Bitumen sheet load by solar radiation

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Resumo

Este trabalho apresenta a influência da radiação solar na temperatura das superfícies de placas de concreto e sua incidência nos pecas de concreto adjacentes em uma coberta. Um dos maiores efeitos da radiação solar se reflete na durabilidade e vida útil de placas de concreto em estruturas de coberta. Embora protegidas com camadas de impermeabilização essas estruturas são submetidas aos efeitos cíclicos e aleatórios da variação da temperatura e ação radiação ultra-violeta.

Palavras-chave: *Placas de concreto. Radiação solar.*

Abstract

This article deals with solar radiation influence on temperature of top surface of bitumen sheet which incidence on adjacent bitumen sheet laps in regular roof area. One of the major effect influencing durability and lifespan of bitumen sheets on roof structures is solar radiation which loads waterproofing layer cyclically and randomly with variation of temperature. UV radiation is although responsible for bitumen sheet aging.

Keywords: *Solar radiation. Bitumen sheet.*

1 Introduction

Factors influencing bitumen sheet durability

Initial bitumen sheet straining occurs already during manufacturing and installation on roof (primary effects):

• strain is carried into enclosure during manufacturing

• differences in stress are defined also by laying method (laid loose and mechanically anchored or loaded with stabilizing layer, solid or non-solid fusing)

After waterproofing layer is installed bitumen sheets are stressed by various external effects (secondary effects). These loads are caused by:

• wind (suction)

• air and light (oxidation changes and subsequent bitumen mixture aging)

• UV spectrum of solar radiation

• temperature (roof deck temperature mode – different thermal stress of roof deck influenced by external climatic factors)

• cyclic bitumen sheet stress by temperature (day-night temperature deviation)

• temperature jumps (extreme temperature deviation)

• water (build in, condesated or rainfall)

Other effects influencing waterproofing membrane from bitumen sheets are:

• material configuration in roof deck (layer sequence eventually sheet protection)

• under layer type (various under layer thermal technical characteristics)

• sheet coating

Influence of bitumen sheet colour and it's under layer on top surface temperature will be discussed in next part.

Theoretical analysis of solar radiation

Temperature is one of the most important factors influencing bitumen sheet functionality. Temperature of bitumen sheets in roof decks is increasing as a result of solar radiation. Enclosure contraction with bitumen mixture stiffness decrease occurs due to high temperatures along with elongation due to volume changes of enclosure and bitumen mixture while enclosure is already stressed from manufacturing (especially for polymeric enclosures).

Energetic heat flux density of solar radiation in distance of 150 million kilometres (Earth – Sun distance) is approx. 1367 W.m-2. Solar radiation spectral pattern is given by structure and composition of the Sun. Very little amount of thermal energy is transmitted in ultra-violet spectrum of solar radiation – only 8-9%. Significantly larger amount of solar energy – approx. 46-47% - is situated in visible spectrum (350 – 780 nm). Rest of the energy – approx. 45% - from solar radiation is component of shortwave infra-red wave (780 - 5000nm).

Part of solar radiation incidenting on Earth's surface is absorbed by atmosphere. This is approximately 25% of total solar energy. Thermal radiation is absorbed (approx. 300 W.m-2) and dissolved by gas molecules, small air particles, water vapour, aerosols and clouds (100 W.m-2) in atmosphere. Part of the energy is reflected back to the universe (usually it's 20% of energy according to amount and condition of clouds) and the rest is incidenting on Earth's surface. The value of 1,000 W.m-2 is considered as standard heat flux density.

Part of the energy is reflected and the other part is absorbed while solar radiation incidents on Earth's surface and object's surface. Most real surfaces are absorbing 75 – 99% of electromagnetic wave in infra-red spectrum of radiation. Other situation is in visible spectrum of radiation. Reflective attributes of real surfaces are perceived by human eye as a colour which is composed from single components of reflected radiation. This surface colour has big effect in absorption of solar radiation by insolated building structure surfaces.

