AGING PROCESS OF POLYMER MATERIALS AND THEIR SERVICE LIFE

Rakhmonov Tokhtasin Nurmamatovich
assistant of the Department of "Materials Science" of the Andijan Mechanical Engineering Institute
+998 91 609 42 63 E-mail: traxmonov1960@gmail.com

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ABSTRACT:

The service life of polymer materials and their aging process are of great importance in industry and everyday life. Physicochemical changes resulting from natural and artificial influences change the structure, strength and functional properties of polymers. This article reviews the causes of polymer aging, methods for their analysis and strategies for increasing service life. Based on the experimental results, the degree of aging of polymers under different conditions was assessed and technological solutions were proposed to extend the service life..

Introduction: Polymer materials are widely used in modern industry, construction, electrical engineering, automotive and medical fields. Their lightness, low cost, corrosion resistance and flexibility make them preferable to traditional materials. However, like any material, polymers begin to lose their initial physical, mechanical and chemical properties over time. This condition is called “aging”. The aging process directly affects the service life of the polymer and reduces its reliability. The causes of the aging process are diverse, among which temperature, ultraviolet radiation, oxygen, humidity, mechanical stress and chemical environments play an important role. These factors lead to the breakage, branching or oxidation of polymer chains, which affects the structure and strength of the material. In particular, polymer products used outdoors are subject to rapid degradation as a result of ultraviolet radiation. The service life of polymers depends on their field of use and external environmental conditions, and the issue of predicting or extending this period is one of the important technical problems. Modern analytical methods, including thermal, optical and spectral methods, are widely used to study the factors that cause aging and combat them. Also, technological approaches such as protective coatings, stabilizers, modified polymer types significantly extend the service life. In this article, we will experimentally study the aging process of polymer materials under various conditions and analyze ways to increase their service life. It is also planned to assess the degree of aging, identify structural changes and develop effective stabilization methods based on laboratory experiments.

Research and methods: In this study, the effect of various factors (heat, UV radiation, mechanical stress and humidity) on the aging process of polymer materials was experimentally studied. Common polymers such as polyethylene (PE), polypropylene (PP) and polycarbonate (PC) were selected. Each sample was exposed to different temperatures (from 25°C to 120°C), radiation intensities (400–800 W/m²) and humidity levels (30%–90%). The intensity of the aging process was assessed by changes in physical and mechanical properties. The main parameters analyzed were tensile strength, elongation limit, surface hardness, color change and molecular weight. Measurements were carried out using a universal testing machine (Instron 3369), FTIR spectral analysis method, thermogravimetric analyzer (TGA) and DSC (Differential Scanning Calorimetry).

In addition, microstructural changes due to aging were analyzed using a scanning electron microscope (SEM). Cracks, yellowing, and arcuate deformations in the appearance of the samples were also documented through photographs. Each sample was exposed to up to 250 hours and measurements were repeated every 50 hours. As a result, it was found that the service life of polymers is significantly reduced depending on the specific environmental conditions. For example, a PP sample exposed to high UV radiation lost 50% of its initial strength within 150 hours. In contrast, a polycarbonate sample reinforced with a stabilizer did not undergo significant degradation within 250 hours.

The second stage of the experiment focused on increasing the service life of polymers. In this stage, two different approaches were used:

1) adding stabilizers;

2) treating the surface with UV-blocking coatings.

Antioxidants (BHT, HALS) and UV absorbers (benzophenone, avobenzone) were used as stabilizers. Silicone-based transparent films and titanium dioxide-modified resins were used for coatings. The effectiveness of these changes was evaluated through experimental measurements. It can be said that the addition of stabilizers extended the service life of the polymer by at least 1.5–2 times, especially in high-temperature and radiation environments. The table below presents the main parameters studied, changes before and after aging. The figure also shows the state of polyethylene samples exposed to UV radiation for 0 hours and 200 hours.

Table 1. Changes in the properties of polymers before and after aging.

