Research on the Process of Paint Removal from Thermoplastic Materials by Laser

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Abstract. The laser cleaning technology offers many advantages compared to the traditional paint removal technologies such as cleaning by chemical solvents or using media blasting. Yet, the effects of this technology depend on the carrier material onto which the paint has been applied. Sensitive carriers with a low melting point such as thermoplastic materials can be thermally damaged or destroyed. This paper analyses the paint removal from standard thermoplastic materials such as polypropylene (PP) by laser and aims at identifying the influence of the laser parameters on the carrier surface. The research includes experiments of paint removal from plastic substrates by a pulsed fibre laser at 1064 nm with various parameter settings and the characterisation of the treated surfaces. The results show that the paint layers can be removed completely while keeping the sensitive thermoplastic substrate unimpaired. The laser energy density, speed and spot size have impact on the paint removal effect and substrate surface quality. After the paint removal it is possible to use again or to recover thus cleaned thermoplastic parts without reducing the quality of the recyclate.

1. Introduction
Painted plastic parts are widely used in various applications. The combination between the inexpensive thermoplastic material and the high resistance of a thin layer of thermoset material offers a reliable product at an attractive cost-effectiveness. Especially in the automotive industry such thermoplastic parts with thermoset coating systems are used to create a nice optical design with different colours and a good resistance for different surface stress situation [1, 2, 3]. During the last years the adhesion between the thermoplastic part and the thin thermosets layer was substantially improved, and the technologies allow complex geometrical parts to have a high paint quality [4]. Such hybrid systems comprise two different material types with different characteristics and proprieties, not only for their fabrication and use, but also for recycling [4]. While the thermoplastics can be heated and formed repeatedly, thermosets undergo a chemical change when they are heated, creating a three-dimensional network. After they are heated and formed, they cannot be re-heated and re-formed. The combination of such different types of plastics is a substantial obstacle to recycling. For example, the recycling of painted plastic parts such as car bumpers, fenders, grilles, etc. is still a challenge for the industry [4]. The easiest way to reuse these plastic components is to melt them and produce new parts. However, the thermoset paint causes residual particles, which cannot be melted. These unmelted particles generate a low quality (mechanical, optical, etc.) of the recycled material, which is not even suitable for medium quality plastic products [4].
2. Different techniques to remove and clean the painted thermoplastic material

Nowadays, to prevent the waste of useful materials is not only a task for scientists but also a political issue. International companies produce considerable quantities of painted plastic material particularly for the automotive industry, where the combination of the thermoset materials with thermoplastics, is used for many years to protect the plastic carrier materials [4]. Presumably, in the future the production of these hybrid parts will even be increased in order to provide for different new applications where the advantage of the painted plastic is indispensable.

Compared with the recycling of metal, plastic recycling is often more challenging because of the low density and low value of the products [4]. The recycling companies complain about the high quantity of painted plastic materials on the market after the lifetime of different products (especially automotive), shown in figure 1.

The recycling of these parts poses numerous technical problems especially due to the thermoset layer, which cannot be melted [4].

![Figure 1. Car bumpers at the Company Höglmeier Polymer-Tech GmbH & Co. KG (HP-T) (courtesy HP-T)](image1)

To recycling, a comparably small amount of coat (approx. 2 % the total weight of the component) proves to be so detrimental, that a separation of the thermoset layer from the thermoplastic carrier is necessary before starting the recycling of the material. To separate the paint from the thermoplastic carrier different treatments are available: chemical, mechanical and physical.

Chemical methods are commonly used for paint removal from metallic and plastic materials due to their cost efficiency [1, 2]. It is, though, perhaps the most destructive method available and often has to be done by a specialist in a safety location [4]. The painted parts are completely submerged into the chemical, often for several days at a time. This removes the paint layers. The used chemical solvents (strippers) such as methylene chloride, benzyl alcohol, hydrogen peroxide, are dangerous for the environment and pose high health risks to the operators. In addition, the solvents are not suitable for stripping the paint from all thermoplastic parts. The thermoplastic carrier can be harmed, and further cleaning techniques are required to avoid a contamination of the polymeric matrix, figure 2. A third problem area is the further treatment and storage of the mix of the remaining solvents and the dissolved paint, which is usually highly toxic and requires professional storage and dispose.

