VETOR

Design of a Low-Cost Ultraviolet Degradation Chamber☆

Projeto de Câmara de Degradação Ultravioleta de Baixo Custo

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Abstract

For the development of engineering projects, the adequate selection of materials is crucial, especially concerning their mechanical properties. In practical applications, these properties can significantly be affected by the material in service undergoing some type of degradation. With the exposure to the external environment in service, a significant degradation is the one caused by the incidence of ultraviolet radiation (UV). This type of radiation has enough energy to break the chains of polymeric materials. Thus, it is important to study the effects caused by UV radiation on the behavior of this material class. To simulate this exposure, standardized degradation chambers are often used. However, this equipment is generally sold in high cost. Without equipment that simulates UV radiation, many research projects are unfeasible. In this work, it is aimed to present a UV chamber design using low-cost UV lamps for the degradation of composite materials. In addition to being more affordable, the chamber allows an accelerated degradation sufficient to carry out experimental academic research about UV degradation in polymeric materials.

Keywords

UV radiation • Degradation • UV chamber

Resumo

Para o desenvolvimento de projetos de engenharia, a seleção adequada de materiais é fundamental, principalmente no que diz respeito às suas propriedades mecânicas. Em aplicações práticas, essas propriedades podem ser significativamente afetadas, devido à degradação que os materiais podem sofrer em serviço. Na exposição ao meio externo, uma degradação que pode ocorrer é aquela causada pela incidência da radiação ultravioleta (UV). Esse tipo de radiação tem energia suficiente para quebrar as cadeias dos materiais poliméricos. Assim, é importante estudar os efeitos causados pela radiação UV no comportamento desta classe de materiais. Para simular essa exposição, muitas vezes são usadas câmaras de degradação padronizadas. No entanto, esse equipamento geralmente é vendido com alto custo. Sem equipamentos que simulem a radiação ultravioleta, muitos projetos de pesquisa ficam inviáveis. Neste trabalho, pretende-se apresentar um projeto de câmara UV utilizando lâmpadas UV de baixo custo para a

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degradação de materiais compósitos. Além de ser mais acessível, a câmara permite uma degradação acelerada suficiente para realizar pesquisas acadêmicas experimentais sobre a degradação UV em materiais poliméricos.

Palavras-chave

Radiação UV • Degradação • Câmara de degradação UV

1 Introduction

In the most diverse applications, materials may be subject to working conditions in which they are exposed to ultraviolet radiation (UV), mainly from the sun. Under these conditions, chemical and physical changes may occur in the material that can impact the desired material properties for the application in question. Ultraviolet radiation (UV) has a wavelength between 100 nm and 400 nm, and this range is divided into the bands: UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm), being the UVC band almost entirely blocked and the UVB band substantially attenuated by the atmosphere [1]. The wavelength range of the UV radiation has the potential to break the chemical bonds of polymers [2-4].

Thus, when it comes to materials of the polymeric class, there is a more expressive effect on the modification caused in the chemical structure because of UV exposure. In this way, breakage of chains and crosslinking of molecules may occur, modifying the physical, mechanical, and morphological properties of the polymeric material, such as color, weight, and degree of crystallinity [5,6]. In addition to these actions, UV radiation can cause photochemical degradation by the interaction of light photons with the polymeric chains [7]. Despite these factors, UV exposure can generate, on the other hand, a post-cure process in polymers, favoring the appearance of crosslinks, and bringing, for example, an increase in the glass transition temperature (Tg) and improvements in mechanical properties such as tensile strength, as highlighted by Barbosa et al. [5].

