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Disadvantages of applied lacquer coatings on polymer substrate

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ABSTRACT

Purpose: The use of polymer parts in automotive industry gives economic and practical savings. This is evoked by weight reduction of the used construction elements. However, polymer parts usually require application of coatings to ensure high quality surface. The painting of polymer materials is one of the most popular and well known methods. Assumptions of the study presented in this article were an attempt to create an atlas of lacquer coating disadvantages.
Design/methodology/approach: Assumptions of this study were an attempt to identify lacquer coating disadvantages. Samples of the parts with disadvantages were prepared with the use of microtome and then viewed on an optical microscope. The defects have been described and the causes of their formation have been identified.
Findings: The paper shows the examples of common disadvantages of polymer coatings' application in automotive industry.
Research limitations/implications: In automotive industry, they are often used as a substrate - metals or other materials. The description and identification of disadvantages of coatings on these substrates requires further study.
Practical implications: The identification of disadvantages of the applied lacquer coatings on polymer substrate allows to eliminate them. Through the improvement and generation of new technologies of coating industry as a major supplier to the very large automotive industry, the industry will continue to thrive, grow and maintain its economical competitiveness in the global marketplace.
Originality/value: Applications of multilayer polymer coatings in automotive industry are rarely described in literature - especially the application on polymers substrate. The description and identification for the emergence of the most frequent reasons of lacquer disadvantage is a novelty in this article.
Keywords: Engineering polymer; Surface properties; Thin & thick coatings; Surface treatment

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1. Introduction

The polymer coatings are applied for protection and decoration of metals, ceramics, woods and polymer materials. These coatings are used in various industries such as automotive, machinery, furniture or even in water and sewer systems [1].

Most all of polymer products experience some kind of decorating process, whether they are decorative coatings, attachment of pricing label, metalizing, surface embossing or

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surface printing of a trademark. Decorating process for polymer parts is unfortunately not as well understood as the primary manufacturing process such as extrusion or injection molding. With polymer products, the decorating processes can be made either during the molding of a part, directly after the moulding or at any time before the final montage and packaging. The most inexpensive decorating process is to apply the decoration as a part of the molding operation [2]. However, painting of polymer materials is one of the most popular and well known methods.

To understand the technology for coating on polymeric materials, it should be remembered that it is an extension of a process originally developed for metal and other non polymeric substrates. The equipment, techniques, terminology and regulation evolved in the coatings industry equally well to the coating of polymer materials [2]. However, the knowledge necessary to provide the quality and performance of lacquering polymer parts is different from the one required for other substrates, such as concrete or steel [2].

The main difference is the low surface energy of polymer parts as compared with metallic materials and the chemical similarity between the coating materials and polymer substrate [2,3,4,5].

The nature of polymer substrates is important and it is revealed in coatings' problems during three stages of product's life [2]:

- During molding of a product;
- During application of the coating;
- During aging of the polymer parts in the environment.

The properties of polymer parts surface such as clean surface, wetability, adhesive strength and resistance to the solvent, are primary important in regard to the application of coatings to polymer materials. However, the mechanical and thermal behaviour of the polymer materials as well as electrical properties, such as conductivity, must be also taken into consideration. Thermosets, for example, are usually extremely resistant to high temperature. By contrast, many thermoplastics lose their dimension stability at temperatures of only between 60 to 100°C [6].

The second problem is that polymers used in processes of products' formation aren't pure in the chemical sense. They always have foreign components. The basic substances added to polymers are [6]:

- Additives such as plasticisers, blowing agents, dyes, stabilisers, antioxydant and etc.;
- Basic substances added to polymers are: water and formaldehyde - these substances migrate to the surface from the inner polymer parts;
- Processing aids applied to the surface such as lubricants and release agents.

The production of surface coating by any method depends primarily on two factors: the cohesion between the film forming substances and the adhesion between the film and the substrate.

Polymer parts for automotive industry are produced from thermoplastic materials primarily by the injection molding, sometimes by the blow injection. The task of polymer materials cleaning is to provide a clean surface for the painting process with the proper surface tension and surface energy. For polymers parts, for cleaning either middle alkaline cleaners or acidic cleaners based on phosphoric acid or organic acid are used. They typically contain sequestering agents, hydrotopics agents, surfactans and alkanole amines in case of alkaline cleaners [7].

