

A NOVEL TOOL FOR CONTINUOUS PROCESSING OF POLYMER-METAL-HYBRIDS

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ABSTRACT

An excellent example for a modern hybrid material is a novel thermoplastic printed circuit board substrate, which has to be laminated with copper for the subsequent structuring of the circuits. Generally these metal foils are laminated on the polymer in a discontinuous process with a double belt press. However, this way of processing is cost intensive and causes additional thermal load for the polymer. To overcome these disadvantages, a novel tool has been invented to combine the metal foil with the polymer directly in the extrusion die.

The presented design shows a novel tool for the processing of metal-polymer-hybrids directly in the extrusion process. By inserting the metal foil directly into the extrusion die, a complete continuous process has been developed for manufacturing metal-polymer-hybrids. This recently developed tool eliminates a second heating step of the thermoplastic substrate and reduces the production costs drastically. Key aspects of the design are the sealing at the foil entry, optimal heating of the foil and a modular setup for different foil thicknesses as well as modular and exchangeable lamination surfaces. The resulting copper-polymer-composite shows a superior adhesion due to the design of the tool and the individual adjustable processing window.

1 INTRODUCTION

The combination of different material classes is state of the art to improve the aesthetic, mechanic or electric properties compared to the single material. Especially polymer-metal-hybrids (PMH) produced by coating or lamination of polymer materials with metal are more and more replacing standard steel parts in the automotive industry and have been used as base material for the fabrication of printed circuit boards for years [1,2].

The department of polymer engineering at the university of Bayreuth has created a new high-performance substrate based on a highly filled thermoplastic polymer, which provides several advantages compared to currently used thermoset based substrates. To eliminate the last disadvantage of the new material, the price, the process of combining the polymer substrate with the copper foil for the circuits has to be more efficient and economical. Current methods to produce PMHs, like electroplating, electroless metal deposition, physical vapor deposition technique, back injection molding, static pressing, double-belt-pressing or lamination by a calendar provide disadvantages in the quality of the PMH or the price efficiency [1-10]. Particularly the lamination of the polymer with a double-belt-press, which is the current method to laminate the copper on the thermoplastic substrate, is an expensive process, based on the high investment costs and the discontinuity of the process. Furthermore the mechanical properties decrease due to the necessity of the second heating step, which

leads to a degradation of the polymer.

Therefore, the company Dr. Collin GmbH in cooperation with the department of polymer engineering at the university of Bayreuth designed a novel tool, which allows the in situ lamination of metal foils onto the polymer melt directly in the extrusion process. Hereby the investment costs are highly reduced and the PMHs can be produced in a continuous process with just one heating step.

2 TOOL DESIGN AND PROCESSING

The presented tool for the continuous processing of polymer-metal-hybrids (PMH) is the heart of the production plant (s. Fig. 1). The whole plant also includes a single screw extruder Typ E 30 PK from the Dr. Collin GmbH with a screw diameter of 30 mm for the plastification of the polymer granulate, as well as a calender Chill Roll CR 136/350S from the Dr. Collin GmbH for the final calibration of the polymer-metal-sheet thickness. The novel lamination unit in the production plant needs to combine the process actions of pre-heating of the metal foil, bringing the polymer melt in the desired shape, build up of lamination pressure, lamination of polymer melt with metal foil and rough calibration of thickness of the PMH.

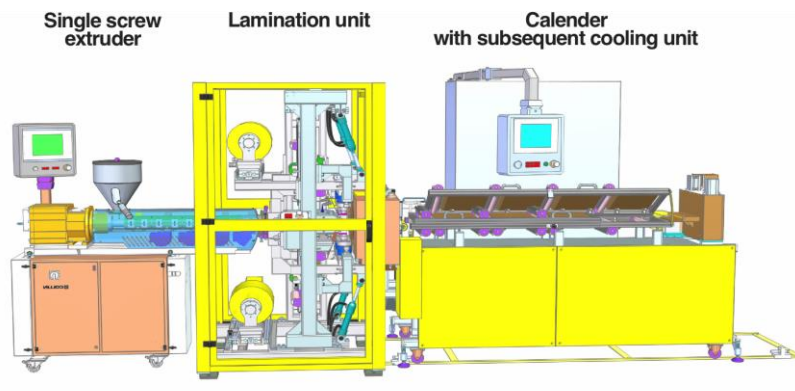


Figure 1: Production plant for continuous processing of polymer-metal-hybrids.

