An Eye for the Essential

Software-Based Tape Stacking with the Aid of Camera Technology Paves the way for Thermoplastic Composites

Thermoplastic tapes are expected to achieve great things, namely to shape the next generation of thermoplastic composites. This calls for highly accurate tape stacking. At the same time, tape processing must not become so complex that it becomes uneconomical. Engel contributes this technology to achieve a breakthrough by combining high-precision control software with camera technology in tape stacking.

For high production efficiency, a tape stacking unit is best equipped with two robots and one camera station © Engel

Many different input parameters influence the outcome of conventionally controlled tape-stacking processes. The quality of the used material is paramount, but ensuring that the specified tape width is maintained with accuracy, for example, play a role too. Sensor technology and intelligent software concepts have the potential to substantially improve product quality during tape stacking. In certain areas, production lines programmed with advanced software solutions are already capable of optimizing the process autonomously.

For even better results in the future, tape-stacking production lines will have to generate additional information that can be used directly to control an ongoing process. The lines' sensing capability is thus evolving into a crucial factor that will determine the extent of further market reach of thermoplastic composites.

In the future, the production lines will need to be able to select the relevant information for a given stacking process from a wide range of sensory data. A key role here will be played by camera technology. Image data provide information, which adapted software solutions can incorporate into the process control setup. This can be carried out specifically for each individual component.

Higher Structural Performance

Thermoplastic composites in the form of organic sheets comprising a fabric made from glass fibers or carbon fibers embedded in a thermoplastic matrix of PP, PA, PC or PEEK are already well established. Tapes represent a further variant of such composites. An advantage of these unidirectionally reinforced materials is the absence of fiber undulation, i.e. waviness, which is typically found in fabrics. The fibers in the component can already be optimally stretched for delivering higher structural performance.

The use of tapes also eliminates the need for a weaving step. The glass-fiber or carbon-fiber rovings are directly embedded into the thermoplastic matrix material in a continuous process. In addition, the materials can be processed in such a way as to minimize scrap. The tapes can be specifically arranged to cope with the expected loads, and differ-

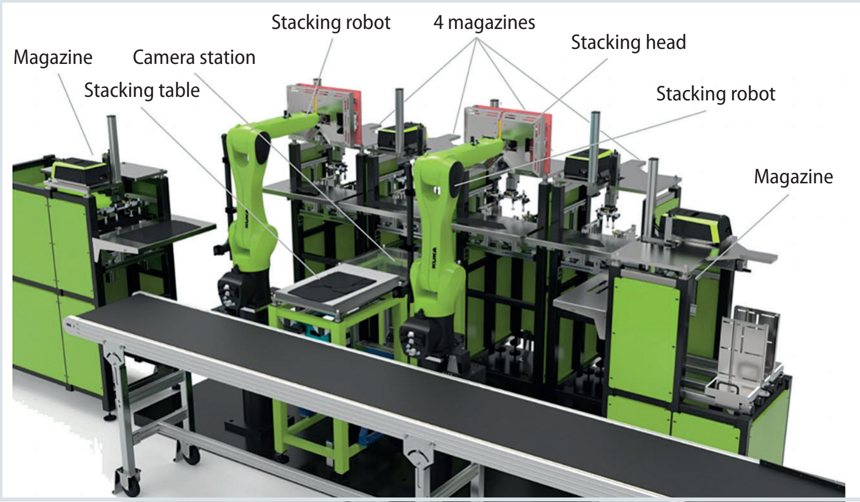

Fig. 1. The laboratory production line is designed for stack dimensions up to 460 x 360 mm © Engel

ent thicknesses can be accommodated within one component. All in all, therefore, the prospects for thermoplastic composites based on tapes are bright.

Stacking Accuracy Determines Quality

In many applications, a single tape fails to provide the required mechanical properties. Several tapes need to be combined together to form a stack which is then consolidated to end up as what is known as a blank. Typical tape thicknesses range from 0.14 to 0.3 mm. A wall thickness of 1.5 mm, for example, calls for five to ten layers of tape. In addition, each tape layer will often consist of several ready-cut tapes, because either a single tape cannot cover the required width or combining several ready-cut tapes helps to minimize scrap.

The ready-cut tapes are spot-welded together during stacking. The next step is to consolidate the tape stack into a solid panel. This is done by carefully melting the entire structure to allow the individual tape layers to fuse together across their entire surface and then solidify into a blank upon cooling. Finally, the actual part is made by heating the resulting semi-finished product in an infrared oven and shaping it in a mold and, if necessary, functionalizing it by means of injection molding.

