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# Visual defects of painted surfaces on ABS/PC injected parts

E. Raynaud, E. Darque-Ceretti, B. Monasse, P. Duquesne, F. Georgi

***Abstract*— A high surface quality is necessary for automotive industry especially for exterior parts. Most outdoors polymers are painted for aesthetic reasons as metallic parts. The quality aspect must be indistinctive of the nature of the substrate, metal or polymer, to produce a global high quality aspect of the vehicle. Whatever the material, metal or polymer, sometimes defects appear in small locations which lead to the rejection of the automotive part. Here is presented a specific defect, aligned dots on the painted polymer part which are not present before painting process. The analytical method is almost universal but the defect is specific. It results from the conjugation of polymer nature and process and from the nature of painting.**

## I. INTRODUCTION.

High gloss surfaces with a well controlled color are the main characteristics of body-car painting. For design reasons the color should be homogeneous on all the exterior surfaces of the car, even if a metal or interference paintings are applied. The design imposes a global appearance with various material exhibiting very different properties. For example stiff door and roof-car are necessary to preserve safety of passengers while soft car-bumpers are necessary for pedestrians and to recover the initial aspect of the car after a little hurt. The way is to use very different materials (metals, polymers) which are juxtaposed and painted [1]. Polymers are widely used to form bumpers, but also door profiles, spoilers and supports for registration plate. The choice of polymer results from weight, mechanical properties and from design considerations. Complex shapes with low radius curvature are easy to produce with polymer materials, by injection molding and much more difficult by metal forming.

Some polymers, like polypropylene and polyethylene, require a surface treatment (flaming, plasma …) to bond the paint-layer and to insure a good adhesion. Many other polymers (polyamide, ABS-PC, …) include chemical functions to form bonds with painting. As an effect of a good compromise shock-resistance, weight and price, elastomer-modified polypropylene is widely used to form bumpers. Other parts (spoilers, support for registration-plate) need a higher rigidity. So ABS-PC (acrylonitrile-butadiene-styrene 65% polycarbonate 35% blend) is preferred for this application [2]. After injection-molding, ABS-PC is easily painted as a result of its chemical functions.

Whatever the material (iron, aluminum, polypropylene, ABS-PC, …) the painting is usually applied without any trouble for wide diffusion products. A wide range of defects are observed such as peeling-off the paint layer, local change of brightness or of color, pit or pluck of the paint. These defects are specific of the material, of the paint and processing conditions. In automotive industry, their appearance is redhibitory for the aspect quality of the vehicle and implies a rejection of the part [3].

The visual defect here analyzed consists in align dots on painted parts. This defect is not present on ABS-PC parts after injection-molding step. It appears in specific zones only at the end of painting process. Only some parts present this defect after painting. The location of the defect is systematic but its appearance seems to be random.

## II. MATERIALS AND METHODS

### A. *Polymer aspect and defect location*

The same ABS-PC, white color, was injected in two different moulds to fix the shape: a support of registration plate and a spoiler. After the injection-molding step no defect is visible on the surface even if a microscopy observation is applied. Small polymer barbs are polished on the edge of the part. Following the industrial process each geometry is painted with a different paint: a blue cap of registration plate (fig. 1) and a white spoiler (fig. 2).

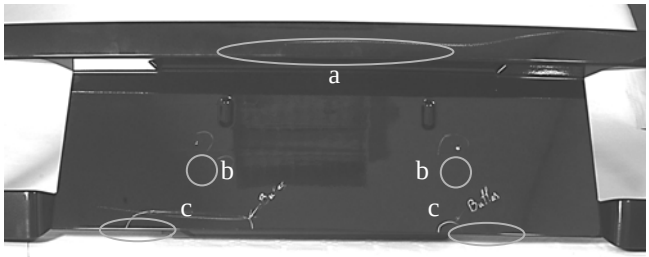


Figure 1. A cap of registration plate (five defective zones are bordered)

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Figure 2. Bottom view of a spoiler (the defective zone is bordered)

More than 99% of the painted surface is glossy with a homogeneous color. The defects appear only very small zones located always at the same location for each geometry (fig. 1, 2): near the mold-gate (fig. 1a), at the contact of weld-lines (fig.1b) and at the end of filling zone (parting-line) (fig. 1c, 2). The weld-line results from a bypass of an obstacle in the mould by the molten polymer. All these locations are tightly connected to process geometry. They appear on flat surface with a complex flow (fig. 1b) and on regions with a very small radius curvature (fig. 1a, 1c, 2). For optical reasons they are more visible on a flat surface than on a small radius.

