CONTINUOUS DATA MEASUREMENT AND ANALYSIS IN AUTOMATED MANUFACTURING PROCESSES FOR HYBRID LIGHTWEIGHT STRUCTURES

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ABSTRACT

The current process development for the production of fibre reinforced lightweight structures requires an elaborate iterative procedure, which leads to long development times and high costs. Novel methods, which allow early analysis and determination of significant process and quality parameters, are therefore an essential basis for an efficient process development. Within this paper, a novel automated process for the large-volume production of lightweight structures in multi-material design is presented. The process chain is equipped with a large number of sensors and monitoring cameras for a continuous data measurement in all process steps. The collected data are automatically processed using a special process analysis mould. This enables fast optimisation of the process parameters and guarantees reproducible high quality products.

1. INTRODUCTION

Polymer-metal hybrid structures offer high potential for an efficient lightweight design using the specific material properties of the single semi-finished products [1]. The intelligent combination of these different materials allows a significantly higher performance compared to classic monolithic designs. Especially in automotive applications, the crash behaviour can be improved by combining metals with textile or long fibre reinforced thermoplastic polymers. The use of efficient production processes with short cycle times enables an economic manufacturing of lightweight components [2-3]. In a previous research project, a novel 3D-Hybrid design and manufacturing process were developed in collaboration with industrial and scientific partners. Here, cold or warm formed steel sheets are combined with local reinforcements using organic sheet. To increase the bending stiffness of the open profile geometry a short fibre reinforced rib structure is integrated on the inner side. The required joint strength between steel and the textile reinforcement is realised using special adhesion promoting layers or a laser structuring of the metallic surface [4]. The manufacturing of the 3D-Hybrid structure in an intrinsic in-mould assembly process (IMA) allows to reduce the number of single parts and needed joining steps. Compared to a conventional post-moulding assembly process (PMA) costs and weight can be significantly decreased. The high potential of these 3D-Hybrid structures was validated in extensive numerical and experimental investigations for a B-pillar of a car body [3]. The project showed that the intrinsic joining of the different materials in a one-shot process is a major challenge and requires deep knowledge about materials and processes. Therefore, within the scope of the “Q-Pro” project a fully automated process chain with inline and in-process measurement systems was installed. This allows a 100% inspection of the semi-finished products as well as the manufactured parts and guarantees the required high quality. Figure 1 shows the single process steps for the manufacturing of a basic structure, which is one of the demonstrator parts of the project.

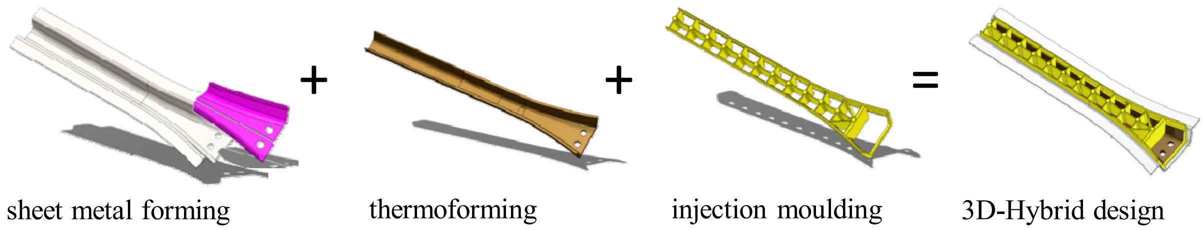

Figure 1: Process steps for manufacturing of a 3D-Hybrid structure

2. MATERIALS AND PROCESS CHAIN

In the “Q-Pro” project, cold-formed dual-phase steel (DP600) and a local reinforcement sheet made of tempered boron alloy steel (22MnB5) are used as metallic sheets. Both components are formed in a separate mould and joined together by spot-welding. Furthermore, organic sheet material from Bond Laminates (Tepex dynalite 101-RGUD600 - 80% of glass fibres in 0° direction - 20% in 90° direction) and long glass fibre reinforced injection moulding material from LANXESS (Durethan AKV30) are used as reinforcement. Both materials have a polyamide 66 matrix system. All selected materials are commonly used in automotive applications.