Different physical methods of modifying such materials' surface layer are used to improve the adhesive properties of polymer materials, notably such as corona discharges, plasma method, laser method and electron - beam irradiation. The methods are based on the initiating reactions causing the formation of polar functional groups in this layer and/or in changing the geometric structure of the modified material's surface [8,9,10].

Many of today's lacquer and paint coatings are complex multi component formulations, designed for decorative, protective and functional applications. Additives are incorporated into coatings for specific reasons (e.g. viscosity modification, surface tension modification, biocidal effects, etc.), but the influence of most additives goes significantly beyond their primary function [11].

The amount of additives in coatings is seldom more than 5% in weight. The average proportion of a single additive in lacquer is usually about 1.5% of the total quantity of the material coating [12].

Polymer substrates can be protected against corrosion by a classic multi-layer coating (primer + topcoat) or by a single-layer coating system. During any multi-layer coatings application, the first coating to be applied is a base coat which protects the substrate from any humidity or any oxidizing substances. Each layer is applied separately and has different functions [13,14]. In most cases, plastic coatings consist of three layers:

- Primers to improve adhesion and to level imperfections of the plastic substrate;
- Base coat for colouring and effects (e.g. metal finish);
- Top coat for colouring and as a protective layer against weathering, solvents and scratching;
- Clear coat as a protective layer against weathering, solvents and scratching.

Primers are used on many polymer materials to provide an initial colour effect and to smooth surface irregularities caused during the production process, such as ridges, dents or molding marks. And most of all, they improve the adhesion of subsequent coatings to difficult substrates. Also, they form a protective barrier between a substrate and potentially aggressive solvents in the base coats or top coats. They usually contain additives for protection against corrosion and barrier effect. The material of this layer uses usually cheap pigments and dyes because it does not affect significantly the final colour of a product. When it comes to selecting, the binder waterborne products have become more and more important because they do not contain any aggressive substances which could affect the plastic substrate [13,14].

The basecoat provides the actual colour and any surface effects such as wet-look and metallic finishes. The intermediate layer primarily hides surface defects and also gives the proper thickness of the coating [13,14].

The top coat is the most important for product's aesthetics. The lacquer of this layer contains the highest quality pigments and other additives. Top coats protect polymer substrates against

external influences such as chemicals or UV light, but they are also important for the colouring and design. Under normal circumstances, top coats are pigmented unlike clear coats. Depending on individual requirements, they can be applied in a single layer (e.g. metallic coats or pigmented effect coats) or as a multi-layer coating (primer, base coat, top coat). Due to their good curing properties at low temperatures, polyurethane systems have become the standard technology for top coats. The surface characteristics such as high-gloss or matt finish, can be adjusted according to individual needs by the use of special fillers, binders or matting agents. Particularly interesting effects can be obtained with soft-feel coatings. They add a comfortable, luxurious and warm touch to plastic substrates of automotive interior or housings of mobile phones [13,14].

Clear top coats for polymer materials obtain certain optical effects such as excellent gloss or matting of the desired degree. In addition, they can be applied to protect against solvents, UV-damage, dirt and scratching [14].

The 1st function of the paint coatings is to protect materials against the environment. The 2nd function, also important, is to decorate. The lacquer coating, which is shiny, uniform and in an elegant colour, reflects high quality of a product and gives it a luxurious character. For example, in automobile industry, coatings are often applied to match the colour of secondary parts or to provide a softer surface to the touch.

The use of polymer materials in interior, exterior and other components of automobiles helps in weight reduction, improves aesthetics, vibration and noise control as well as cabin insulation. Properties of polymer materials such as easy moldability, recyclability, scratch resistance, high volume to weight resistance, thermal stability, impact strength and resistance to abrasion make them suitable for the use in automobiles. Among all the automotive polymers, polypropylene leads consumption by 36% followed by polyurethanes (17%), ABS (12%), composites (11%), HDPE (10%), polycarbonates (7%), and PMMA (7%) due their easily forming properties and their availability at cheaper price than other materials [15].

