RESISTANCE OF ADDITIONAL ROOFING UNDERLAYS OF PITCHED ROOFS AGAINST ARTIFICIAL AND NATURAL AGEING

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ABSTRACT

In this paper, the author deals with the resistance of light polymer foils based on microporous functional film, used as additional waterproofing layers of pitched roofs. He exposes these foils to the effects of natural ageing and the effects of artificial ageing according to the methodology of the European test standard. Subsequently, it verifies the tensile properties of the exposed foils and compares the effects of natural and artificial ageing in order to determine the possible cause of premature degradation of these materials, which often occurs in practice. He concludes that the cause of this degradation is not excessive leniency of testing standards, but the insufficient quality of materials supplied to the European market.

KEYWORDS

Additional roofing underlay; Artificial ageing; Natural ageing; Roof membrane; Polymer degradation.

INTRODUCTION

Due to their versatile applicability, polymer materials are used in a wide range of industries, such as healthcare, the automotive industry, the textile industry and even the construction industry. It is in the construction industry that they are used, among other things, in the form of polymer waterproofing coatings [1], which protect buildings from underground water in the case of substructures, or against rainwater, as is the case with roofs. An example can be additional roofing underlays of pitched roofs.

Additional roofing underlays (ARU) are layers inserted under the folded covering of pitched roofs, in order to protect the interior from the action of water, snow, wind and dirt that penetrate through this covering. When designing ARU, you can choose from a whole range of different materials, depending on whether the so-called safe slope of the covering (BSK) required by the manufacturer of this covering is met or exceeded, and depending on the structural complexity of the roof or the way the attic spaces are used. ARU can be designed in the form of heavy polymer or asphalt waterproofing strips, sheet materials, or, most often, in the form of lightweight polymer foils.

Light-type polymer foils can be further divided according to the structural basis, into microperforated, microporous, microfibrous (see for example [2]), monolithic and other special types of films. Each of these foils has its advantages and disadvantages. The most used type are microporous foils.

These foils are a multi-layer material consisting of two layers of protective geotextile, which has the task of ensuring the mechanical properties of the final product, and one (middle) layer, in the form of a microporous polyethylene or polypropylene functional film (see Figure 1), produced by hot or cold drawing [3], which ensures waterproofness and vapor permeability of the material. Microporous foils stand out for their good workability, relatively low purchase price and excellent vapor permeability, which is key for the proper functioning of the roof covering [4]. Their biggest problem is a relatively high susceptibility to premature degradation and loss of key properties due to the influence of the external environment, which can lead to a loss of waterproofing and a limitation of the functionality of the roof covering as a whole.

The degree of degradation of ARU is mainly influenced by sunlight, temperature changes, rainwater, humidity, air, dirt and chemicals. According to available materials [7] [8], the key influences are mainly solar radiation and increased temperature. The part of the solar radiation spectrum referred to as ultra violet (UV) radiation, with a wavelength of 100 - 400 nm, representing up to 5% [9] of all solar radiation

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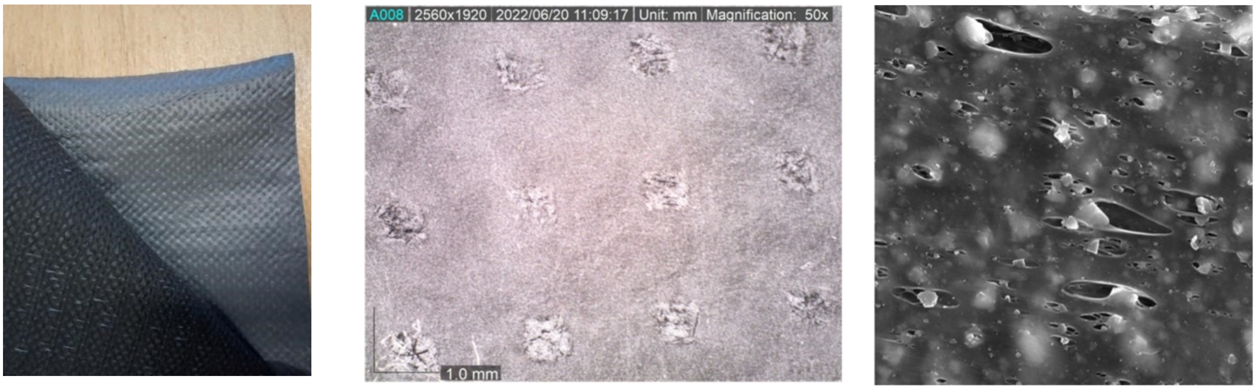

Figure 1. Detail of microporous functional film [5], [6].

(see Figure 2), causes photooxidation of polymers. It is a chemical reaction that results in changes in the chemical structure of the material, such as branching or cross-linking of polymer macromolecules, as a result of which the mechanical properties of these materials change. The combination of elevated temperatures and atmospheric oxygen further accelerates the degradation processes (see for example [10]).

