Paint removal from thermoplastic materials and its influence on the physical-mechanical properties for the recycling of the polymer

A Sover*, M. Zink, M. Michalak

1Ansbach University of Applied Sciences, Faculty of Engineering Sciences, Residenzstr. 8, Ansbach, Germany

*Corresponding author’s e-mail: a.sover@hs-ansbach.de

Abstract.
Laser technology offers many advantages when removing paint (coating) layers from different substrates such as metals, plastics or ceramics. Sensitive carriers with a low melting point like thermoplastic materials can easily be thermally damaged or destroyed using this technology. This paper analyses the quality of the thermoplastic material after removing the thermoset layers from its surface by laser and aims to identify the changes of the most important properties of the polymeric material. The physical-mechanical properties of thermoplastic materials which were coated were investigated before as well as after the removal of the coating layers and compared with parts which were not coated. The focus was on melt flow rate, impact strength, and tensile stress as well as strain. The results show that even a small amount of the paint (coating) can change the behaviour of the thermoplastic material and thus has an impact on further processing. Moreover, it was found that removing the thermoset coating from the thermoplastic material leads to a considerable improvement of its physical-mechanical properties and consequently also extends the possibilities of recycling (reuse) of this polymeric material.

1. Introduction
To protect resources and the environment, it is inevitable to improve the recycling paths for plastic materials. Painted plastic components, which are an integral part of numerous consumer goods and are particularly widespread in the construction and auto-motive industries [1, 2], constitute a great proportion of such materials whereas the painting/coating of such thermoplastic parts massively impedes recycling. Consequently, new paint stripping technologies are necessary [2]. During the last years, the adhesion between the thermoplastic part and the thin thermosets layer was substantially improved, and the technologies allow to have a high paint quality on plastic parts [4]. There are two different material types of such hybrid systems with different characteristics and proprieties, not only for their fabrication and use, but also for recycling [1]. While the thermoplastics can be heated and formed repeatedly, thermosets undergo a chemical change when they are heated, in which a three-dimensional network is created which impedes a re-heating and re-forming the parts. The combination of such different types of plastics is an 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 [1, 2]. The recycling of painted plastic parts poses numerous technical problems especially due to the thermoset layers as paint or protective varnish, which cannot be melted. Such a plastic part is shown in figure 1.
To recycling, a comparably small amount of coat 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.[1]

A new technology in paint removal is the use of lasers. Compared with the traditional surface cleaning technologies, laser cleaning has several advantages: a high cleaning rate, needlessness of toxic substances like cleaning agents, and low maintenance costs [1, 3]. Consequently, laser cleaning is widely used in the fields of paint removal which is presented in different articles [1, 2, 3, 4, 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 the sublimation and ejection of the target material [1, 4, 5, 6]. Various research works have contributed to improve this method for different substrate materials such as aluminium, steel or thermosets [4, 5, 6, 7].

In recently published articles [1, 2] it was demonstrated that this technology can be used also for paint removal of thermoplastic materials. Even on thermoplastic materials that have a lower melting and glass transition point, this technique can be used to clean the thermoplastic parts from the thermosets coating without damaging, i.e. carbonisation or melting, the plastic carrier. Damaging the surface can have an adverse effect on the quality of the recyclate materials. The above-mentioned articles illustrate this paint removal technology on polypropylene (PP) and acrylonitrile-butadiene-styrene copolymer (ABS). However, this research paper investigates the quality of thermoplastic material after the application of this technology by testing the striped plastic parts and comparing them with the painted parts.

2. Preparation of the thermoplastic parts

For this research paper plastic parts of ABS Novodur were used as shown in figure 2. For the investigation and characterisation of the quality of the thermoplastic material the following parts for sample preparation were used: original ABS granulate, injected moulded part (not painted), paint striped part (the paint was removed by laser) and painted part (no paint was removed).
Figure 2. ABS parts used for sample preparation: a) granulate raw ABS; b) unpainted part; c) part with removed paint by laser; d) painted part.

