Development and evaluation of concepts for the removal of backing foils from prepreg for the automated production of UD reinforced SMC parts

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Abstract

Backing foil or paper needs to be removed from the raw material prior to the processing of Sheet-Moulding-Compound (SMC) or unidirectionally reinforced prepreg (UD-Tapes). In present automated production processes, this step is conducted after unrolling the raw material and prior to the cutting. In a process chain, which is conducted in the authors project, the backing foil needs to remain at the material after the cutting step. For these process chains, a method needs to be found to remove the backing foil from the material. In the state of the art, methods are shown to remove backing paper from prepreg. In this paper new methods are developed and tested for the removal of backing foil together with existing concepts. The main difficulty is the transition from backing paper to backing foil which has a higher tack to the material, is thinner and mechanically less strong. Concepts which are investigated use compressed air, mechanical forces or the stiffness of the foil. The application of compressed air is tested between foil and prepreg. Mechanical forces can either be introduced using grippers, brushes, friction to rubber or adhesive tape. The stiffness of the foil is used when removing it through bending the prepreg.

1. Introduction

Due to their high specific stiffness and strength, composite materials offer great potential for the reduction of fuel consumption and CO2 emissions via lightweight design. Composites reinforced with continuous fibers like unidirectionally reinforced Tapes (UD-Tapes) offer the best mechanical properties and the best weight-saving possibilities at high production cost. Discontinuously reinforced plastics like Sheet-Molding-Compound (SMC) offer a competitive price with lower mechanical performance. To exploit the advantages of both material types, the International Research Training Group (IRTG) at KIT is developing an integrated engineering chain to combine SMC and UD-Tapes at the regions of the part most suitable for the particular material type. Part regions with complex geometry and low load will, for instance, be made of SMC while UD-reinforcements are used on highly loaded areas. These continuously-discontinuously reinforced parts will be called CoDiCo parts. In the IRTG, a production method was developed in which relatively small pre-cuts of the raw material are processed. In the developed process chain, it is necessary to keep the backing foil at the material after cutting to enable the handling of the material and to protect it from environmental influences. To automate this process chain, backing foils therefore need to be removed from the pre-cuts. This article focuses on concepts for the automated removal of backing foils from SMC and UD-prepreg pre-cuts. In the regarded process chain, the SMC is still uncured when the foils are removed while the UD-Tapes are partly cured in order to avoid movement relative to the mold when co-molding with the SMC.

2. State of the art

The protective foil of SMC is usually removed before cutting. After initially connecting the foil to a roller, it is pulled off continuously by rotating the roller [1]. [2] deals with an approach to remove the protective foil of SMC after cutting. It states, that this step is one of the main problems in automation. Experiments with brushes and vacuum grippers were unsuccessful. The best solution is said to be pulling it off using adhesive tape. The precut SMC parts get transported from a magazine into a gap between two pairs of rollers. On both sides between SMC and rollers, adhesive tape, coming from a stock roll, is applied to the foil, pulled off again together with the foil and winded on another roll. The source does not mention the width of the used adhesive tape and the arrangement and conveying direction of the SMC parts. It is assumed that the SMC parts are conveyed along their diagonal axis. Otherwise, the adhesive tape would have to be as wide as the SMC parts to initiate the separation between foil and SMC.