Determination of the resistance of ARU against external influences in the territory of the European Union is governed by the European test standard 13859-1:2014 [11], which precisely defines the conditions of artificial ageing as tests simulating natural ageing. The qualitative requirements for ARU are then regulated at the national level. For example, in the Czech Republic these are determined on the basis of the "Rules for the design and execution of roofs" of the Guild of Plumbers, Roofers and Carpenters (CKPT) [12], and in Germany according to the publication entitled "Deutsches Dachdeckerhandwerk – Regeln für Dachdeckungen" [13].

ARU based on microporous functional films have faced problems with premature degradation and loss of functionality almost from the very beginning. There are a number of cases where, due to the loss of this functionality, leaks have occurred in roof structures after only a few months of use. For this reason, the insufficient resistance of microporous ARU against the influence of the external environment has been a topic of discussion for many years. This issue was dealt with, for example, by [14], [15] or [16]. The expert public is in the midst of a debate as to whether the cause of premature degradation is non-compliance with the minimum quality of materials supplied to the European market, or whether the cause can be found in the excessive leniency of the test standard. We will try to find an answer to this question in this article.

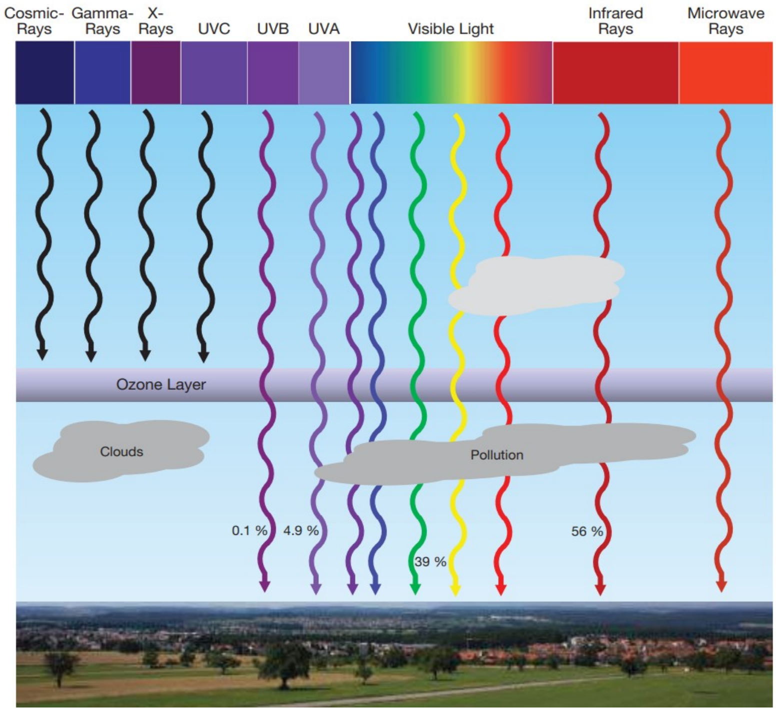

Figure 2. Detail of microporous functional film [5], [6].

Table 1. Selected properties of samples declared by manufacturers according to EN 13 859-1:2014.

Sample	Type of foil	Number of layers	Material of the functional layer	Material of protective layers	Imported from	Price including VAT [€/m²]	Weight [g/m²] EN 1849-2	Fire resistance [class] EN ISO 11925-2	Resistance against water penetration [class] EN 1928
1	microporous - multilayer	3	PP	PP	Germany	1,36	130 (+20;-10)	E	W1
2	microporous - multilayer	3	PP	PP	France	1,16	140 (+15;-15)	F	W1
3	microporous - multilayer	3	PP	PP	CR	1,16	140 (+-10)	E	W1
4	microporous - multilayer	3	PE	PP	—	1,40	135 (+-15)	F	W1
5	microporous - multilayer	3	PE	PP	Poland	0,80	150 (+-25)	F	W1
6	microporous - multilayer	3	PP	PP	Hungary	0,60	135 (+-20)	E	W1
7	microporous - multilayer	3	PP	PP	Austria	1,28	110 (+-10)	E	W1

— missing data

Table 2. Selected properties of samples declared by manufacturers according to EN 13 859-1:2014 – continuation of Table 1.

Sample	Permeability (Sd) [m] EN ISO 12572	Tensile strength in longitudinal direction [N] EN 12311-1	Tensile strength in transverse direction [N] EN 12311-1	Elongation in longitudinal direction [%] EN 12311-1	Elongation in transverse direction [%] EN 12311-1	Tear resistance in longitudinal direction [N] EN 12310-1	Tear resistance in transverse direction [N] EN12310-1
1	0.02 (+0.04;-0.01)	220 (+-20)	165 (+-15)	20-40	40-100	115 (+-25)	150 (+-30)
2	0.03 (+-0.015)	265 (+-50)	165 (+-50)	70 (+100;-40)	120 (+100;-70)	160 (+-50)	210 (+-60)
3	0.02 (-0.01;+0.015)	290 (+50;-30)	205 (+45;-30)	45 (+35;-15)	80 (+40;-25)	150 (+70;-40)	180 (+70;-50)
4	0.02 (+-0.019)	240 (+-85)	155 (+-85)	80	80	130 (+-90)	160 (+-90)
5	0.03 (+-0.015)	265 (+-50)	165 (+-50)	70 (+100;-40)	120 (+100;-70)	160 (+-50)	210 (+-60)
6	0.05 (+-0.015)	200 (+-40)	110 (+-28)	60	60	80 (+-20)	70 (+-18)
7	>2	200 (+-30)	135 (+-30)	—	—	135 (+-30)	160 (+-30)

— missing data

MATERIALS

For the purpose of finding an answer to the above questions, a number of tests were carried out on various polymer films commonly used as ARU. Specifically, these were seven samples of lightweight foils based on microporous functional film, with a weight of 110-150 g/m², in the price range of 0.60-1.40 €. These samples then represented the most commonly used materials in the market. The selected properties of the material used can be seen in Table 1.

