Progress in Organic Coatings 61 (2008) 308–315

PROGRESS IN ORGANIC COATINGS

www.elsevier.com/locate/porgcoat

Relation between chip resistance and mechanical properties of automotive coatings

M. Lonyuk [a,*], M. Bosma [b], C.A.M. Vijverberg [b], A. Bakker [a], M. Janssen [a]

[a] *Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands*
[b] *Nuplex Resins B.V., Nieuwe Kanaal 7/N, 6709 PA Wageningen, The Netherlands*

Received 5 June 2007; accepted 4 September 2007

Abstract

This work addresses the correlation between stone-chip resistance and mechanical properties of automotive solid colour coating systems. Single-impact tests, which are believed to realistically simulate chipping due to stone impact, were performed to investigate eight different coating systems. Additionally, conventional tests on chip resistance currently used in automotive industry were performed. Results were related to mechanical properties of the coatings, measured by dynamic mechanical thermal analysis and double cantilever adhesion test. It is found that coating systems with a low glass transition temperature for the primer have better stone-chip resistance.

Keywords: Stone-chip resistance; Single-impact test; Automotive coatings; Glass transition temperature

1. Introduction

Stone-chip resistance of automotive coatings, i.e. the ability to withstand impact by stones with a minimum damage, is considered to be one of the important characteristics during service. Modern automotive coatings are applied as multi-layer systems. The study of their stone-chip resistance requires complicated testing and analysing equipment. Therefore, especially in the early stage of coatings development, it is useful to know the relation between stone-chip resistance and other mechanical properties. The dynamic mechanical thermal analysis (DMTA) is a well-known method to characterize polymeric materials. It is frequently used to obtain structure-property relationships and more specifically to study the effect of the coating formulation, curing schedule and weathering on mechanical properties of coatings. Several authors address in their works the analysis of DMTA test results of automotive coatings [1–6]. Zorll [7] conducted impact tests on automotive coatings in a wide range of impact velocity, angle and experimental temperature. He addresses the complexity of this phenomenon, concluding that it is possible to optimise the impact resistance of coating by carefully choosing the individual layers in composite coating system. Bender in his work [8,9] analysed stone-chip resistance and mechanical properties of polymer coatings and found that the glass transition temperature of the primer coating is the controlling factor in coating chipping. He showed that a coating with a low glass transition temperature has a better chip resistance compared to one with a high glass transition temperature. The experiments on chip resistance were done by a multiple impact procedure on an SAE J 400 Gravelometer test apparatus. The factors that increase glass transition temperature, such as increasing baking temperature, increasing catalyst level, and decreasing oil length, result in a decrease of the chip resistance. Bender also showed that chip resistance was mostly affected by the primer and much less by the topcoat. According to this author, the glass transition temperature of the topcoat was too high to have any effect on the chip resistance of the coating system. But there are not many similar studies to be able to draw a general conclusion on this subject.

The aim of the present work is to gain a better understanding of the relation between stone impact damage, measured on the basis of a single-impact test method developed at Delft Uni-

* Corresponding author. Tel.: +31 152782229; fax: +31 152786730.
E-mail address: m.lonyuk@tudelft.nl (M. Lonyuk).

0300-9440/$ – see front matter
doi:10.1016/j.porgcoat.2007.09.036

Table 1
Curing schedule and layer thicknesses of primers

Primer formulation	2	3	4	5	7	8	9	10
Curing schedule								
Time (min)	–	30	20	30	24	24	24	24
Temperature (°C)	–	140	160	140	140	140	140	140
Primer thickness (μm)	39	33	41	40	31	48	42	40

versity of Technology, and mechanical properties of the coating systems.

2. Experimental

2.1. Materials: coatings and substrate

Eight different coating systems were investigated in the present study. The tested coatings consisted of three layers: an electrocoat, a primer and a topcoat. The only variable in these coating systems was the primer. The primer formulations, curing schedules and thicknesses are given in Table 1.

