Influence of the Quantity of Fillers on Crucial Thermal-Technical Parameters of Bitumen Waterproofing Sheets

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Abstract. Bitumen sheets are mainly used in the building industry as a waterproofing material. The waterproofing function in bitumen sheets is ensured by the bitumen mass and its quantity and composition. The important component of bitumen mass is the filler. An increased amount of filler reduces the cost of bitumen and thus the cost of a complete bitumen sheets. The amount of bitumen filler is mostly limited by the technological capabilities of the production equipment used in the production of bitumen sheets. However, the amount of filler can adversely affect some properties of the bitumen mass and hence the bitumen sheets. One of the basic features influencing the application of bitumen sheets is a low temperature flexibility. An increased amount of fillers also degrades workability in the work place. This paper deals with the analysis of the composition of the bitumen mass for the production of bitumen sheets used for the isolation of concrete bridges. The paper based on the analysis of samples of bitumen sheets selected from various manufacturers describes the usual amount of bitumen fillers. At the same time, the paper answers the question of the hypothesis - whether the increased or decreased amount of fillers affects one of the basic thermal-technical properties of bitumen sheets - the flexibility under low temperatures. The authors of this article found during the previous research that dependence is influenced both by the type of the bitumen mass and by the type of the surface treatment. It has been statistically proven that the decisive factor is not the amount of the filler but the type of bitumen in the terms of modification. The aim of this paper is to confirm or confute the hypothesis that there is some relationship between the flexibility at low temperature and the composition of the bitumen with an expanded amount of samples. Thus, new results can confirm or disprove previous research results. Results were formulated based on the statistical evaluation of data obtained from the laboratory measurements.

1. Introduction

This contribution deals with analysis of the composition of the bitumen substance of bitumen waterproofing sheets used for concrete bridge decks [1] (bitumen sheets in the next text). This contribution examines the samples of bitumen sheets from various manufacturers in terms of the bitumen areal weight and the quantity of fillers in the bitumen substance. This contribution also answers the hypothesis of whether the quantity of bitumen sheets is increased or decreased and the filler affects the basic thermal-technical properties of bitumen sheets, such as its flexibility at low temperatures [2]. The verification of the hypothesis is carried out by the statistical evaluation of the dependence of the flow resistance at elevated temperature on the quantity of fillers.
The authors of this article found during the previous research that dependence is influenced both by the type of bitumen material and by the type of surface treatment [3]. It has been statistically proven that the decisive factor is not the quantity of filler but the type of bitumen in terms of modification.

The aim of the paper is to confirm or rebut the hypothesis that there is some relationship between the flexibility at low temperature and the bitumen composition with extended sample sizes. Thus, new results confirm or disprove previous research results. Results were formulated based on the statistical evaluation of data obtained from laboratory measurements.

2. Material and methodology

2.1. Used material

Thirty-four samples were selected for testing. They are used for monolayer applications for the insulation of concrete decks in the Czech and Slovak Republics. Nineteen samples have coarse grained gritting, nine have fine grained gritting and six samples are without gritting. There are twelve samples with the mass modified by plastomers and fourteen samples with the mass modified by elastomers in the selected file. The basic bitumen sheets characteristics are described in Table 1. All samples had a supporting insert made of polyester, which has been impregnated by the bitumen matter.

2.2. Determination of the flexibility at low temperature and the quantity of fillers in the bitumen substance

The flexibility at low temperature is performed according to [2]. To determine the quantity of fillers in bitumen sheets, no standard test procedure is prescribed, so a custom procedure has been established. This process involves the firing of three test bodies of the bitumen mass of the given bitumen sheets in a furnace at a temperature of 1000 +/- 50 °C. The arithmetic mean of the percentage of fillers of the three test bodies is considered as a final result. In terms of filler type, the bitumen sheets were divided into two sets according to the type of fillers – ash and limestone.

2.3. Methodology of the statistical evaluation of the influence of fillers on the flexibility at low temperature

Since the quantity of fillers is generally a numerical variable, we performed three categories (A - up to 20 % inclusive, B - more than 20 % and maximally 30 %, C - more than 30 %). Due to the nature of the data, was used the nonparametric statistical test - Kruskal-Wallis test and the parametric test (ANOVA) was performed for comparison of results. However, due to the nature of the data, the importance of the nonparametric tests is more important. All tests were performed at the significance level α = 0.05, i.e. with 95% confidence.

3. Results of tests

3.1. The flexibility at low temperature

The value of the temperature for flexibility at low temperature for the upper surface was moving from 0 °C do -25 °C. The value of the temperature for flexibility at low temperature for the low surface was moving from 0 °C do -25 °C. The overview of total results is collected in Table 2.

3.2. Determination of the quantity of fillers and the type of fillers in the bitumen mass

Values of the quantity of fillers oscillated in the interval from 0 °C to -25 °C. The overview of total results is collected in Table 2.