One of the ways to lower temperature is finish coating of bitumen sheet by spread. Silica sand, ceramic grit and foliaceous flakes are usually used for spread. Experimental measurements were made for acquiring exact numeric values for specific spread type and colour. Goal of this measurements were to prove big temperature deviations originated on sheet cover. Not only colour but also type and particle size of spread is important for solar radiation absorption.

2 Methodology

Modificated bitumen sheet with coarse-grain foliaceous spread (80% in fraction 0.5-2.0 mm) in blue, red, green and grey colour was used for experimental measurements. Black-grey underlining sheet with fine-grained foliaceous spread (80% in fraction 0.18 - 0.63 mm) was measured for comparison.

Sheet specimens 300 x 300 mm were loosely laid on existing flat roof waterproofing from bitumen sheets and exposed directly to solar radiation. The roof construction is regular lean roof with 2° lean to the north insulated with 100 mm of expanded polystyrene.

Measurements took place on roof in Oslavany in Central Europe cca 50° N geographical latitude. Roof is situated according to wind streams in rippled area on single standing building without protection, cca 330 m above sea-level, height of the building is 3,5 m. Protective screen was raised for elimination of wind effect, screen was removed for shading elimination in early morning and evening times. Thus wind effect can be reflected in these measurements. Temperature was measured by non-contact method (IR thermometer MINITEMP, Raytek, accuracy of 0.5 °C)

Emissivity of the thermometer was set to 0.92. Advantage of this method is the fact that thermometer registers IR spectrum of solar radiation in range 7,000 – 12,000 nm. Measurement was not influenced by reflected solar radiation and real temperature of the bitumen sheet was registered while majority of solar energy is emitted in range 300 – 5.000 nm.

Temperature measurement was carried out during warm summer day on 11 of August 2004. Average ambient temperature during the day was + 29.38 °C. Temperature was registered every hour.

3 Measurement results

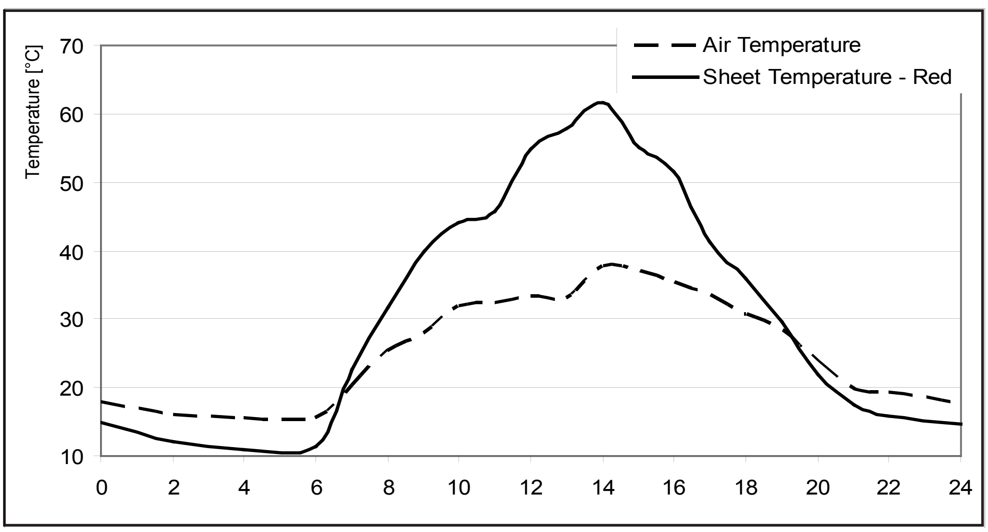
Arithmetic average was calculated of measured temperature is shown in Table 1.

Table 1: Summary of measured top surface temperature values of bitumen sheet during warm summer day in dependence of spread colour.

