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Effect of stick-slip on the scratch performance of polypropylene

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ABSTRACT

For the scratch process of polypropylene (*PP*), the stick-slip phenomenon always exists and contributes to the observed periodic surface damage patterns. The stick-slip, one main cause for scratch visibility, alters the surface characteristics of substrate and eventually induces scratch visibility. Both ASTM/ISO and Erichsen scratch test methods are employed to study the stick-slip phenomenon and its effects on scratch behavior of *PP*. Image analysis shows that the stick-slip phenomenon was responsible for material removal and severe surface damage. Possible solutions to improve the scratch performance of polymeric materials are also discussed in this paper.

1. Introduction

Widely utilized in automotive industry, consumer electronics, mechanical engineering and package industry, polypropylene (*PP*) has shown certain limitations, such as poor thermal barrier performance, low modulus, weak impact strength, and poor scratch resistance. The visible scratch damage on surface, one crucial concern for *PP*'s applications, induced by other relatively harder objects can diminish esthetic appeal, thus causing the loss of attractiveness or durability, but the intended functionality of components may still serve. The injection molding auto parts including control panel, door, and glove box will inevitably experience scratches during the process of manufacturing, transporting and daily using. To overcome this obstruction, it is necessary to understand the fundamental mechanism(s) behind the visibility induced by scratch.

Recently, many research works have been performed on the scratch behavior of polymeric materials [1–12]. It has been found that many factors, such as the crystallinity, additives, slip agent, toughening agent and surface texture have influences on the scratch resistance of *PP* based material. The recently established ASTM/ISO scratch test method [13,14] makes it possible to evaluate the polymer scratch resistance systematically and quantitatively. Investigations have been done on the scratch damage modes for different types of polymers including *PP*, PE, Epoxy, PS, PC, Nylon, SAN [1–12,15,16] and their micro/nano-composites [17–28]. Various scratch patterns, such as mar, fish-scale, parabolic crack, and material plow have been observed [15,29–31]. The shape of those surface scratch patterns, as well as the possible damage mechanisms, can be quite different [15,16]. What has been observed is that all of them are in a similar periodic fashion. The recurring scratch pattern can be observed not only on polymer materials [32,33] but also on non-polymeric materials such as ceramic and glass [34,35], as well as in nano-scale polishing process [36], thus proving that the recurrent scratch damage pattern is a common phenomenon for most materials. The periodic change of stress/strain status induced by the stick-slip is found to be an important mechanism of polymer scratch damage behavior [15,29]. Physically, the stick-slip between scratch tip and substrate is the instability from the couple of scratch head and underlay substrate. It is regarded as the physical cause of the repeated pattern of polymer scratch.

Generally, the onset of scratch visibility of *PP* based materials always occurs close to the beginning of periodic fish-scale pattern caused by stick-slip [6,15,29]. To improve *PP*'s scratch resistance and postpone the onset of scratch visibility, it is crucial to explain the physical nature of such a periodic feature. An analytical model has been proposed to explain the mechanistic process of the oscillatory stick-slip movement of the scratch tip [37]. In this paper, two types of scratch loading approaches, linearly increasing normal load per the ASTM/ISO method and constant normal load per the Erichsen delta-*L* method, are performed to analyze the stick-slip feature. The experimental results certify that the stick-slip phenomenon is well correlated with the scratch visibility. The effectiveness of the analytical model to describe the stick-slip phenomenon is also presented.

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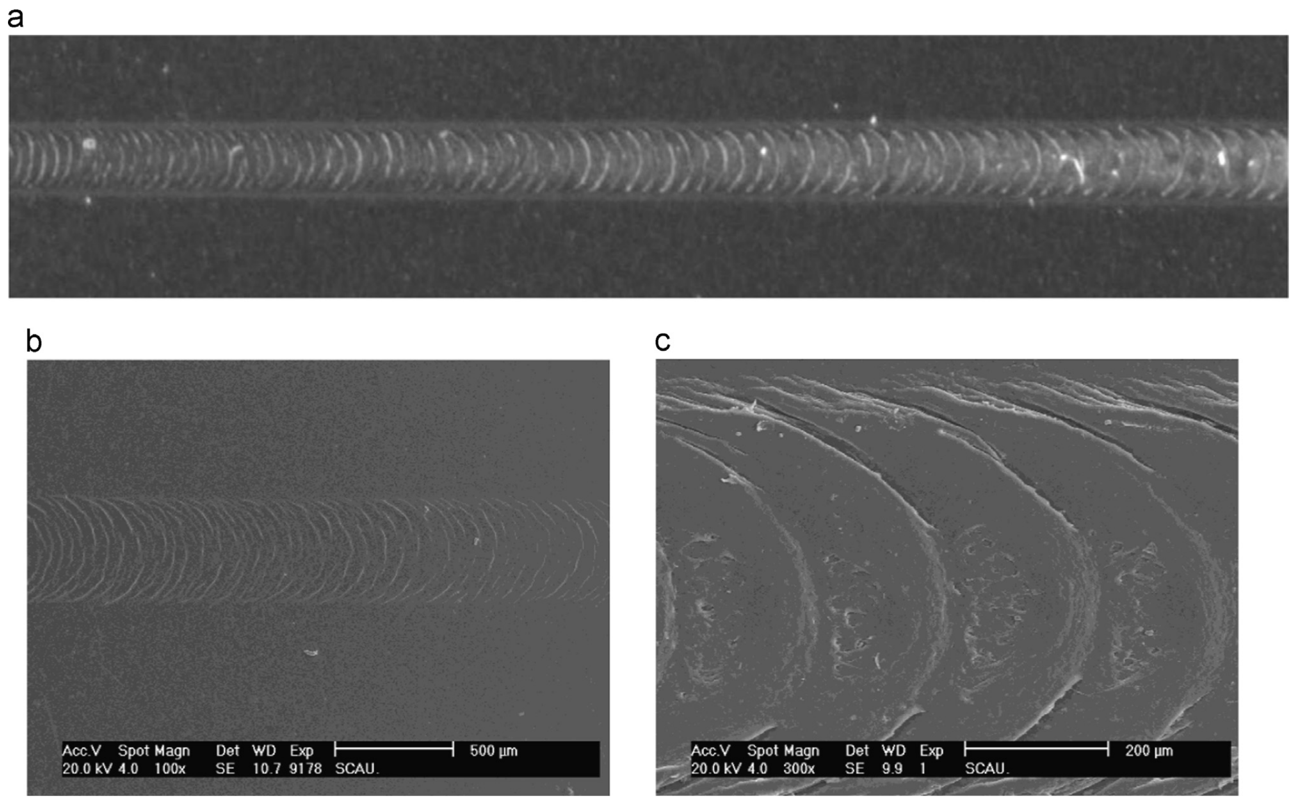