METHODS

If we want to verify whether the method of artificial ageing specified by the standard [11] corresponds to the real conditions that can realistically occur on the roof, it is easiest to compare these conditions with each other. Such a comparison can then be made on the basis of a comparison of the material characteristics of the ARU exposed to these conditions.

For this purpose, a total of three test series bearing the designations A, B and C were assembled. Test series A consisted of seven test samples, while each test sample was represented by three test specimens for the longitudinal direction (parallel to the direction of production - LD) and three test specimens for the transverse direction (transverse to the production direction – TD). The size of the specimens was chosen with regard to the possibilities of clamping in the test device, namely 135 x 45 mm. These specimens were clamped in stainless steel holders (see Figure 3) and placed in an artificial ageing device in the form of a xenon test chamber, Xenotest Alpha+. The test itself was conducted in accordance with EN ISO 4892-2 [17] with modifications according to EN1297 [18] and EN 13 859-1 [11]. The test specimens were irradiated with a xenon lamp with a Xenochrome 300 filter, filtering its radiation,

Figure 3. Test objects clamped into stainless steel holders.

Figure 4. Test specimens attached in wooden frames, placed in drying oven.

Figure 6. Image of sensor of solar radiation and UVA radiation.

Table 3. Relative spectral portion (RSP) of radiation energy.

XENOCHROME 300		ISO 11341 (1) ISO 4892-2 (A)
Wavelength [nm]	RSP [-]	RSP [-]
<290	0,002	0,15
290-320	4,65	2,6-7,9
321-360	34,77	28,2-38,6
361-400	58,86	55,8-67,5
290-400	100	100

for radiation with a wavelength of 290-400 nm (the relative spectral radiation can be seen from Table 3). The test took place for 336 hours, at radiation intensity (45 ± 5) W/m^2, BST temperature (20 +3/-0) °C and relative humidity inside the chamber (10 ± 5) %. The sum of UVA radiation falling on the surface of the exposed specimens was 55 MJ/m^2.

After being exposed to UV radiation at an elevated temperature, the objects were taken from the holders and their size was adjusted to 121 x 35 mm, which corresponds to the size of the irradiated area of the object. The modified objects were attached to auxiliary wooden frames and placed into a drying oven according to EN 1296 [19]. Exposure to the elevated temperature took place in accordance with ČSN EN 13 859-1 [11], for a period of 90 days, at the temperature of (70 ± 2) °C, with the air exchange rate of 50 h^{-1} (see Figure 4).

Test series B, with the same number of test specimens and bodies as series A, was subjected to natural ageing. The test samples were placed on the auxiliary structure (see Figure 5) and exposed to the effects of the external environment, with continuous recording of global solar radiation values and UVA radiation values, using calibrated sensors (see Figure 6). After reaching the total amount of UVA radiation on the exposed samples of 55 MJ/m2, the material was removed and test specimens with dimensions of 121 x 35 mm were prepared. The accumulative UVA radiation by date, showing the daily differences, across the total exposure timeline, can be seen in Figure 7.

Test series C consisted of a total of seven test samples, while each test sample was represented by three test specimens for the longitudinal direction (parallel to the direction of production) and three test specimens for the transverse direction. This was a test series whose test samples were not subjected to any ageing and should therefore not show any changes in material characteristics. This series has been included purely for further comparison purposes.

Figure 5. Test samples exposed to external factors.