Primer 2 is a commercial product. Primers 3, 4 and 5 are one-component (1 K) melamine cured primers, while primers 7, 8, 9 and 10 are two-component (2 K) isocyanate cured primers. The binders in all paint formulations are different. Primer 3 was prepared on the basis of saturated polyester. Primers 4 and 5 have the same binder, which was urethane-modified saturated polyester. An acrylic polyol with 1.8% OH was used to formulate primer 7. Slightly branched polyester polyol with 5.8, 4.3 and 8% OH was used to formulate the 2 K primers marked as 8, 9 and 10, respectively. All primer formulations have the same pigment to binder ratio of 110%. Primers were formulated at Nuplex Resins B.V.

The topcoat is a commercial product: Rouge Flash of PPG Industries. The thickness was 37 μm and curing was performed for 20 min at 150 °C. The paint formulations were prepared simultaneously for all tests in this study.

For the substrate standard automotive steel sheet (0.7 mm thickness) with a conversion phosphate layer and electrocoat (E-coat) supplied by PPG Industries was used. The interstitial free (IF) steel has the following composition (wt.%): 0.002% C, 0.011% Si, 0.1% Mn, 0.012% P, 0.007% S, 0.05% Al, 0.08% Ti. The yield strength and ultimate tensile strength of the steel were 141 and 276 MPa, respectively. The thickness of the E-coat was 19 μm.

2.2. Test methods

2.2.1. Conventional stone-chip tests

Conventional tests on stone-chip resistance were carried out, i.e. the VDA test and the BMW test. The VDA test, which falls into the category of multiple impact tests, is conducted at +20 °C. According to the VDA test procedure the panel is shot twice by 500 g of steel shot driven at a pressure of 1 bar. Between shooting the panel is soaked in water for 16 h at 40 °C. The appearance of the tested sample is then compared to standard photographs to determine the grade.

In the BMW test a wedge-shaped impacting body is pushed into the coated test panel, which in turn is supported by a massive metal plate. Before testing the apparatus and test panel is brought into a climate room at −20 °C for at least 1 h. The test result is expressed in terms of the width of the introduced damage.

2.2.2. Single-impact stone-chip test

Single-impact stone-chip tests were performed according to a method developed at Delft University of Technology. This test method, described in more detail in [10], is believed to realistically simulate actual stone chipping and to yield more quantitative information on stone-chip resistance than the conventional tests. A steel projectile with a cylindro-conical tip and a mass of 0.27 g is used to impact a coated panel at a certain angle, velocity and temperature. Afterwards adhesive tape is applied to remove chips of paint that are delaminated but not separated completely from the panel. The extent of the damage is then determined as the area of coating removal for each individual layer using an optical microscope.

In this work the impact angle was chosen as 45° and the impact velocity ranged from 7 to 39 m/s. Tests were carried out at +20, 0 and −20 °C. Five impact tests were conducted at each velocity. Subsequent analysis of the damage mechanisms was done using a scanning electron microscope.

2.2.3. Dynamic mechanical thermal analysis (DMTA)

To characterise the mechanical behaviour of the primers dynamic mechanical thermal analysis was performed on free-standing primer films that were prepared by spraying onto a polypropylene substrate. The typical film thickness used in the study was 40 μm. After subsequent curing of the film, rectangular samples of 3 mm × 40 mm were cut. The grip-to-grip distance during the DMTA was 30 mm.

DMTA was carried out on a modified Rheovibron analyser Toyo Baldwin DDV-II-C. The tests were performed under uniaxial tension at a frequency of 11 Hz and a heating rate of 5 °C/min. The storage modulus, E', and the loss modulus, E'', of the primers were determined in the temperature range from −50 to + 200 °C.

2.2.4. Double cantilever adhesion test (DCAT)

The adhesion level between the various primers and the topcoat was determined using a DCAT [11]. A polymer substrate was coated with one of the primers and successively with the topcoat. After curing both layers, a rectangular epoxy block was glued in the centre of the coated sample using a cold-curing epoxy adhesive. Subsequently a three-point flexure test was carried out on a Zwick tensile tester recording the force-displacement curve. From this plot the critical energy release rate, i.e. the amount of energy required to delaminate the coating from the substrate per unit area, was determined.

Tests were carried out at a number of temperatures in the range from −40 to +30 °C. Four samples were tested at each temperature. After the test it was established where failure occurred.