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Simultaneous Grasping and Heating Technology for Automated Handling and Preforming of Continuous Fiber Reinforced Thermoplastics

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Abstract

Nowadays large-scale production systems for lightweight car-bodies made of composite materials become increasingly important. Especially, the use of thermoplastic matrix materials makes these composites worthwhile for large quantities. However, these so-called organo-sheets must be heated above melting temperature before manufacturing. In this state, the composite becomes form unstable, which complicates the handling in an automated process. To simplify the handling, this paper presents an approach, which allows the handling, heating and preforming of organo-sheets. This includes the introduction of a robot-tool, which is composed of heatable vortex-grippers and a folding mechanism, as well as a analysis of its automation potential.

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Keywords: robot; gripper; organo sheet; thermoforming; preform; woven fiber

1. Introduction

Modern lightweight design of car bodies in automotive industry and the increasing product varieties lead to suitable manufacturing and handling systems for fiber composite materials. Especially the processing of thermoplastic continuous fiber reinforced plastics (hereafter referred to as organo sheet) poses major challenges for robot grippers as well as production technologies. A completely heated flat organo sheet must have been processed within approximately ten seconds after heating. If this time is exceeded, the manufacturing could result in fiber failures and destruction of the polymer matrix during the forming process. The idea of producing a preform, as is the case with dry fibers, is hardly possible due to this short processing time. However, current developments in processing techniques focus on near-net shaping and over-all manufacturing costs [1]. For this reason, existing forming technologies, which were originally developed for metal forming, were transferred to composite materials in order to achieve higher quantities. Among other manufacturing processes, thermoforming is one of the frequently used stamp forming technologies for the manufacture of thermoplastic organo sheet components. During thermoforming, the thermoplastic matrix of the composite must initially be melted in a heating technique to accomplish a deformation of the flat fabric. The formability of organo sheet into given geometries depends strongly on the type of fiber reinforcement [1,2]. Since corners and edges with small radius on the stamp forming tool causes wrinkles or local fiber failures on the composite, high requirements on a process adapted material-feeding-system are necessary. For this reason, a simple robot gripper can barely handle this task. It is necessary to implement an active draping support into the gripper system. In a general production process, on the one hand, the entire organo sheet can be heated e.g. within an infra-red-radiator for preforming. On the other hand temperature elevation can be realized only in areas where large fiber deflection is required. A practicable approach which also maintains form-stability could be to partially heat the organo sheet only in those areas. Thereby, less energy for temperature elevation for the preform step is needed. Another advantage is the simplified transportation of the solid preform from a preform station to the actual stamp forming step. By the means of a purposeful preforming of organo sheet, a folding before thermoforming could avoid large fiber deflection while forming and therefore lead to a minimization of fiber wrinkling. In this paper, a function-integrated robot gripper to fold woven organo sheet in a preform process is presented. Since the handling and heating of thermoplastic fabrics are separate processes in a sequence, this gripper combines these two processes into a combined one using vortex levitation. The gripping principle of a vortex nozzle is a pneumatic non-contacting handling approach that uses a swirling air flow. This is similar to the Bernoulli-effect which shows a decrease in pressure, if air flows along an edge with high speed. If the flowing air gets heated by a special air heater, an organo sheet can be preformed at melting temperature easily.

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2. State of the Art

2.1. Thermoplast preforming

Many investigations regarding the drapeability of different dry fiber and prepreg fabrics started in the last few years [1]-[4]. Rozant et al.[1] and Mohammed et. al.[3] analysed different dry textile fabrics for stampable thermoplastic preforms. Therefore, tensile and sheer properties of woven fabrics at various fiber-orientations and the locking angle (Trellis effect) were determined. Drapeablity tests were performed in order to detect the necessary forming energy and the maximum sheer-deformation to predict the wrinkling of the fiber fabric after reaching its locking angle. As a result, Rozant et al. show that the deformation energy of woven fabrics is significantly higher than of knitted fabrics [1]. The maximum strain at different fiber orientations is thereby lower using woven fabrics. For this reason knitted fabrics can be draped in more complex geometries. Additionally, Mohammed et. al. studied four types of woven fabrics and presented different drapeability in terms of wrinkling as well [3]. The fabrics were draped over a hemispherical dome whereby it was shown that the use of tight plane weave provides the worst results compared to satin and a twill weave. Another interesting aspect are different material properties by manufacturing dry or fully impregnated fabrics. Chen et. al. [4] indicate that the applied deformation-force depends on the deformation-speed and the shear angle of the fabric itself. While dry textiles need less forming energy and according to this a lower forming force, pre impregnated fibers (prepregs) such as organo sheets require high environmental temperature for softening the polymer matrix. Related to this, Chen et. al. analysed a carbon woven fabric and Polyphenylene Sulfin matrix with a melting point at 280 °C [4]. It could be observed when the impregnated fiber was sheared, that more force would have to be applied compared to dry fiber preforming. However, an increase of the temperature gives weak influence to the sheer behaviour.