![Figure 2. Contaminated plastic surface after chemical immersion in ethyl acetate (C\(_2\)H\(_4\)O\(_2\)) for 60 min (courtesy Mr. C. Schmal)](image2)
Therefore, recycling companies are searching for new nontoxic solvents or other methods for paint removal from plastic materials [3].

The mechanical methods for paint removal from plastic or metallic carriers use different abrasive strippers, such as brushes or small particles which are accelerated and applied to the coated surfaces. To remove paint from different surfaces numerous abrasive materials can be used, i.e. sand, glass spheres, walnut shells, ice (dry ice) or also plastic media such as small granulates. The softer materials are used for paint removal on more sensitive components, particularly in the aeronautical and automotive industry [1]. As an environmentally friendly process, dry ice blasting is very interesting since it does not produce any secondary waste. First tests with plastic pellets and dry ice were promising, but not very efficient and are presented in the next figure.

![Figure 3. Paint striping on thermoplastic materials using blasting technique with dry ice (left) and plastic pellets (right)](image)

While by dry ice blasting approximately 2 cm² of coat per minute were removed from the part, the paint of entire component as shown in Fig.3 could be taken off within 3 minutes. To increase the removing speed (efficiency) a high input of energy would be necessary. Both methods are not very effective because of the good adherence of the paint on the thermoplastic carrier and can be applied only for certain thermoplastics types. Therefore, both methods are extremely labour intensive and require a considerable period of time, and cannot be applied for paint removal on a large scale [1].

Physical recycling of painted thermoplastic materials is the remelting and reextrusion of plastic material using melt filters, trying to separate the paint residues from the melted thermoplastic material. Different extrusion filters can be used for this technique. The disadvantage of this method is the relatively high energy consumption. Additionally, despite all filtering it is impossible to separate all paint particles from the carrier material. The extruded material cannot be used for high quality products/applications.

A new technology in the area of paint removal is the use of lasers. Compared with the traditional surface cleaning technologies, laser cleaning has several advantages: a high cleaning rate, no toxic substances as cleaning agents and low maintenance cost [5, 6]. Consequently, laser cleaning is widely used in the fields of paint removal [5, 6]. It is also widely used for surface treatments, including discoloration or foaming of plastics and darkening or annealing of metal parts. Offering a repeatable non-contact process, laser paint removal is a clean, low dust (or no-dust) way to selectively remove coating layers [5]. A pulsed laser beam is directed onto the surface at a specific energy level. It breaks down the paint and primer coatings and produces a minimal waste stream. Powerful, very short laser pulses produce shockwaves and thermal load resulting in sublimation and ejection of the target material [6, 7, 8].

Up to now the laser cleaning technology is widely used for metallic, ceramic or other surfaces with a relatively high thermal resistance, where a focused laser beam precisely vaporizes the coating without damaging the carrier surfaces [5, 9, 10, 11]. Different research works have contributed to improve this
method, which is also called laser paint stripping (LPS) technique, for different substrate materials such as aluminium, steel or thermosets [5, 7, 12, 13].

However, on thermoplastic materials with a lower melting and glass transition point, this technique can cause a thermal damage, i.e. carbonisation on their surfaces, an adverse effect on the quality of the recyclate.

3. Experimental coat removal from thermoplastic materials by laser

For the experiments of paint removal from thermoplastic material a used car bumper was used, which was manufactured in 2008 and used for some years on the car, see figure 3. The part was collected from a garage, where it had been removed from the car after some damage. Information about the fabrication date and material is provided by the stamp on the plastic component produced in an injection moulding process, figure 4 right.