In addition to these changes in the material properties, when multiple degradation factors have effects on the material, UV radiation can cause the intensification of degradation by other factors, such as humidity. In this case, UV rays can generate microcracks on the polymer surface that favor water permeability, intensifying the degradation generated by water absorption [8]. The degradation caused by UV radiation in materials can change their mechanical behavior to the point of making their use in external environments unfeasible. Therefore, knowing the performance of the material when degraded is important to ensure the application of materials in environments exposed to UV radiation. It can also reduce the uncertainties of the projects, avoiding oversizing. To investigate this performance, according to the ASTM D904 [9] standard for exposure of adhesive specimens to artificial light, there are the degradation methods A and B. By method A, fluorescent UV-A lamps are used. This condition can be reproduced with actinic tube lamps. Degradation method B adopts xenon lamps, which are more expensive than fluorescent lamps. Thus, this article seeks to propose the development of a low-cost UV chamber using actinic tube lamps, obtaining degradation properties according to the method A. Considering the referred standard, it is also considered the degradation cycle II, in which all the samples are exposed to 24h of continuous UV radiation, without the use of condensation. The produced chamber is demonstrated to be feasible for allowing academic studies about UV degradation in polymeric materials.

2 Materials and methods

The UV degradation chamber was designed to expose the joints to artificial ultraviolet radiation with fluorescent lamps, according to the method A of the ASTM D904 [9]. The dimensions of the designed chamber were about 60 cm in length, 30 cm in depth and 35 cm in height. These dimensions are similar to those of the chamber designed by Chennareddy et al. [2], also applied to degrade composite materials. In addition, the adopted size is compatible with the standardized dimensions of specimens for tensile and flexural tests for polymeric and composite materials.

To estimate the needed number of lamps in the chamber, it is necessary to estimate the irradiation E for each one of the lamps in the chamber, given by Eq. (1):

$$E = \varphi / 2\pi a l \,, \tag{1}$$

where φ is the total radiation flux, a is the distance in relation to the lamp and l is the length of the lamp [10]. The needed number of lamps is determined to provide a desired irradiation over the samples, considering the sum of the irradiations given by each one lamp in the chamber.

2.1 Components of the UV degradation chamber

Actinic tubular lamps, model TL-BL T8 UV-A 15 W, with a radiation peak at 365 nm (Lucmat, China) were adopted for building the chamber. The lamp data, provided by the importer, is shown in the Table 2 of the Appendix A. Other similar chambers, based on the same standard, has been designed using actinic tubular fluorescent lamps similarly by other authors [2,11,12].

To connect the lamps, 2x15W high power factor instantaneous starter electronic ballasts with 220V/127V power supply were used. This configuration provided a better cost-benefit ratio than the adoption of individual ballasts for each lamp, in addition to reducing the consumption of wires. The connection between the lamps and ballasts was performed with 22 AWG (0.644 mm) copper cables, tin-lead solder, T8 sockets for connecting the lamps and brackets for fixing the lamps on the chamber wall by using screws.

3 Results and discussion

Based on the ASTM D904 [9] and G154 [13] standards, which deal with UV exposure devices, the irradiation potential to be generated over the samples for degradation was determined. Considering the Table x3.2 of the ASTM G154 [13] standard, the potentials of the range from 320 nm to 360 nm were added to those of the range from 360 nm to 400 nm, which are the bands that have the same range as the irradiation of the lamp. Thus, the chamber was designed to produce a radiation of 60.34 W/m^2 over the center of the samples.

By Eq. (1), the calculation of the irradiation over a given sample depends on the distance between the sample and the lamp. Thus, it was necessary to determine the distances from the lamps to the center of the chamber, where the center of the samples will also be, in general, probably located. Evaluating similar projects [2,11,12], with similar lamps and dimensions, it was noted that at least six lamps would be needed. Therefore, the distribution of the lamps in the chamber was made, as shown in Fig. 1. In the same figure, there are the distances of the lamps from the center of the box, where c and b represent the greatest and smallest distances, respectively, of a lamp from the center of the box. This is the point for the highest irradiance within vertical central plan of the chamber, parallel to the lamps.

Actinic tubular lamps were chosen, model TL-BL T8 UV-A 15 W with radiation peak at 365 nm (Lucmat, China). Lamps with this peak has already been used by other researchers [2,11,12]. The lamp data provided by the importer is shown in the Table 2 of the Appendix A. According to the G154 [13] standard, the most used lamps have a radiation peak at 340, 350 and 313 nm. The use of UVA lamps is justified since UVB and UVC rays are highly absorbed by the atmosphere [1]. Among the options for applicable lamps, alternatives with different brands and models can be found, as well lamps with different irradiation potentials, range, and peak of UV radiation. These variables must be carefully decided since the use of lamps with different characteristics can impact the degradations. Additionally, exposure conditions, ambient temperature, and geometric configuration of the arrangement of the lamps inside the chamber, especially in relation to the samples, are also factors with potential influences on the results. In this sense, these differences are considered by the ASTM D904 standard [9], which suggests that all degradation details need to be clearly described in the degradation methodology adopted, especially the specifications of the adopted lamps.