Spread colour	Maximum	Minimum	Average	Maximum temperature deviation
	[°C]			
Green	57.7	11.1	37.7	46.6
Gray	60.0	11.1	38.3	48.9
Red	61.7	11.1	38.5	50.6
Blue	60.1	11.1	37.5	49.0
Black-grey	63.2	11.1	38.9	52.1

Ranking after average value calculation (descending): red, grey, green and blue. The highest average temperature was recorded on black fine-grained spread.

Maximum temperature was recorded in 14:00 hours – value + 61.7 °C on red surface, maximum deviation of highest temperatures was between red and green colour – value 4.0 °C. Minimum measured temperature was in 04:00 hours – value +11.1 °C on all surfaces. Maximum deviation of minimum temperatures was 0 °C. Temperature gradient during one day was in maximum 52.1 °C on black-grey surface. Surface temperature behaviour on bitumen sheet with red spread colour is in Graph 1.



Graph 1: Surface temperature behaviour on bitumen sheet with red spread colour (0 is equal 24:00)

Influence of under layer on bitumen sheet surface temperature

Next factor influencing temperature of bitumen sheet in roof deck is heat capacity of under layer material. Heat capacity of building materials b ($W^2.s.m^{-4}.K^{-2}$) represents ability of the material with defined moist absorption of heat and is given by calculation formula:

$$b = \lambda \cdot \rho \cdot c \qquad (1)$$

where: λ – heat conductivity coefficient [$W. m^{-1}.K^{-1}$],

c – specific heat capacity [$J.kg^{-1}.K^{-1}$],

ρ – bulk density [$kg.m^{-3}$].

General axiom is that the bigger heat conductivity of under layer is so lower surface temperature of bitumen sheet is.

Two eventualities can occur according to material configuration in roof deck:

a) Bitumen sheet will be applied on load-bearing structure or on layer with high heat capacity (concrete, reinforced concrete, steel)

b) Bitumen sheet will be applied on thermal insulation with low heat capacity which is mainly created by expanded polystyrene, extruded polystyrene, foam polyurethane or mineral wool boards.

Summary of thermal technical characteristics for most commonly used underlayer materials are in Table 2.

Table 2: Summary of thermal technical characteristics for most commonly used underlayer materials.

Material	Heat conductivity coefficient	Specific heat capacity	Bulk density	Heat capacity
	[$W.m^{-1}.K^{-1}$]	[$J.kg^{-1}.K^{-1}$]	[$kg.m^{-3}$]	[$W^2.s.m^{-4}.K^{-2}$]
Expanded polystyrene	0.04	1,270	30	1,524
Mineral fibre	0.044	880	100	3,872
Expanded clay concrete	0.36	900	1,000	324,000
Reinforced concrete	1.46	1,020	2,500	3,723,000
Galvanized sheet metal	58	440	7,850	200,332,000
Copper sheet metal	372	380	8,800	1,243,968,000

Bitumen sheet with bitumen mixture modified with thermoplastic rubber SBS (styren-butadien-styren), thickness 5 mm with coarse-grained foliaceous spread (80% in fraction 0.5-2.0 mm) in grey colour on various under layers was used for experimental measurements. As under layer materials were chosen: concrete, expanded polystyrene (thickness 50 mm), expanded polystyrene (thickness 80 mm) and galvanized steel sheet (thickness 0.6 mm).