Fig. 1. Typical scratch periodical fish-scale feature of *PP*: (a) system 1 (scanner), (b) system 2 @6N (SEM) and (c) system 3 @14N (SEM).

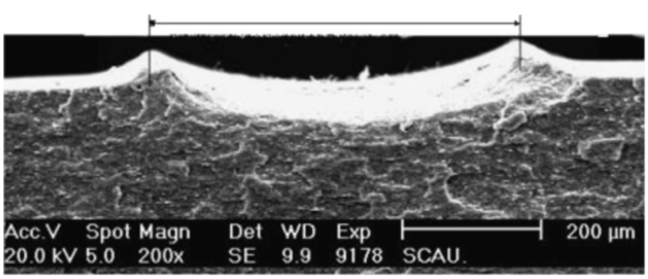

Fig. 2. Cross section SEM photograph of the system 3 (Delta-*L*=5.1).

2. Experiment

A scratch machine (SMS V4) following the ASTM/ISO polymer scratch standard was utilized to perform the linearly increasing normal load (1–30 N) scratch tests on the injected *PP* panels (system 1, with 70% polypropylene and 30% ethylene–propylene rubber (EPR), Advanced Composites). The diameter of scratch tip is 1 mm. The scratch test is conducted at the speed of 100 mm/s. High resolution optical scanner (Epson 4870) was used to investigate the periodic fish-scale scratch feature.

Utilizing the scratcher Erichsen 430P, other two injected *PP* sample panels (system 2 and 3) were tested following the plastic interior components testing of scratch resistance (PV3952, Volkswagen Automotive) to create cross-hatch scratch patterns. The diameter of scratch tip is 1 mm. The scratch test speed is performed at the speed of 1000 mm/min. The system 2, modified with Talc 3000 (GuiGuang Talc Development CO., LTD.) and commercial available anti-scratch additives, antioxidant (B225, CIBA), was supposed to exhibit better scratch resistance than the system 3 which is composed of copolymer (HHP6, SINAOPEC) and POE (ENGAGE8150, Dow's Chemical) without the additives. Both systems were scratched with different levels of constant normal loads: 6, 10 and 14 N respectively. Scanning Electron Microscope (HITACHI S3000N) was then employed to analyze the characteristics of scratched surface. The brightness increase of the cross hatch scratched area was measured with a Spectrophotometer (ColorQuest XE, HunterLab). The brightness difference from a scratched and non-scratch surface was obtained as the so-called Delta-*L* to give an expression of the brightness deviation in numeric values.

3. Results and discussion

3.1. *The evaluation of scratch resistance: Delta-L vs. scratch width*

Many parameters can be adopted to evaluate the scratch performance of polymeric materials. While the critical load level at the onset of scratch visibility is reported in the ASTM/ISO method, the difference of the brightness of sample surface (*L*) before and after the scratch test, named as Delta-*L*, is employed by Erichsen method to evaluate the material scratch performance. The worse the scratch resistance the material performs, the larger the value of Delta-*L* is. Although there is no straightforward correlation between these two parameters, the value of Delta-*L* could be a good qualitative index to evaluate the scratch resistance under certain load level.

The generally agreed upon view is that the scratch width, the residual scratch path left by the tip movement, is the characteristic of scratch deformation with great significance [37], which can be conveniently measured by the top-view or cross-section images, either from optical scanner (Fig. 1a) or SEM (Fig. 1b and c, Fig. 2).