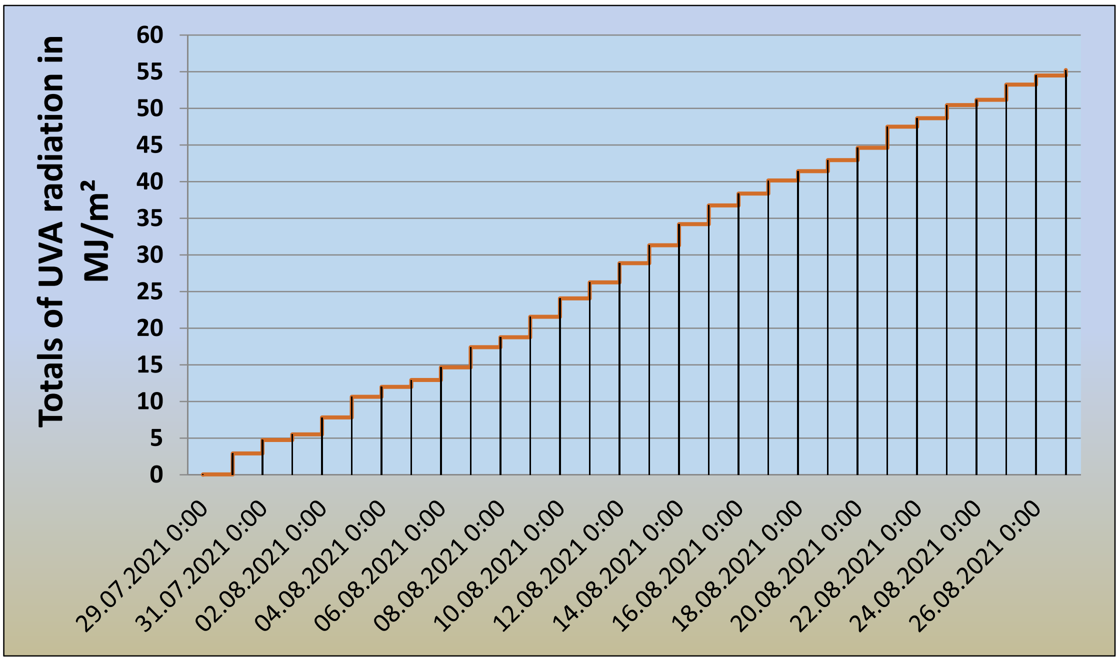

Figure 7. Daily totals of UVA radiation.

After the end of the exposure of the respective test series to artificial and natural aging, the tensile properties of the individual test specimens were verified. The tensile properties test was carried out in accordance with the guidelines of EN 13 859-1 [11], with some minor changes. The first change was the number of test specimens, which was reduced from the original five specimens for each direction (transverse and longitudinal to the production direction) to three test specimens. This reduction was made due to the limited number of exposures available in the Xenotest Alpha+. The second change was the size of the test bodies. While the test standard [11] speaks of test bodies of 100 x 200 mm (+double the length of the body clamping), for the purposes of this work, bodies of size 121 x 35 mm were used. The size of the test bodies was changed again to ensure the possibility of clamping in the Xenotest Alpha+ test device.

In order to determine the difference between the effects of natural and artificial ageing according to EN 13 859-1 [11], the tensile properties of the tested materials were compared. The first variable compared was the tensile strength. The tensile strengths of the test specimens of series A and B were compared with the tensile strength of the corresponding specimens of the reference series C. The comparison of these strengths was made by determining the difference between the reference and measured values. This difference was then expressed as a percentage of the reference value, and subsequently converted to a point evaluation. The last step was to add up the point evaluations across the test series, whereby the greater the point gain of the respective series, the greater the change in the tensile strength of the tested material and thus the greater the change in the material itself.

The second variable compared was the elongation (ductility) of the test specimens. The elongation of the individual specimens was first expressed as a percentage of the original length and was then again compared with the elongation values of the specimens of the reference test series C. This comparison was then carried out by determining the difference between the measured and reference values and expressing it in the form of a percentage relative to the higher of the elongation values. (While the tensile strength will decrease after exposure to external influences, due to the degradation of the material, the elongation (ductility) may in some cases also increase. However, this condition also points to a change in the material and should therefore be taken into account. From this the reason is the difference between the measured and reference values of elongation, always relative to the higher value, not always to the reference value.) In the final step of the extension evaluation, the above percentage was expressed as a point rating and all these ratings were summed across the test series. Again, the greater the point gain of the respective series, the greater the change in ductility of the tested material and the greater the change in the overall condition of the material. The last step of the evaluation was the summation of the results of the tensile strength and ductility test within the individual test series. However, it was not possible to simply add up the results of point evaluations. If, for example, the tensile strength results were in the order of hundreds and the elongation results were in the tens (in the case of tensile strength, the point evaluation was based on the strength of the specimens in newtons, while in the case of ductility, the point evaluation was based on the percentage elongation), after adding up these results, distortion will occur. It was therefore necessary to find a way of expressing the results that would completely eliminate the risk of this distortion. For this reason, the results of point evaluations within the relevant test and the relevant series (e.g. the result of the point evaluation of ductility of series A) were expressed as a percentage of the sum of the results of the relevant test for both series A and B. Furthermore, these shares were added across the series and this sum was expressed as a point rating. By comparing the overall point evaluations of series A and B, the degree of effects of individual methods of exposure was determined.

RESULTS AND DISCUSSION

Figure 8 shows the mean values of the tensile strengths measured for individual test samples across the test series. Each test sample is then represented by two values, depending on the orientation of the test bodies (longitudinal and transverse direction). From this graph it can be seen that, in nine cases the largest strength drops occurred in test series A, in three cases the strength drop between series A and series B was comparable, and in two cases the highest strength drop was recorded in test series B. One of the cases (4TD) even exceeded the tensile strength reference value. However, this excess was only slight (approx. 2 N) and could therefore be characterized as measurement inaccuracy.