The quality of the final product hinges on the accuracy with which ready-cut tapes are stacked. For, once positioned, the tapes cannot be realigned. So, tape stacking is the one and only opportunity for making corrections. Any gaps remaining between tapes create lanes in which matrix material accumulates during consolidation and into which the fibers can be shifted sideways. In the worst case, a needle-shaped cavity may form during consolidation. Also, if two tapes overlap at the point where they meet, the fibers will be shifted during consolidation. The effect of cavities and overlaps is to generate weak points in the component.

The Influence of Gap and Overlap

The Center for Lightweight Composite Technologies at Engel Austria GmbH, St. Valentin, Austria, set out to study these interrelationships more closely by producing coupon samples from which »

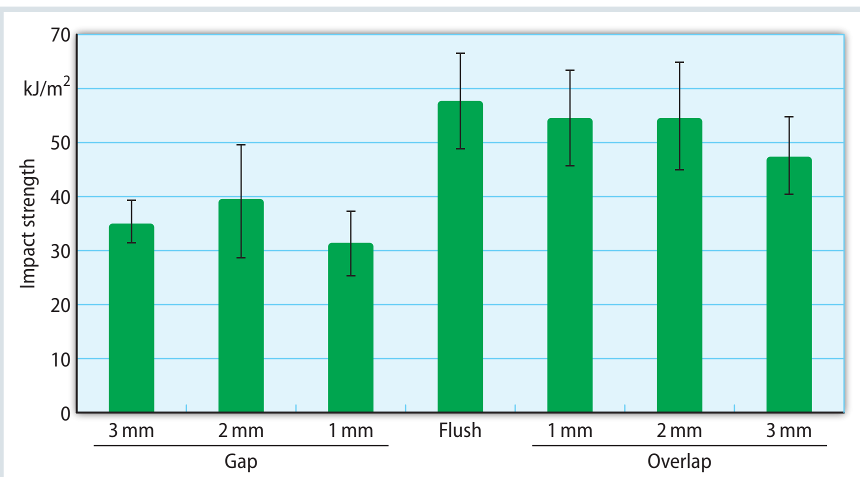

Fig. 2. Flexural bending test with tape blanks featuring deliberately incorporated defects: gaps and overlaps each reduce the impact strength compared with the blank produced with optimal butt alignment Source: Engel, graphic: © Hanser

Efficient Lightweight Design

Melting and solidification are the central physical processes that characterize thermoplastic processing. These changes of state can occur in a comparatively short time. That is why thermoplastics processing methods have above-average productivity. Composites are characterized by the use of long fibers, ideally continuous fibers. These confer extremely high rigidity and strength values combined with low component weight. Thermoplastic composites offer the best of both worlds: high process efficiency and outstanding lightweight design properties. That is precisely why they are so exciting for mass production of lightweight designs.

The Authors

Dr. Norbert Müller is Head of the Center for Lightweight Composite Technologies at Engel Austria GmbH in St. Valentin, Austria; norbert.mueller@engel.at

Paul Zwicklhuber, M.Sc., is a development engineer in the Center for Lightweight Composite Technologies; paul.zwicklhuber@engel.at

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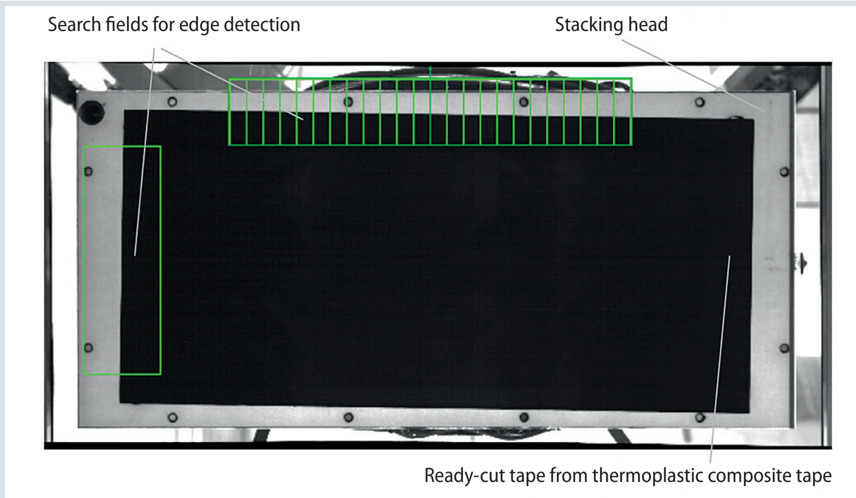

Fig. 3. Search fields for determining edge runs: measurements are taken at 25 positions to join the points together by means of a line of best fit © Engel