In contrast to the removal of backing foil from SMC, the literature [3–6] enlists a lot of different approaches for the removal of backing material from UD-prepregs. Unlike the process looked at in this paper, they all deal with pulling off the material from the wet prepreg before any preforming step. Therefore the adhesion between the prepreg and the backing material mainly depends on the tack of the prepreg and its viscosity. Furthermore most literature deals with backing paper instead of backing foil. In contrast to paper, the used foil in this research is thinner and less rigid hence it only transfers tensile forces. Nevertheless, a transfer of the approaches to the use for process of this paper was performed. In automated tape laying, backing paper is removed similar to conventional SMC production before cutting, lacking any new approaches. In the process of automated pick and place, backing paper is mostly removed after cutting. Despite the differences in curing process and backing material, the process is the most similar one to the one regarded in this paper and literature enlists numerous approaches. [6] divides the process of the removal of protective material into two steps. The first and more complicated one is the initiation which is preferably performed at a corner of the workpiece. After a small piece of paper or foil is detached, it is accessible by both sides and therefore can be gripped more easily for the complete removal. [3, 5, 7, 8] use liquefied gases or compressed air to locally cool down the prepreg and thus decrease the tack to simplify the initiation step. Since the adhesion between foil and prepreg material regarded in this paper is not defined by viscous tack, this approach is not considered as potential solution. [5] describes two different methods for initial separation of wet prepreg and backing paper without thermal or chemical treatment. The first one is to bend a corner of the prepreg by a simple machine. The second mentioned method is to use an injection needle to inject air between prepreg and backing paper. Directed by a foot, pressed on the prepreg, the air flow creates an air bubble, separating prepreg and paper. To completely remove a beforehand separated backing paper, numerous sources recommend the combination of a vacuum gripper with a simple claw. After lifting the paper, it is clamped between the pivoting claw and the vacuum gripper, preventing it from sliding off the vacuum cup. [4] describes a roll with a rubber surface and an integrated vacuum cup. A corner of the paper is lifted by the vacuum cup and then rolled up, using the static friction between the paper and the roll. The width of prepregs is limited to the width of the roll and depending on the shape and size of the prepreg, two attempts are necessary. One starting at a corner, separating a larger bit of the paper along the angle bisector and one more starting at the short edge and rolling up the complete paper. [9] describes a similar solution, using two rolls, rotating in opposite directions. The paper is lifted by a vacuum cup and then conveyed between the two rolls.

As already mentioned, the presented methods are based on wet prepregs and mostly paper in contrast to prehardened prepregs or SMC and foil. Other production branches also deal with the removal of protective foil for instance from sheet metals, using different methods. [10] uses a rotating wheel with rubber elements to initially separate foil, which has been cut beforehand, from sheet metal. [11] uses rotating brushes for a minimum initialization and air jets for further separation of foil and sheet metal. In this paper the removal off small patches from prepreg is examined.

3. Removal Concepts

The existing concepts for initial separation and complete removal of the foil were supplemented with own approaches and tested on prehardened prepregs and SMC. The prehardened carbon fibre prepregs had different 2D-shapes with rectangular sharp and also some rounded corners with either one, two or three layers (0° or 0°/90° or 0°/90°/0°) of carbon fiber. The glass-fiber-SMC was cut to single layered rectangular pieces with rectangular corners. On tests for initial separation, every side of every corner was considered as a single experiment, saying parts with four corners and foil on each side led to 8 results. Most experiments were performed on a simple self-made vacuum table, consisting of a coanda ejector and a 6 x 10 cm polyamide gripper with suction holes with a diameter of about 1 mm. Suction holes which were not covered by the specimen were in some cases covered by adhesive tape to increase the effective vacuum.

3.1 Bending

The approach of initial separation by bending or flicking a corner of the specimen was tested manually with bare hands and with pliers. Different methods can be seen in Figure 1. The prepregs turned out to be too rigid for strong bending without breaking. A separation of foil and prepreg could not be achieved. SMC however could be bent and flicked several times without any damage to the material but due to the high flexibility of the foil in contrary to the backing paper described in [5], the foil was only separated from the SMC in small areas instead of on the whole corner of the specimen. The only method leading to an extensive separation in some cases was bending and then rolling the folded material between the fingers, similar to the method shown on the right in Figure 1. Due to the rather poor results, the method was not investigated any further.

