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LEGO® under stage light: studying the ABS light-stability through a complementary multi-analytical approach

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Abstract. Throughout the 20th Century, plastics found extensive use in fashion, art, and design due to their versatile nature. However, their degradation over time poses challenges, impacting material integrity, particularly in museum collections. To tackle this issue, different scientific techniques have been employed to study polymers. In this work, a complementary multi-analytical approach is proposed to investigate the light stability of ABS compounds, selecting LEGO® bricks as reference material. The method is based on fluorescence emission and lifetime integrating point-like analysis and imaging systems to corroborate chemical and spatial information specifically addressed at the surface level. The latter has shown promising results in studying ABS objects, offering insights into degradation and aiding conservation efforts.

1 Introduction

Plastics have changed the face of society and economic status since the introduction of the first semi-synthetic polymer, i.e., cellulose nitrate at the end of the 19th Century. From that time, the plastic industry registered a great expansion, especially during the World Wars when the research of synthetic alternatives to natural resources gained priority. Moreover, since the early beginning of the 20th Century, plastics have been extensively used in the fields of fashion, art, and design. Their versatility mainly depends on the type of formulation from which the polymeric structure is obtained. Colorants together with other additives may be added to enhance the aesthetical, physical, and chemical properties required for specific applications. However, they have proven to degrade over time, causing changes in aesthetics, material loss, and the production of dangerous volatile species that affect surrounding objects. Their study and identification in museum collections, where they are particularly susceptible to environmental parameters, are essential to setting specific conservation guidelines [1].

To address this issue a wide range of scientific techniques, both invasive and non-invasive, have been selected to investigate the chemical and thermal properties of Acrylonitrile-Butadiene-Styrene (ABS) based polymers [2]. Since the chosen analytical protocol was mainly based on bulk thermal analysis, the present work has been proposed as a complementary multi-analytical approach based on studying optical fluorescence emitted by fluorophores at the surface of ABS-based objects. Excitation-emission fluorescence spectroscopy (EES) together with time-resolved photoluminescence (TRPL) spectroscopy will be applied to LEGO® bricks made of ABS polymer. Intact and artificially aged LEGO® bricks will be studied to determine how fluorophores are modified by plastic degradation. A further step will be the integration of imaging systems to assess spatial changes to the properties of fluorescence emission from LEGO® bricks, as was successfully applied to study ABS objects [3]. Microscopic and macroscopic analysis will be finally considered to cross-reference the results obtained with morphological changes on the surface of LEGO® bricks.

2 Experimental

2.1 Samples

Green LEGO® bricks (The LEGO Group) have been studied in this work since made of ABS formulation. The samples were purchased and photoaged artificially by the CNR-SCITEC group according to Sabatini *et al.* 2023 [2]. Two stages of the photoaging process have been selected to highlight changes in the samples: not degraded (t0, 0h of light aging) and 525h degraded (t525, 525h of light aging corresponding to a dose of 621 kJ/cm^2).

2.2 Analytical protocol

In this work, LEGO® bricks were studied using EES which has proved to be a valuable analytical technique in the classification of plastic materials [4] and detection of additives residues [5]. However, the characterization of fluorophores is not so straightforward. Thus, the study of the decay kinetics of the optical emission improves the

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overall comprehension of the fluorescent compounds present on ABS surface and how fluorophore concentration changes during degradation. The fluorescence techniques will further allow us to assess the presence of fluorescent additives and/or colorants in the ABS matrix, and how they are affected by photodegradation. To evaluate spatial changes of the optical emission at the surface of LEGO® brick fluorescence spectral and lifetime imaging (FLIM) will be further considered since the two techniques have already produced precious insight into the degradation of ABS design objects [3].

Morphological changes on the surface of LEGO® bricks were assessed with two optical imaging methods made available by the CNR-INO group: (1) laser microprofilometry and (2) spectral-domain optical coherence tomography (Sd-OCT), as a function of aging time. Both techniques operate on a micro-scale axial resolution, the latter having a higher spatial resolution. The first technique is based on the conoscopic holography using visible laser light (λ=649 nm) [6] while the second on the interferometric measurements exploiting near-infrared broad-band radiation with a central wavelength at λ=900 nm and bandwidth of 150 nm [7]. Laser microprofilometry has been used to acquire the entire unaged and photoaged sample surface topography while Sd-OCT to probe regions of interest through the acquisition of OCT tomocubes (2x2x0.5 mm) (Fig. 1).

3D models obtained through measurements with a laser microprofilometry of unaged and aged sample surfaces (Fig. 2) clearly show morphologic changes induced by artificial aging followed by ethanol treatment that can be further quantified in terms of roughness characteristics.

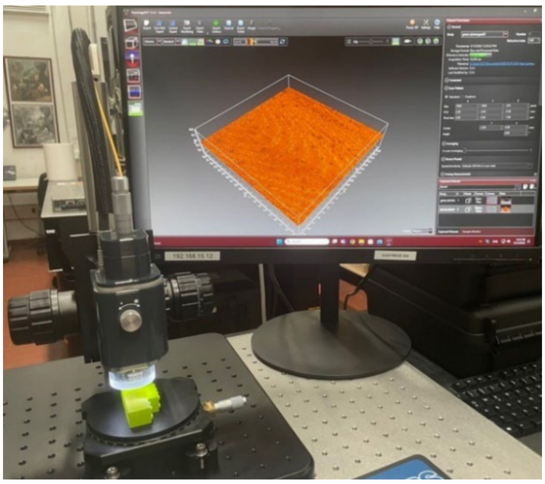

Fig. 1. Set-up for the SD-OCT acquisition of the OCT tomocubes.

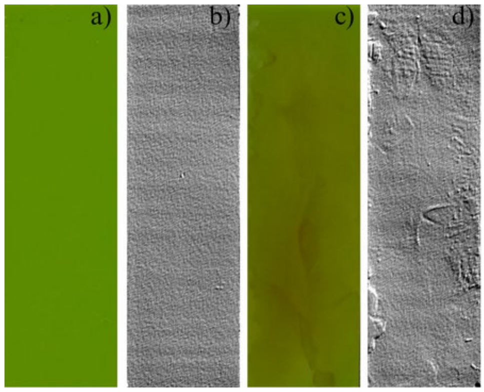

Fig. 2. Visible images of a) unaged and c) photo-aged LEGO® bricks (1x3.1 cm); respective 3D maps acquired with laser microprofilometry displayed as raking light images b) unaged, d) aged.

3 Conclusion

This multi-analytical approach proposed will complement the study of ABS-based materials from a superficial and morphological point of view, in the framework of [2]. Therefore, the monitoring procedure in museum collections of degraded plastics will be achievable. Further information may arise from the study of the effect of additives and/or polymer residues on the degradation process through spectral imaging systems.

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