An additional factor about UV lamps is their lifetime. Generally, UV lamps have a usability limit of 8000h, but this can vary among different manufacturers. After this time, they may still emit light, but it is probable being no longer capable of producing UV radiation as it is ideally expected. Thus, the recommendation is that the lamps should be changed when their useful life limits are reached.

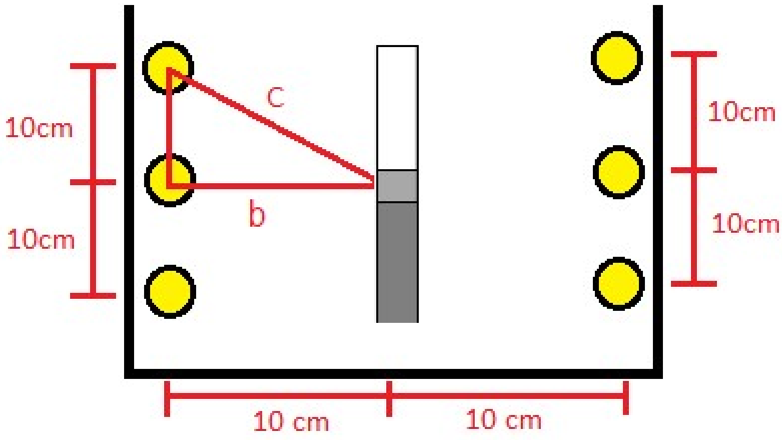


Figure 1: Positions of the lamps and the samples in the UV degradation chamber.

In the chamber, the distance b is 10 cm and the distance c is 14.14 cm. It is considered that the right side of the samples is directly irradiated by only three lamps and the left side by the other three lamps of the other side of the chamber. Taking into account the distances of each lamp in relation to the center of the chamber and that the adopted lamps have an approximated radiation potential of 3.5 W in the UV range according to the Table 2 of the Appendix A, the irradiation received at the center of the chamber is at least 61.4W/m^2. This value is equivalent to 221 kJ/h.m^2 and is slightly higher than the reference value calculated based on the standard, which is 60.34 W/m^2.

In order to compare the irradiation potential of the chamber with the average irradiation occurring in a given city, annual solar irradiance data were used, collected from the Sergio de S. Brito Reference Center for Solar and Wind Energy database - Electric Energy Research Center (CRESESB - CEPEL) [14]. Data from the Niteroi city, located at the Rio de Janeiro state, Brazil, were selected. In Fig. 2, there is a graphic that presents the average monthly global irradiation potential of the Sun in the city of Niteroi. There is a variation in the total values of irradiation over the months, compatible with the changes in the seasons over the year.

It should be noted that only about 5% of the entire energy potential of the solar irradiation is related to UV radiation [15]. Thus, as the global irradiation potential in Niteroi in one year is around 6284.20 MJ/m^2, considering only the UV range, there is a potential of 314 MJ/m^2 per year, approximately. Therefore, to simulate this solar exposure for one year with the designed chamber, approximately 60 days of exposure in the chamber would be necessary.