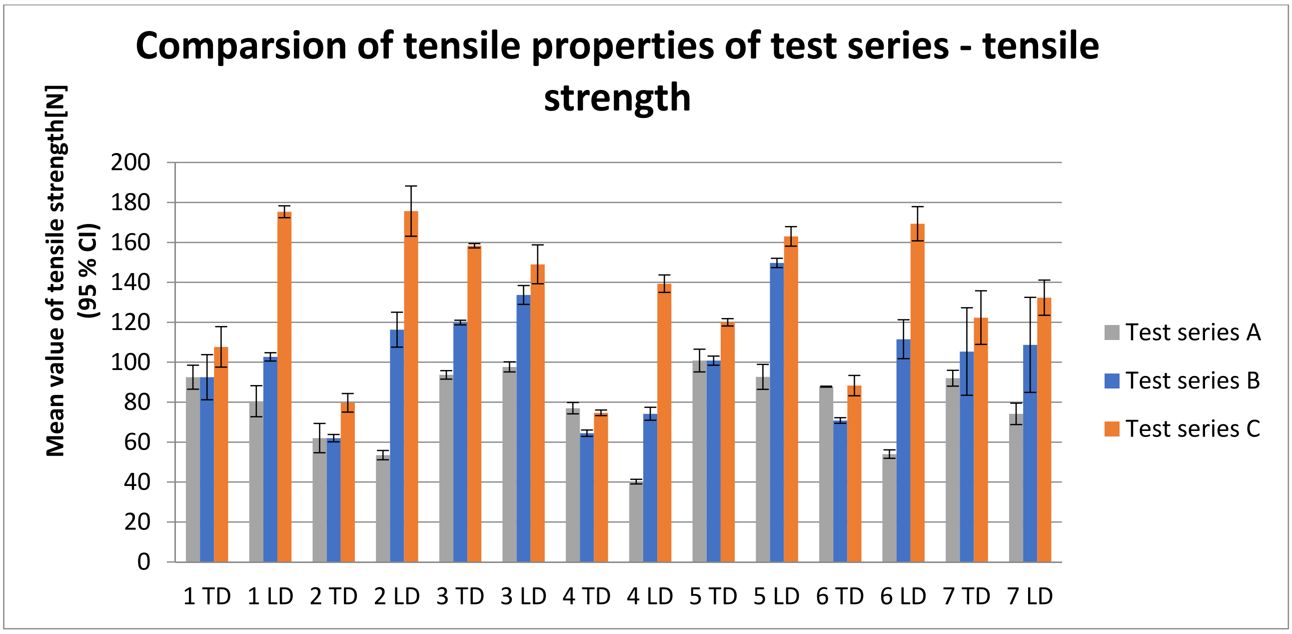

Figure 8. Tensile strength comparison.

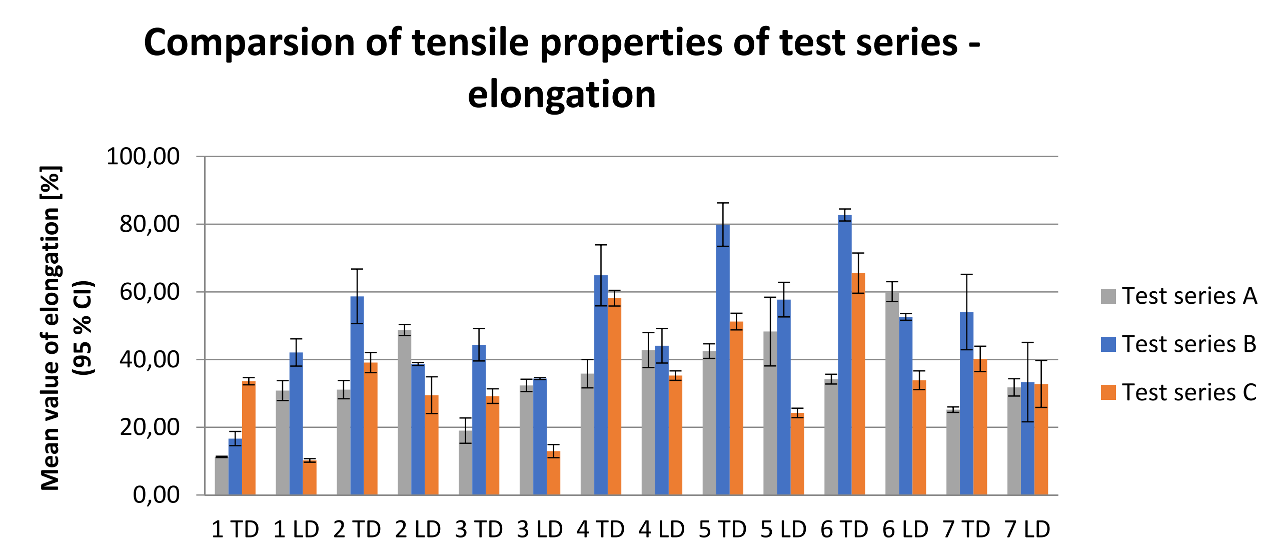

Figure 9. Elongation comparison.

