Effect of UV Radiation on Mechanical Properties of Biodegradable Films

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The article is an attempt to answer the question, what is the effect of UV radiation on mechanical properties of printing bases such as biodegradable films. Technical development in production of biodegradable materials has been observed in recent years. At present on the market there are various biodegradable materials which characterize totally different properties. The samples of three kinds of biodegradable films (based on: PLA, starch and cellulose) were used in the study of effect of UV radiation on plastics printing bases.

Introduction

Ultraviolet radiation gives rise to light ageing, which is an unfavorable phenomenon. The wavelength of ultraviolet radiation (UV radiation) is 100-380 nm. A source of UV radiation is a part of solar light arriving to the earth surface, with the wavelengths within 280-400 nm, or commonly used fluorescent, halogen or neon lamps. Ageing is a process that leads to a weakening of properties of a given material with time. It destroys all elements of the environment, both living and dead ones. Paper ageing is a phenomenon which has interested research workers and scientists, as well as common people, for many decades. Systematic studies have been carried out since the second half of the past century to identify the mechanisms and characteristics of factors that accelerate the degradation of library collections, mainly of paper. Undoubtedly, besides such elements as water, fire, or atmospheric pollution, among the most harmful elements threatening the possibility of saving bibliophilic works for future generations, are variations of temperature, increased humidity and light, particularly in the UV range. The same factors produce changes of mechanical properties of other materials used as printing bases in typography [2].

From the viewpoint of the destructive effect on printing bases, radiation is one from the five models of artificial ageing. Radiation-induced ageing consists of exposing the samples of material to the action of radiation imitating the radiation present on the earth and comprising electromagnetic radiation in the region from ultraviolet through visible up to infrared. Formerly such tests were carried out under natural conditions, by locating a sample on a window pane and exposing to daylight. Thanks to the development of technology, accelerated ageing has come into practice with the use of laboratory equipment such as Ksenotest, now Suntest [2].

Investigation Methods

Biodegradable films were subjected to artificial ageing by UV irradiation. The time of UV treatment was different for different films, being 6, 24, 53, 77 [h] for films: 1, 3 and 4, and 6 and 53 [h] for film 2. The artificial ageing applied with the use of UV radiation is comperable correspondingly to 4, 15, 34, 49-day action of solar radiation.

Following the UV treatment the films were subjected to mechanical strength testing. Artificial ageing by means of UV radiation markedly decreased the mechanical strength of the film 1, film 3 and film 4 in both directions 1 and 2. The film 2 has no anisotropic properties hence the tests were performed for only one direction [1].

Characteristics of the Printing Bases

Four different samples of materials which represented three kinds of biodegradable films were used in the study of the effect of UV radiation on plastic printing bases. All films are made of natural raw materials and they are completely biodegradable. The first kind of material is a starch based film (designated as film 1). The second is based on cellulose (designated as film 2) and films 3 and 4 are the samples of polylactide (PLA) materials. Essential properties of the films are collected in the table (Table 1).

Artificial ageing

The process of artificial ageing involving irradiation with UV was realized with the use of Suntest CPS device by courtesy of Polish Security Printing Works (PWPW S.A.). The device enables the necessary experiments to be performed in a short time owing to the increased content of UV radiation relative to other wavelengths. It consists of a xenon radiator surrounded with a system of filters, composed of mirrors reflecting selectively the radiation, and a small quartz glass cup. The construction of the mirror reduces the access of infrared radiation and enhances the effect of visible and ultraviolet light. The range of wavelengths emitted by the device is 280-830 [nm] which is similar to natural visible light. The cooling system included in the Suntest enables a required constant temperature to be maintained throughout the whole ageing process (~50oC). The intensity of radiation in the band emitted by the device is 830 [W/m^2]. The equivalent energy of natural radiation recorded in Central Europe within one year in a room is produced by the device within about 24 days. A 29-day exposure of a sample in Suntest gives a dose of radiation comparable to that obtained in a one year exposure outdoors. Artificial ageing does not guarantee the reproduction of the slow action of natural agents in time but it provides merely some imitation of such conditions. Hence it should be regarded merely as a convenient, comparative method that gives a possibility to obtain quickly some information on processes occurring in a material under the action of external agents [3].