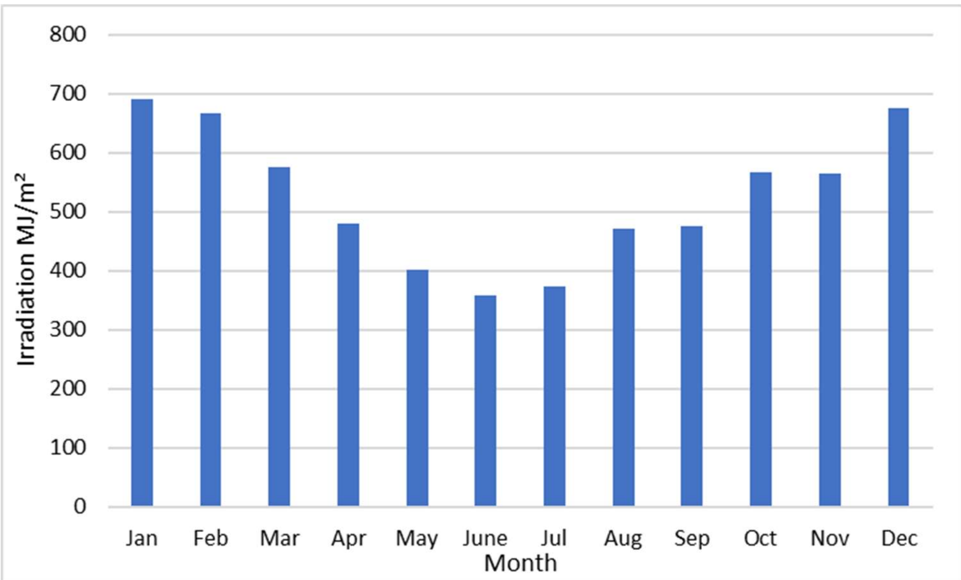


Figure 2: Monthly global radiation for Niteroi [14].

It should be noted that the walls of the entire chamber were covered with aluminum foil. It provides a mirrored surface, reflecting all the radiation that does not fall directly on the specimens, with the aim of making better use of the radiation produced by the lamps and making the effect of degradation more uniform on the samples. Furthermore, for the calculation of the potential, only the irradiation generated in a straight line over the joint was considered, disregarding the diffuse effect of irradiation along the entire length of the lamp. Therefore, the chamber produces enough radiation to meet the requirements of the standard and the values obtained are compatible with those obtained by other authors. In Fig. 3, we have the image of the designed chamber, in (a) it is presented the interior of the chamber and the distribution of the lamps, and in (b) the chamber is turned on.

Since these lamps have heating potential, the chamber temperature was checked during operation. A thermocouple was used to measure the temperature. It should be noted that the measured temperature suffers small variations depending on the ambient temperatures throughout the day and in the different seasons of the year. The average temperature observed was around 60°C. Temperature is also a factor responsible for modifying polymers, being responsible for favoring post-cure effects, for example.

(a) (b)

Figure 3: Internal view of the UV chamber, turned off and on.

3.1 Cost

The present work seeks to propose not only a project for the construction of a UV chamber that follows the normative standards, but also to provide a low-cost project that can be easily reproduced, favoring possible new research in the context of ultraviolet degradation.

In this section, the number of items used in the produced chamber and the average cost of each one based on the values found on websites are presented. Table 1 shows the items, the needed quantities, the average unit cost and the total cost of each group. It lists the lamps, ballasts, sockets (lamp connectors), clamps and screws, which are the items directly related to the operation of the lamps. Other components are needed to build the chamber, but, in this project, there are some reused items from other electronic equipment, such as cables and connectors. In addition, tin solder wires, insulating tape, aluminum foil and nails are needed to build the chamber, which are lower cost items. For these items, the value of R$50.00 was attributed.

Table 1: Items adopted by the chamber and respective costs.

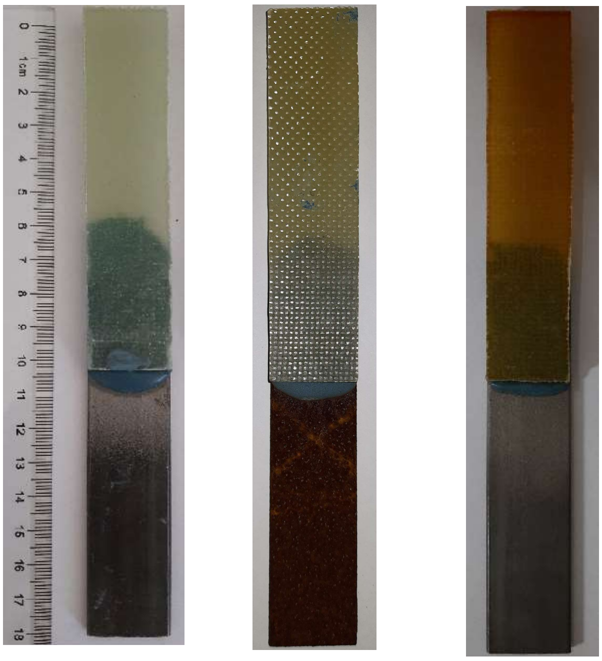
Items	Quantity needed	Unit cost [R$]	Total cost [R$]
Lamps	6	40.00	240.00
Ballasts	3	30.00	90.00
Sockets	12	2.50	30.00
Clamps	12	2.00	24.00
Screws	12	0.35	4.20
Other items	1	50.00	50.00
		TOTAL	R$ 438.20

