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Test Method

Testing and evaluation of mar visibility resistance for polymer films

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ABSTRACT

A key aspect of the perceived quality of polymeric materials is their resistance to visible scratch and mar damage. An effective set of testing and evaluation tools is needed for quantitative assessment of scratch and mar damage on polymer surfaces, which is critical for the development of scratch and mar resistant polymers. Mar damage is particularly challenging to quantify because the damage is subtle and is sensitive to imaging techniques, especially for white and transparent samples. In this study, a mechanical procedure for marring white and transparent polymeric films in a reproducible fashion that allows for study of the fundamental materials science is introduced. In the second stage of the process, an optical imaging instrument that exposes the marred films to light in a manner mimicking how our eyes perceive the mar damage is used. Finally, a machine-vision procedure is used for handling the images and quantitatively measuring the visibility due to surface damage. A good correlation is found between the machine-vision and the perceptions of a human panel. This methodology is useful for quantitatively assessing resistance of a sample to mar damage. It can also be used for establishing structure-property relationships between polymer material/surface characteristics and mar damage.

1. Introduction

Polymeric materials and thin films are extensively used in a wide range of industrial applications due to their good mechanical properties, lightweight, and processibility. They are increasingly replacing conventional materials like metals, wood, and concrete. However, their performance is significantly affected by different surface damages. For instance, sliding damages such as scratch and mar are frequently encountered in automotive, labeling and packaging, and electronic applications. Up to recently, the terms "scratch" and "mar" have been exchanged carelessly in some papers as if they meant the same damage [1]. However, scratch usually refers to medium to severe sliding damage while mar refers to shallow and faint sliding damage. An ASTM/ISO standard has been introduced to consistently study scratch behavior on polymeric systems [2,3]. Using this standard, extensive studies were recently conducted to reliably investigate the scratch resistance of polymeric systems [4–7]. The impact of different material properties and experimental parameters such as surface roughness [8], laminate structure [9], test rate and direction [10,11], thermal history [12], molecular weight [13], and molecular orientation [14] on scratch behavior was investigated.

Due to its subtle appearance and complex behavior, the standards and techniques developed for mar test are significantly immature compared to scratch standards. Very limited studies have been conducted to characterize mar behavior. Initially, mar damage was experimentally obtained using simple experimental techniques such as Amtec laboratory car wash test [15]. Although this test is realistic, it cannot be used to quantitatively describe mar resistance. To overcome this issue, previous studies showed that ASTM/ISO scratch standard can be reliably used to investigate mar behavior [16–18]. Mar testing can be conducted using test similar to this standard by replacing the sharp spherical tip used for scratch test by a tip with a wider area. This approach paved the way for new studies to better understand mar behavior and ultimately improve mar resistance of polymers.

The subtleness of mar damage on polymeric products makes it more associated with the degradation of their perceptual properties. Similarly, scratch damage affects not only the functional performance of polymeric materials, but also their aesthetic properties. Therefore, many attempts were made to characterize and improve scratch and mar visibility resistance. Rangarajan et al. used an optical imaging methodology to determine scratch visibility resistance on polymeric systems by measuring the contrast between the scratch damage and its

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surrounding area [19]. The promising results of this method encouraged other researchers to develop it and use it for scratch visibility analysis. Jiang and coworkers established a correlation between scratch visibility and scratch features, namely the height and depth of scratch grooves [20]. Recently, Hamdi et al. investigated the impact of perceptual properties (color, gloss, transparency, texture …) on scratch visibility resistance [17,21]. They demonstrated that it improves with bright, green, textured, and mate polymeric surfaces.

Similar attempts were also made to characterize and improve mar visibility resistance. A contrast-based analysis showed that mar visibility resistance improves with modified and textured surfaces [16]. In this previous study, mar perception was quantified using mar visibility onset based on previous studies on scratch damage. However, Hamdi et al. reviewed this method and demonstrated that, unlike scratch, the whole mar damage should be considered to determine mar visibility resistance [17]. The characterization of mar damage is still an ongoing effort. Since faint mar damage is more dependent on surface properties, perceptual properties like brightness and transparency have more significant impact on its visibility resistance [17,21]. Much more parameters and properties should be investigated to gain a better insight on mar visibility resistance. This necessitates the development of new experimental and computer-based techniques that facilitate the study of mar damage.