Testing of mechanical properties of the biodegradable films

The studies were performed with the use of Lloyd Instruments AMETEK LRX Plus tensometer with a software enabling computer analysis of the results. The device was made available by Warsaw Factory of Graphic Inks (WFFG S.A.). Samples for the tests were prepared conforming to ISO 527-3:1998 [4]. The width of the strip was 10 [mm] and the length was 200 [mm] for all films tested, initial distance of the clamps was set to 50 [mm]. The speed of stretching was 100 [mm/min]. For each film 10 samples were tested and mathematical average was taken as the final result.

Results and discussion

Mechanical properties of the films before and after artificial ageing under UV irradiation are presented on the figures: 1 to 6. On the figures are used the abbreviations, which mean:

- film 1/1 – film based on the starch with anisotropic properties, measurement in direction 1,
- film 1/2 – film based on the starch with anisotropic properties, measurement in direction 2,
- film 2 – cellulose film without anisotropic properties,
- film 3/1 – PLA film with anisotropic properties, measurement in direction 1,
- film 3/2 – PLA film with anisotropic properties, measurement in direction 2,
- film 4/1 – other sample of PLA film with anisotropic properties, measurement in direction 1,
- film 4/2 – other sample of PLA film with anisotropic properties, measurement in direction 2,
- initial peak load of total test 1 – measurement of initial peak load of total test in direction 1,
- initial peak load of total test 1 – measurement of initial peak load of total test in direction 2,
- maximum load between extension limits 1 – measurement of maximum load between extension limits in direction 1,
- maximum load between extension limits 2 – measurement of maximum load between extension limits in direction 2,
- average load between extension limits 1 – measurement of average load between extension limits in direction 1,
- average load between extension limits 2 – measurement of average load between extension limits in direction 2.

Table 1. Characteristics of biodegradable films used in the study

	Film 1	Film 2	Film 3	Film 4
Kind of material	starch based	cellulose based	PLA	PLA
Degradability	biodegradable compostable	biodegradable compostable	biodegradable compostable	biodegradable compostable
Tensile strength [MPa]	20-50 ASTM D882	70-125 ASTM D882	35/27 ISO 527	-
Ultimate elongation [%]	20-150 ASTM D882	22-70 ASTM D882	320/250 ISO 527	>110 ISO 527
Tear resistance [N/mm]	20-120 ASTM D1938	-	-	-

Figure 1: Changes of mechanical properties after ageing under UV

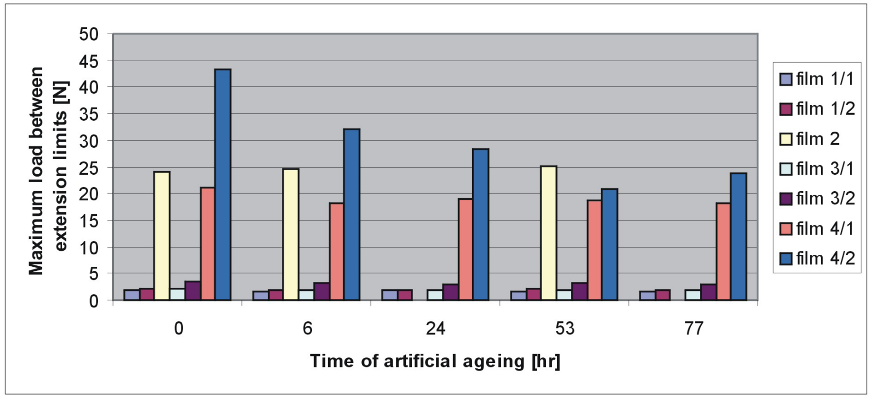
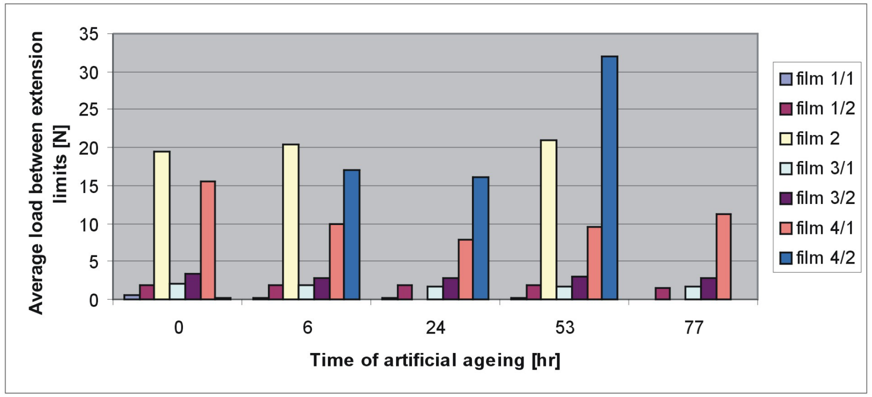