![Figure 4. Car bumper for testing (left) fabrication and material information (right).](image)

The body (carrier) of the car bumper is a thermoplastic material, polypropylene (PP), a homopolymer reinforced with 20% talc. The thermoplastic material contains also additives like fire retardancies, thermal and light stabilizers, and is designed for the injection moulding process. The material exhibits high mechanical strength, dimensional stability, high thermal-resistance, and is easy to process. About the paint and coatings are no information available.

After cutting and cleaning a part of the car bumper several rectangles with different laser parameters were applied on the red painted surface, figure 5. The application was done using a 50 W fibre laser produced by Coherent-ROFIN. Seven arrays (10x10mm) where applied horizontally and vertically by changing the laser current (horizontally) and frequency (vertically). The other parameters (e.g. power, speed, line width) where kept constant.

![Figure 5. Laser application on the PP painted plastic parts.](image)

On the horizontal axis the current was varied from zero to 30 A in 5 A steps and on the vertical axis the frequency was varied from 20 to 140 kHz in 20 kHz steps. The pulse length was 50 ns and the speed was 8000 mm/s with a line width of 0.04 mm.
One can observe that in the lower left corner the paint has no processing marks and in the upper right corner the plastic surface is thermally damaged. The plastic carrier (PP) is harmed and on the surfaces carbonisation took place. This damage is disadvantageous for any further recycling.

Upon closer inspection one can see, that some of the test squares do not show severe damage nor carbonisation. They rather look like blisters. Figure 6 shows that at these squares the thin layer of paint can easily be separated from the carrier (PP) with the help of a scalpel.

Figure 6. Paint layer separation from the processed surface.

The best results were obtained at the current intensity of 15 A and the frequency of 60 kHz. As far as there are any residuals between the coat layer and the carrier material they can easily be removed as well. Another test was carried out on an increased surface of 20 mm² at the optimal laser parameters. This treatment of the surface was also successful, and the paint layer could be very easily removed, figure 7. The adhesion between the paint layer and the carrier surface is destroyed after the laser processing, so that the paint layer (thermoset) can be very easily detached without damaging the thermoplastic material. The figure 8 shows that the coat contains also several layers which are completely removed after the laser processing.

Figure 7. Laser processing of 20 x 20 mm surface with paint removal.  
Figure 8. Microscopy cross section of the processed plastic part.

In the cross section of the plastic part, figure 8, one can observe the areas before and after laser processing. It is obvious that the paint was removed and the surface was not harmed by the processing. The process is very stable, so that more areas of the coated parts were processed with very good results. At the same parameters a larger surface of 100 x 100 mm could be processed.
4. Conclusions
In order to recycle painted thermoplastic parts such as car bumpers, fenders or grilles without a loss of quality of the recyclate, it is essential to separate the thermoset coat from the thermoplastic carrier material.

The laser clean technique shows very good results in removing the paint layer from sensible thermoplastic materials without damaging the surface. Areas of 100 x 100 mm were processed with very good results. In comparison with the other cleaning methods this technology offers great advantages: It is easy to operate and quiet, has low operating costs, and does not require any consumable or even environmentally hazardous media (no abrasives, chemicals or solvents). Laser beam settings can be precisely adjusted to optimize the process, its speed and the stress it poses to the surface. The process can also easily be automated. In this way a high quality reconditioned recycled material can be obtained. Paint removal from thermoplastic materials is an increasingly important field, because these materials are intensively recycled.

Acknowledgments
A special gratitude I give to the Company Höglmeier Polymer-Tech GmbH & Co. KG, which supported the project by providing different plastic parts. Special thanks for the financial support of the research goes to the German Federal Environmental Foundation (DBU) and “Biomasse Institut” Ansbach University of Applied Sciences. A special gratitude I give to technical staff of the Ansbach University of Applied Sciences. Special thanks for her support go to Ms Antje Sover for reviewing the article.

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