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Contrast-based evaluation of mar resistance of thermoplastic olefins

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ABSTRACT

The physical aspect of mar behavior is studied by applying a standardized progressive sliding load methodology to smooth and textured automotive-grade thermoplastic olefins. It is shown that surface texture has a strong effect on light scattering and, hence, the propensity for mar visibility. It is also shown that digital imaging *via* a desktop scanner can be used to quantitatively and objectively assess mar resistance using contrast as a basis. Incorporation of slip agent definitively improves the mar resistance for both types of surfaces. Relationships between contrast, gloss and surface roughness in relation to mar visibility are discussed.

1. Introduction

Surface appearance is a key point of interest for the manufacturing of many consumer products. Today, customers will often judge the quality of automobiles, cellular phones, digital media players, LCD displays and many other products on their esthetic appeal as much as their functionality. When minor deformation is present on a surface, it might disrupt the virgin appearance of the surface and can lower the esthetic value. Common deformation includes warping, chips, cracks and damage arising from sliding contact. This last type of deformation is referred to as "mar" or "scratch" in literature [1–4] and is evaluated by various industrial testing standards (Ford BN 108-13, General Motors GMN3943 and Daimler-Chrysler LP-463DD-18-01). Basically, a "mar" or "scratch" can be viewed as a linear or curvi-linear surface deformation feature caused by the sliding of an asperity or asperities acted upon by an applied normal load.

Polymers are being increasingly incorporated into consumer products because they are lightweight, cost-effective and, often, environmentally friendly (i.e. recyclable or "green") alternatives to metals and ceramics. When surface appearance is important, one key factor of concern for the use of polymers over other materials is that their surfaces are typically more prone to surface deformation and damage. At a critical applied load, the magnitude of the resulting surface deformation will reach a level at which it is visible to the eyes of a human observer. The assessment of esthetic quality has long been qualitative and rife with subjectivity. However, recent advancements have brought closer an understanding of the relationship between the physical nature of polymer surface deformation and visual perception.

There are many methods currently in existence that have the aim of characterizing mar and scratch resistance of polymers [5–11]; but, on a grand scale, definitions for the terms "mar" and "scratch" have not been explicitly outlined. From convention, it seems that "scratch" damage is most commonly related to surface deformation resulting from a sliding asperity, which is visible to unaided human eyes. This is brought about by a phenomenon termed "stress whitening" where the deformation is brighter than the background [11]. "Mar", on the other hand, appears to be related to the same type of surface deformation; but it is either more visually subtle than the visible scratch damage or is not as severe to the extent of plowing, cracking or tearing [9]. At times, "mar" is compared to the damage that results from a process such as a car wash [7]. All in all, the differentiation between these two types of deformation arising from the same process is quite ambiguous.

The 5-finger scratch and mar test employed by automakers specifies that, under the same loading conditions, a spherical tip with a diameter of 1 mm is to be used for characterizing "scratch" damage and a 7 mm diameter tip be used for "mar" damage. From this specification it would appear that "mar" damage is indeed related to subtle deformation from a sliding asperity as a larger tip provides larger contact area and, thus, a lower level of applied stress. Additionally, Sue and co-workers have differentiated between mar and scratch by employing a progressive load test [4–6]. Using this methodology, the surface deformation existing before the onset of scratch visibility has been termed the "mar" region. The difficulty in differentiating between these two terms is that they have been used rather loosely without first being explicitly defined. At any rate, "mar" and "scratch" do appear to

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be uniquely different, but the physical aspects of each need to be better understood.

The aim of the current work is to explore the physical aspects of surface deformation under low-stress sliding contacts, namely, the mar behavior. It will be shown that a strong relationship exists between changes in surface roughness, gloss and contrast that influence the visual perception of a surface and the notion of esthetic quality. It will also be demonstrated how digital image analysis can be used to assess visible surface deformation as it would be perceived by the average human observer.