The main idea of the new tool was to combine an extrusion die with two lamination units (s. Fig. 2).

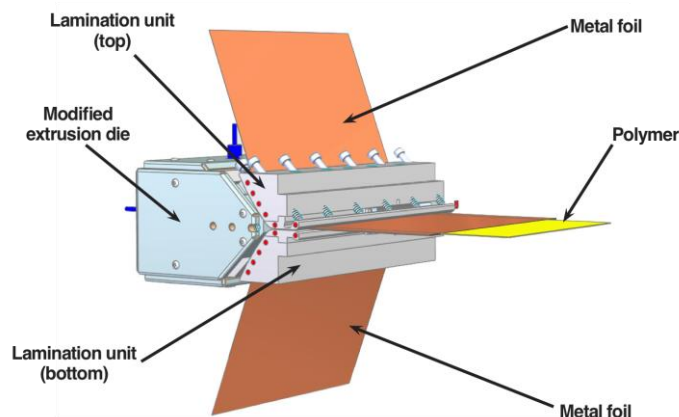


Figure 2: Setup of the modified extrusion die and the top and bottom lamination unit.

The die is a high temperature slit die (HT-die) with a width of 250 mm (s. Fig. 3) from the Dr. Collin GmbH. To ensure a constant melt volume across the complete width of the die, it is equipped with eight flex-elements to adjust the gap heights of the die. Furthermore the bottom part of the die is

rounded and fits to the shape of the bottom lamination unit. Hereby a narrow adjustment of the metal foil entry can be realized to ensure no melt leakage at that point. However, the main modification of the die is at its lip. Compared to a normal die lip, which is designed with a sharp edge at the exit, the lip gap of the lamination unit die is enlarged. This specific design feature allows a controlled increase of the melt volume at the die exit. The necessity of these modifications will be described later on.

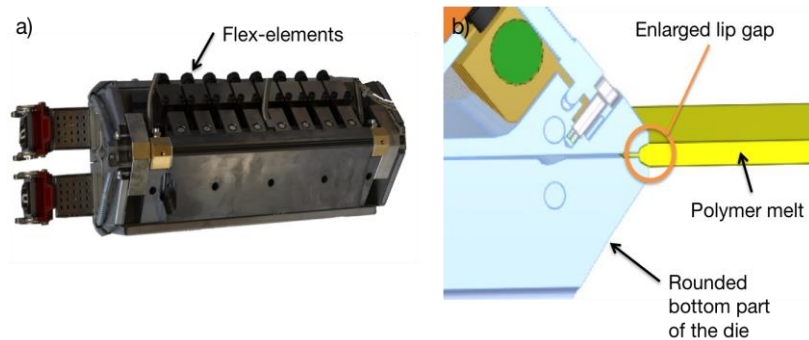


Figure 3: a) Modified HT-die of the lamination unit with flex-elements, b) depiction of the enlarged lip gap and the rounded bottom part of the modified HT-die