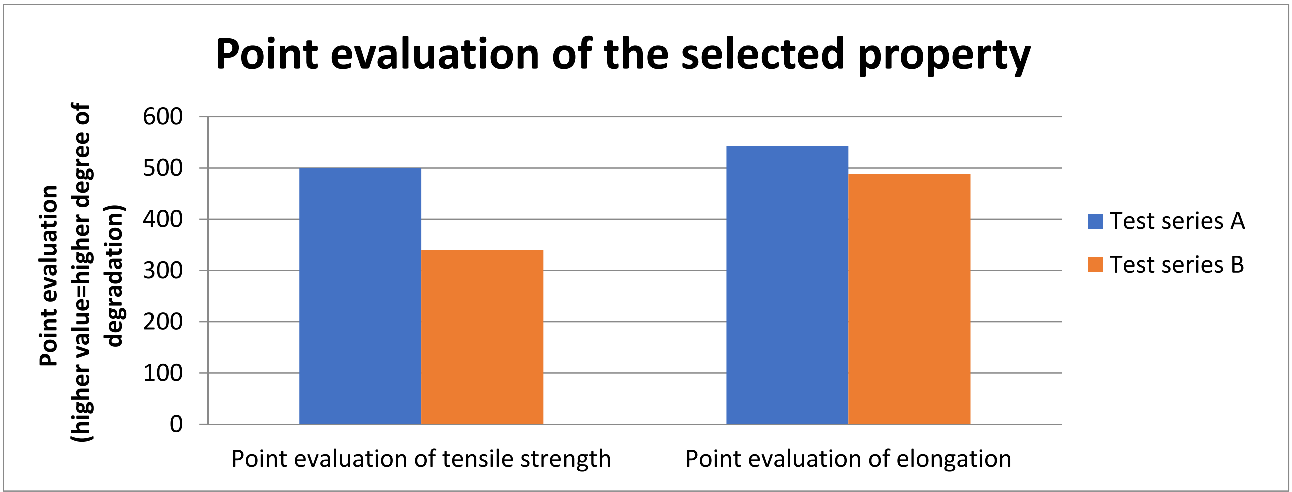

Figure 10. Comparison of point evaluation of tensile strength and elongation.

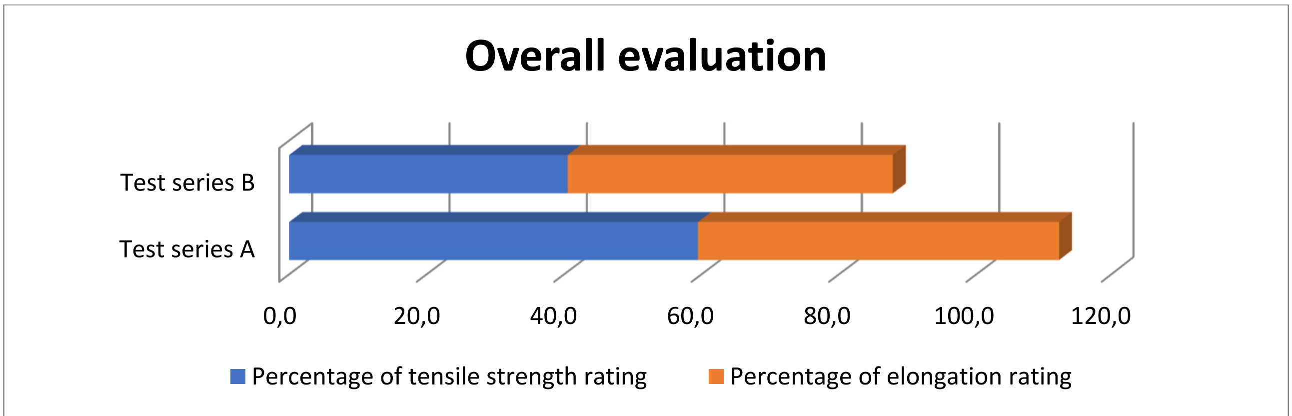

Figure 11. Overall evaluation ofexposed ARU.

The elongation of test specimens of individual test samples and series can be evaluated in a similar way. Figure 9 shows the mean values of elongation of individual test specimens. It can be seen from this graph that while in some cases there was an increase in elongation, in some cases it was decreased. Both states are a change compared to the original state and can therefore be considered as indicators of the influence of the relevant exposure on the ductility of the film.

The decrease in the strength of the test specimens of individual test series, as well as the change in elongation values, can be expressed as a percentage of the reference value (or the higher of the values). If we then convert these percentage shares into a point rating, we can determine the degree of influence of the relevant exposure on the relevant property of the material by a simple sum of these ratings, across the test series. From Figure10, it can be seen that test series A showed higher point gains than series B in the evaluation of tensile strength and in the evaluation of elongation, which points to a higher degradation of the material of series A. If we then express these gains as percentages of their sum and these shares are then added up in accordance with the methodology described above, we get the overall point rating of the individual test series and thus also the overall rating of the individual methods of exposure (see Figure 11).

Figure 11 shows that while the total score of the B test series was 87.8 (which accounts roughly for 44 %), the total point score of A test series was 112.2 (which accounts approximately for 56 %). It can thus be stated that the test objects in the A series showed tensile properties by 12 % lower that the objects in the B test series.

