Calculation of the durability of sealing and awning materials

*Timur Koutsenko*¹[0000-0002-3371-8057], *Nikolay Shelihov*¹[0000-0002-9447-5511], and *Svetlana Kutsenko*²[0000-0001-7024-798X]

¹Kazan State University of Architecture and Engineering, 420043, Zelenaya st., Kazan, Russia

²Kazan State Power Engineering University, 420066, Krasnoselskaya st., Kazan, Russia

Abstract. The article discusses the hypotheses for determining the equivalent laboratory modes for assessing the durability of sealing and awning materials, and evaluates the accuracy of the proposed method. Qualitative research of operational factors influence (UV, temperature) on sealing and awning materials durability was conducted. Purpose of the study: a method for predicting the durability of sealing and awning materials. Methods: Methods for fast assessment of durability and methods of equivalent factors. Results: Based on the obtained regularities of the behavior of sealing and awning materials under conditions of repeated loading and ultraviolet radiation, as well as the accepted hypotheses about the summation of damage and irreversibility of the destruction process, a laboratory test mode was determined that was equivalent in terms of the level of introduced destruction to the operating mode, including the action of multiple loads and ultraviolet radiation.

Based on the equivalent accelerated test mode and the characteristics of the operating mode of loading and irradiation, a method for assessing the durability of sealing and awning materials is proposed.

Keywords: awning structures, sealing materials, assessment and calculation of the durability of materials, operating factor, assessment of the accuracy of the proposed method.

1 Introduction

According to the analysis of literature sources and our own research, we have selected the main operational factors: multiple loading and ultraviolet radiation to develop an accelerated method for assessing the durability of materials for soft building fences.

We see the essence of the method in finding durability according to the results of laboratory tests, without resorting to lengthy experiments. Proceeding from this, for the development of the method, it is necessary to determine the scientific provisions that make it possible to transform the real processes of repeated loading and ultraviolet irradiation into equivalent laboratory modes corresponding to the operational ones in terms of damageability. At the same time, laboratory modes should contain factors that accelerate

* Corresponding author: koutsenko_timur@mail.ru

the process of assessing durability in comparison with full-scale tests, because only in this case the effectiveness of the method is manifested [1-5].

Determination of the laboratory load mode equivalent to the operational one.

To accelerate the assessment of durability using the developed method, we will take the following as accelerating processes:

- a) An increased frequency of the laboratory loading mode in comparison with the natural loading mode by wind pulsations (however, the frequency should not lead to self-heating of the sample);
- b) Greater intensity of ultraviolet radiation, acting in laboratory tests, in comparison with natural (but with equal doses of radiation received by the material before destruction);
- c) Extrapolation usage when constructing a relationship $P\text{-log } N$ in the area of large values of endurance (low loads) for small values of endurance (large loads), based on the straightness of the relationship $P\text{-log } N$ in laboratory tests.

When assessing the durability of sealing and awning materials under operating conditions, two ways can be used [6-8].

The first way is to implement the real nature of loading in laboratory tests. For example, in works, researching the durability of materials, we tried to reproduce the random loading process and directly determine the durability. However, the complexity of the equipment and the experiments themselves do not allow this method to be applied on a large scale. It is also necessary to take into account the fact that the reproduction of the real nature of loading in laboratory conditions does not reduce the test time.

The second way is to replace the random loading process with a schematized process, which, in terms of the level of introduced fatigue damage, should be equivalent to the real one. In this case, it is possible to reduce the test time due to the use of an appropriate equivalent mode [9-10].

As you can see, the second way is the most acceptable, and in the further discussion we will use it.

Considering the stress in the material of a soft fence against wind loads, it is possible to represent the process of changing the stress in the form of a sequence of cycles with a variable amplitude, which has a random distribution. For the loading mode presented in this way, we need to find the equivalent laboratory mode.

We will take the equivalent mode in the form of multiple repetitive cycles with a constant loading amplitude.

Thus, the problem of finding the equivalent mode is reduced to finding the equivalent load amplitude. To find the latter, we will use the above-accepted hypothesis of summation of damages.

2 Methods

Work on the development of a methodology for assessing the durability of sealing and awning materials is carried out on the basis of the laboratory of the Federal State Budgetary Educational Institution of Higher Education «Kazan State University of Architecture and Engineering».

In accordance with the set goal, it was necessary to implement the following tasks:
Select a method and implement equivalent impact factors for modeling the factors responsible for the destruction of sealing materials and materials of soft shells.

Conduct research of sealing and awning materials under the influence of operational factors and determine the main patterns.

For definition, consider multiple loading from an energy standpoint.

Considering that the loading energy is proportional to the product $P^2\omega$, where P is the load in the cycle, ω is the loading frequency, the share of the energy introduced in one cycle will be equal to:

$$\Delta E_o = \frac{P^2\omega}{N}, \quad (1)$$

and under the action of n loops ($n < N$):

$$\Delta E_i = \frac{P_i^2\omega_i}{N_i}n_i \quad (2)$$

where N_i is the number of cycles to failure for every i load [11-13].