In automotive industry, there are three categories of polymer parts with coatings [16]:

- Interior trim - instrument panel skin, bolsters, door trim panels, door handles, bezels, glove box doors, air bag covers, etc.
- Exterior trim/fascia - fascia, body side trim and cladding, rocker panels, pillar covers, grilles, license pockets, door handle pockets, door handles, mirror housings, etc.
- Exterior body vertical/horizontal panels - door panels, quarter panels, fenders, hoods, roof panels, deck lids, etc.

The differences between each category are significant and result in varying probabilities of displacement for each of the coating technologies (Fig. 1).

As shown in Fig. 1, painting is still one of the most important coating technology of polymeric materials. However, this technology has both advantages and disadvantages.

The most important advantages of the paint coatings applied on polymer materials are [2]:

- Possible several inexpensive methods;
- Pre-treatment of most polymer materials isn't necessary;
- Variation of methods and design may hide imperfections of substrate;
- A significant number of coatings is available for various aesthetic and performance functions;

A new solvent - free paint systems (waterborne, UV cured, high solid content) have been developed.

The painting process on polymer substrates has also few disadvantages [2]:

- Some polymer materials are solvent sensitive;
- Hand methods of paintings have high labour cost;
- Paint reduces cold impact resistance;
- A plastic surface must be cleaned carefully;
- Solvent may be health and safety hazard;
- Over drying may be a problem with some heat high sensitive thermoplastic materials.

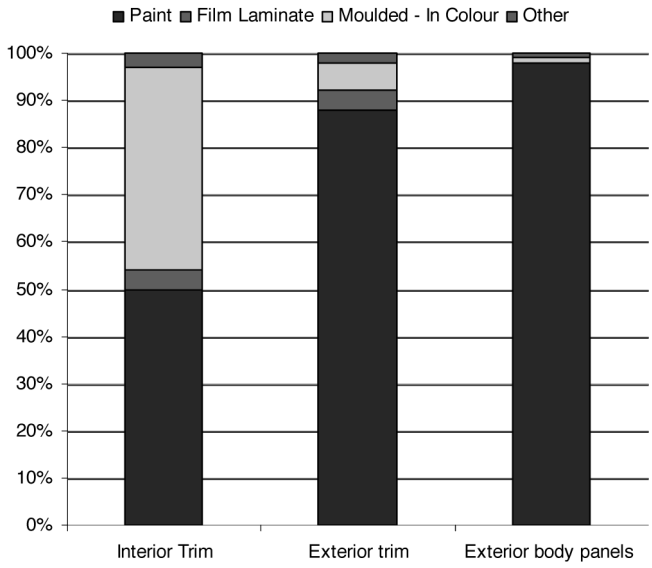


Fig. 1. North American automotive decorating technology market share [16]

For these reasons, not all of the coatings materials will want to join with good adhesion to a substrate material. Common paint system used to coat polymer materials is presented in the Table 1 [2].

Frequent incompatibility of coating with the substrate compels manufacturers to do many tests of adhesion properties, for example, the tests of environment influence on the coatings properties [17].

The surface analysis methods are one the most important tests. These methods are important for the study of such coatings, including:

- Investigation of lacquer and paint delamination (adhesive and cohesive failures);
- Analysis of other coating disadvantages including craters, particulates and other changes in appearance;
- Evaluation of coating integrity e.g. uniformity and distribution, thickness, homogeneity (phase separation, additive segregation).

Table 1.
Common paint system used to coat polymer materials parts [2]

Polymer material	Urethane	Epoxy	Polyester	Acrylic	Waterbone
ABS	R	R	NR	R	R
Acrylic	NR	NR	NR	R	NR
PVC	NR	NR	NR	R	NR
Polystyrene	R	R	NR	R	R
PPO-PPE	R	R	R	R	R
Polycarbonate	R	R	R	R	R
Polyamide	R	R	R	NR	NR
Polypropylene	R	R	R	NR	NR
Polyethylene	R	R	R	NR	NR
Polyester	R	R	R	NR	NR