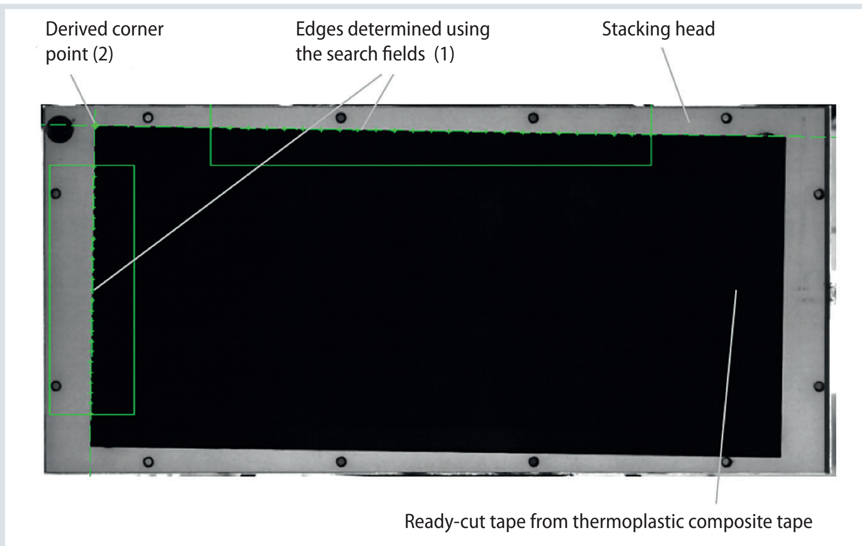

Fig. 4. The corner position results from the determined edge runs. This method is much more accurate than direct optical measurement because tapes do not always have sharp corners © Engel

specimens could be prepared for flexural bending tests. The coupon samples were produced on a laboratory production line (**Fig. 1**) from five layers of tape (PA6-CF60). A layer structure comprising 90° and 0° layers was chosen (90/0/0/0/90) that contained deliberately incorporated defects in the form of different gap and overlap widths in the 0° middle layer. This was achieved by splitting the middle layer and then laying the tapes flush (in abutment), in overlap, and with a gap of up to 3 mm. It was found that each gap or overlap reduces the impact strength, with the gap causing a much greater decline in impact strength than the overlap (**Fig. 2**).

Consequently, tape stacking should be highly accurate in order to arrive at the ideal situation in which the edges are as flush as possible. Technical specifications typically permit gaps or overlaps of ±1.0 mm, with some applications allowing just ±0.5 mm.

Processes that employ sliced tapes of constant width are dependent on exact adherence to the nominal tape width for the sake of stacking accuracy. Variations in tape width will automatically alter the accuracy of the stacking process. The challenge then becomes one of how to overcome this dependency with the aid of software solutions. This is where pick-and-place comes in.

Taking Correction Values into Account for each Stacking Position

The starting point for tape stacking by the pick-and-place method is to use the largest-possible ready-cut tapes from wide rolls. Simple shapes are cut direct from the roll. More complex shapes are punched. The two main governing principles are minimize waste on one hand and maximize line output on the other. Ideally, the tape stack will have been conceived in such a way during the component design phase that the best possible use is made of the tape roll and that the material can be processed into stacks with as few stacking operations as possible.

A classically controlled pick-and-place process requires highly accurate ready-cut tapes and precise guideways in the magazines, as well as additional alignment and centering modules. Optical metrology opens up new possibilities here, because it can render a production line capable of precision, controlled alignment (**Title figure**). An end-of-arm tool (EOAT) picks up the ready-cut tape – accuracy of the tape is not critical here, nor is its position on the EOAT. The position of the ready-cut tape relative to the reference marks on the EOAT is only determined once the camera station has been reached. This information is used to influence position targeted by the robot as it stacks the ready-cut tape on the table.

The transition from tape to background is determined at numerous positions on an area along the edge of the tape – 25 such positions are shown in the example (**Fig. 3**). These points are joined together to produce a line of best fit which is projected beyond the search window. The same is done on a second edge. The outcome is a corner point formed by the projection of the two straight lines (**Fig. 4**). This corner point can be determined much more accurately by means of the ready-cut edges than by direct optical measurement, because punching or cutting often fails to produce precise, sharp corner points.

The information on the position and angle of the tape on the EOAT is used for positioning the tape as it is laid on the table. The points along the edge of the tape can be determined to within three pixels. On the laboratory production line, a laying accuracy of ±0.5 mm and less was achieved over several series of measurements. In other words, the gap or the overlap was less than 0.5 mm. However, the attainable laying accuracy also depends on how straight the cut or punched edges are. Further factors affecting the determination of edges are the color of the tapes and the contrast against the background.

Tape stacking accuracy is the metric around which the entire process is optimized. However, it is the concept behind achieving this high laying accuracy that is paramount. Through the use of the camera technology, information can be gathered which supports active software-based readjustment for the purpose of optimizing stacking accuracy. The software keeps working to produce the best result, i.e. the highest possible stacking accuracy.

High Performance in Real Time

In the medium term, software-based or software-dominated process technologies will leave conventional solutions far behind them in many areas. Even if the latter can achieve comparable quality by means of precision testing, adjustment and validation, a high dependency on mechanical elements and the quality of the raw material always remains. This approach is nearing its natural limits.