The plastic parts b), c), d) figure 2 were shredded by a cutting mill. All the plastic parts (a, b, c, d) were then processed by extrusion, using a single screw extruder, and thus granulated. Afterwards the granulate of each processed part was prepared by injection moulding to form the samples for tensile testing and Charpy impact test or for measuring the melt mass flow rate (MFR), figure 3. The samples were prepared and tested according to the standards ISO 1133 (MFR), DIN EN ISO 179 (Charpy impact properties) and ISO 527 (Determination of tensile properties). These processing steps are typical in the recycling industry for thermoplastic materials, to provide a further usage for the thermoplastic material.

Figure 3. ABS granulate after extrusion and samples prepared by injection moulding.

The measurements of the melt flow rate and mechanical properties were conducted in the laboratory of Ansbach University of Applied Sciences. Samples of different plastic parts, see figure 2, were prepared. Microscopy was also used to observe different characteristics of the samples. The main goal of the investigation is to identify the influence of the laser paint removal on the characteristics of the thermoplastic materials and the influence of the paint layer on the properties of the recycled plastic material.

3. Results

The Melt mass-Flow Rate (MFR) indicates the ease of flow of the melt of a thermoplastic polymer. It is defined as the mass of polymer, in grams, flowing in ten minutes through a capillary of a specific diameter and length by a pressure applied via gravimetric weights for different, prescribed temperatures [8]. It is one of the most important properties for processing a thermoplastic material especially by injection moulding. The next figure presents the MFR-result of each plastic material after the extrusion process according to figure 2.
Figure 4. Results of MFR measurements from five samples of each prepared material

The average value of the MFR measurements are 12.41 g/10 min for raw ABS material; 11.791 g/10 min for the unpainted plastic part; 15.75 g/10 min for the stripped part and 23.41 for the painted part. All the tested samples were processed with the same parameter on the single screw extruder before the measurement.

One can observe that the results for raw ABS material is very close to the unpainted material. After drying the ABS raw material and again testing it, the same results as for unpainted part were achieved (11.9 g/10 min for raw ABS and 11.83 g/10 min for unpainted part). The MFR value of the painted part is approximately two times as high as the one of the raw ABS or the unpainted plastic part, which means that the material flows more easily. The next observation is that the after striping the paint by laser the MFR improve and reaches a smaller value close to the unpainted ABS parts. This change shows that after cleaning the ABS plastic parts of the thermosets paint, the Melt mass-Flow Rate comes close to the unpainted parts.

Tensile testing is an essential test for materials science and engineering in which a sample is subjected to a controlled uniaxial tension until failure. The properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation, and reduction in area. From these measurements different mechanical characteristics can be determined as strain, maximal force, deformation, Young’s modulus, Poisson's ratio, etc. The next figure shows the two important properties of the tested samples, deformation at break and maximal force occurred during the uniaxial tension.

Figure 5. Deformation at break (left) and max. Force (right) of all tested samples
One can observe that the deformation at break values and the max. force are clearly different between painted and unpainted ABS parts. The samples of painted parts break at 6.52 mm comparing with the samples of unpainted parts 20.37 mm. The painted parts show a brittle behaviour compared to the unpainted parts and raw material. Due to the paint particles which are in the plastic material the mechanical behaviour of the painted samples is inferior to the unpainted samples. The mechanical characteristics of laser stripped parts are between these values which shows that the removal of the paint is an improvement regarding the mechanical properties. The measurements of deformation at break rise by 124% from 6,52 mm to 14,65 mm. The maximal force increases only by a small value from 1719 N to 1747 N.

A further mechanical characterisation was done by the Charpy impact test. This testing method is carried out at high strain-rate and determines the amount of energy absorbed by a material during fracture. Absorbed energy is a measure of the material's notch toughness. This test is widely used in the plastic product industry, as it is easy to prepare and conduct and results can be obtained quickly and cheaply. The next figure shows the testing results for 5 samples of each prepared material according to figure 2.