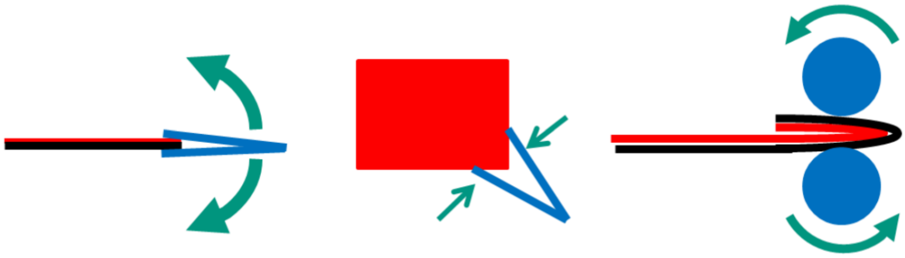

Figure 1: different approaches for initial separation by bending

3.2 Friction to Rubber

By using a common eraser, it was tested whether friction can be used for initial separation by creating lateral forces directly at the corner of the prepregs. Tests with translational, rotational and combined movement with different levels of contact pressure were performed. The strong adhesion between the prehardened prepreg and the foil prevented any separation. An initial separation at SMC material was strongly dependent of the local adhesion and minimal debondings caused by previous cutting and handling. For the case of strong and complete adhesion between foil and SMC, numerous attempts with high contact pressure were necessary for an initial separation. This led to high forces, moving the SMC on the vacuum table and in some cases lifting it. Additionally, the high contact force between the rubber and SMC material where the foil was already removed lead to disintegration of the SMC. A side effect was also the disintegration of the eraser, leading to additional debris, which could be prevented by using an appropriate material. Due to the damage to the SMC, high forces and non-suitability for prepregs, no further investigations were carried out.

3.3 Brushes

Another approach to induce force directly at the corner of the foil for an initial separation is by using brushes. Tests with simple brushes showed that, depending on the diameter and material of the bristles, quite many tries were necessary to initially separate foil from SMC. In case of prehardened prepregs, an initial separation could only be achieved in a very low number of cases. The acting forces were high and varied widely. By using rotating brushes, driven by a cordless screwdriver and guided manually, an initial separation of a corner of foil could be achieved on both SMC and UD-prepreg. Encountered problems were the acting forces as well as damage to the foil and the semi-finished materials. When processing SMC, the inflicted damage was limited to the pulverization of the resin and therefore the exposure of the glass fibers (Figure 2 a+b). The prehardened resin of the UD-prepregs showed less damage. Instead, foil damage was caused by the stronger bond between foil and prehardened prepreg and the consequent transfer of high forces between foil and bristles (Figure 2 c+d). Another problem was the lateral force moving the workpiece on the vacuum table and making the handling of the brush more difficult.

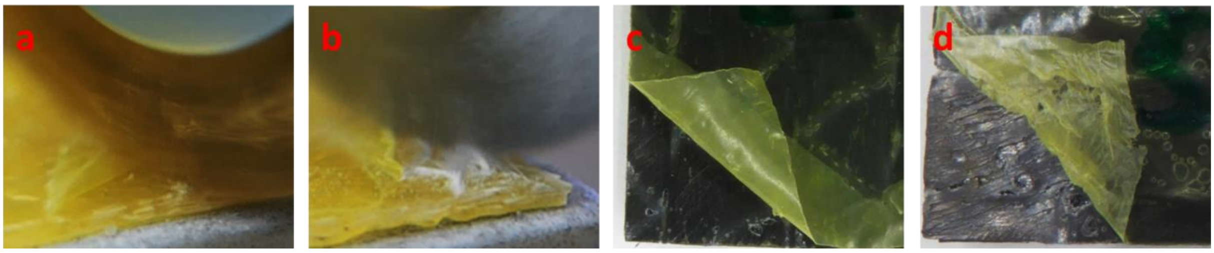

Figure 2. Initial separation of foil from SMC (a&b) and different results on prehardened prepregs (c&d)

Damage and lateral forces could be reduced to a minimum by using the right parameters of bristle material and diameter, contact pressure and rotation speed. The used bristle materials and diameters were: nylon (0.15 mm), brass (0.1 mm, 0.2 mm and 0.25 mm) and steel (0.1mm, 0.15 mm and 0.2 mm). The more flexible the bristles, the more contact pressure was necessary to peel the foil. The nylon and the 0.1 mm brass bristles did not separate the foil from the prehardened prepregs at all. When used on SMC, the high contact pressure led to high damage of the SMC. The more rigid the bristle, the more damage was done to the foil. Rigid bristles also require more sensitive handling and lead to strongly changing forces. Best results on both semi-finished products were observed with the 0.2 mm brass brush. Three different rotation speeds of 100 rpm, 350 rpm and 1300 rpm were tested. High speeds reduce the necessary contact pressure and therefore the lateral forces and also minimize the variation of the counter torque. On the other hand, high rotational speeds also come with more contacts between bristles and materials per time, summarizing small damages very fast and therefore leading to a ripped foil when interacting too long. 350 rpm showed the best results for both SMC and prehardened prepregs. Conclusively, the right parameters led to very good results for SMC. Separating a corner of the foil to prepare it to be gripped with the combined vacuum-clamping-device (described in chapter 3.6) succeeded in nearly 100 % of the experiments. From prehardened prepregs, the foil could be separated in a way that it could later on be pulled off completely by the combined vacuum-clamping-device in 108 of 115 experiments using optimized parameters. It is assumed that further improvement by optimizing the brushes in number, length and thickness of bristles is possible.