The A test series was exposed to artificial ageing according to EN 13 859-1 [11] (UV radiation with the total of 55 MJ/m2 and others). The B test series was exposed to natural ageing, which simulated the exposure of the foil on the roof, where the foil was used for temporary covering of the structure. The total UV radiation on the foil surface was equal to the A series (i.e. 55 MJ/m2).

Based on the above, it can be stated that the conditions of artificial ageing determined by the aforementioned standard [11] are less favourable for ARU based on lightweight foil compared to the conditions the foils are normally exposed to in real life (the B test series was exposed to the conditions in summer, when the solar radiation shows the highest intensity. For more details, see e.g. [20]. If the exposure had taken place in a different season, it would probably be prolonged due to lower daily amounts of radiation. Given the facts described above, the prolonged exposure should not lead to deterioration of material properties of the ARU tested compared to the ARU tested in the summer months for a shorter period of time. It can thus be said that the exposure of the B test series was the least suitable alternative of the above exposure to natural ageing.).

Therefore, if excessive leniency of standard requirements is excluded as a cause of the frequent premature degradation of ARU based on lightweight microporous foils, it can be stated that the only cause possible is an insufficient quality of these materials.

To be completely functional, ARU needs the correct design, and particularly correct installation. This issue has been often encountered in the case of flat roofs. For more details, see e.g. in [21].

In accordance with the aforementioned rules for design and construction of roofs [12], ARU can be divided into three quality classes marked A, B and C. A material that cannot be included in one of these classes is unsuitable to be used for ARU. The rules specify (among others) the tensile strength of material must be classified into one of the above classes (see Table 4), and that the maximum reduction in tensile strength both for transverse and longitudinal direction after the exposure to artificial ageing according to EN 13 859-1 [11] is 35% of the initial strength of the material (i.e. tensile strength of material must be at least 65 % of its initial values, see also Table 3). These rules further determine that the maximum change in the elongation of the material, after artificial aging, is 35% (that is, the elongation of the material must be at least 65% of its original value). The exact value of the permissible elongation is not determined (see Table 4).

Table 6. Requirements for individual qualitative classes of ARU.

Requirements for tensile strength according to EN 13 859-1			
	Class A	**Class B**	**Class C**
Before artificial ageing, longitudinal direction	≥250N/50mm	≥200N/50mm	≥120N/50mm
Before artificial ageing, transverse direction	≥200N/50mm	≥150N/50mm	≥110N/50mm
After artificial ageing, longitudinal direction	≥65% i)	≥65% i)	≥65% i)
After artificial ageing, transverse direction	≥65% i)	≥65% i)	≥65% i)
Requirements for elongation according to EN 13 859-1			
Before artificial ageing, longitudinal direction	Should be declared by manufacturer	Should be declared by manufacturer	Should be declared by manufacturer
Before artificial ageing, transverse direction	Should be declared by manufacturer	Should be declared by manufacturer	Should be declared by manufacturer
After artificial ageing, longitudinal direction	≥65% i)	≥65% i)	≥65% i)
After artificial ageing, transverse direction	≥65% i)	≥65% i)	≥65% i)