Subsequent of the modified HT-die, the polymer melt is merged with the metal foil from the top and the bottom between the two lamination units. The constructive layout of the lamination units is designed to undertake several tasks for the successful lamination of the polymer (s. Fig. 4). First of all, the lamination units are equipped with six heating cartridges along the surface, to regulate the lamination temperature. Additionally the metal foil is preheated up to the melt temperature of the polymer in the entry area. Thus, a change of the melt viscosity or freezing of the polymer by bringing the polymer in contact with a cold metal foil can be avoided. To ensure a gentle guidance of the metal foil, especially for thin foils of 17 μm , and to always guaranty contact between the metal foil and the lamination unit for optimal heating, the entry area is rounded. Furthermore, due to a modular design of the lamination units the lamination surface can be varied by installing longer or shorter lamination elements. This constructive feature provides the capability of influencing the surface pressure as well as having control over the friction between metal foil and tool to prevent damaging of the foil due to an increased friction. Similar to the modified HT-die, the top lamination unit is equipped with adjusting screws to change the gap of the lamination area. This facilitates the change of the lamination geometry from a parallel setup to a conical setup with decreasing gap heights for a increased pressure buildup (s. Fig. 4).

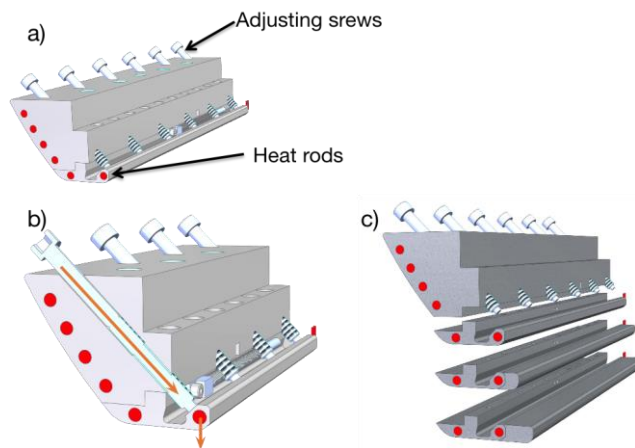


Figure 4: Setup of the lamination units; a) General setup; b) Work principle of the flexible lip of the top lamination unit; c) exchangeable lamination surfaces

To provide easy handling, especially while inserting the cooper foil, and also to realize an extrusion without lamination, both lamination units can be opened or closed via four hydraulic cylinders. Furthermore the lamination tool is equipped with a couple of additional parts for an increased flexibility in the process and part thickness as well as process monitoring (s. Fig. 5). The quality of the final product is highly dependent on the positioning and speed of the metal foil. Therefore two foil bearings with brake motors and the possibility of adjusting the position of the foil in every direction were used. The brake motors can be adjusted by torque or by the tensile force which is measured via two deflection pulleys. For an online monitoring of the actual forces during the lamination, the tool can be equipped with four load cells. Four adjustment screws realize an exact control of the distance of the lamination units over the whole width, which leads to an exact control of the thickness of the PMH (s. Fig. 6).

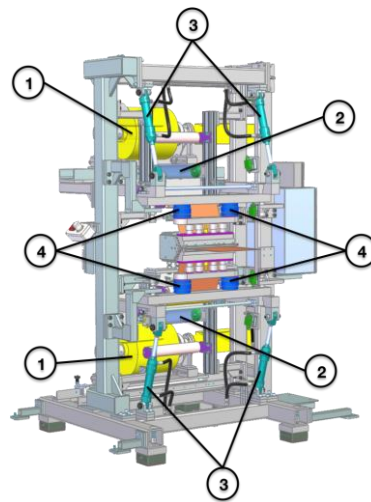


Figure 5: Lamination unit with: 1) Foil bearing; 2) Deflection pulleys for monitoring the tensile force at the foil; 3) Hydraulic cylinders; 4) Load cells

