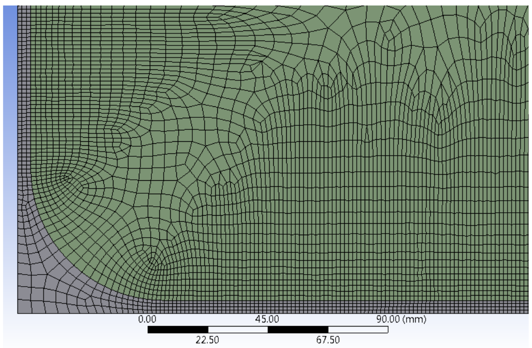

Fig. 3 − Mesh detail of the 2D simulation.

On Fig. 3 can be observed mesh elements from both the dump truck and the mass of asphalt.

For the continuous monitoring of the temperature, it was considered 6 points in which the temperature was recorded during the 3D simulation and 4 points in which the temperature was recorded during the 2D simulation.

The temperature monitoring in the 3D simulation points were considered:

1. At 0.7 cm from the asphalt surface;
2. At 12 cm from the asphalt surface;
3. At 22 cm from the asphalt surface;
4. At 37 cm from the asphalt surface;
5. At 57 cm from the asphalt surface;
6. At 78 cm from the asphalt surface.

The placement of the temperature monitoring points in the mass of asphalt is presented in isometric view and in sections view in Figs. 4-7.

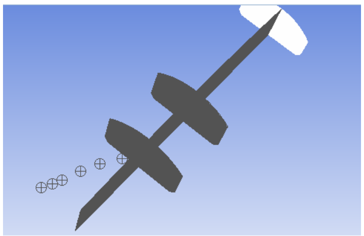

Fig. 4 – Monitoring points. Isometric view.

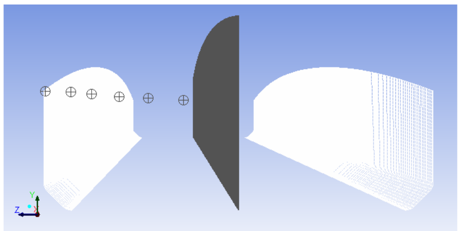

Fig. 5 – Monitoring points. View Y-Z.

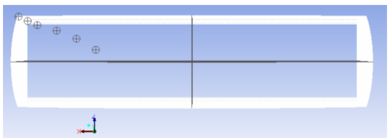

Fig. 6 – Monitoring points. View X-Y.

Fig. 7 – Monitoring points. View Y-Z.

It was also considered two directions for the representation of final temperature distribution, at the end of transport.

The first direction was considered a "*diagonal*" from a corner through the middle of the asphalt mass. This first direction was named "*diagonal*".

The second direction was considered "*normal*" to the asphalt mass from the centre of the outside surface to the middle of the asphalt mass. This first direction was named "*normal*".

The temperature monitoring in the 2D simulation points were considered:

1. At 1 cm from the steel wall of the dump truck;
2. At 5 cm from the steel wall of the dump truck;
3. At 10 cm from the steel wall of the dump truck;
4. At 25 cm from the steel wall of the dump truck.

3. Results and Discussion

3.1. Results of 3D Simulation

The initial temperature distribution in the mass of asphalt (175°C) is presented in Fig. 8.

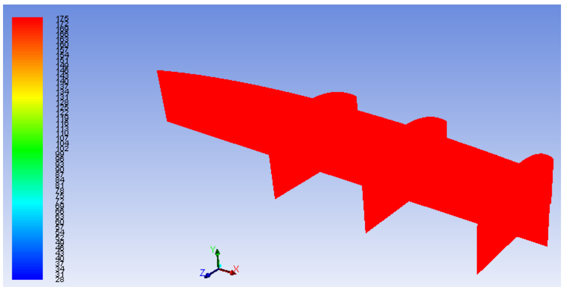

Fig. 8 − Initial temperature distribution in the mass of asphalt (175°C).