i) from initial values

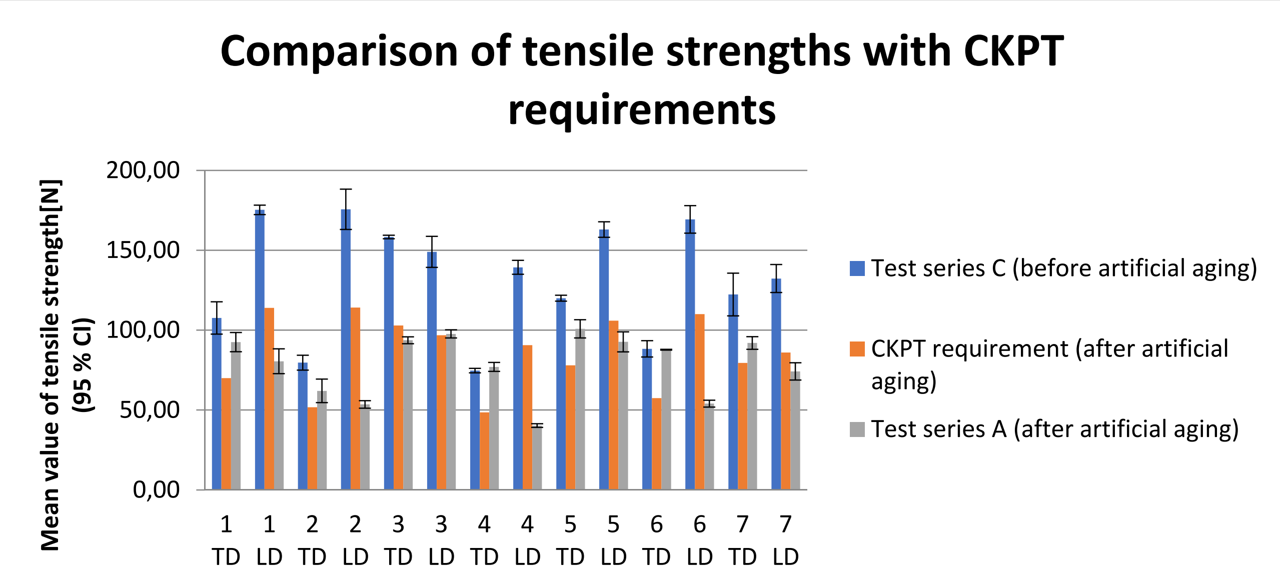

Figure 12. Comparison of tensile strength with CKPT requirements

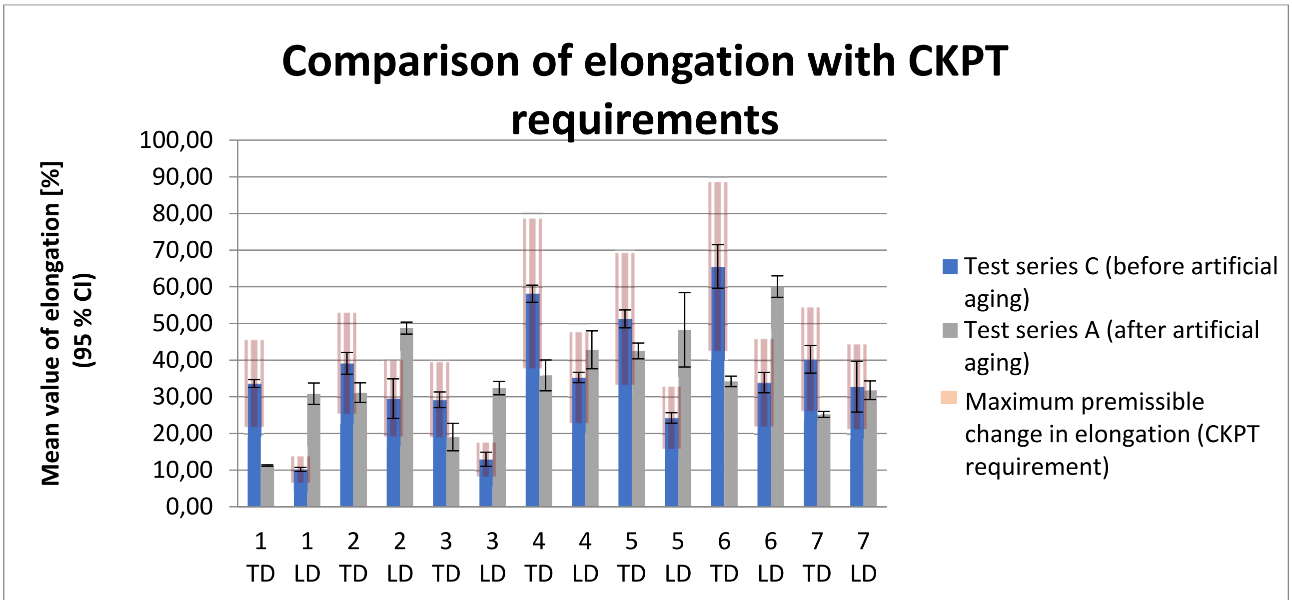

Figure 13. Comparison of elongation with CKPT requirements.

When comparing the required tensile strength values with the values declared by manufacturers, it turns out that two samples can be classified into Class C, four samples in Class B, and one sample in Class A. The comparison of initial tensile strength values (the C test series) and the values measured on test objects after their exposure to artificial ageing (the A test series) showed that none of the samples achieves the required 65 % of the initial values according to the standard (see Figure 12) and cannot thus be classified into one of the quality classes, which means they are not suitable to be used as ARU. The same evaluation of the samples can be done based on the elongation comparison. However, it follows from the facts described in the previous chapter that in the case of stretching, it is not always possible to evaluate only its reduction, but always only its overall change. If we then consider that the maximum permissible change in material elongation is 35%, it can be said that even in the case of elongation evaluation, none of the test samples met the quality requirements, as well as for tensile strength (see Figure 13).

CONCLUSION

Additional roofing underlays based on lightweight polymeric foils with microporous functional film show a number of advantages, making them oneof the most commonly used materials. Their main disadvantage is a limited durability connected with the low resistance against the effect of external factors, predominantly UVA radiation and high temperatures they are often exposed to. European testing standard EN 13 859-1 [11] determines the conditions of artificial ageing, which shall simulate the situation when ARU is embedded in roof cladding and thus exposed to external factors. These conditions are relatively strict and less favourable than the conditions ARU in common roof cladding can be exposed to. The problem is thus not the leniency of the testing standard but the insufficient quality of the materials supplied to the market as ARU.

There are relatively big differences between individual materials in terms of quality, however final customers still choose a material primarily according to its price; at best (not ideal case), according to its weight. Materials of worse quality and often also cheaper materials do not show the necessary resistance against the effects of external factors and are thus unsuitable for ARU. Some leading manufacturers are aware of this fact and try to inform professionals and the non-expert public about it. However, even some materials from well-known manufacturers (usually, these are materials of the lowest price categories within the product range of a given manufacturer) are not capable of passing the test of artificial ageing and do not show material characteristics that would enable their classification into some of the quality classes applicable for the purposes of ARU.

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