If the amplitude of loading changes with time, and the sample is tested until failure, then the sum of the energies introduced by cycles with loads of different values can be equated to the energy introduced by the equivalent load P_{eq} at the moment of destruction of the sample, that is

$$\frac{P_{eq}^2 * \omega_{eq} * N}{N} = \sum \frac{P_i^2 * \omega_i * n_i}{N_i} \quad (3)$$

3 Results and discussion

Since it was shown in the literature review that the loading frequency in the region of 50 Hz has practically no effect on the number of cycles to failure, in order to simplify the reasoning, we will accept the same loading frequency for all amplitudes.

Fig. 1. Determination of the equivalent number of cycles to failure according to the laboratory dependence of endurance. Material-2 T=49 °C.

According to All-Union State Standard GOST 30740-2000. «Interstate standard. Sealing materials used in joints of aerodrome coats. General specifications. Official edition» and GOST 9.707-81 «Unified system of corrosion and ageing protection. Polymeric materials. Methods of accelerated climatic ageing tests» the energy introduced in one cycle will depend only on the amplitude of the load, and the equivalent load will be determined as: [14-17].

$$P_{eq} = \left[\sum \frac{P_i^2 n_i}{N_i} \right]^{\frac{1}{2}} \quad (4)$$

Calculation of the durability of sealing and awning materials, taking into account the operating factors.

Therefore, we have established that the multiple loading mode with a temporary load amplitude can be replaced by an equivalent mode with a constant load amplitude, which we named P_{eq} and determined by formula (4).

Hence, by the equivalent amplitude of loading of a random process, using the dependence P-log N for a continuous laboratory loading process with a constant load in a cycle, it is possible to determine the value of endurance and, in accordance with the hypothesis of the irreversibility of the nature of destruction adopted above, this value will correspond to the actual endurance of the material under loading conditions an intermittent random process with a variable load amplitude corresponding to the nature of wind pulsations (for awning materials) [18-20].

It should be borne in mind that in addition to pulsations from wind loads, a soft fence is subject to static stress from a stabilizing force, the value of which is determined by the shape and purpose of the structure, as well as by the type of fence material. Hence, the total stress in the fence material will be composed of the pulsation component and the statistical component.

When comparing the modes of multiple loading, it was shown that only the maximum value of the load amplitude is of primary importance for durability. As a result, it does not matter whether this value is composed of a statistical and dynamic component, or only from a dynamic one. Taking this into account, the amplitude of the equivalent loading mode $\bar{P}_{eq}$ will be equal to the sum of the equivalent load value and the value of the fence stabilization force. That is, $\bar{P}_{eq} = P_{eq} + P_{stab}$ and the number of cycles before failure under multiple loading with amplitude P_{eq} will be equivalent to the number of cycles before failure under variable amplitude loading corresponding to the nature of stress pulsations in a soft enclosure under wind loads [21].

Now it is necessary to take into account the effect of ultraviolet radiation on the sealing and awning materials. From the literature, we have determined the intensity of radiation for laboratory tests, which is equivalent to intake per one cycle of natural radiation loading. Since it is known that in winter ultraviolet radiation is very insignificant, then in the developed method we will take into account its combination only by positive temperatures. This combination is the most unfavorable for organic materials, and the estimate of durability will obviously be somewhat underestimated [22-23].

Having constructed the dependence P-log N at the intensity of ultraviolet radiation J_{eq} and a temperature equal to the average temperature of the surface heated by the sun rays per day, we determine the number of cycles before destruction of N_{UV} from the load $\bar{P}_{eq}$ under conditions of ultraviolet exposure, Figure 2. Knowing N_{UV} , it is possible to estimate the durability in units of time from a simple ratio:

$$\tau = \frac{N_{UV}}{\bar{N}^*}, \quad (5)$$

where τ is the durability, $\bar{N}^*$ is the number of repeated loading cycles acting per unit time of the actual loading process, N_{UV} is the number of cycles before failure under the conditions of the action of an equivalent load ($\bar{P}_{eq}$) and an equivalent intensity of ultraviolet radiation according to laboratory tests.

Fig. 2. Nomogram for determining endurance of N_{UV} in laboratory tests. 1, 4 – material-1, 2,3 – material-2, 1,2 – multiple loading, 3, 4 – multiple loading and ultraviolet irradiation ($J = 60 \frac{Wt}{m^2}$)

In view of the above, an assessment of the durability of the materials under study is given. The assessment was carried out for two values of the stabilization force (P_{stab}) of the fence (5 and 10 % of P_0) the average number of loading cycles and the equivalent amplitude of loading the material of the soft fence by wind pulsations, according to the data given in the appendix, equal to 20 N/cm [1-2].