### *B. Painting*

A part of the answer comes from the painting process which must be detailed. The first step is the deposit of a primer layer (7 to 8 µm thick). Then it was desolvated during 8 min. This polyurethane primer presents a high energy of adhesion with the substrate and allows fixing layers superior to the polymer. Then a basecoat including colored pigments is then applied. Its thickness depends on color: 30 µm for white and 17 µm for blue paint. The deposit is done in two steps with 9 min total desolvation time. A 25 to 35 µm thick topcoat is deposited and desolvated during 10 min. Lastly the whole part is heated at 85°C during 40 min in a drying oven.

The defect does not appear during these intermediate periods for painting. They are observed after cooling from the oven.

## III. RESULTS

It is necessary to observe with a closer view the defects to define their nature and origin. They appear as dots distributed along a line (fig. 3) and along a weld-line. This parting- line is usual after injection-molding process. The painting is insufficient to mask this geometrical defect and this line is usually observed after painting. The dots are strongly connected to this processing detail.

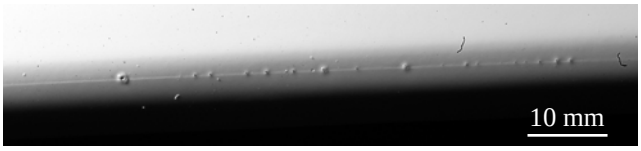


Figure 3 : Macrography of dots aligned on the top the spoiler

An observation by optical microscopy under reflection (Leica DMRX) shows out that each of these dots seems to be a bubble (fig. 4).

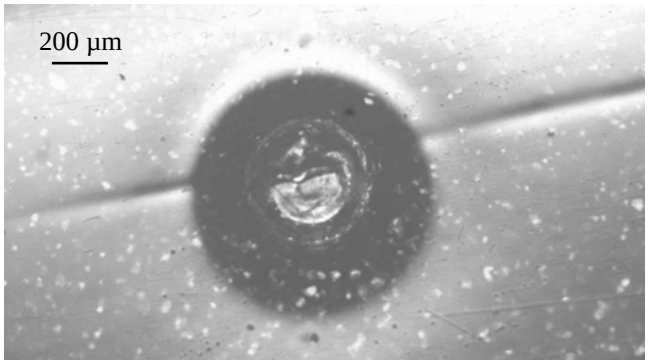


Figure 4 : A bubble (dot) observed by optical microscopy on a line defect

The bubble is centered on the parting-line and its size varies from 50 µm, for the smallest, up to 400 µm. Their size is sufficiently large to be observed, 60-70 µm is the norm for a detection of an isolated detail (1” arc) with naked eye. Hypothetic individual bubbles with a size smaller than 10 µm could be undetected following the industrial test of quality. The size of the defect and their correlation (alignment) are crucial for their detection. The dark ring around a bright circle including some details results from a protuberance of the surface which produces this optical effect (dark-field reflection) (fig. 4). The blue pigments inside the basecoat can be also observed as clear dots on figure 4. The bubbles can be observed in more detail with SEM (FEI/Philips XL30ESEM) (fig. 5).

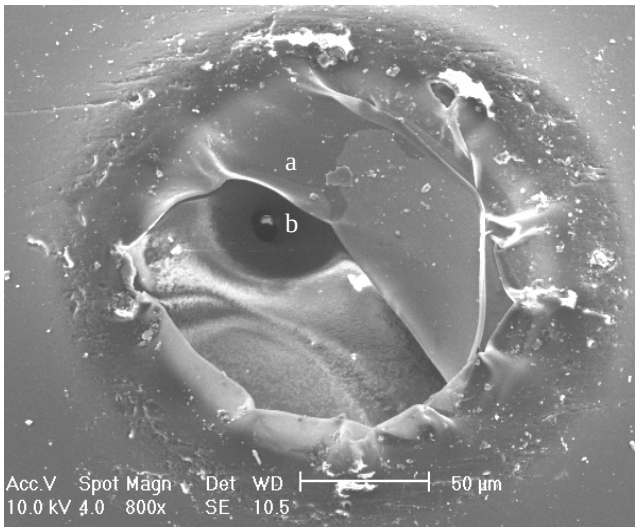


Figure 5: SEM observation of a bubble with a broken foil a) and a hole b)

A small bubble (diameter ~200µm) is presented in figure 5 which is significant of all the bubbles observed on the

painted parts. They are formed by a cavity partly covered by a very thin foil which mainly produces the protuberance observed by optical microscopy. The foil is not complete and has been broken (fig. 5a). A hole is shown out in the bottom of the bubble (fig. 5b). From these observations it is suspected that the bubble is located in the paint layers with no clear evidence of its presence in a specific layer.