In summary, woven fabrics are highly prone to wrinkling and the forming energy even increases with the use of prepregs. In addition, there is a rapid cooling after a previous heating, which makes handling more difficult. A possible solution is to heat the composite partially and to form it only in areas where high fiber deflection is desired. This would also preserve shape stability of the organo sheet and thus facilitate handling. A worthwhile approach in order to combine a pick up operation and partial temperature elevation is the use of vortex levitation. The difference to conventional handling tasks e.g. wafer manufacturing, where vortex grippers are used is hot instead of cold air to lift up the work piece.

2.2. Vortex levitation

Using vortex levitation to grasp and lift work pieces originally comes from e.g. wafer and food handling. In both cases a contact with the work piece must be avoided to protect the touch sensitive surface or to prevent the work piece from being contaminated. Xin et. al.[7] analysed the potential of a vortex gripper for a wafer pick and place process. Therefore, a work piece placed under a vortex nozzle, as shown in figure 1, can be picked up and held in an equilibrium position. The reason is, the lifting force depends on the gab thickness h between the vortex nozzle and the work piece at a fixed air flow rate. Inside this narrow gab, the lifting force decreases if the work piece moves from the equilibrium position in direction of the vortex nozzle and increases if the work piece deviates away.

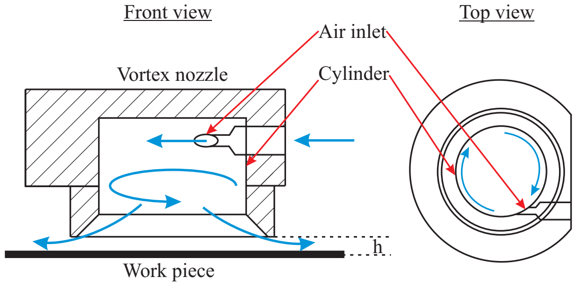

Fig. 1. Design of the vortex nozzle

According to the dimensions of the nozzle, a maximum gripping force of approximately $0.55N$ was detected with an air flow rate of $24.2 \cdot 10^{-5} m^3/s$. However, there are many other approaches to realize vortex levitation in a handling scenario [5]-[10]. Wu et al. [9,10] analysed a similar vortex nozzle with a diversion body. Contrary to [7,8] the conical tapering diversion body in the center of the nozzle causes a decrease of flow velocity in the middle and an increase in the outer areas of the gripper. As a result, the gripping force was slightly increased. Another approach presents Xin et al. [8] with the introduction of a non contact gripper using swirl vanes. The gripper mainly consist of a motor and a set of blades, that take air in and causes it to swirl inside a chamber. Therefore, the centrifugal force pulls the air from the center to the edge of the gripper and creates negative pressure underneath. Since moving parts produce negative pressure as a rotating system using swirl vanes, the seals or bearings of the gripper could be damaged by high air temperatures.

In summary, a hot air stream flowing through a vortex gripper can perform both a vacuum to lift the work pieces as well as the heating of the organo sheet. Compared to the swirl vane or a conventional Bernoulli-gripper, a vortex gripper has certain advantages like no moving parts or seals. The cup-shaped and entirely aluminium-made body of the nozzle provides good resistance against high temperatures.

Vortex levitation in conjunction with hot air can be a worthwhile approach for the preforming of organo sheet. The next section introduces the mechanical design of a robot gripper for picking up and preforming a flat organo sheet in a fully automated process. During the handling operation, the organo sheet is partially softened in order to fold it onto a die.

3. Mechanism and Design

In a conventional thermoforming process, the form-stable handling of a fully heated, flexible fabric as well as the cooling rate after the heating process are challenging in terms of limp material behaviour and the low sheet thickness. Therefore the main aspect is to develop a robot mounted handling system which fulfills the mentioned challenges sufficiently. After picking up the organo sheet, it is important to maintain form stability in order to achieve a near net shape preform of the flat composite on a certain preform tool. Using a simple handling technology without any draping functionalities for given