2. Experimental

2.1. Model systems

The thermoplastic olefins (TPOs) used in this study were provided by Advanced Composites, Inc. in the form of black injection-molded plaques that are commonly used in automobile interior applications. The dimensions of the TPOs were 150 mm by 100 mm with a thickness of 3 mm and the surfaces were produced with two textures: smooth and simulated leather grain. The TPOs were also prepared with and without a fatty amide additive intended to reduce surface friction and improve mar and scratch resistance [12].

2.2. Mar and scratch tests

Scratch tests were performed in compliance with ASTM D7027/ISO 19252 using a 1 mm diameter stainless steel spherical tip. A progressive load range of 1–30 N was employed at a speed of 100 mm/s for a length of 100 mm.

Progressive load tests were also performed using two other tip geometries: a 7 mm diameter sphere and a "barrel"-shape tip with a length of 12 mm and a diameter of 10 mm (Fig. 1); both made of stainless steel. The barrel tip was constructed with a single-axis tilt feature to allow for self-alignment to ensure that the entire length of the cylinder contacts the TPO surface. The axis was oriented perpendicular to the direction of tip movement as shown in Fig. 2. A progressive load range of 1–150 N was employed for both tip geometries at a speed of 100 mm/s for a length of 100 mm.

For all tests, the direction of tip movement was aligned with the melt flow direction of the injection-molded plaques. At least three test runs were performed on the same plaque of each model TPO system to ensure repeatability. The tips were cleaned with a paper tissue prior to each test to remove any possible material accumulation.

Fig. 1. Photographs of tips used for mar testing.

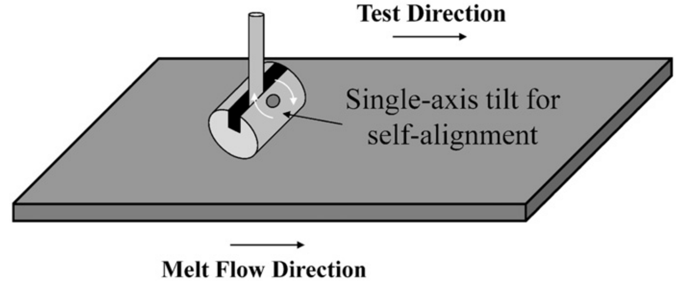

Fig. 2. Setup for tests employing a "barrel" tip.

2.3. Surface roughness evaluation

The surface roughness of the model systems before and after testing was evaluated with a Keyence VK-9700 violet laser scanning confocal microscope (VLSCM) using a 10× objective (NA=0.34). The wavelength of the laser is 408 nm and maximum spatial and height resolutions are roughly 120 and 1 nm, respectively. Image stacks were obtained using the VK Viewer software package while the VK Analyzer software package was used to process the resulting images and obtain roughness measurements. Processing steps included noise reduction and tilt-correction. Roughness was measured for the undisturbed TPO surface as well as for the deformed surface at points along the damage path spaced 10 mm apart. A 5 mm by 5 mm area was chosen to measure the roughness for comparison with specular gloss measurements.

2.4. Gloss measurement

The specular gloss of the model systems after mar testing was measured using a BYK Gardner Micro-TRI glossmeter at points along the damage path with 10 mm spacing. As with surface roughness, gloss was measured for the virgin TPO surface, as well. The measurement window for specular gloss in 60° geometry is 10 mm by 10 mm.

2.5. Digital image analysis

After testing, the surfaces of the samples were scanned in 24-bit color mode using an Epson Perfection Photo 4870 at a resolution of 300 dpi. A Munsell mini colorchecker card was scanned simultaneously to ensure that the resulting digital image represents the true surface nature. ImageJ (http://rsbweb.nih.gov/ij/) was used to capture the portion of the scratch path that was either darker or brighter than the mean virgin brightness by at least three percent.

3. Results and discussion

3.1. Scratch resistance of model TPO systems

The results of the ASTM/ISO progressive load scratch tests are shown in Fig. 3. From these results, it can be seen that incorporation of the scratch additive imparts a significant degree of improvement in scratch resistance to the TPO systems, regardless of texture.