Figure 2: Changes of mechanical properties after ageing under UV radiation



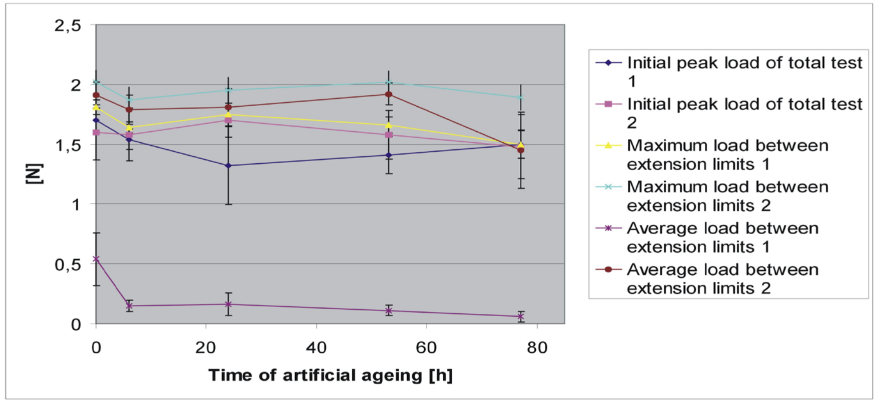


Figure 3:
Changes of mechanical properties after ageing under UV radiation for Film 1

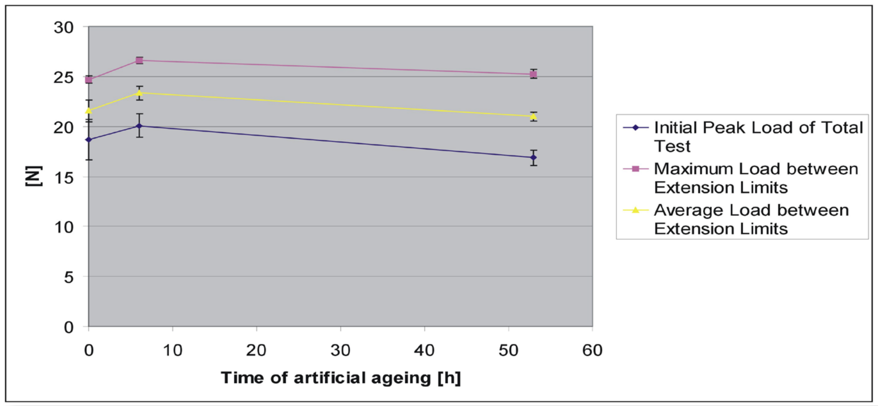


Figure 4:
Changes of mechanical properties after ageing under UV radiation for Film 2

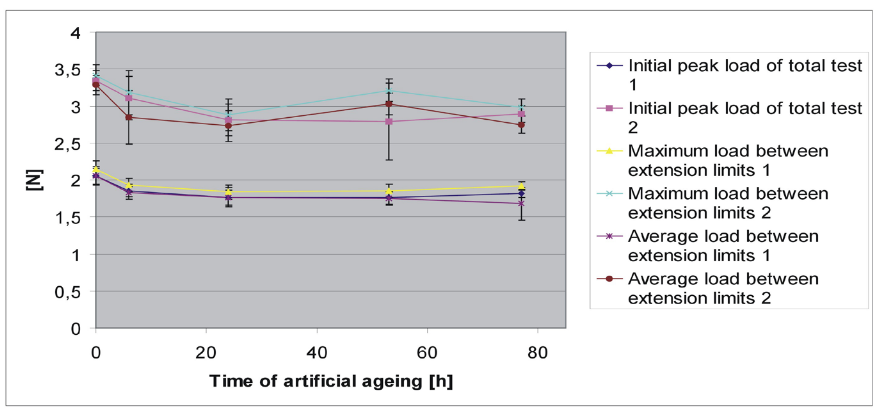


Figure 5:
Changes of mechanical properties after ageing under UV radiation for Film 3