The quantity of fillers in the bitumen substance oscillated from 9.7% to 50.9% with average value 27.7 % and standard deviation 8.3 %. Ash was used for 16 bitumen sheets with the average value of 26.3 % and standard deviation of 4.6 %. The quantity of ash in the bitumen substance oscillated from 19.9 % to 38.3 %. Limestone was used in the case of 18 bitumen sheets with average value of 23.9 % and the standard deviation of 10.8 %. The quantity of limestone in the case of the bitumen substance oscillated from 9.7 % to 50.9 %. The overview of total results is collected in Table 2.
Table 1. Selected characteristics of the test samples.

| Characteristics of the test sample / number of test sample | 2    | 3    | 4    | 6    | 7    | 8    | 9    | 10   | 14   |
|------------------------------------------------------------|------|------|------|------|------|------|------|------|------|
| Upper surface adjusting                                    | HP   | N    | HP   | N    | JP   | HP   | JP   | HP   | JP   |
| Bitumen matter type                                         | P    | P    | E    | P    | E    | P    | P    | P    | P    |
| Supporting insert, area weight [g/m²]                      | 230  | 200  | 230  | 200  | 250  | 220  | 230  | 230  | 230  |
| Thickness [mm]                                              | 5.20 | 5.24 | 5.3  | 4.83 | 5.10 | 5.50 | 4.85 | 5.16 | 6.25 |
| Positioning of the insert                                  | C    | A    | A    | A    | C    | B    | B    | B    | D    |
| Application location (state)                               | CZ/ SK | CZ/ SK | SK | SK | SK | SK | SK | SK | CZ/SK |

| Characteristics of the test sample / number of test sample | 15   | 16   | 17   | 18   | 22   | 23   | 25   | 26   | 28   |
|------------------------------------------------------------|------|------|------|------|------|------|------|------|------|
| Upper surface adjusting                                    | HP   | JP   | HP   | HP   | HP   | HP   | N    | HP   | HP   |
| Bitumen matter type                                         | E    | E    | P    | E    | P    | E    | P    | E    | P    |
| Supporting insert, area weight [g/m²]                      | 230  | 230  | 230  | 250  | 250  | 280  | 280  | 250  | 250  |
| Thickness [mm]                                              | 5.46 | 4.80 | 5.6  | 5.05 | 5.22 | 4.80 | 5.18 | 4.75 | 5.30 |
| Positioning of the insert                                  | C    | D    | C    | B    | A    | C    | B    | A    | A    |
| Application location (state)                               | CZ   | CZ   | CZ   | SK   | SK   | SK   | SK   | SK   | SK   |

| Characteristics of the test sample / number of test sample | 29   | 30   | 31   | 32   | 33   | 34   | 35   | 39   | 40   |
|------------------------------------------------------------|------|------|------|------|------|------|------|------|------|
| Upper surface adjusting                                    | N    | HP   | HP   | HP   | HP   | JP   | N    | N    | N    |
| Bitumen matter type                                         | P    | P    | P    | E    | E    | E    | P    | P    | P    |
| Supporting insert, area weight [g/m²]                      | 250  | 250  | 280  | 250  | 250  | 230  | 250  | 280  | 280  |
| Thickness [mm]                                              | 5.04 | 4.81 | 5.2  | 5.4  | 5.34 | 4.81 | 4.99 | 5.12 | 5.00 |
| Positioning of the insert                                  | B    | C    | B    | C    | B    | C    | B    | D    | A    |
| Application location (state)                               | CZ   | CZ   | SK   | CZ   | SK   | SK   | SK   | SK   | SK   |

| Characteristics of the test sample / number of test sample | 41   | 42   | 43   | 44   | 45   | 46   | 47   |
|------------------------------------------------------------|------|------|------|------|------|------|------|
| Upper surface adjusting                                    | N    | HP   | HP   | HP   | HP   | JP   | |
| Bitumen matter type                                         | E    | P/E  | P/E  | P/E  | P/E  | P/E  | |
| Supporting insert, area weight [g/m²]                      | 230  | 230  | 250  | 230  | 250  | 230  | |
| Thickness [mm]                                              | 5.41 | 5.41 | 4.90 | 4.97 | 4.50 | 4.92 | 5.19 |
| Positioning of the insert                                  | C    | C    | A    | C    | C    | A    | |
| Application location (state)                               | CZ   | CZ   | CZ   | CZ   | CZ   | CZ   | CZ |

Legend: HP – coarse gritting, JP – fine-grained gritting, N – the finish of the geotextiles weighing about 20 [g/m²], PES – polyester fleece, P – mass modified by plastomers, E – mass modified by elastomers, A – under the surface, in the upper 1st twelfth of the thickness of the sheet, B – in the upper 2nd - 3rd twelfth of thickness of the sheet, C – in the upper 4th -5th twelfth, D – in the upper 6th twelfth of thickness of the sheet.
Table 2. Results of the test. The flexibility at low temperatures according to [2], the quantity of fillers and the type of fillers in bitumen sheets for given samples.
Source: [3] and authors.