The temperature distribution in the mass of asphalt after 70 min of transport with 60 km/h, considering the two values of asphalt conductivity, is presented in corresponding Figs. 9 and 10.

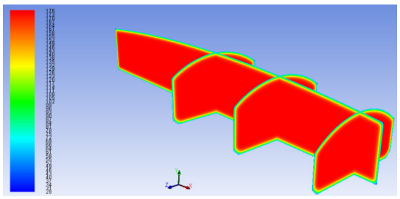

Fig. 9 − Temperature distrib. after 70 min (60 km/h; 0.75 W/mK).

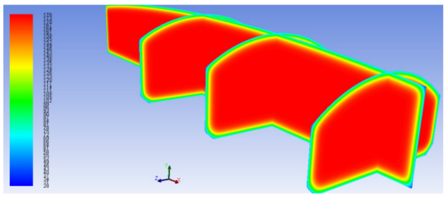

Fig. 10 − Temperature distrib. after 70 min (60 km/h; 1.5 W/mK).

Details of temperature distribution in the mass of asphalt after 100 min of transport (70 min with 60 km/h and 30 min with 10 km/h), considering the two values of asphalt conductivity, is presented in corresponding Figs. 11 and 12.

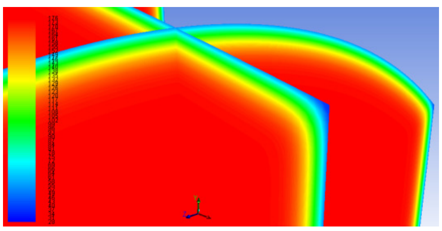

Fig. 11 − Detail of temperature distrib. after 100 min (60 km/h + 10 km/h; 0.75 W/mK).

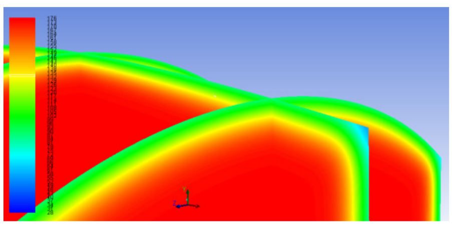

Fig. 12 − Detail of temperature distrib. after 100 min (60 km/h + 10 km/h; 1.5 W/mK).

The temperature variations in the monitoring point (1), at 0.7 cm from the asphalt surface, with both conductivities are presented in Figs. 13 and 14.

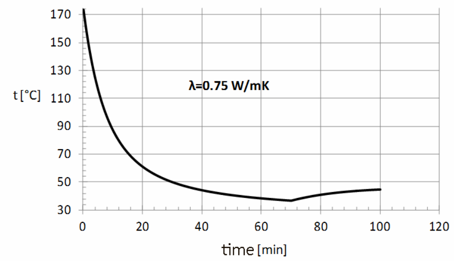

Fig. 13 − Temperature variation in time at 0.7 cm from the surface (0.75 W/mK).

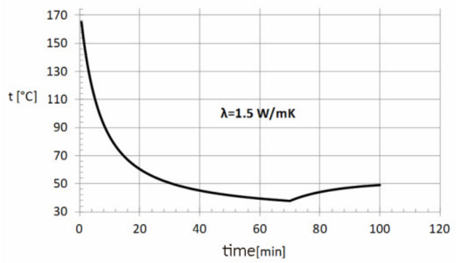

Fig. 14 − Temperature variation in time at 0.7 cm from the surface (1.5 W/mK).

It can be observed that during the low speed stage of transport, for the corresponding period of 30 min in the monitoring point (1 – near surface) the asphalt temperature begin to increase due to the decrease of the heat transfer intensity between the asphalt and the ambient near the surface and due to the constant heat transmitted through conduction from the middle zone.

In the situation in which the asphalt conductivity was considered higher, in the monitoring point (1 – near surface) the final temperature is higher with ≈5°C than if the asphalt conductivity was considered lower.

