Aging Simulation of Plastic Products due to Weather Conditions

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Abstract. The paper describes the aging of plastic products due to weather conditions. It focuses on the analysis of aging and weathering of plastic products, or parts of building structures. As part of the research, the Xenotest Alfa device was used to simulate the weathering of plastic products. Xenotest Alfa simulates, for example, variable temperature, solar radiation, humidity and different types of climate. Samples of plastic and wood-plastic products were placed in the device, where the test of accelerated degradation and light stability was performed. The motivation for using the device is the effect of UV radiation on the samples, which causes the aging of the material and its gradual degradation, which may in the future cause the product to malfunction or degrade its color, as shown by this research.

1. Introduction

Polymers are substances that simultaneously extend their action through various industries. The reason is the replacement of common materials, such as metal, wood or glass. Polymers are chemically pure macromolecular synthetic or natural substances that are made up of large chains of large molecules [1,2]. The basic building block of polymers is a carbon atom. Macromolecular chains can be formed by different or the same building blocks that are connected by a covalent bond. In addition to the carbon atom, these building blocks can also be hydrogen atoms and, to a lesser extent, oxygen, nitrogen and chlorine atoms.

Polymer plastics offer a wide range of properties such as lightness, durability, color fastness, transparency and ease of processing [3]. Due to the growing use of polymeric materials, initiation is being formed to understand the degradation processes of these substances. The process of polymer degradation is explained as a change in the structure and properties of polymers caused by decomposition reactions. Degradation of the material occurs already during the processing phase, when polymeric substances are exposed to high temperatures, pressures and mechanical stress [4]. During the processing of the molten polymer, for example, the chains are degraded and cleaved, and flue gases are released. Then, when the material is processed or in the solid state, a second degradation step takes place. This degradation is less intense but long-lasting. It is caused mainly by weather influences. The changes are usually manifested by loss of gloss, discoloration, loss of transparency or cracks on the surface [5].
All materials are exposed to long-term exposure to the outdoor environment - specifically to weather conditions, which with their variability create a diverse range of operating conditions. Specifically, weather conditions, which with their variability form a diverse range of operating conditions. These conditions result in lower service life of the material, loss of the original mechanical or physical properties. In order to predict the life and stabilization of a given material, it is first necessary to understand the principles and mechanisms of degradation. The ideal solution would be to verify the polymer properties in real-time, which is often very difficult or even impossible. High demands are placed on materials, mainly for their service life, in some cases up to decades. Given the required operating time and the rapid development of new materials, it is difficult to wait for such a long period of time to verify the properties of these substances. For life prediction, they were thus invented methods that are called methods of accelerated weathering.

2. Materials and methods

The long-term effect of the external environment on the material causes changes that can be described as the weathering of polymers. This process is mainly influenced by light (or sunlight), UV radiation, temperature and its changes, humidity, oxygen and ozone. The sum of these external factors affecting the material is considered to be climatic conditions. There are other factors such as chemicals, the action of microorganisms, dust, air flow or other influences, but they are monitored only in special cases.

The greatest influence on the aging (weathering) of polymers has solar radiation, specifically ultraviolet (UV) radiation, which is part of sunlight. Ultraviolet rays usually break the bond between two atoms in the chain of a macromolecule, and the macromolecule breaks down into smaller units that react easily with atmospheric oxygen. We call this process photooxidation.

With the growing share of plastics in the outdoor environment, especially in the automotive industry, it is necessary to perform weather aging tests. It is with regard to the weather that the aging of polymers can be observed in either a natural or artificial way. In the method of accelerated aging, the main benefit is the fact that the results can be observed in a significantly shorter period of time. However, these results are only close to real natural aging, so they are only approximate. In natural weathering, however, it is necessary to wait a long period of time, which does not correspond to the speed of material development. Evaluation of natural and artificial weathering of polymers is evaluated according to the following Table 1.

| Table 1. Evaluation of natural and artificial weathering of polymers. |
|---------------------------------------------------------------|
| **External appearance of the exposed part**                  | Loss of gloss - discoloration - formation of cracks, depressions or irregularities - erosion by water, dust - cracking of the test specimen |
| **Mass (weight)**                                            | Weight change - loss of plasticizers |
| **Mechanical properties**                                    | Impact toughness, elongated at break, tensile strength, flexural strength |
| **Dielectric properties**                                    | Surface insulation resistance, volume electrical resistance electrical breakdown strength |
| **Mechanical properties of the exposed surface**             | Britteness of the surface layer, hardness of the surface layer |
Devices that can create conditions simulating natural weather are so-called veterometers. These devices can be used to simulate, for example, variable temperature, solar radiation, humidity, or various types of climate. The basic criterion according to which the residence time of bodies in the instrument is determined is the equivalent of the amount of light energy incident on an area unit of samples.

As part of the research, the aging of plastic products was simulated and analyzed using the Xenotest Alfa for lightfastness tests and simulation of weather conditions. All samples of plastic and wood-plastic products were placed on holders rotating on a carousel around a xenon lamp, and then an accelerated degradation and light stability test was performed.