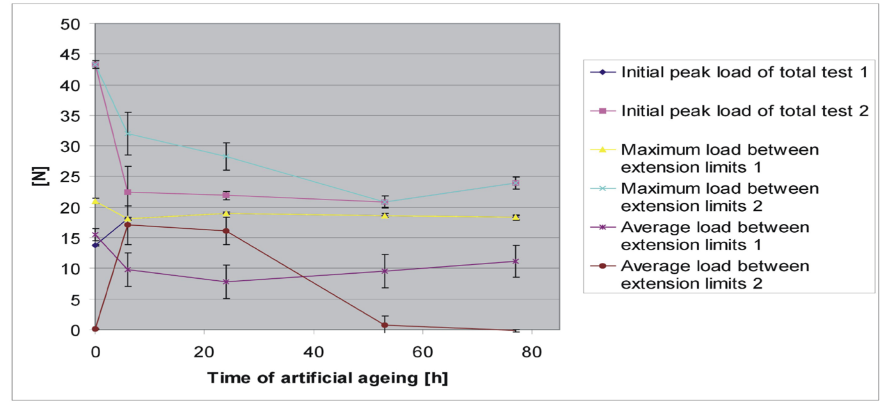


Figure 6:
Changes of mechanical properties after ageing under UV radiation for Film 4

Artificial ageing under UV radiation considerably changed the maximum load between extension limits of all films tested, but the greatest changes were observed in film 4 (fig. 1). The values of maximum load between extension limits for film 4 in direction 2 reduced markedly. Like in the case of maximum load between extension limits, the changes of the values of average load between extension limits were visible in all films, especially in film 4 in both directions 1 and 2 (fig. 2).

Film 1 exhibited a very high extension at rupture in the direction 2 (fig. 3). After the process of UV radiation ageing the extension was still high, but somewhat lower than previously. The tensile strength in direction 1 was considerably lower than in direction 2. The 6-hour irradiation of film 1 resulted in a greater decrease in strength than did the 24-hour irradiation. Seventy seven hours of exposure to UV radiation caused a decrease in rupture resistance of about 90% in direction 1 (average load between extension limits fell from 0,54 to 0,06), and about 25% in direction 2.

Mechanical strength of the film 2 increased minutely after irradiation with UV light (fig. 4). The values incrise did not fall within the experimental error. The values of maximum load between extension limits for film 2 decreased not more then 2-3% in both ageing times. As in the case of maximum load between extension limits the changes of the values of average load between extension limits were very low.

Compared to the other films the chanes of mechanical properties of the film 3 were the least changed (fig. 5). The changes of mechanical strength parameters between directions 1 and direction 2 were in similar range and amounted about 59%. UV irradiation of film 3 in both directions did not caused large changes of values of both parameters such us: maximum load between extension limits and average load between extension limits, and amounted not more then twelve percent.

Seventy seven hour irradiation of film 4, what conformed 49-day of natural ageing, resulted very low tensile strength of material (fig. 6). Maximum load between extension limits in film 4 in direction 2 were changed considerably. The changes of this parameter in direction 1 were almost insignificant. Even so, shorttime ageing such as 6-hour irradiation of film, corresponding to 4-day natural ageing, caused an almost 50% decrease of strength in direction 2 and about 13% in direction 1 [1].

Conclusions

On the basis of the experimental works performed it is possible to state that mechanical properties of PLA films and films based on starch change more under the UV radiation ageing than the cellulose based film. Based on the kind of material, establishment of the general effect of UV radiation on mechanical properties of biodegradable films is therefore evident. The range of changes in the same kind of material depends strictly on the composition and initial properties. First PLA film differ from the second one as for streght parameters and composition. The influence of UV radiation on the mechanical properties of films with anisotropic properties can depends on the direction of material. The changes of values of maximum load between extension limits for PLA film (film 4) are significant bigger in direction 2 (45%) than direction 1 (13%). For film 1 and film 3 this changes are almost insensible.

A much wider scope of investigation is necessary to determine the all effect of UV radiation on biodegradable films. The research will be continuing [1].

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References

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