The temperature variations in time in the monitoring point (2) at 12 cm from the asphalt surface, with both conductivities are presented in Figs. 15 and 16.

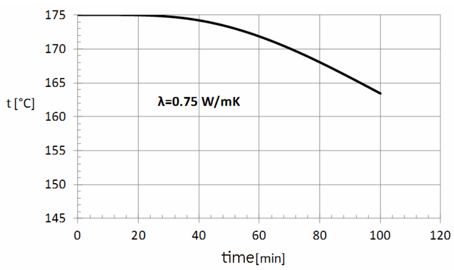

Fig. 15 − Temperature variation in time at 12 cm from the surface (0.75 W/mK).

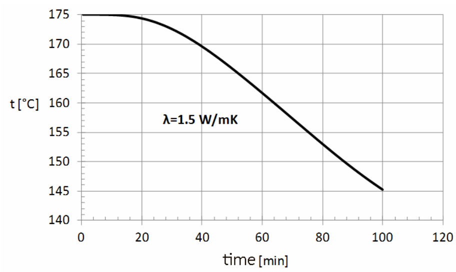

Fig. 16 − Temperature variation in time at 12 cm from the surface (1.5 W/mK).

In the monitoring point (2) at 12 cm from the surface, the temperature increase during the low speed phase of transport is no longer observed.

In the situation in which the asphalt conductivity was considered higher, in the monitoring point (2) at 12 cm from the surface, the final temperature is lower with ≈18°C than if the asphalt conductivity was considered lower.

The temperature variations in the monitoring point (4) at 37 cm from the asphalt surface, with both conductivities are presented in Figs. 17 and 18.

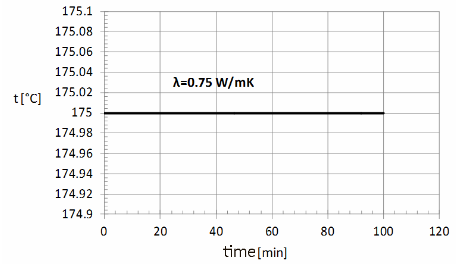

Fig. 17 – Temperature variation in time at 37 cm from surface (0.75 W/mK).

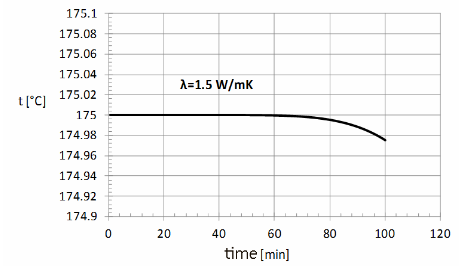

Fig. 18 – Temperature variation in time at 37 cm from surface (1.5 W/mK).

In the monitoring point (4) at 37 cm from the surface, the temperature remains constant in the situation with the lower value of the asphalt conductivity and decrease with only ≈1°C in the situation with the higher value of the asphalt conductivity.

It is obvious that this point is located outside the crust zone.

The temperatures in the monitoring points (5) and (6) situated far from the surface maintained constant during the whole simulation period.

The final temperature distribution after the considered "*diagonal*" direction is presented in Figs. 19 and 20 and after the considered "*normal*" direction is presented in Figs. 21 and 22.

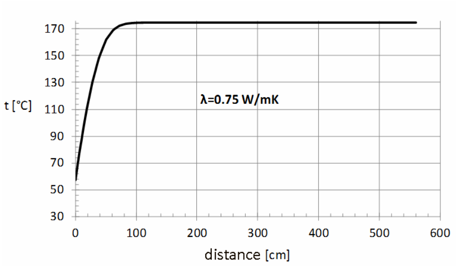

Fig. 19 – Final temperature distrib. by the "*diagonal*" direction (0.75 W/mK).