The measurement was performed according to the standard CSN EN ISO 4892-2 from 2013 (64 0152). The measurement lasted a total of 1,000 hours. Exposure settings for filters using daylight simulating filters (artificial aging) are illustrated in table 2.

| Cycle no. | Exposure time (minutes) | Irradiation intensity (E, W/m²) | Black standard temperature (BST, °C) | Chamber temperature (CHT, °C) | Relative humidity (RH, %) |
|-----------|-------------------------|---------------------------------|------------------------------------|-------------------------------|---------------------------|
| 1         | 102.00 (drying)         | 60.00                           | 65.00                              | 38.00                         | 50.00                     |
|           | 18.00 (water spray)     | 60.00                           | OFF                                | 38.00                         | OFF                       |

3. Results and discussions

The research was simulated and analyzed the aging of plastic products using Xenotest Alfa for lightfastness testing and simulation of weather conditions. A total of 17 samples were placed in Xenotest Alfa. The list of samples of tested materials is in table 3. The evaluation of the artificial weathering of the tested polymers is given in table 4.
**Table 3. Overview of tested materials.**

| No. | Manufacturer - product                  | Material                     | Application                  | Lifetime a |
|-----|-----------------------------------------|------------------------------|------------------------------|------------|
| 1   | Lanit plast - Marlon ST IR Blue         | Cellular polycarbonate       | Roofing and vertical glazing | 10-year    |
| 2   | Woodplastic – Style plus Inox           | Wood plastic                | Terraces                     | 25-year    |
| 3   | Rehau - windowsill                      | PVC                         | Windowsill                   | -          |
| 4   | Inoutic - Adorn plastic window white    | PVC                         | Window frame                 | -          |
| 5   | WPC – Legacy Moca                       | Wood plastic with foil      | Terrace, railings, fence     | 30-year color |
| 6   | WPC – Premium forest Pallisander        | Wood plastic                | Terraces                     | 25-year color |
| 7   | WPC – Prémium star Inox                | Wood plastic                | Terraces                     | 25-year color |
| 8   | MAX WPC - terrace board dark brown      | Wood plastic                | Terraces                     | 25-year color |
| 9   | Polycasa Príbram - Elventa polycarbonate | Polycarbonate with UV filter | Translucent strips, roofing | 15-year    |
| 10  | MAX WPC - Lock tile gray                | Wood plastic                | Terraces                     | 25-year color |
| 11  | Lanit plast – Marlon ST Bronze          | Cellular polycarbonate       | Roofing and vertical glazing | 10-year    |
| 12  | Inoutic - Adorn plastic window black    | PVC                         | Window frame                 | -          |
| 13  | Polycasa - Elventa corrugated PVC, profile 76/18 | PVC with UV filters | Roofing                     | -          |
| 14  | Ecolux – Societe Ondex Cristal Jaune    | PVC with UV filters         | Roofing                      | 5-year     |
| 15  | Irpen Group                             | Polycarbonate               | Roofing                      | -          |
| 16  | MAX WPC - Anthracite interlocking tiles | Wood plastic                | Terraces                     | 25-year    |
| 17  | Freelite – Corrugated Translucent PVC   | PVC                         | Roofing                      | -          |

a Warranty stated by the manufacturer.

**Table 4. Evaluation of tested materials.**

| No. | Loss of shine | External appearance of the exposed part | Weight deviation (g) | Pre-weight | After-weight |
|-----|---------------|----------------------------------------|-----------------------|------------|-------------|
| 1   | Yes           | Minor                                   | Surface damage        | 4.12       | 4.12        |
| 2   | -             | Major                                   | No                    | 63.82      | 63.14       |
| 3   | Yes           | Medium                                  | No                    | 3.40       | 3.39        |
| 4   | No            | Minor                                   | No                    | 12.98      | 12.97       |
| 5   | No            | Minor                                   | No                    | 134.58     | 134.58      |
| 6   | Yes           | Major                                   | Surface damage        | 113.55     | 113.53      |
| 7   | -             | Major                                   | No                    | 47.54      | 47.53       |
| 8   | Yes           | Major                                   | Significant surface damage | 39.2       | 39.00       |
| 9   | No            | No                                      | No                    | 9.32       | 9.25        |
| 10  | -             | Major                                   | No                    | 33.83      | 33.60       |
| 11  | Yes           | Minor                                   | Surface damage        | 2.41       | 2.40        |
| 12  | No            | Minor                                   | No                    | 15.12      | 15.12       |
| 13  | Yes, Minor    | Minor                                   | No                    | 2.79       | 2.79        |
| 14  | No            | No                                      | No                    | 2.69       | 2.69        |
| 15  | No            | No                                      | No                    | 12.19      | 12.19       |
| 16  | Yes           | Medium                                  | No                    | 35.63      | 35.63       |
| 17  | Yes           | Major                                   | No                    | 3.55       | 3.55        |
The appearance of the samples before and after exposure to the weathering simulation can be seen below. The sample is tested on the left after testing and on the right before testing.

**Figure 2.** Appearance of samples before and after exposure to weather aging simulation.
4. Conclusions

The paper describes the process of polymer degradation. Samples of plastic and wood-plastic products were placed in the device Xenotest Alfa, which can create conditions simulating weather conditions. Thanks to this simulation, the aging of polymers can be observed rapidly. Before and after the simulation, the external appearance of the exposed part and the change in weight are monitored. Evaluation of all tested materials is in the Results chapter. The most significant changes occurred in cellular polycarbonates, polyvinyl chloride (PVC) without UV filters and especially in wood plastics. The manufacturers of the tested wood-plastics guarantee a color fastness of 25 years, while all of them have significantly changed their color and one of them has even significantly damaged the surface. This study contributes information on the aging of plastics and wood plastics. This knowledge is necessary and useful for the development of new materials.

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