Polymer tur	Aging time (hours)	Strength (MPa)	Elongation (%)	Color change (ΔE)
PE	0	22.5	540	0
PE	200	11.2	310	15.3
PP	0	32.1	470	0
PP	200	13.7	180	17.8

PC+ stabil.	0	58.4	150	0
PC+ stabil.	200	52.1	135	4.6

Figure 1. Appearance of polyethylene samples before (left) and after (right) aging (after 200 hours of exposure to UV radiation).

Conclusion and discussion: The results of the study showed that the aging process of polymer materials has a significant impact on their service life and usability. All tested materials begin to lose their initial properties under the influence of external factors. In particular, thermoplastic polymers such as polyethylene (PE) and polypropylene (PP) lost their physical and mechanical properties in a short time under the influence of UV radiation, heat and moisture. This phenomenon is associated with the processes of oxidation, decomposition and radical formation of polymer chains. The appearance of carbonyl groups in the FTIR analysis results (around 1730 cm^{-1}) confirmed the oxidation process of the polymer. Also, based on DSC and TGA measurements, it was determined that the aged polymers lost their thermal stability. The degradation stage in the samples shifted down to 30–50°C, which indicates a decrease in their thermal stability. SEM analysis revealed microcracks, texture distortion and cavitations on the surface. These processes also directly affected the surface hardness and elasticity of the polymer.

In addition, the presence of color changes in the range of ΔE values in the range of 15–18 indicates a deterioration in the appearance of polymers. Under the strong influence of UV radiation, yellowing, fading of color, and roughness of smooth surfaces were observed. These conditions negatively affect not only the aesthetic appearance, but also the operational properties of the material. For example, polyethylene bags, car parts, or elements of outdoor structures that are used for a long time in the sun become deformed and unusable in a short time. Polypropylene, despite its high hardness, quickly layers and becomes prone to breakage due to its sensitivity to heat and light. These conditions reduce the operational reliability of the material.

At the same time, measures taken to extend the service life have proven effective. Structural damage was practically not observed in polycarbonate samples with the use of stabilizers (antioxidants, UV absorbers). The use of BHT (butylated hydroxytoluene) and HALS (light stabilizer) prevented the formation of radicals, and the polymer chains remained in a stable state. As a result, the mechanical properties of these materials remained stable for a long time, and the service life increased by 1.5–2 times. In particular, among the samples tested under the influence of UV radiation, it was found that the samples protected by a silicone-based surface coating retained a high level of smoothness, elasticity and strength. FTIR spectra showed that new functional groups were not formed in these materials, that is, the degradation process was not noticeable. The study showed that it is possible to plan and control the service life of polymer materials using protective layers and modified stabilizers. In practice, these technologies are environmentally and economically effective. For example, in the automotive industry or in construction materials that are in direct contact with the external environment, such approaches reduce material turnover and reduce maintenance costs. At the same time, technological solutions also increase the possibility of reducing material waste in the production process, reducing waste and increasing recycling. These results indicate the need for widespread implementation of advanced modification and protection technologies in the polymer industry.

Conclusion: The results of this study showed that the service life of polymeric materials can be significantly reduced depending on their exposure to external factors, such as heat, ultraviolet radiation, mechanical stress and humidity. The physicochemical changes that occur as a result of the aging process reduce the main properties of polymers, including strength, elasticity, surface smoothness and thermal stability. In particular, polyethylene and polypropylene materials have been observed to quickly yellow, become brittle and deform under the influence of UV radiation. This condition limits their long service life and reduces operational reliability. However, it has been proven that this process can be significantly slowed down when stabilizers and protective coatings are used. Stabilizers such as BHT, HALS, as well as silicone-based UV-blocking coatings have been shown to reduce the aging process of the material and maintain its molecular structure. Studies show that polymers with an extended service life are not only beneficial in terms of longevity, but also in terms of environmental and economic benefits. This will help to increase efficiency in polymer production, reduce waste, and expand recycling opportunities. On this basis, it is scientifically and practically important to study in depth the aging mechanism of polymer materials, apply optimal stabilization and protection methods, and apply an approach to material selection that is appropriate to the conditions of use. Such a systematic analysis of the approach will create the basis for the sustainable development of the polymer industry, the creation of innovative materials, and their widespread use.

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