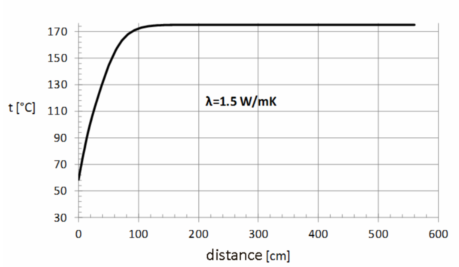

Fig. 20 – Final temperature distrib. by the "*diagonal*" direction (1.5 W/mK).

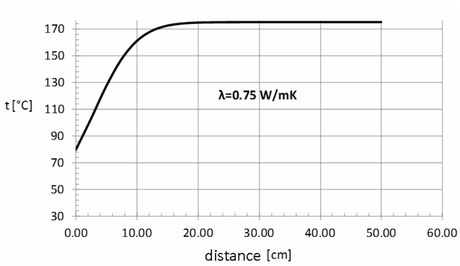

Fig. 21 – Final temperature distrib. by the "*normal*" direction (0.75 W/mK).

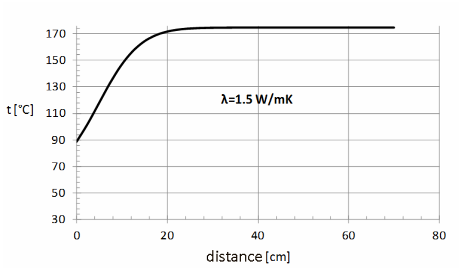

Fig. 22 – Final temperature distrib. by the "*normal*" direction (1.5 W/mK).

The temperature at the surface resulted lower when asphalt conductivity was considered lower, than when it was considered higher.

The width of the area where the temperature variation can be observed (the crust width) resulted higher when asphalt conductivity was considered lower, than when it was considered higher.

The average value of the asphalt mass temperature resulted 174°C with higher asphalt conductivity and 175°C with lower asphalt conductivity.

The average value of the asphalt surface temperature resulted 87°C with higher asphalt conductivity and 79°C with lower asphalt conductivity.

3.2. Results of 2D Simulation

The temperature distribution after 100 min, at the end of the 2D simulation in the considered plan is presented in Fig. 23.

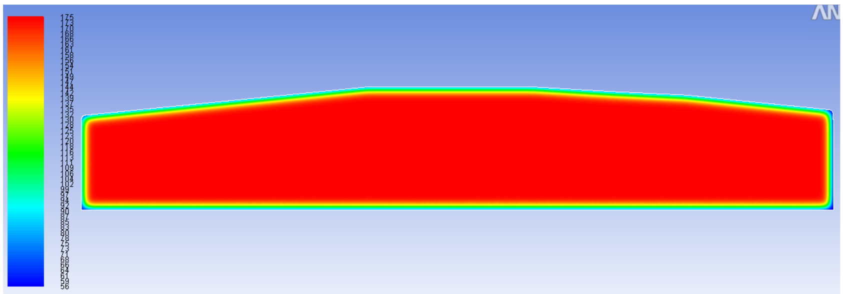

Fig. 23 – The temperature distribution at the end of the 2D simulation [°C].

The crust formation is visible after the 2D simulation, just as after the 3D simulation.

The temperature variations in time in the monitoring points are presented in Figs. 24 - 27.

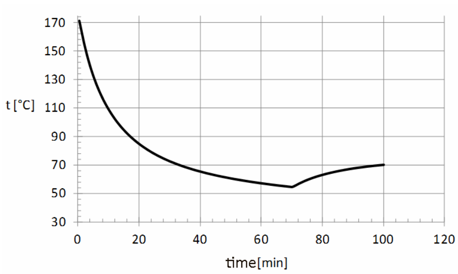

Fig. 24 – Temperature variation at 1 cm from surface.