Legend: R - recommended; NR - not recommended

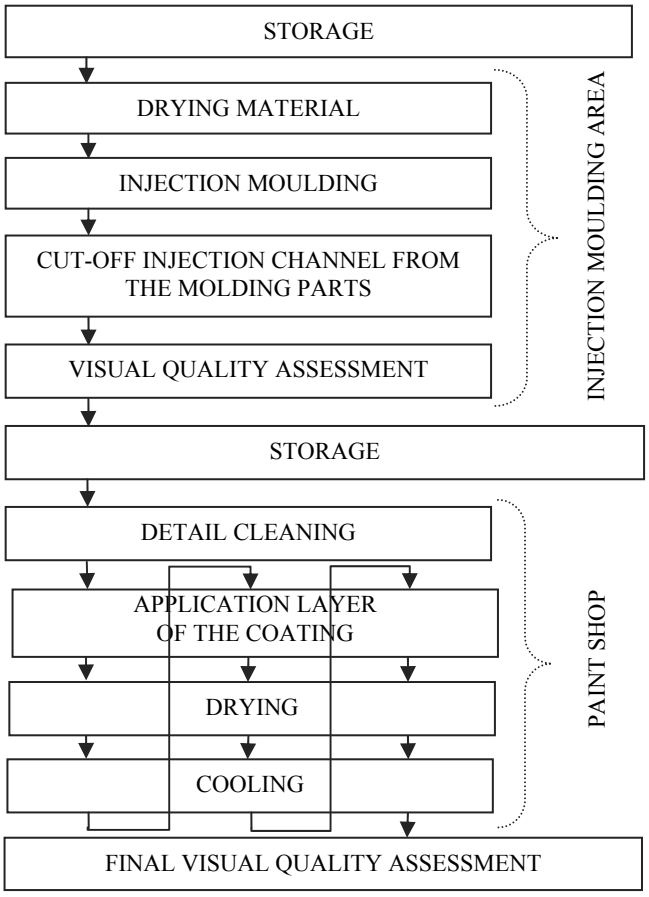


Fig. 2. The manufacturing process diagram of production painted automotive parts made of polymeric materials

2. Assumptions of the research work

Assumptions of this study were an attempt to create the atlas of lacquer coating defects. The defects, which were used for the description and identification, were obtained from Huf Poland company. The company has an automatic painting of polymer materials facility in which about 115,000 parts are painted per day. In this company, firstly - automotive parts are made by injection molding and then they are covered with the multi-layered paint system (Fig. 3). The block diagram of the technology process is shown in Fig. 2.

Due to commercial confidentiality, the used polymer materials for substrates and coatings are not presented in that paper. However, the presented results of macro and microscopic observations relate primarily to errors resulting from the technology of injection molded parts and coatings and in a small degree due to properties of materials.

3. Disadvantages of polymer coatings

Specimens have been collected from a variety of automotive parts made by Huf Poland. They were parts with defects detected by the quality control. An example is shown in Fig. 3.

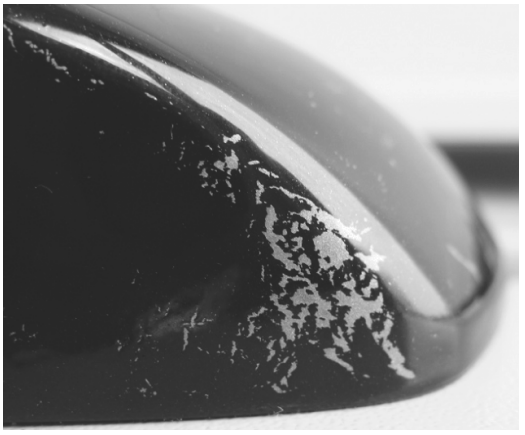


Fig. 3. Disadvantage of paint coating on a car doorknob

To prepare samples for tests, thin strips from different automotive parts with coating defects have been cut. The strips were cut on microtome made by Microm, model KM340. The samples' dimension was the thickness of 25 microns and the width of 5 millimetres. The samples were glued to a microscope slide. The main research was carried out on Zeiss Discovery V 20

stereoscopic microscope equipped with a camera and connected to the computer.

The research helped to identify seven types of defects, to classify them, to identify the causes and to prevent the formation of these coating mistakes.

During the tests, different types of errors have been identified. They have been classified into two groups:

- Paint coating defects formed during the injection moulding process;
- Paint coating defects formed during the painting process.

For comparison, Fig. 4 shows a picture of the correct layout of the multilayer paint system.