It should be noted that the presented project was built using a wooden crate box. In Fig. 4, there is an external photo of the built chamber, being also presented its dimensions. At least two boxes were used to get enough wood to completely close the box and build the lid. Internally, the chamber is lined with aluminum foil, the escape of light through the gaps between the wooden slats of the box is small and can be minimized by sticking tape over the gaps. This proposal proved to be efficient and very economical, being an alternative that significantly reduced the costs of preparing the chamber structure.

From Table 1, it can be noted that, for the UV chamber shown in Figure 4, approximately R$ 438.20 were spent, a significantly lower value than commercial UV chambers, a fact that may enable new studies in UV degradation. Small UV chambers that use only two UV lamps of 8W, that is, much less power than the designed chamber, used for biological analysis, have an average cost around R$ 1500.00. It should be noted that these models are not standardized to ASTM D904 [9]. Models based on the standard, sold by specialized companies in laboratory equipment, are more complex devices and allow combining exposure to UV radiation with continuous condensation. For these models, a much higher cost is expected, costing around R$80,000.00 the simplest models. Therefore, the cost of the proposed chamber is significantly lower, which may allow more researchers aimed at the degradation of polymeric materials.

Figure 4: Degradation chamber built in a wooden crate box.

It should be noted that the produced chamber has already been used to degrade polymeric composites reinforced with glass fiber and metal/composite adhesive bonded joints with epoxy adhesive. In Figure 5, in (a) there is a metal/composite adhesive bonded joint without UV degradation, in (b) one exposed for 180 days in the external environment, subject to solar radiation, and in (c), a joint exposed for 180 days in the projected UV chamber.



(a) (b) (c)

Legend: Joints in (a) without degrading, (b) exposed to external environment for 180 days, (c) exposed to UV radiation for 180 days.

Figure 5: Effect of external degradation and artificial UV exposure on metal/composite adhesive bonded joints.

In these degradations, the severe effect of UV radiation on the exposed materials is evident, being more significant in the color change in the composite adherent exposed to the artificial UV radiation produced in the chamber. The obtained results are presented in more details in the reference [16].

4 Conclusions

The mechanical behavior of polymeric materials can be modified by the action of environmental factors in which the material is subjected in service. Ultraviolet radiation is one of those agents that can change the performance of the material. Thus, in this work, it is sought to present a UV degradation chamber that follows the standards and a low cost to be produced. In this way, it was presented the development of a UV degradation chamber with an investment of less than R$500.00. The project meets the requirements of the referenced standards and is compatible with the work of other researchers who have already developed research using similar projects. The designed UV chamber makes it possible to emit, in 60 uninterrupted days of exposure to radiation, the equivalent of exposing the materials to one year of sun radiation.

It should be noted that improvements that make the project safer and more efficient can be carried out, but at a higher cost. Among these improvements, one can mention: protecting the polymeric items of the chamber, such as adapters (sockets) and cables from UV radiation, adapting a viewfinder with a UV filter that allows viewing the inside of the chamber in operation and the use of a radiometer to verify the operation of the lamps in the UV spectrum.

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APPENDIX A

Table 2: Used lamp technical data.

Information	Data
Rated power	15 W
Irradiation potential between 320 and 400 nm*	3,5 W
Radiation peak	365 nm
Model	T8
Electrical terminal	G13
Diameter	2.6 cm
Length	45 cm
Lamp life	8000 h

* Estimated data