Surface Visualization Analyzer (SVA) software is one of the main techniques developed to automatically quantify scratch visibility resistance in polymers. This software is designed by Surface Machine System company [22]. Initially, scratch and mar images introduced to SVA were obtained using a scanner [20]. To improve SVA capabilities, a new sophisticated black box setup based on CIE D65 standard was recently introduced to capture scratch and mar damages [17]. The parameters introduced in SVA software are based on previous studies that approximated human perception [23]. These parameters consist of contrast, feature size, and continuity. The conditions considered by SVA software are threefold (1) the scratch should have at least 3% contrast against the background, (2) its feature size needs to be larger than 90 µm, and (3) its span within twice the diameter of the scratch tip should be continuous for at least 90% [23].

Although progress has been made, current test protocols are usually application-specific and have not yet been standardized. The goal of this work is to develop a standardized procedure for measuring scratch and mar that are applicable to a wide range of materials and applications. This procedure might replace several application-specific tests and allow us to establish fundamental correlation between material properties and mar visibility resistance. For example, if tensile strength could be correlated with resistance to visible mar damage by using this procedure, a manufacturer or formulator would be able to develop materials with enhanced tensile strength to improve the mar visibility resistance.

2. Experimental

2.1. Materials

The model films used in this study are summarized in Table 1. They consist of three white films (W1, W2 and W3) and three transparent films (T1, T2 and T3). These films were produced using a multi layer cast coextrusion and subsequently oriented in machine direction. To make the mar visibility resistances of the model films different with each other, films W3 and T3 were coated using an acrylic-based top coating, and the remaining films were prepared based on different polymeric blends as indicated in the table. All the model systems were provided by Avery Dennison Corporation. More information related to the materials investigated in this study is summarized in Table 1.

Table 1
Model films used in this study.

Sample	Color	Top Coating	Tested Skin Surface Composition	
			White Pigments	Polymer Base
W1	White	NO	NO	Blends of LLDPE and EVA
W2		NO	NO	Blends of LLDPE and EVA
W3		YES	Not Applicable	Not Applicable – Top Coating
T1	Transparent	NO	NO	Blends of PP and PE
T2		NO	NO	Blends of LLDPE and PP
T3		YES	Not Applicable	Not Applicable – Top Coating

2.2. Mar test procedure

Mar tests were conducted according to ASTM D7027/ISO 19252 standard [2,3] using a scratch machine manufactured and commercialized by Surface Machine Systems company [22]. This standard consists in applying a linearly increasing load on the model systems and observing the different damage transitions and features. The applied load increased from 1 N to 15 N, over a distance of 100 mm at a rate of 10 mm/s. This load range was selected to reliably induce consistent mar damages on the samples. Although our instrument can apply loads as low as 0.5 N, we chose 1 N as the minimum starting point to be completely within the reproducible range.

To fix the films to the backing material and reduce extraneous movements during scratch test, a custom-built vacuum fixture was employed, as shown in Fig. 1. This fixture was machined from a block of aluminum with a slot in the center to accommodate different backings. In this study, an aluminum backing was chosen to carry out the mar tests. The studied films were fixed to the backing by applying a vacuum pressure. Previous studies demonstrated that a pressure of 85 KPa was sufficient to obtain uniform stress on the studied films and exerted good adhesion to the substrate [9,14,24].

A self-aligned stainless-steel tip was employed to generate roughening-induced mar damages on the model films. It has a flat square surface with an area of 7 mm × 7 mm, as shown in Fig. 2. Preliminary tests showed that mar damages created using this tip are consistent and even across the width of mar area on the model films. To control mar-induced roughening on the model films, gritted sandpapers with different roughness levels can be mounted to the mar tip using double-sided tape (Scotch® Indoor Mounting Tape). In this study, FEPA standard 1200 grit and 4000 grit sandpapers were employed to create visible mar damages. Three mar tests were done on each film sample by each sandpaper to demonstrate consistent and reliable results. After performing the roughening mar tests on these samples, a time period of 24 h was allowed for elastic recovery before the film samples were imaged and analyzed for comparison. The same test conditions were considered for all the samples.

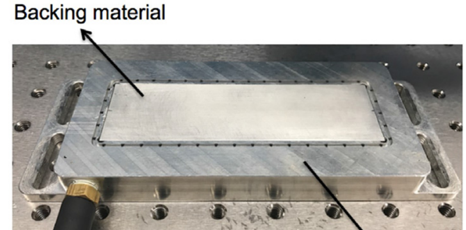

Fig. 1. Vacuum fixture for film samples.