3.1. Paint coating defects formed during the injection moulding process

The faults of this group are mostly burrs, cavities, cracks formed during the injection moulding. The causes of their formation are usually technological or human errors. Unfortunately, if errors occurred during the production process, they were not usually detectable before the painting. Lacquer surface coating will emphasize a disadvantage.

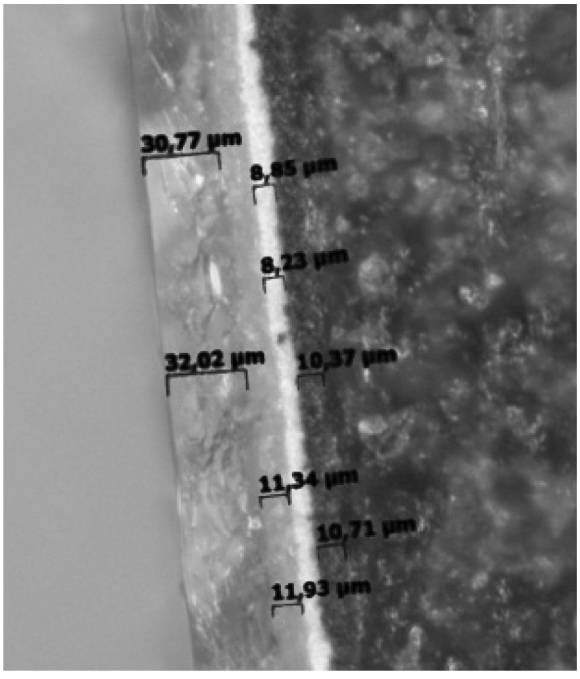


Fig. 4. The photography of cross-section view of the whole liqueur coat layers' system

Cracks or cavities on the molded piece are the first type of disadvantage.

It is difficult to spot disadvantages of this type on the surface of a product. However, the surface is rough on the product. The analysis of the microscope picture (Fig. 5) shows that the problem of inequality observed on the painted parts appeared due to defects or damage resulting from the technology processes before coatings applied. These damages could arise, for examples:

- During the transport of a product from the injection molding area to the painting zone;
- During injection molding as a result of contamination of the mold;
- When accidentally scratch during the cut-off injection channel from the molding parts;

Contamination attached to the surface is the second type of the disadvantage.

The disadvantages revealed as rough on the edge of parts. The microscope analysis (Fig. 6) showed that the cause is on the raw materials, under the coating.

The photo shows inequality in the form of small risers and inequalities which may remain after the grinding process. Grinding is used to get rid of the inequalities in the point of injection, the footprint of the mould form split and etc.

This situation causes that the uneven distribution of the individual layers of lacquer gives the impression protrusions' formation on element's formation.

These type of disadvantages are rarely encountered.

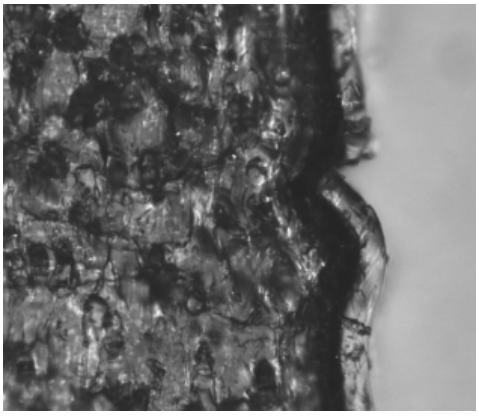


Fig. 5. A disadvantage which is the result of mechanical damage of an item before the painting

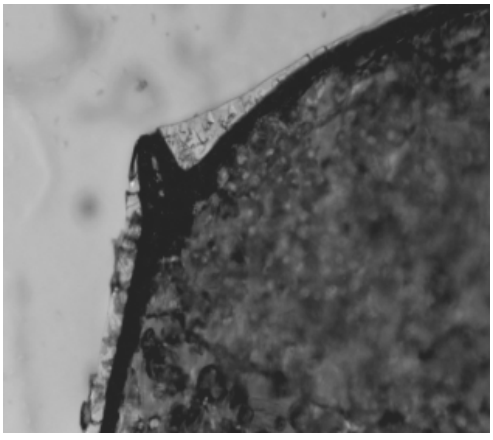


Fig. 6. A disadvantage which is the result surface's contamination of an item before the painting

3.2. Paint coating defects formed during the painting process

The 3rd type of the disadvantage is caused by the too fast gelation of a part of colorless lacquer.