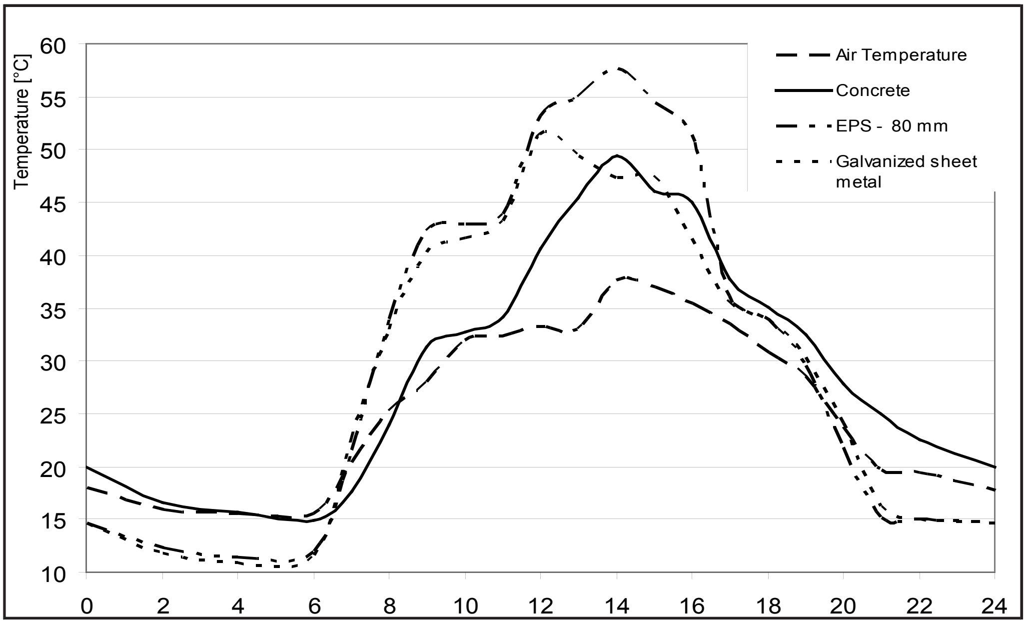
Specimens from bitumen sheet with dimensions 300 x 300 mm were in case of concrete and sheet metal fused to the under layer. Specimens on expanded polystyrene were glued to the under layer with polyurethane glue. Specimens were placed loosely on flat roof while measurement conditions and devices were exactly the same to those used for measurements for influence of spread colour and spread dimensions. Results are in Table 3.

Table 3: Summary of measured top surface temperature values of bitumen sheet during warm summer day in dependence of underlayer.

Underlayer	Maximum	Minimum	Average	Maximum temperature deviation
		[°C]		
Concrete	49.4	14.9	31.1	34.5
Expanded polystyrene (50 mm)	57.3	11.4	32.3	45.9
Expanded polystyrene (80 mm)	57.7	11.4	33.2	46.3
Galvanized sheet metal	51.5	10.9	31.3	40.6

Ranking after average value calculation (descending): thermal insulation, galvanized sheet metal and concrete. Highest average bitumen sheet temperature was on sheet applied on expanded polystyrene while this was expected.

Maximum temperature was recorded in 14:00 hours, value +57.7 °C on bitumen sheet applied on 80 mm of expanded polystyrene. Maximum deviation of maximum temperatures – value 8.3 °C was recorded between sheets applied on 80 mm of expanded polystyrene and concrete under layer. Minimum temperature +10.9 °C was recorded in 04:00 hours on sheet applied on galvanized sheet metal. Temperature gradient during one day was maximal 16.3 °C on sheet applied on 80mm of expanded polystyrene. Surface temperature behaviour on bitumen sheet with various underlayer materials is in Graph 2.



Graph 2: Surface temperature behaviour on bitumen sheet with various underlayer materials (0 is equal 24:00)

4 Theoretical conclusions

Experiments proved that colour and type of the spread have significant influence on surface temperature of bitumen sheets and thus on speed of aging. In case of colour the main factor is critical area of visible solar radiation spectrum which is absorbed by sheets. Theoretical conditions were verified through practical measurements. Practical measurements also proved that thermal technical characteristics of under layer material effects surface temperature of bitumen sheets. Measurements results can be applied in manufacturing process and also in constructional roof design. During lifespan prediction of roofing made from bitumen sheets it's important to consider the fact that temperature increase of 10 °C results approx. in doubling chemical reactive speeds and thus in lowering lifespan of bitumen sheet.