3.4 Compressed Air

[5] says that backing paper can be lifted from wet prepreg by injecting compressed air between prepreg and paper with an injection needle. Tests with needles with outer diameters of 0.4 mm, 0.6 mm and 0.9 mm and up to 6 bar with SMC and prehardened prepregs showed rather bad results in lifting the backing foil. The hardness of the prehardened prepregs prevented the insertion of the needle far enough to inject air between foil and prepreg. Only the 0.4 mm needle could be bent and therefore be inserted between foil and prepreg. Nevertheless the air flow through this needle was too low to lift the foil and the risk of breaking the needle was very high. Several tests on SMC with different needles, angles, with and without barrier for guidance for the air bubble showed, that the thin foil is not rigid enough to be separated from the SMC in a large area. Instead of creating an air bubble becoming larger and lifting the whole corner, in most cases small channels to the environment formed and the growth of the bubble stopped before reaching the corner. By using the biggest needle with maximum pressure and optimized angle of insertion to guide the air stream into the direction of the corner, separation from SMC in fact could be achieved. The success rate however was still at maximum 75 %.

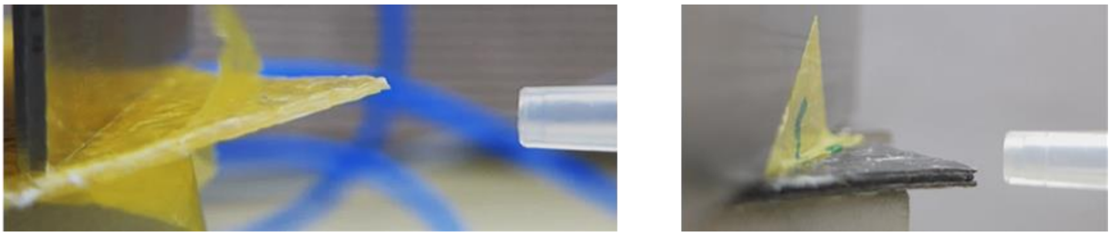

Figure 3. Removal of the foil with compressed air

Another approach was to use an air stream generated by compressed air with up to 6 bar, flowing out of a nozzle with an inner diameter of 2.3 mm. The air stream, directed on the corner of the material, and the generated impact pressure separates foil and raw material to a stopping element or until the pull-of-force gets too high. Trials without relative movement between workpiece and nozzle showed strongly varying results. Even minimal alternating angles or different arrangement of the specimen on the vacuum table could either lead to successfully pulling of an edge of the foil, bending the specimen in the case of SMC with or without separating the foil or to no effect at all. A disadvantage of bent SMC is that later gripping of the foil for complete removal can get more complicated depending on the degree of springback. By implementing a relative movement between nozzle and workpiece, the results could be improved a lot. Best results were achieved by moving the nozzle downwards along the normal direction of the material, starting slightly above the material with the air stream flowing parallel to the material (Figure 3). By doing so, the upper foil of SMC, placed protruding on the vacuum table, could be separated in every try. In most cases, the bottom foil could be separated too. For prehardened prepregs, the described method, followed by an upward movement was repeated 3 times to create a small separation on each side of the prepreg. This only succeeded in 28 of 58 tries. If the prepreg was prepared using rotating brushes to create minimal separations for the impact pressure to take effect, the success rate could be improved to 43 of 47 tries. Two extra air streams, one per each side, directed in an angle of approx. 30° to the prepreg were used to enlarge the separation area. The advantage compared to the use of rotating brushes alone is less foil damage. Main problem on trials with both materials was the impact pressure also taking effect between the workpiece and the vacuum table and the desired stop against an uncontrolled foil removal. In order to minimize the effect of the air flow, the workpiece has to be clamped on both sides with line contact to avoid pressure build-up in a long gap, similar to a lubricating wedge. Another problem of the method is the loud noise caused by the air stream.