It is necessary to observe the inner part of the material with the three paint layer to locate the bubble. Thin layers (5 μm thick) were cut-out in planes perpendicular to the surface and perpendicular to the line defined in figures 3 and 4. These cut were done all through the bubble (fig. 6).

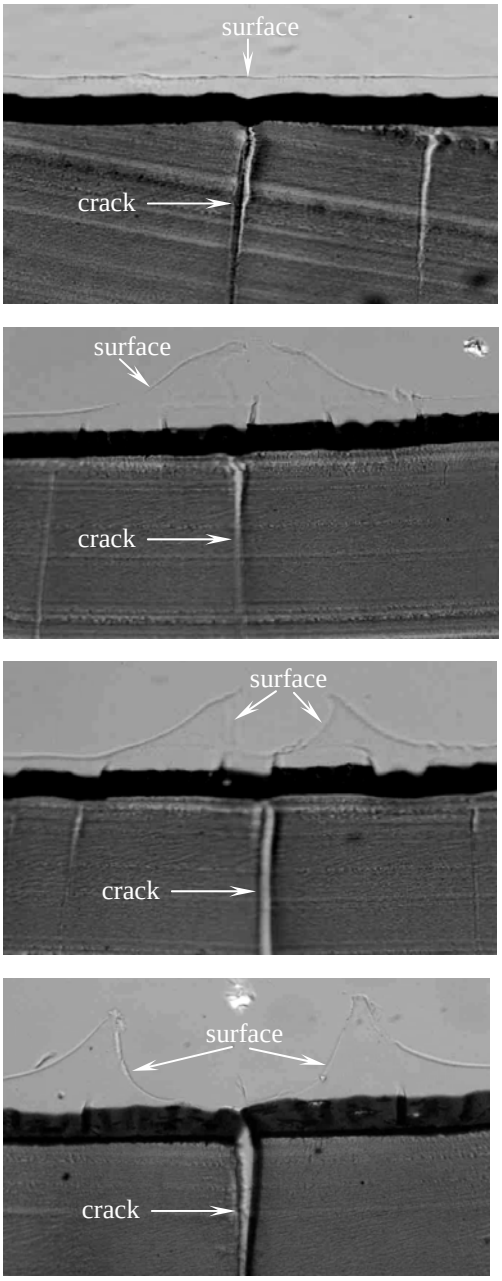


Figure 6: optical microscopy under transmission of thin cuts through half a bubble: from a border (a) to the diameter (d)

The bubble is confined in the topcoat and results from deformation of the material only in this superficial layer. These bubbles and volcanoes have very similar shapes. An observation of superficial part of ABS-PC shows the presence of a crack perpendicular to the polymer surface. This crack is stopped at the boundary with the primer layer (fig. 6a to 6c) aside in the centre of the bubble where the primer and the basecoat are broken (fig. 6d). This rupture is observed as a hole in the bottom of the bubble (fig. 5b). In that point, there is a direct connection between the crack inside the polymer and the bubble.

## IV. INTERPRETATION

The strong correlation between these different experimental facts strongly suggests an explanation. A simple one is to suppose a crack is provoked by some painting solvents which initiate the crack in the polymer. In combination with this primary effect, the solvent diffuses inside the crack. At the end of the industrial process the painted part is heated. The solvent contained inside the crack is vaporized and strongly expanse. Gas escape from the crack at the weak points of the primer and basecoat to form holes (fig. 5b). Then the gas inflates the bubble in the topcoat up to the rupture of the thin foil (fig. 5a).

This model implies various hypotheses and critical points for the formation of these defects. A direct connection of the cracks with the parting-line is required. The model implies the role of polymer cracking by some solvent. It also implies that the solvent diffuses inside the crack very early, during the primer or basecoat deposit. A random weakness of the primer and basecoat along the surface explains why the holes, and therefore the bubbles, are randomly distributed along the line. Finally, this interpretation implies that the topcoat is still a liquid-like material during the bubble inflation. These various points should be checked to strengthen the model.

The effect of solvents can be studied by immersion of injected parts inside some of these solvents during a time of painting (10 min at room temperature) (fig. 7).