Figure 2 shows a schematic overview of the equipment used for the automated manufacturing process of the basic structure. At the beginning of the process, the quality of all semi-finished products is checked inline using an optical measuring station. Two cameras are used to scan the geometry of the steel part and the organic sheets cutting. Furthermore, the optical system detects defects like fibre misalignments in the textile or incorrect welding points at the steel part. If the quality is approved, the steel part and the organic sheets are transferred by a robot. The steel part is inserted in the upper half of the mould, which is positioned in a fast stroke press. The mould temperature is regulated at 110°C. The steel part heats up by contact. At the same time the robot deposits the organic sheets in an infrared unit. Here the sheets are heated above the melting temperature of the polyamide matrix up to a maximum process temperature of 320°C by infrared radiation. Subsequently, the robot is used to grip the organic sheets and put them in the lower mould. The organic sheet is thermoformed by closing the press and is bonded to surface of the steel part. When the mould is closed, the long fibre reinforced thermoplastic mass is injected and fills the rib structure inside the profile by an injection moulding machine. After a cooling time, the finished hybrid structure is demoulded and transferred to the measuring station for an end-of-line inspection.

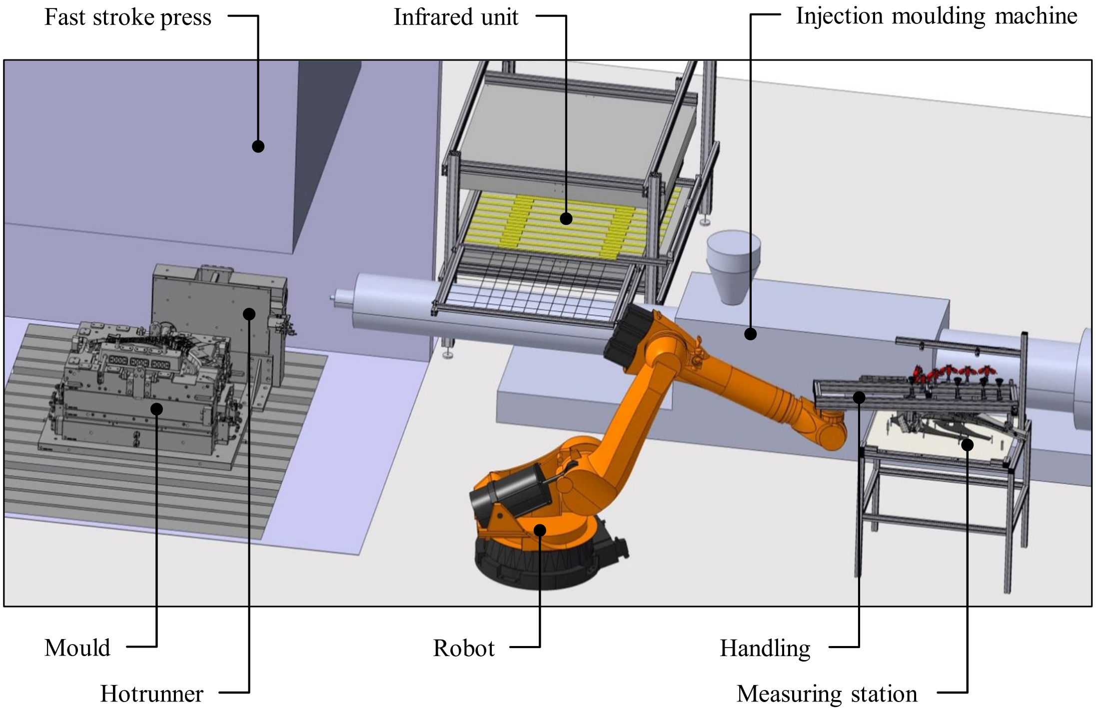

Figure 2: Scheme of 3D-Hybrid production process

3. CONTINUOUS DATA MEASUREMENT

During part production, process parameters for each cycle are continuously recorded. All machines are equipped with special interfaces and connected to a central computer via Ethernet. Customised software automatically transfers the live data from the machines into a central database. The trigger points for start and stop of the data measurement are controlled centrally by the robot. At the beginning of the process, a camera scans a QR code on the metal part. This component identification allows all data to be assigned to the respective cycle. After this, the data monitoring starts with a quality check of the different semi-finished products. Two CMOS camera systems capture 2D images in a measuring station (Fig. 3 right).

The acquired data is evaluated live via image processing software. A tolerance limit is used to determine whether "pass" or "fail" is returned to the process. Relevant geometrically features of the steel part are the dimensional accuracy, the relative position of the welded parts to each other and the presence of inserts. The performance of the hybrid structure is primarily influenced by joining quality. Therefore, weld spots and the applied adhesion promoting layer are checked. After completing the evaluation of the steel part, the organic sheets are analysed using the same method. Strength-relevant influences are mainly related to fibre angle alignment and geometric divergences. The cutting edges are evaluated with regard to their quality by a contour control to exclude delamination and burr formation.