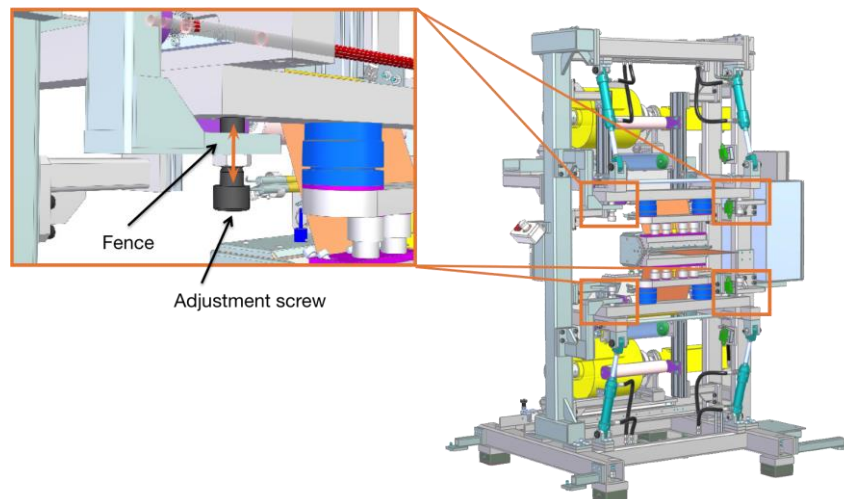


Figure 6: Lamination gap adjustment with four adjustment screws

Like stated before, the lip of the extrusion die is modified in a way that the melt volume can be increased when it exits the die. This feature is necessary to generate the lamination pressure. By decreasing the gap again when the metal foil and the polymer melt are joined in the lamination area, the melt abundance has to be distributed over the width and creates an increase in pressure. Hereby an optimal adhesion should be achieved (s. Fig. 7).

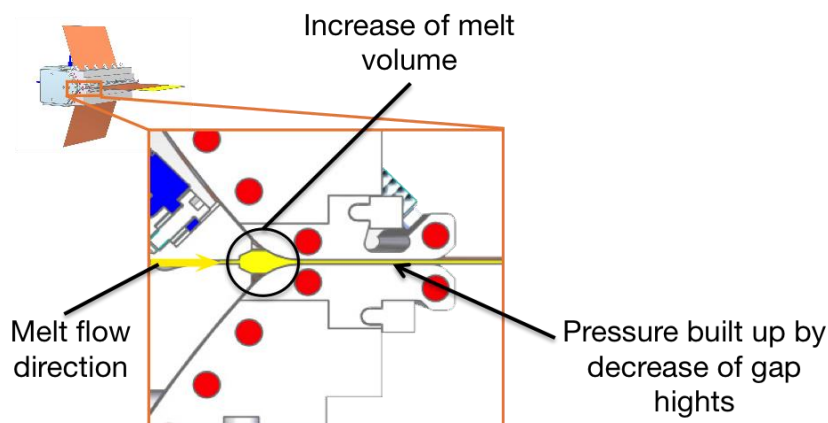


Figure 7: Work principle of the lamination

3 EXPERIMENTAL

The lamination process development has been carried out with a highly filled compound based on Polyetherimide Ultem 1000 from the company Sabic with a glass transition temperature of 217 °C. The polymer was laminated with two 35 µm thick copper foils JTCHTEHP from the company GOULD electronics, which possess a rough and a smooth side. The rough side with an R_z of 5 – 8 µm was laminated on the polymer. The lamination experiments were run with a die temperature of 360 °C and a die gap of 0.8 mm. The gap between the lamination units was set to 0.77 mm at the end of the lamination units to ensure a polymer thickness of 0.7 mm. Additional experiments were carried out with varying die and lamination gap to analyze the thickness limitations of the process. In order to understand the influence of the lamination unit temperature on the adhesion and the quality of the final PMH, it was varied between 300 and 350 °C. The haul-off speed was kept constant at 0.6 m/min.

To assess the adhesion between the copper and the polymer, the copper peel strength on the top and the bottom of the PHMs as well as in machine direction (MD) and cross direction (CD) was measured according to the IPC-TM-650.