A much more efficient approach is to enable the production line to recognize and evaluate the properties of the material at hand and to take the appropriate action. Added value is obtained by using the sensor technology additionally to check the tapes for cracks, uneven fiber runs or missing corners, and in so doing to detect much finer deviations than would be noticeable to an attentive production line operator.

The preferred design of tape stacking unit has two robots and one camera station. The first tape is held at the stacking table by means of a vacuum. All subsequent layers are spot-welded to the layers below.

The ready-cut tapes are separated at the stacking magazines and placed on pick tables where they are held in position; the robots can therefore approach the tables at high speed (**Fig. 5**). The EOAT is equipped with vacuum grippers for picking up the ready-cut tapes. This configuration makes for a highly dynamic stacking process at every step of the process. Over several test series and with the robots operating in alternation, a stacking time of 3.4 s per tape blank was achieved on the test production line.

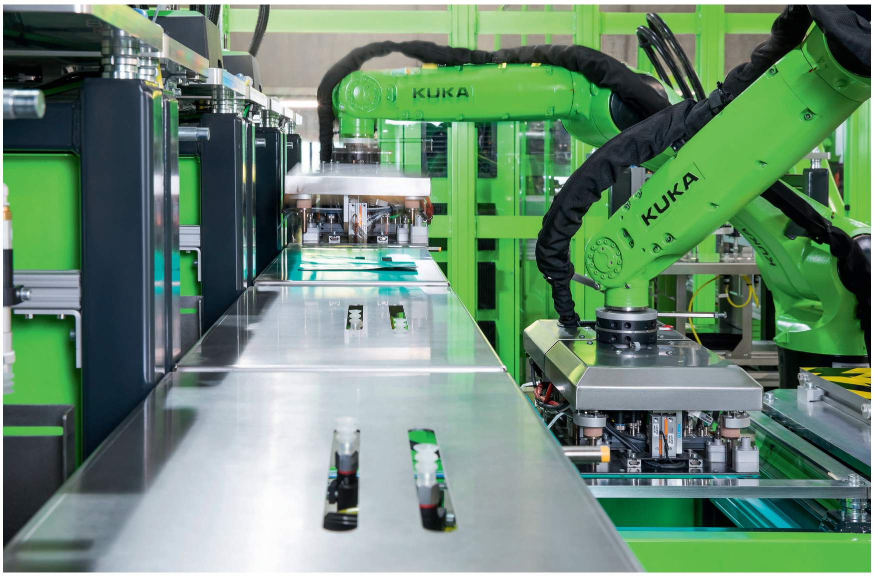

Fig. 5. The ready-cut tapes are separated at the stacking magazines and held in position on pick tables for collection by the robots © Engel

To help the optical measuring system readily identify the tape on the EOAT, the full receiving surface is illuminated with an electroluminescent film and the EOAT together with the tape is pressed against a glass plate. The edges are detected, the corner points of the ready-cut tape are determined and the results are referenced against the tool center point of the EOAT. This information is then transmitted to the robot controller so that it can correct the position and angle of the tape.

Consequently, the tape can be laid with precision and flush with an existing edge. The algorithms for determining the exact stacking position work on the digital image material as the tape is already making its way to the stacking table. This approach thus places very high demands on the real-time performance capability of the production line.

Pick-and-Place for Hybrid Stacks too

With a pick-and-place tape stacking unit, tape stacks can be produced within a very short time and with great accuracy. For the sake of high laying rates and timely provision of required correction data, only selected edges and corner points are determined during optical measurement. However, the camera data can be saved so that stack quality can be assessed and analyzed afterwards. The product specification determines which files are automatically saved along with the process data. All image data are stored in the case of safety-critical components; otherwise, it is best to save only those images which are associated with process errors and rejects.

A great advantage of the pick-and-place concept is the possibility of producing hybrid stacks. As the stacking magazines can accommodate not only tapes, but also organic composites composed of several fabric layers, already consolidated tape blanks of constant wall thickness, or other thermoplastic semi-finished products, it is possible to use inexpensive, multilayer semi-finished products as base material and to merely reinforce these locally.

Glass Fibers and Carbon Fibers for Different Load Ranges

Tape stacking is a key technology for cost-efficient lightweight design. By reinforcing components locally and according to the load path, it is often possible to reduce the nominal wall thickness. Consequently, hybrid material structures not only can reduce weight but can often also lead to much lower costs. Thus, as the nominal wall thickness of the component decreases, more consideration can be given to expensive carbon fibers for large-scale production setups. Areas of the component that carry light loads could then be reinforced with inexpensive glass fibers, while areas that have to withstand heavy loads could be reinforced with carbon fibers. ■