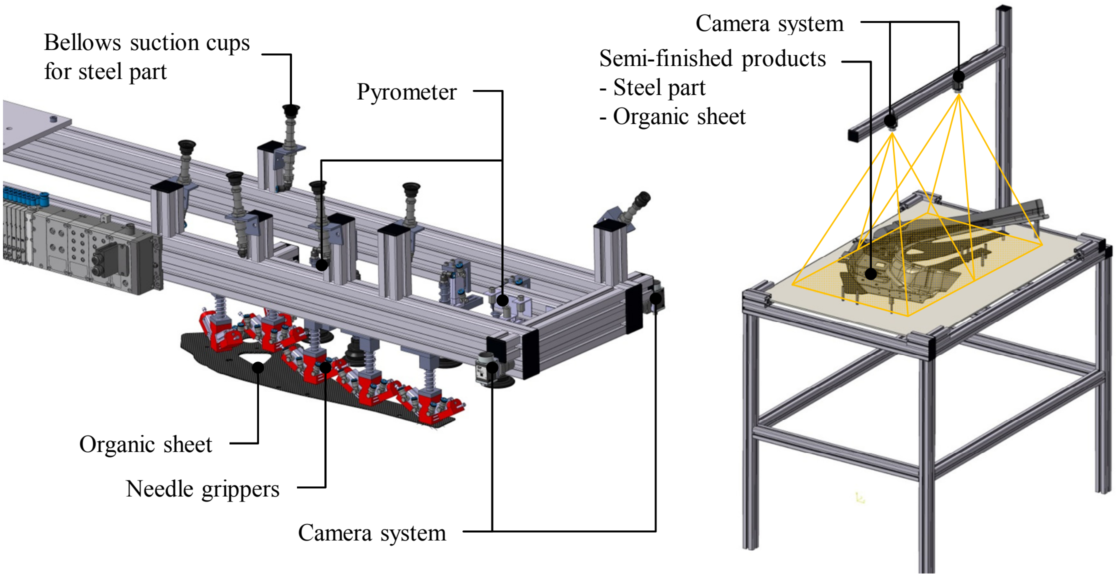

Figure 3: Inline measurement using industrial image processing with camera system and non-contact temperature measurement with pyrometer during the whole handling process for quality control and process parameter analysis

Manufacturing studies were conducted in order to identify crucial parameters and effects during thermoforming process [5-7]. Here a precise temperature control is essential. For this purpose, pyrometers and sensor elements are implemented in order to monitor and control the temperature profile. The infrared unit (Fig. 2) is equipped with one pyrometer to measure the temperature of the organic sheets. The organic sheets are heated to a maximum process temperature to compensate cooling during the transfer process into the mould and not damaging the glass fibres during the thermoforming process. The heating process ends after a defined holding time, which starts when a predefined surface temperature of the organic sheet is reached. For the automated and quick transfer into the mould special needle grippers are used. To ensure a continuous temperature recording at the organic sheet surface pyrometers are also installed in the handling system (Fig. 3 left). Two additional pyrometers at the opposite side of the handling system measure the temperature of the metal surface, when the steel part is inserted into the upper mould and before the mould closes.

At the front of the handling system, two further CMOS cameras are installed. These check the correct position of the steel part in the upper mould. Therefore damages of the mould due to incorrectly inserted components can be prevented. Furthermore the cameras are used to check the position of the organic sheets during the transfer and the depositing process. In case of an inaccurate placement of the blank, the altered draping process and thus also the fibre orientation leads to adverse effects of the component properties.

After transferring the semi-finished products, the press closes and the organic sheet is formed. Here, the fast stroke press records the relevant parameters like time, distance, speed and pressure. When the mould is closed, the rib structure is formed by injection moulding. Here, on the one hand, data from the injection moulding machine (time, injection pressure, holding pressure, temperatures and injection speed,) as well as data from the mould (mould temperature and mould internal pressure at two positions) are recorded. After demoulding, the finished component is further cooled to room temperature and subsequently measured and tested using the optical measurement technique.