The results show a significant difference between the raw material respectively unpainted ABS parts to the painted parts, see Table 1. The samples prepared with the painted material can take 288% less energy before they break. When the material is striped the values increase with 116% compared to the painted parts. The quantitative result of the impact tests is the energy needed to fracture a material and can be used to measure the toughness of the material. The paint particles in the ABS material have a significant influence on the material's notch toughness and deteriorate the mechanical behaviour under impact load. Removing the paint of the ABS material improves the impact behaviour of the material more than two times, which allows the use of the recycled stripped material in different applications. The next table presents the values of Charpy impact testing for all four materials.

![Figure 6. Results of notched impact test for different samples](image)

| material        | Impact Energy [J] | notched impact strength [kJ/m²] |
|-----------------|-------------------|---------------------------------|
| raw ABS         | 1.058             | 33.062                          |
| unpainted part  | 0.956             | 29.87                           |
| striped part    | 0.532             | 16.62                           |
| painted part    | 0.246             | 7.687                           |

With the help of optical microscopy one can see the fractured surface of the samples after impact testing. Here different patterns of defects are seen but also impurities or contaminations of the material e.g. with
paint particles. The next figure shows the microscopy pictures of the unpainted part, striped part, and painted part.

![Microscopy pictures](image)

**Figure 7.** Microscopy of the samples of different materials after Charpy testing; a) unpainted part, b) painted part and c) striped part

The first picture in the figure shows the unpainted part at the fracture surface after Charpy test. No contamination of the material can be observed. In the second picture different impurities of the thermoset paint particles can be observed. These impurities have different dimensions and they are spread inhomogeneous overall cross section of the sample. Some of them are sharp and large. The third picture presents the laser striped surface. Here only very small remains of the paint particles are visible. They are very small and good integrated in the polymer matrix. This last information from the picture shows that some small particles of paint are still in the material after laser paint striping, which indicates that the parts should be cleaned better by laser processing and after. Further investigations are planned to remove also the last small impurities from the plastic material.

### 4. Conclusions

To recycle painted thermoplastic parts 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. The result of the rheology and mechanical characterisation shows that properties after laser stripping the painted thermoplastic parts are superior to the painted parts. The Melt mass-Flow Rate (MFR) was improved by approx. 30% compared to the painted and striped plastic parts. The deformation at break was increased by 124% from 6.52 mm to 14.65 mm for striped parts. The notched impact strength was also improved by 116 % from 7.67 [kJ/m²] to 16.6 [kJ/m²]. All these results demonstrate that by using the laser paint striping technology we can improve the properties of the recycled material (e.g. ABS), which would enable the industry to reuse the plastic material for different applications. With this method of cleaning surfaces thermoplastic parts are turned from non-recyclable materials to recyclable ones and thus the circular economy can be supported and the waste of plastic reduced.

### 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). 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.

### 5. References

[1] A Sover 2019 IOP Conf. Ser.: Mater. Sci. Eng. 564 012028

[2] Zink, M., Sover, A., *Study on the Process of Paint Removal from Thermoplastic Materials by Laser Technology*, Proceedings of the 2nd International Conference of the University of
Xiaodi Z, Wenbin Qin, Jing L, Zhiyong W, Research on mechanism and process of paint removal with pulsed fiber laser MATEC Web Conf. 189 01008 (2018)

Schweizer G, Werner L, Industrial 2-kW TEA CO2 laser for paint stripping of aircraft Gas Flow and Chemical Lasers: Tenth International Symp. International Society for Optics and Photonics 57-62 (1995)

Zhang H, Liu W W, and Dong Y Z, Experimental and mechanism research on paint removal with low frequency YAG pulsed laser (Laser & Optoelectronics Progress vol 50) 114-20 (2013)

David V, d. W., Laser Ablation for Advanced Surface Treatments, Clean automated process improves production and increases throughput, Lasertechnikjournal, Volume14, Issue3, June 2017, Pages 34-37

Kuang Z, Guo W, et al, Nanosecond fibre laser paint stripping with suppression of flames and sparks, Journal of Materials Processing Technology, 266, 2019, p 474-483

M. Guessoum, N. Medjdoub, S. Nekkaa and N. Haddaoui, Rheological and mechanical properties of recycled poly(ethyleneterephthalate)/high density polyethylene blends, MATEC Web of Conferences 5, 04026 (2013)