4 Conclusions

1. Thus, we have shown that using the developed method, it is possible to fairly accurately assess the durability of sealing and awning materials. Moreover, the time for assessing durability in comparison with full-scale tests, for the materials studied, is reduced by up to 20 times.
2. A formula for determining the load in the equivalent multiple loading mode is derived.
3. Based on the use of an equivalent accelerated test mode for sealing and awning materials and data characterizing the operating mode of loading, a method for assessing the durability of materials is proposed and the durability of two types of materials is estimated.

Acknowledgements

The authors are grateful to Alfred Midkhatovich Suleimanov, Doctor of Technical Sciences, Professor of the Department of Building Materials of the Federal State Budgetary Educational Institution of Higher Education «KSUAE» for all-round assistance in the implementation of experiments in the laboratory.

References

1. D. Byadovsky, S. Blinov, T. Kutsenko, A. Suleimanov, *Calculation of the durability of materials of awning structures taking into account the operating factors*, Collection of scientific papers «Actual problems of military scientific research»: collection of scientific Proceedings, St. Petersburg: Publishing House of the Polytechnic University, 3, 4, 283-292 (2019)

2. T. Koutsenko, N. Shelihov, *Calculation of the durability of awning structures*, All-Russian competition of scientific works «Lobachevsky – 2020»: electronic collection of abstracts of the Open competition of scientific works among students for the prize named after N. I. Lobachevsky (Kazan, 22-23, 2020)
3. A. Suleimanov, N. Shelihov, *Durability of awning materials under static loading*, Efficiency of building materials based on and using local raw materials and industrial waste: interuniversity. Sat., 15-20 (1992)
4. R. K. Mukhametrakhimov, A. R. Galautdinov, A. M. Garafiev, *Izv. KGASU*, **4**, (2020)
5. Md Safiuddin, K. A. Soudki, *Sealer and coating systems for the protection of concrete bridge structures*, International Journal of Physical Sciences, **6**, 37 (2011)
6. A. Suleimanov, in IOP Conf. Ser. Mater. Sci. Eng. **890**, 012100 (2020) DOI: 10.1088/1757-899X/890/1/012100
7. R. Mukhametrakhimov, L. Lukmanova, in IOP Conf. Ser. Mater. Sci. Eng. **890**, 012082 (2020) DOI: 10.1088/1757-899X/890/1/012082
8. B. Xu and H.Y. Li, *Study on Durability of Silicone Rubber Sealant for Pavement Joint*, Advanced Materials Research, **496**, 30-33 (2012)
9. R. A. Kayumov, D. E. Strakhov, A. M. Sulejmanov, E. B. Tuysina, in IOP Conf. Ser. Mater. Sci. Eng., **934**, 012096 (2020) DOI: 10.1088/1757-899X/934/1/012042
10. R. A. Kayumov, A. M. Suleymanov, I. Z. Muhamedova, in IOP Conf. Ser. Mater. Sci. Eng., **934**, 012041 (2020) DOI: 10.1088/1757-899X/934/1/012041
11. A. M. Sulejmanov, *Zavod. Lab. Diagnostika Mater.*, **71**, 44 (2005)
12. A. M. Sulejmanov, *Stroit. Mater.* **62** (2005)
13. A. Sulejmanov, D. Smirnov, G. Khairullin, in IOP Conf. Ser. Mater. Sci. Eng., **890**, 012103 (2020) DOI: 10.1088/1757-899X/890/1/012103
14. R. K. Mukhametrakhimov, L. V. Lukmanova, *Mag. Civ. Eng.*, **102**, 10206 (2021)
15. N. Guanhuab, D. Kaiab, L. Shangab, S. Qianab, H. Dongmeiab, W. Ningc, C. Yanyingde, *Development and performance testing of the new sealing material for gas drainage drilling in coal mine*, Powder Technology, **363**, 152-160 (2020)
16. A. Pelton, *Evaluation of Mechanical Fatigue and Durability*, Handbook of Vascular Motion (2019)
17. S. Nanukuttan, K. Yang, J. McCarter, P. A. M. Basheer, *Methods of assessing the durability and Service life of concrete structures*, Institute of Concrete Technology, Yearbook (2017)
18. P. Boisse, A. Gasser, B. Hagege, J. Billoet, *Int. Journal of Material Science*, **40** 5955-5962 (2005)
19. H. Heß, Y.C. Roth, N. Himmel, *Composites Science and Technology*, **67**, 6, 1081–1095 (2007)
20. A. Wolf, *Durability Testing of Sealants*, The Trouble with Sealants Sealant Technology Conference, Oxford Brookes University, School of Technology, 13 October 2004, Oxford, United Kingdom
21. A. J. Lewry, *Approaches to testing the durability of materials used in the construction and maintenance of buildings*, Construction and Building Materials, **8**, 4, 211–222 (1994)
22. M. Bomberg, T. Kisilewicz, *Durability of materials and components*, Methods of building physics (2015)
23. H. Yamaguchia, K. Higuchia, K. Sakatab, T. Akiyamac, K. Kasamurab, Y. Nakashimade, Y. Nakanishi, *Hydrophilic sealing material for live centers in machine tool,s*, Wear, 203838 (2021)