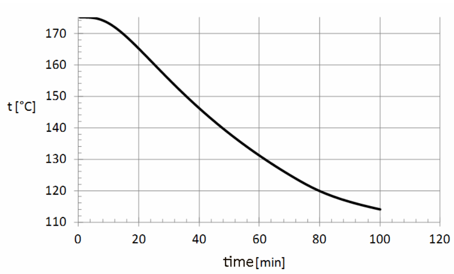

Fig. 25 – Temperature variation at 5 cm from surface.

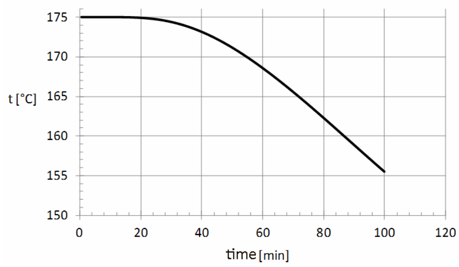

Fig. 26 − Temperature variation at 10 cm from surface.

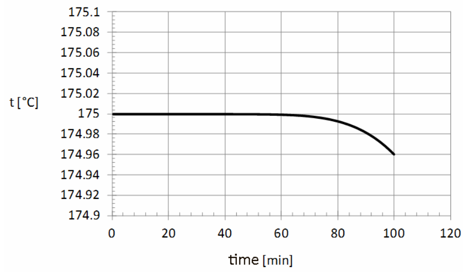

Fig. 27 − Temperature variation at 25 cm from surface.

At 1 cm from the dump truck it can be observed the temperature increase in the low speed phase of transport do to the decreasing of convection intensity that determines the asphalt cooling.

At 5 cm from the dump truck, temperature increase is no longer observed.

At 10 cm from the dump truck, the temperature variation is much lower than at 5 cm from the dump truck.

At 5 cm from the dump truck, the temperature is almost constant, with a variation of ≈0.04°C.

The temperature distribution at the end of the simulation on the "*normal*" direction from the centre of the asphalt surface through the middle of the asphalt mass is presented in Fig. 28.

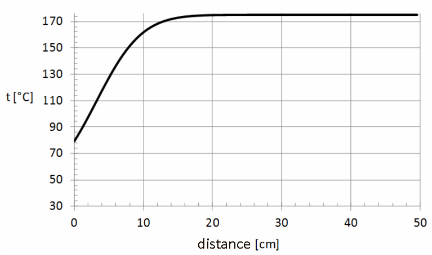

Fig. 28 − Temperature distribution at the end of simulation on "*normal*" direction.

By comparing the temperature distributions on the "normal" direction, obtained by 3D simulation and by 2D simulation, it can be observed almost complete similarity, meaning that the influence of the dump truck can be neglected.

4. Conclusions

The results obtained by both 3D and 2D simulations lead to the following conclusions:

− During the transport a cold crust is forming in the peripheral zones of the dump truck, in agreement with practical observation and with the literature;

− The results obtained by 3D and 2D simulation are in very good agreement between each other;

− The results of the simulations confirm that the influence of the bin on the cooling process of the asphalt can be neglected;

− The results of the simulation are presented both in time and in space, in several representative monitoring points;

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STUDIU PRIVIND FORMAREA CRUSTEI ASFALTULUI
ÎN TIMPUL TRANSPORTULUI

(Rezumat)

Studiul se referă la procesul de răcire a asfaltului în timpul transportului de la locul de fabricaţie la şantier şi a fost realizat pentru a analiza evoluţia câmpului de temperaturi în timp şi spaţiu, la suprafaţa şi în interiorul masei de asfalt.

Studiul este important deoarece calitatea stratului de asfalt şi gradul de compactare care asigură durabilitatea, sunt puternic afectate de crusta formată în timpul transportului.

Studiul a fost realizat prin modelare matematică 3D şi 2D, referindu-se la o situaţie reală de răcire a asfaltului în timpul transportului, cu formarea de crustă.

Rezultatele obţinute sunt în concordanţă atât între ele, cât şi cu observaţiile practice şi cu literatura de specialitate.