3.5 Vacuum Gripper

Tests with different sizes of flat and bellow suction cups showed that neither initial separation nor the gripping of beforehand separated corners of the foil and removing it completely are possible. Since the thin and flexible foil has nearly no bending resistance, forces directing away from the suction cup peel the foil from the suction cup at a corner, leading to a loss of vacuum and therefore pulling the foil completely off the gripper. The only way to bypass this problem is to arrange the suction cup in a way that the peeling force directs into the suction cup instead of away from it. This leads to collision problems and due to the flexibility of the foil and its interaction with the suction cup, a stable process is not possible and the transferrable forces are low. The use of a simple sheet metal, similar to [5], does not prevent peeling the foil off the suction cup except for the case that it covers the complete cup. Foil can be clamped between the suction cup and the sheet metal but the usable force is limited by the flexibility of the cup.

3.6 Combined Vacuum-clamping-device

Based on the insufficient results with the combination of vacuum grippers with a sheet metal for clamping, another approach to combine the gripping technologies was examined. The outcome was a simple 3D printed part (Figure 4) with a coanda ejector to suck a part of the beforehand separated foil into a suction chamber. By activating a pneumatic cylinder, the foil gets clamped between the wall of the suction chamber and a clamping element with a line of hot melt to increase the static friction and to distribute the clamping force of 24 N evenly.

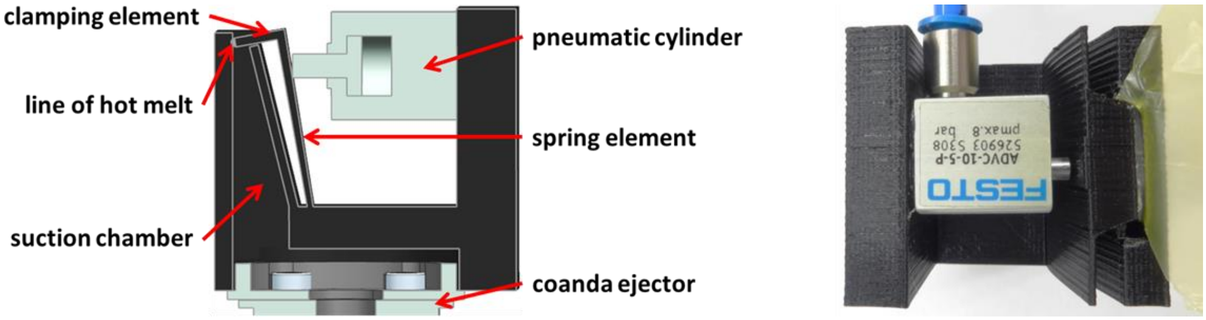

Figure 4. Combined vacuum-clamping-device

Tests showed that the device is very effective to pull off foil from SMC and prehardened prepregs. A beforehand separated corner of foil with an edge length of only 8 mm was sufficient for a good grip. When gripping partially damaged foils, for example by initial separation by brushes, it was found out to be useful to only pull of a small piece of foil, release it and clamp again the now newly pulled off and therefore undamaged foil. Since that way the foil can be clamped across a larger width, regripping can also be used to prevent foil ripping when removing foil from large workpieces. It also is helpful to evenly distribute the tensile stress in the foil when changing the direction of pull-off on complex parts.

