Quantifying the scratch resistance of commercial polymers

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Working Party on Structure and Properties of Commercial Polymers

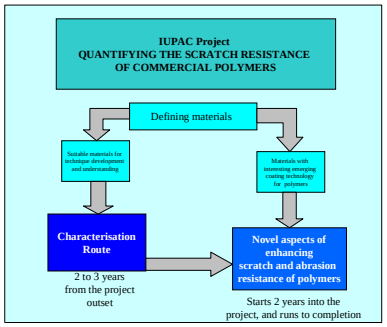
OBJECTIVE

To consider the range of scratching, abrasion and erosion techniques used in the plastics industry and to apply a more fundamental understanding of the issues that contribute towards scratch resistance. Using generic techniques to manufacture materials with a so called 'scratch resistant' surface. The project aims to identify some key links between bulk or coating mechanical properties and scratch and abrasion resistance.

Undertaking a project of this nature in the medium of an IUPAC Working Party, allows members to contribute interesting materials, and brings many different disciplines of polymer and materials science to a new but related subject.

PROJECT PLAN

The project is going to take two paths, each route will address an important issue in this field:-
1) Technique comparison and development for characterising the scratch resistance of polymers.
2) The characterisation of the emerging coating technologies that are being applied to polymers.



MATERIALS

In the preliminary part of the project, which considers techniques, industry standard tests, and new approaches, two amorphous polymers (high molecular weight polymethylmethacrylate and lower molecular weight (melt processable) polycarbonate) will be used as the substrates for coating technologies.
Each polymer will be characterised in terms of their fundamental mechanical properties such as modulus of elasticity, stress/strain function, toughness by fracture mechanics, and by established methods of assessing their scratch resistance.
On both polymers, two coating technologies will also be deployed. A traditional hard-coat, which is a UV- or thermally cured acrylic polymer with dispersed colloidal silica particles, and a novel soft-coat which offers contrasting behaviour.

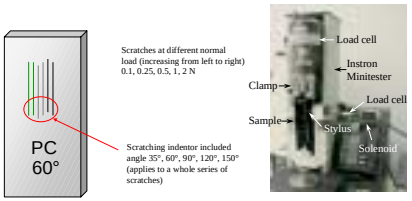
Polymer substrate	*Base polymer*	*Silica particles in cured acrylic coating*	*polystyrene-polyisobutylene-polystyrene triblock copolymer (thermoplastic elastomer)*
PMMA	✓	✓	✓
PC	✓	✓	✓
	Fundamental Material character	Mature Product technology	Novel Product technology

PRELIMINARY STUDY

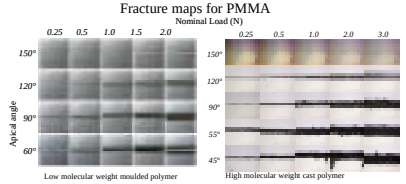
In order to help select the materials for the study, the polymer substrates (Polycarbonate and PMMA) have been scratched using the instrumented scratching approach. This allows the scratch resistance of a material to be mapped, in terms of it's scratch failure mechanism, friction and hardness characteristics.
The criteria for selection of the two amorphous polymers was that they differ in their behaviour, and in this way the role of any coating could be determined in the context of it's performance on a differing substrate.
Initially, plaques were injection moulded from both PC and PMMA, but this provided materials which were very similar in terms of their scratch performance. Consequently we decided to source a cast ultra-high molecular weight PMMA, and this was found to be both harder and exhibited crazing and brittle failure over a broader regime than the lower molecular weight PC counterpart.

EXPERIMENTAL

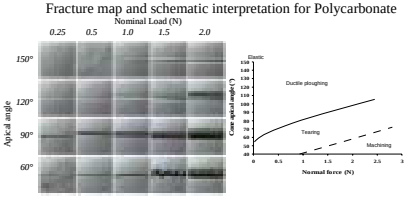
The instrumented single asperity scratch apparatus is shown in the photograph below, and the measures required for the calculation of friction and hardness are shown schematically.
Our aim in characterising these materials is to measure intrinsic properties as described earlier, then to generate a window of system properties (scratch and abrasion) using a simple geometry. Once this picture is complete, we aim to take industry tests (of which there are very many) and position them within the framework of the more fundamental and systematic measurements.

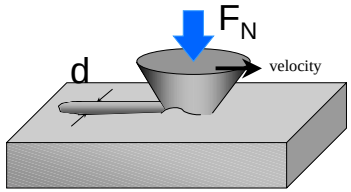


Fracture maps for PMMA



Fracture map and schematic interpretation for Polycarbonate

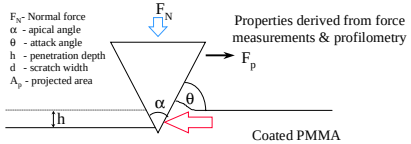




$$\text{Scratch hardness} = q\frac{4F_N}{\pi d^2}$$

$$\text{Coefficient of friction} = q\frac{\tan\theta}{\pi}$$

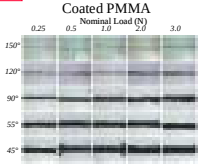
$$\text{Ploughing hardness} = \frac{F_p}{A_p}$$

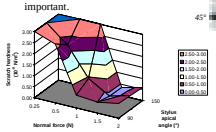


Properties derived from force measurements & profilometry

In coated systems, the coating properties can provide enhancement over the polymer substrate in terms of resistance to sharp asperities, or to indentation at high normal loads. At higher levels of penetration into the coating, the role of an interface and ultimately the substrate itself becomes important.

Coated PMMA





PROJECT STATUS AND FUTURE

The project is now ready to start in earnest. Materials have now been produced and will be circulated to all participants. The data shown here is the preliminary examination to ensure our materials requirements are satisfied.
This allows us to progress the characterisation part of the project. In parallel, work is starting to gather together the novel coatings that are emerging. These include coating technologies which may impart self-healing, anti-graffiti, electrically conductive properties in addition to scratch and abrasion resistance.

Working Party IV.2.1 (Characterisation of the structure and properties of commercial plastics) is enthusiastic about this new area of polymer science.

PROJECTS PARTICIPANTS

INDUSTRIAL - Bayer, ICI, BASF, Ausimont, Solvay
ACADEMIC – Ankara (Turkey), Warsaw, Lodz & Gliwice (Poland), London (Canada), Murseburg & Bayreuth (Germany), Cranfield & London (UK), Geneva (Switzerland).

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