| Property/sample number | 2   | 3   | 4   | 6   | 7   | 8   | 9   | 10  | 14  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Flexibility at low temperature - upper surface [°C] | -7  | -9  | -18 | -4  | -11 | -11 | -8  | -16 | -5  |
| Flexibility at low temperature - lower surface [°C] | -8  | -6  | -25 | -5  | -19 | -18 | -9  | -16 | -6  |
| Quantity of fillers [%] | 14.1| 18.7| 24.1| 24.6| 21.3| 25.4| 19.7| 20.0| 21.7|
| Type of fillers         | V   | V   | V   | P   | P   | P   | V   | V   | P   |

| Property/sample number | 15  | 16  | 17  | 18  | 22  | 23  | 25  | 26  | 28  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Flexibility at low temperature - upper surface [°C] | -12 | -19 | -11 | -9  | -2  | -16 | -25 | -22 | -5  |
| Flexibility at low temperature - lower surface [°C] | -14 | -23 | -21 | -18 | -18 | -16 | -20 | -11 | -4  |
| Quantity of fillers [%] | 26.0| 24.4| 26.7| 35.0| 13.0| 14.6| 30.9| 19.9| 26.2|
| Type of fillers         | P   | P   | P   | V   | V   | V   | V   | V   | P   |

| Property/sample number | 29  | 30  | 31  | 32  | 33  | 34  | 35  | 39  | 40  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Flexibility at low temperature - upper surface [°C] | -2  | -9  | -14 | -8  | 0   | -6  | -15 | -19 | -25 |
| Flexibility at low temperature - lower surface [°C] | 0   | -14 | -18 | -12 | 0   | -18 | -19 | -19 | -11 |
| Quantity of fillers [%] | 22.3| 23.2| 38.3| 50.9| 31.6| 40.0| 35.2| 22.3| 9.7 |
| Type of fillers         | V   | P   | P   | V   | V   | V   | V   | V   | V   |

| Property/sample number | 41  | 42  | 43  | 44  | 45  | 46  | 47  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|
| Flexibility at low temperature - upper surface [°C] | -11 | -11 | -25 | -10 | -14 | -25 | -15 |
| Flexibility at low temperature - lower surface [°C] | -19 | -14 | -13 | -18 | -12 | -25 | -18 |
| Quantity of fillers [%] | 28.9| 26.5| 10.1| 27.3| 30.8| 22.7| 24.7|
| Type of fillers         | P   | P   | V   | P   | P   | V   | P   |

3.3. Results of the statistical evaluation of the influence of the quantity of fillers on the flexibility at low temperature

The results of the test, see Table 3 and 4, show the value of the test statistics, \( p \)-value and the Figure 1 and 2 offer the graphs of Tukey's multiple comparison of mean values of the flexibility at low temperature by categories.
Table 3. The flexibility at low temperatures – the lower surface.

|                  | ANOVA  | Kruskal-Wallis |
|------------------|--------|----------------|
| Test statistics  | 1.193  | 4.326          |
| p-value          | 0.316  | 0.115          |

Figure 1. The graph of Tukey’s multiple comparison of mean values of the flexibility by categories.

Table 4. The flexibility at low temperature – the upper surface.

|                  | ANOVA  | Kruskal-Wallis |
|------------------|--------|----------------|
| Test statistics  | 0.384  | 0.441          |
| p-value          | 0.684  | 0.802          |
4. Discussions

4.1. The flexibility at low temperature and the determination of the quantity of fillers and types of fillers in the bitumen mass

The obtained results show that bitumen sheets with the fillers based on limestone achieved a larger dispersion of the percentage mass of the fillers and worse average values of the flexibility at low temperature at the lower surface, although the mean value is lower than using that ash. This can be explained by the fact that bitumen sheets are imported from southern European countries.

In terms of the type of modification, the bitumen sheets with the mass modified by polymers of elastomeric character achieved the value of 31.1% and the standard deviation of the value 7.16%. Bitumen sheets with the mass modified by polymers of plastomeric character achieved a value 20.8% and the standard deviation of 6.5%. In general, it can be seen that bitumen sheets with the mass modified by polymers of a plastomeric character contain a smaller quantity of fillers.

4.2. Results of the statistical evaluation

The results of the statistical processing indicate that the quantity of fillers does not affect the flexibility at low temperature at either the lower or the upper surface. The p-value of all tests is greater than the significance level 0.05 and graphs show that all the interval estimates of the mean values of the flexibility values according to the filling quantity categories contain zero, so the differences are not statistically significant.

5. Conclusions

The usual quantity of fillers for bitumen sheets, which are used for insulation of concrete bridge in the Czech and Slovak Republics, can be set to the value 26.5%. It is furthermore possible to say that bitumen sheets whose mass is modified by plastomers have a lower content of fillers than bitumen sheets with the mass modified by polymers of elastomeric character.

The hypothesis assuming that the type and the quantity of fillers have an effect on the flow resistance at elevated temperature has not been confirmed.
References
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