5 Practical conclusions

All measurements lead to these conclusions desirable for practical usage:

- Spread colour is substantial factor influencing aging process and bitumen sheet lifespan, thus colour is one of the most monitored factor.
- Black colour and dark shades of the spread should be eliminated in warm climatic zones.
- Concrete under layer is very suitable for bitumen sheets in warm climatic zones.
- In case of under layer with low heat capacity (thermal insulations) spread with very light colour should be used for bitumen sheets. Optimal colour is white eventually spread made from reflective pre-oxidized aluminium flakes, which reflects solar radiation back to the atmosphere very well.
- Dark shades of spread eventually black colour can be without major incidence on bitumen sheet lifespan used in cold climatic zones (southern Chile and Argentina, northern Canada, Alaska, in Europe Scandinavia and northern part of Russia.
- Average year temperature has to be considered in selection of spread colour for Central Europe where Czech Republic belongs. Light shades can be used in lowlands with warm climate while dark shades of spread for bituminous sheets can be used in mountain areas.

6 Exact failures of bituminous sheets

As mentioned above colour of spread for bituminous sheets (eventually protective coating colour) together with other chemical components included in atmosphere and with UV spectrum of solar radiation noticeably influence lifespan of bituminous sheets. Failures always appear first on the outer surface of the sheet where it is possible to retain and make appropriate sanitation procedures in early stage of failure. Complete renewing is needed in developed stage of damage. Characteristical destructive types of bituminous sheet surface are:

- blister appereance in top surface bitumen material layer (see Fig. 1)
- small sag (crater) appereance in top surface bitumen material layer (see Fig. 2)
- top surface bitumen material layer flow off (see Fig. 3)
- cracking of top surface bitumen material layer – cracks form usually disordered network and they reach enclosure of the bituminous sheet (see Fig. 4).

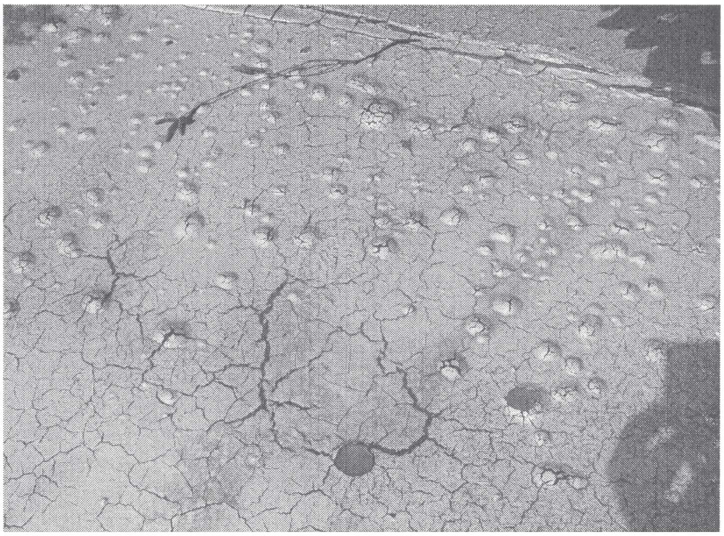


Fig. 1: Blisters in top surface bitumen material layer

Figure 2: Sags (craters) in top surface bitumen material layer

Figure 3: Top surface bitumen material layer flow off.

Figure 4: Disordered network of deep cracks in top surface bitumen material layer.

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ABOUT THE AUTHOR

Born 1949 in Czech Republic Graduated on Faculty of Civil Engineering in Brno in 1973. After undergoing professional service as construction manager he returned to Department of Building Structures on Faculty of Civil Engineering in Brno, where he worked as an assistant, from 1989 as Associated Professor. In 1991 he was designated as expert appointed by court for roof structures. He is author of 10 books dealing with roof deck solutions, author of approx. 50 articles in expert and science journals. Attends and lectures periodically on professional conferences and seminars. Author of many designs of roof structures for various utilization – from family houses, public housing and sporting structures to very challenging designs for swimming pools, airport terminals etc. He is very active in expert activities involved in roof structure failure analysis and reconstruction of roof structures.