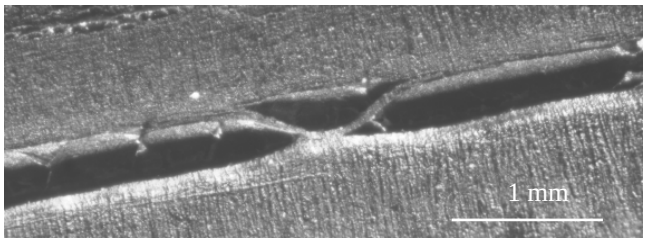


Figure 7: Macrograph of a crack on the surface after immersion inside solvents

The crack appears on the surface along the line defined in figures 3 and 4. The present crack and observed on

painted polymer have almost the same depth. The result of this experiment confirms the role of solvents to open polymer crack and to form a reservoir for the solvent.

In the location of the bubbles, the primer and the basecoat layers have an almost constant thickness when the topcoat is highly deformed up to form a very thin foil (fig. 5). This observation implies that during bubble expansion the primer and basecoat were almost solid materials and topcoat almost a liquid. It must be noticed that the diffusion coefficient of solvent in material in solid-state is considerably lower than in a liquid-state. This general behavior implies that the solvent widens polymer crack was present either in primer or in basecoat solutions.

Thus these solvents open a crack only along the line described in figures 3 and 4 and along the weld-line. The rest of the surface, almost the complete surface, is unaffected by the contact with the solvents. The crack formation is not the result of an intrinsic sensitivity of polymer to the solvents. A local detail of the injected-polymer should explain this sensitivity. This detail has been searched along the line after injection-molding. You should remember that polymer is polished in that zone before painting. Microscopic observations have been done on injected-parts before and after polishing (fig. 8).

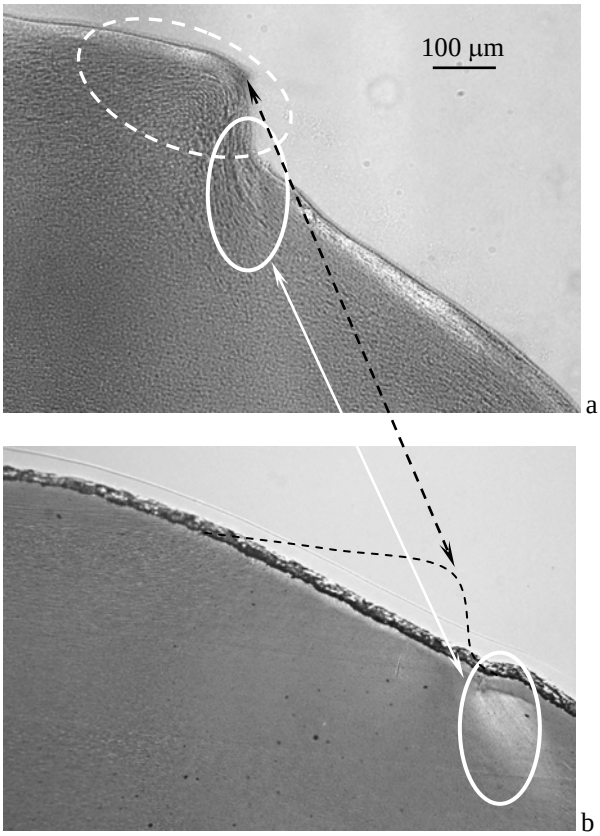


Figure 8: optical microscopy observation under polarization with a lambda plate of thin cuts (e = 5 µm) from injected parts before (a) and after polishing (b)

Observation under light polarization shows-out the molecular orientation parallel to the surface (fig. 8a) which is partly erased by polishing action. The orientation is complex in this initial protuberance [4]. It leads to a molecular orientation almost perpendicular to the surface after polishing and an initial crack can be detected in this particular zone (fig. 8b). The diffusion of solvents inside the polymer part is easier as an effect of this initial crack and of molecular orientation which favors the solvent diffusion. The solvent only widens the crack. This effect of a complex orientation on polymer cracks formation is observed on this zone without polishing and on weld-line where a complex orientation is also present. The cracks result from a local molecular orientation in conjunction with contact with solvents. The heating bursts the solvent and highly deforms the topcoat to form the bubbles. This is the critical step for the formation of the visual defect.

## V. Conclusion

The quality of a painted part is largely conditioned by the presence of detectable defects. Their size and location is crucial. All the surface need to present the same high quality. In this paper, a specific defect is analyzed with a method with a wide experimental range. The present defect results from the conjunction of the nature of polymer (ABS-PC) of paint layers (solvents) and of processing condition (molecular orientation). To prevent this defect formation, various ways are possible: modification of processing conditions to prevent crack initiation, modification of the mold-geometry to avoid complex flow (welding-line, parting-line), curing between basecoat and topcoat deposit to evaporate the solvent inside the crack, change in solvent composition of the paint. The devil is in the detail.

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