Disadvantages of this type form a protrusion on product's surface . After the microscopic analysis (Fig. 7), it can be stated that partially faster gelation colorless lacquer is the reason of this defect. The resulting pellets cause uneven distribution of lacquer.

To avoid such disadvantages, regular care and frequent maintenance services of paint spray guns and paint supply lines must be provided. The filter system, which is installed in the line that gives paint to a gun, is the additional applied safeguard.

Presence of gas bubbles between the layers' coating is the 4th type of disadvantage.

Before the microscopic analysis, the defect has been manifested by the bulge. The cross-sectional analysis of the failure (Fig. 8) indicates that a problem arises during the application of the coating. The picture shows that the cause of defects in the bubble is located between the first and second layer of the applied coating. Probably, the bubble is filled with steam of water or air. Bad times of evaporation or drying of the coating layers are probably the reasons. Wrong temperature during the drying is also probable.

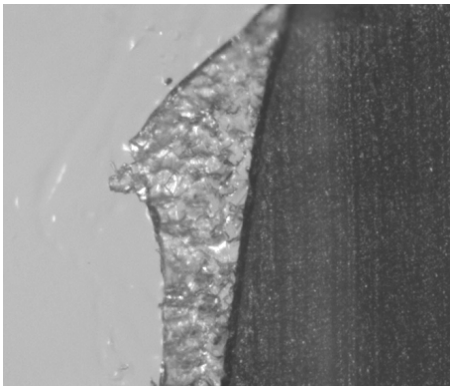


Fig. 7. A disadvantage which is the result of the too fast gelation of part's colourless lacquer

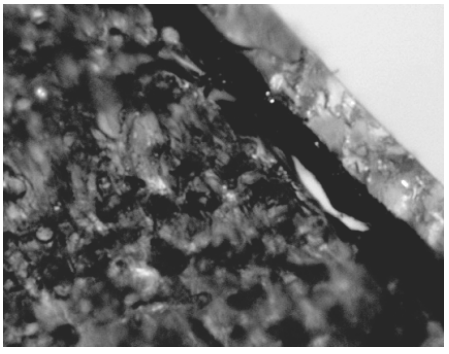


Fig. 8. A disadvantage which is the result of gas bubbles' presence between the coating layers

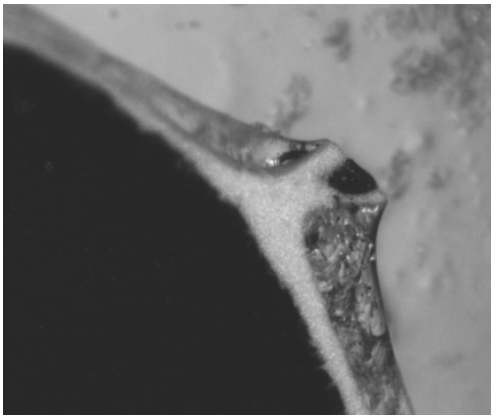
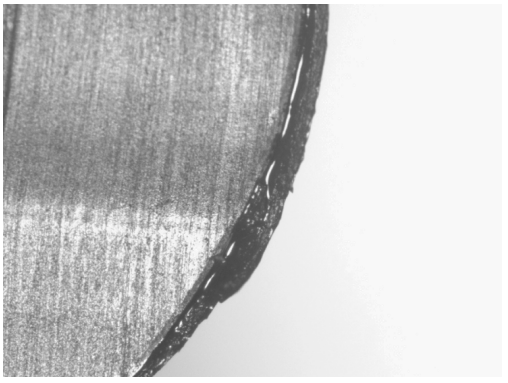


Fig. 9. A disadvantage which is the result surface's contamination of an item during the painting

a)



b)