3.7 Adhesive Tape

Adhesive tape can be used for initial separation and complete removal of foil in one step. For the case of SMC, nearly every adhesive tape was successful by simply attaching a piece of adhesive tape by hand and pulling it off with the foil attached. To initiate a separation of foil from prehardened prepregs, the parameters had to be adjusted. A synthetic rubber adhesive tape with paper back was used for maximum initial tack. Since the tack of the used tape strongly depended on the used contact pressure, different compression methods were tested. The most effective was to use a piece of sheet metal with a slightly rounded edge (Figure 5 left). By pressing it firmly with a force of 15-25 N and a vertical angle of 45° on the tape and moving along the angle bisector from inwards to outwards, a maximum contact pressure at the corner was achieved. This procedure was performed twice and lead to some damage to the tape when performed with 20 N or more but had no negative effect on peeling the foil, which was successful in 89 of 89 tries. Tests using a plastic roll for compression were also performed. Due to the distribution of used compression force on a larger area, a force of approx. 100 N and 3 rounds (Figure 5 right) were necessary to achieve a success rate in peeling of 100 % (30 tries). The process of removing the complete foil was dependent on the width of used tape to avoid ripping the foil. Advantages of removing foil with adhesive tape are the low lateral forces on the workpiece and the low chance of damaging the material. Furthermore, only one step is theoretically needed to both initiate a separation and completely remove the foil. However, regarding the provision of adhesive tape on rolls, the compression step and the removal of tape and the foil, the process itself is more complicated than others. Since the foil cannot be separated from the adhesive tape without ripping, either the tape or the foil has to be cut at one point of the process, making the process even more complicated. Possible ways of automation still have to be developed.

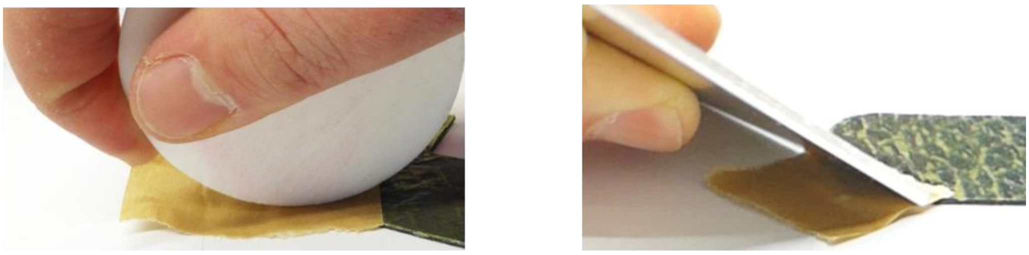

Figure 5. Compression methods for the adhesive Tape

3.8 Hot Melt

Due to the good results with adhesive tape, the use of fluid adhesives was chosen to be tested too. In this case, the use of hot melt with two different methods was examined. The first method was to apply a point of hot melt with a customary glue gun, cool it with a stream of compressed air and grip it with tweezers. The effectiveness of this method was very good, both on SMC and prehardened prepregs, but it also had some downsides. To enable effective peeling and to minimize the acting forces on the workpiece, the glue point had to be set at the very corner of the foil, which led to the risk of glue running above the edge and thereby contaminate the material itself. Furthermore, gripping the glue point with tweezers needed a bit of training and sensitivity, making an automation rather complicated.

A second method was tested in which the hot melt was applied to a wire which then was pressed on the corner of the workpiece. The rest of the wire protruding the workpiece provided a lever, leading to a high peeling force. However, despite preheating the wire, the hot melt cooled very fast, affecting the adhesion to the foil. Combined with the problem of small area of contact, a corner of the foil of prepregs could only be separated in about 70 % with this method. Both methods had in common, that completely removing the foil of a large workpiece led to ripping the foil due to the small area of force transmission. Furthermore, at least 15 seconds of cooling with compressed air were necessary for curing the hot melt. Other methods of cooling, for example with liquid nitrogen, are rather complex and can cause condensation and therefore add water, negatively affecting further processing.

4. Conclusion and Outlook

The economical production of CoDICo Parts requires the automated removal of the backing foil of the raw material. In this paper, several methods to do so have been presented and compared to the state of the art. In the evaluation of the concepts, mostly the result of the separation has been evaluated. Very successful approaches were the removal of the foil with adhesive tape and the combination of brushes for the initial separation and a clamping-gripper for the pulling off. Although the concepts were developed with regard to automation, no automation concept exists for all the approaches. Therefore, the development of separation concepts is the first step for an economical production of these hybrid parts and the concepts need to be automated in a second step.

Acknowledgments

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