4. AUTOMATED DATA ANALYSIS

The main target of an automated data analysis is a sufficient description of measured values or curves using quantitative data. Required characteristic features of the curves have to be defined and the relevant information has to be filtered out of the dataset. For process monitoring common error detection and classification methods such as limit value, tolerance window and envelope curve monitoring are already used. In comparison to the envelope curve, the window monitoring method requires less time for evaluation, because only the data in the windows are evaluated, whereas the entire curve data is analysed in the envelope curve [8]. Monitoring and optimisation in the pressing process have already been investigated using an automatically calculated and dynamically adjustable envelope curve [9].

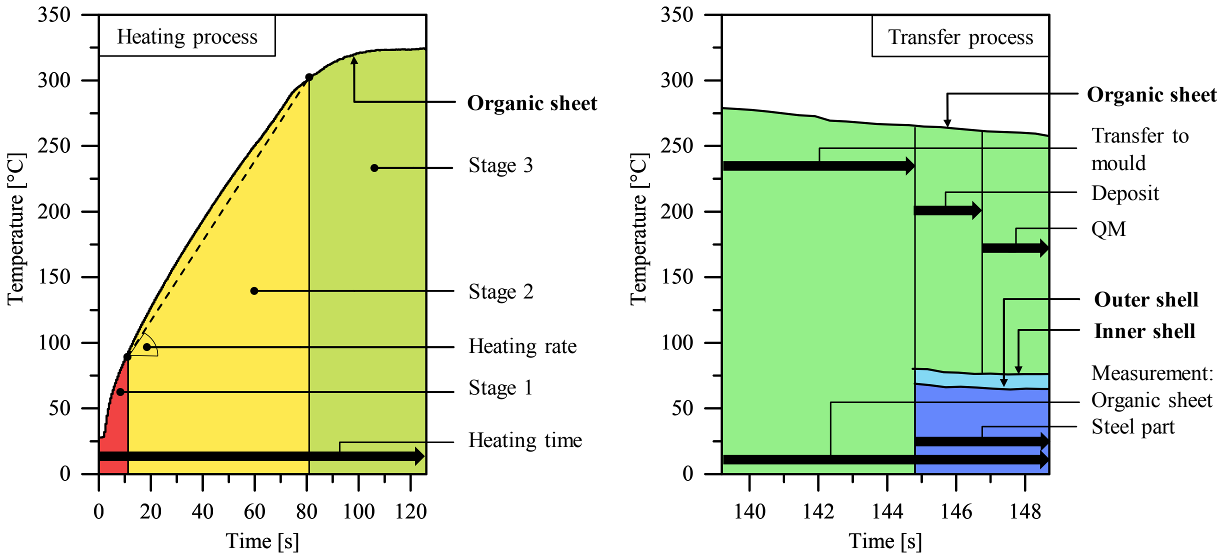

Figure 4: Curves of automatically recorded temperature data of organic sheet during heating process (l.) and transfer process in mould (r.); Characteristic points are evaluated with an automated algorithm for each cycle

The analysis of the measurement data is described in detail using two selected examples. For this purpose, data of the heating and of the transfer process as well as from optical measurement are shown. In the left diagram of figure 4 on the left the heating process of the organic sheet is shown. The curve can be divided into three characteristic stages. The first stage describes the start-up of the heating process, which ends after 11 seconds as soon as the heating rate reaches an approximately constant value. In stage 2, the organic sheet is heated up to a predefined setpoint temperature following with a constant holding time in stage 3. Relevant parameters such as start and maximum temperature, heating rate, holding time and total time are extracted from the graph. The start of the process simultaneously defines the starting temperature. At the end of stage 1, until the setpoint temperature is reached, the curve is interpolated linearly and the heating rate is calculated from the slope. The maximum temperature is defined by determining the highest value of the recorded temperature values. The total heating time is recorded from the two trigger points of the robot for heating process start and end. The formation of the temporal integral between the start and end time generates another value which characterises the total energy transferred into the organic sheet during heating.