4 RESULTS

During the design of the lamination tool, an increased focus was set on the homogeneity of the melt flow and the increase of the melt volume before the lamination units. Therefore, like stated before, several features were implemented to have an efficient control over the melt. This increased focus proved itself in practice as utterly important. To obtain a good surface quality without any cavities or blemishes, the space between the die and the lamination entry had to be filled with enough melt (s. Fig. 8). Thus, the enlargement of the lip die in interaction with the screw speed of the extruder provides an increased and controlled melt volume in that area. Furthermore the distribution of the polymer melt across the whole width of the die had to be homogeneous. Otherwise locally the amount of melt got too much and hereby the pressure between the lamination units became too high, which led to ripping of the foil. Due to the flexible lip the melt flow could be regulated locally so that a homogeneous melt flow was achieved (s. Fig. 8) and ripping of the foil avoided.

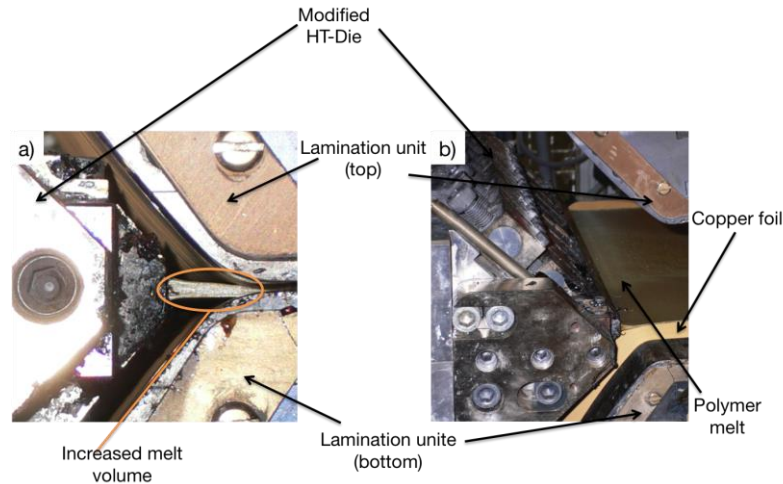


Figure 8: a) Increased melt volume before lamination units; b) homogeneous melt distribution

Lamination trials were carried out with varying temperature of the lamination units from 300 °C up to 350 °C. Hereby it was observed, that a temperature of 300 °C led to poor adhesion between the polymer and the copper foil. This is attributable to the high viscosity of the melt, which did not allow for good wetting of the metal foil and therefor led to poor mechanical adhesion. An increase of the temperature up to 330 °C already lowered the viscosity so far that the melt could wet the surface of the metal foil. This resulted in good adhesion between the copper foil and the polymer, which will be shown later on in the measured peel strength. A further increase of the temperature up to 350 °C did not improve the adhesion any more, but led to the negative effect that the copper foil oxidized at the surface.

Due to the flexible lips of the modified die as well as the four adjustment screws for the adjustment of the gap distance, PMHs with varying thickness can be produced. With the current tool design the trials showed that PMHs with a polymer core between 0.3 and 1.5 mm can be produced.

Assessing the quality quantitatively, the PMHs produced with a lamination temperature of 330 °C and a substrate thickness of 0.7 mm were tested on their peel strength. All tested specimen showed a good peel strength of 1.3 ± 0.1 N/mm.

5 CONCLUSION

The design of a novel tool for the direct lamination of 35 µm thick metal foils in the extrusion process on the polymer melt for an efficient production of polymer-metal-hybrids was described. Furthermore the successful production of PMHs with the new tool was shown with a highly filled polyetherimide and copper foil.

The lamination of the polymer with metal foil is highly dependent on the melt homogeneity, the increase of the melt volume and the lamination temperature. Due to the layout of the tool, like the flex lip, the enlarged die lip or the lamination units, as well as the modular design of the lamination units, it was possible to produce a polymer-copper-hybrid with good adhesion. So far the new lamination tool is able to produce different PMHs with a substrate thickness in the range of 0.3 up to 1.5 mm.

Therefor, the novel lamination tool realizes a continuous in situ production of PMH-sheets with the economical advantage that no investment in a double belt press is required. Also the polymer does not need to be exposed to a second heating step, which positively affects the mechanical properties of the polymer.

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