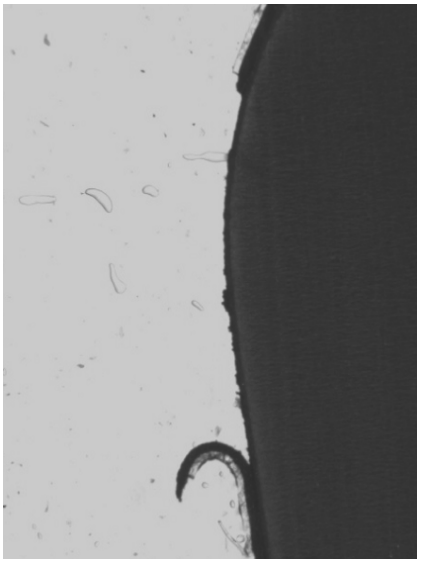


Fig. 10. A disadvantage which are the result of water bladder's presence between the coating layers: a) before cutting the bladder, b) after cutting the bladder

Presence as a perceptible form a crater-like protrusions is the 5th type of the disadvantage. The analysis (Fig. 9) revealed that dirt that got into the paint shop from the outside was the source of disadvantages. Probably it was caused by the contamination of the transport system in the paint shop as well as by pollution provided by employees.

The contamination in a paint shop is the most common problem during this process. A number of security sets is used in companies. Before entering a paint shop, employees are required to dress in appropriate work uniforms. Workers' hair should always be covered with a suitable cap.

Polymer materials parts are blown with compressed air before the primer layer is applied. The floor is covered with a special sticky substance to which any contamination is stuck. Of course, even with the best security, cleaning of the workplace is the most important. Unfortunately, most contaminants get into a paint shop through transport system and ventilation.

The 6th type of disadvantages is the presence of large stratification between the layers of the coating.

A defect on an element takes a form of a flat bladder (Fig. 10a). After cutting one of them, it turned out that the bubbles are filled with water (Fig. 10b). The image (Fig. 10a) shows that the bladder was made between the primer and base which suggests that the cause originates in the process of painting. Water based paint is used during the process, therefore it can be said that it appropriate drying time before applying the next layer wan not applied. Moisture was closed between the layers which resulted in the further process of gasification and formation of bubbles.

The 7th type of disadvantages is the presence of irregular colour pattern on the coatings. An example of that defects can be seen in Fig. 3.

The microscopic analysis (Fig. 11) showed that the base coat is missing in areas of disadvantages. This looks like a mistake of an operator working in the paint shop. These types of defects are often due to a difficult access for a person who does the painting, e.g. to the first and last row of elements suspended on transport hangers. When painting, one needs to pay more attention to such places.

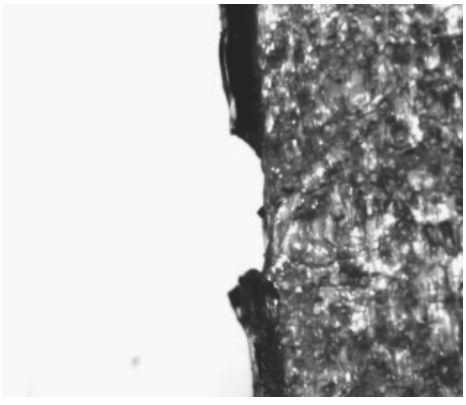


Fig. 11. A disadvantage which are the result of base coat missing

Gasification under layers of paint is also noticeable - they lead to the destruction of total coating.

4. Conclusions

Condition and quality of coatings is the decisive criterion for the total evaluation of a product. Visual condition of the product is essential for the sale, especially in the business such as automotive industry. The coating applied to a product has first of all a decorative role. Protective role is of secondary importance. A disadvantage on the surface of the paint coating also disqualifies the entire product on which the coating is located, regardless whether a product meets all the technical assumptions.

Disadvantages of the paint coatings can be divided into faults caused by wrong application way of coatings or by faults caused by imperceptible defects or contaminations located on a product before the coating is painted. Causes of defects in coatings are mainly human errors. The most common are:

- Poorly cleaned surface, which causes loss of adhesion of the paint and blistering as a result of contamination left behind;
- Too early painting after the cleaning, do not respect the necessary time between technological processes. It causes loss of adhesion and blistering;
- Too short a period of drying between coats of lacquer. It causes loss of adhesion between the layers;
- Insufficient flexibility of the paint which makes it fracture in relation to the substrate material.

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