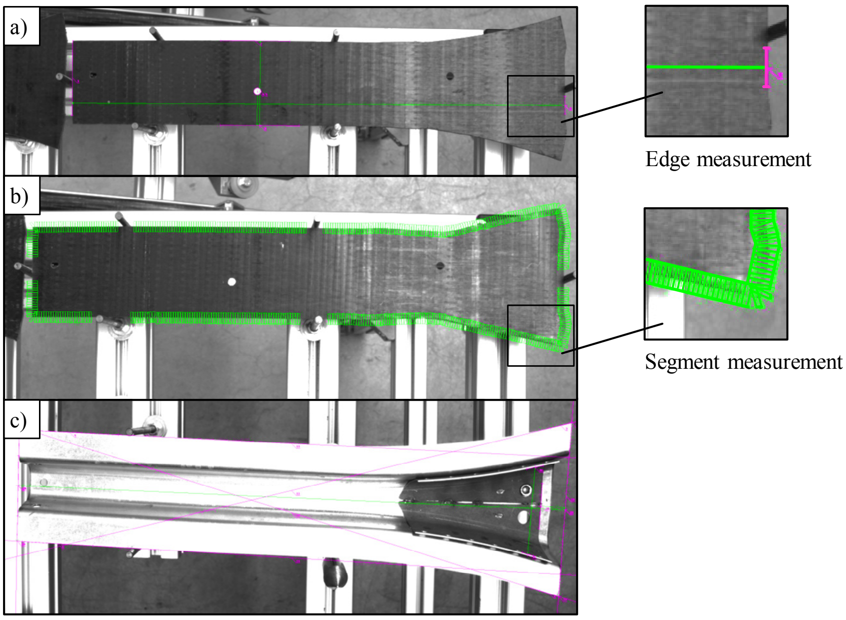

Figure 5: Automated inline measurement using industrial image processing for quality control a) Monitoring of the geometry and fibre angle of the organic sheet cutting; b) Detection of irregularities at cutting edges by contour control; c) Monitoring of the geometry of the semi-finished metal part

The temperature profile of the organic sheet and the metal components during the transfer process are shown in the right diagram of figure 4. The most important characteristic values here are the measured temperature at the gripping position, the last measured temperature before the handling leaves the mould and the resulting cooling rate. For this purpose, the robot control gives a trigger signal for starting and stopping the measurement. The cooling rate is calculated by linear interpolation of the two temperature values for the organic sheet described above. The temperature of the steel component is measured parallel when the robot places the organic sheet in the lower mould. For this purpose, two measuring points at the steel part were defined on the outer shell and the inner tempered shell. The last temperature value for the organic sheet is determined after the optical measurement is done and before the handling leaves the mould.

For the optical quality control, industrial image processing is used. The required functions are implemented with adapted algorithms and software tools. Relevant functions such as presence control, component identification, feature localisation and property measurement are applied. The position of characteristics is extracted by edge detection (Figure 5 a, c). These characteristics are usually straight lines, arcs or circles. The positions and dimensions of the characteristics are measured by means of constructed graphic elements. For each nominal dimension, an upper and lower limit, as well as an upper and lower warning threshold, are stored. In addition to the status messages, metrology also supplies the values of the individual dimensions. During contour control, the entire inner and outer contour of the test pattern is divided into narrow segments (Figure 5 b). A warning threshold and a tolerance limit are stored for the position of the test object edges relative to the positions of the segments, which do not need to be the same at each position. When a component is inspected, image processing shows the status of each segment.

Based on the extracted data, process fluctuations can be analysed which provide conclusions on the dynamics of the individual and overall process chain. The dependencies of the structural properties of the primary influencing variables in the process are tested by means of parameter studies on the basic structure. To this end, several components are produced and their process parameters are varied, which have been selected in advance using simulation. In structural parts, mechanical characteristic values such as stiffness, maximum force and energy absorption capacity are determined. At the same time, in the virtual process chain, real-time data from the process is simulated in the structure simulation and is validated with the experimental results [10]. A novel modelling approach makes it possible to evaluate the entire process chain by a parameter-property correlation. For this purpose, the technology data analysis tool "Detact" (by the software company Symate GmbH) transfers all data from the process, simulation and component tests in a virtual process chain. Statistical methods are used to analyse the relationship between process and component structure. The process can be further optimised in this way and the structural properties can be increased. The process windows for the individual process parameters can be defined for a series-based application and the components can be evaluated over a tolerance limit.

5. CONCLUSIONS

The combination of specific materials within multi-material-design leads to outstanding advantages for efficient lightweight solutions. A high degree of freedom in design, processing and performance is achieved by combining textile reinforced thermoplastic composites with short reinforced thermoplastic injection moulding compounds and metal profiles. The manufacturing of these complex hybrid structures is a challenging task. To guarantee reproducible high quality parts a fully automated process with a continuous data measurement and analysis method was built up. By integration of sensors and camera systems in the different process steps, the behaviour of the semi-finished products can be described in detail along the entire process chain. The new process analysis tool "Detact" allows an automated processing of all process parameters. Together with results from experiments and simulation the significant process parameters can be optimised. Further, the process understanding leads to increased part quality and improved validation possibilities of simulation results.

6. ACKNOWLEDGMENTS

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