Kurzfassung

Die konventionelle Verarbeitung naturfaserverstärkter, thermoplastischer Kunststoffe zu Bauteilen erfolgt derzeit in einem aufwändigen, mehrstufigen Pressverfahren, welches mit hohen Investitionskosten und hohem Platzbedarf verbunden ist. Ausgangsmaterial bilden Hybridvliese aus Naturfasern und thermoplastischen Schmelzfasern, welche eine Straße mit mindestens zwei Pressen durchlaufen müssen. In der Heizpresse wird das Vlies unter Wärmezufuhr und Druck kompaktiert und die Naturfasern dabei imprägniert. Anschließend erfolgt die Formgebung in einer Umformpresse. Das Verfahren hat den wirtschaftlich großen Nachteil, dass die Imprägnierung und die Formgebung zeitlich wie räumlich direkt aneinander gekoppelt sind, da es keine Alternative zur Erwärmung der Hybridvliese mit gleichzeitiger Imprägnierung gibt.

Im Rahmen dieser Arbeit wird ein neuartiger Aufheizprozess für naturfaserverstärkte Thermoplaste auf Basis von Infrarotstrahlung entwickelt, der diese Probleme aufgreift. Als Ausgangsmaterial hierfür werden bereits imprägnierte und vorkompaktierte Naturfasermatten verwendet, mit denen die hocheffizienten Thermoform-Prozessketten genutzt werden sollen, wie sie beispielsweise bei glas- oder kohlenstofffaserverstärkten Thermoplasten zum Einsatz kommen. Aufgrund der thermischen Restriktionen von Naturfasern bei der Verarbeitung wird eine materialselektive Infrarot-Erwärmungsmethode konzipiert und untersucht, deren Ziel eine optimierte, maximierte Absorption der Strahlung durch das Polymer darstellt. Es wird gewährleistet, dass die Absorption durch Naturfasern auch bei der Variation der Rohstoffqualität minimal ist. So können auch geringfügig kompaktierte Naturfaser-Halbzeuge mit hohem Porengehalt mithilfe des Aufheizprozesses auf eine ausreichende Umformtemperatur erwärmt werden, ohne die Verstärkungsfasern thermisch zu schädigen. Die Untersuchung des Prozesseinflusses im Hinblick auf mechanische Eigenschaften sowie Geruch und Emissionen validiert die Großserientauglichkeit des entwickelten Aufheizverfahrens.

Die Ergebnisse dieser Arbeit werden in Richtlinien für die Verarbeitung thermoplastischer, vorimprägnierter und kompaktierter, naturfaserverstärkter Kunststoffe zusammengefasst und sollen dem Verarbeiter eine gezielte Auswahl von Halbzeugen und die Minimierung der Prozesszykluszeit ermöglichen.

Abstract

Natural fiber reinforced polymers have been used since decades for semi-structural applications in the automotive industry like door panels, roof stiffenings, backrests and others. Compared to glass fibers, natural fibers have a lower density and, in combination with good mechanical properties, a good lightweight potential. Moreover, the production of natural fiber composites can save up to three-fourths of the greenhouse gas emissions compared to a similar part made of glass fiber composites. By now, there is a trend in applying thermoplastic based natural fiber composites, because they can be manufactured by using novel hybrid processing methods like thermoforming with a simultaneous back injection. The weight of a door panel processed thereby can be reduced furthermore by 20 % compared to a conventional natural fiber composite door.

However, the conventional processing of thermoplastic natural fiber composites is performed by a multi-stage press process, associated with high investment costs and floor space requirement. The basic material for this process is a hybrid nonwoven consisting of natural fibers and thermoplastic melt fibers. It passes through a press plant with at least two presses. The first one is the compression molding press in which the nonwoven is compacted and heated to melt the polymer fibers and impregnate the natural fibers. Afterwards, the forming process to a finished component takes place in a forming press. The great economic disadvantage of this process is the fact that impregnation and forming are directly linked to one another, because there is no alternative for the heating of hybrid nonwovens with simultaneous impregnation possibility. The highly efficient and automated thermoforming processes used to produce glass or carbon fiber reinforced thermoplastic polymers, cannot be applied for natural fiber composites.

Therefore, the aim of this work is to address these disadvantages by developing a novel heating method for thermoplastic based natural fiber composites based on infrared radiation. The basic material for this process is an impregnated and precompacted natural fiber mat similar to already applied glass or carbon fiber organic sheets. By means of natural fiber organic sheets, the efficient thermoforming process chains can be used for the manufacture of parts.

Due to thermal constraints of natural fibers, an absorption optimized infrared heating method is designed and investigated. Goal is a selective, maximized absorption of radiation by the polymer, which can only be met by using a middle-wave infrared heater.

Also, the absorption is minimized for natural fibers regardless of their retting degree or chemical composition. First Fourier transform infrared spectroscopy (FTIR) tests show that a completely selective heating of the polymer is not possible due to the superposition of the spectra of both material partners. However, the radiation absorption by the polymer is higher than for natural fibers at heater temperatures below 625 °C. Experimental studies validate these findings and show an optimum temperature process window for the infrared heater between 500 °C and 590 °C. In the following course of the work, a temperature of 572 °C has been selected as compromise between quick and careful heating of natural fiber organic sheets.

In a next step, FTIR tests were performed on hemp fibers with different retting degrees and thus, different colors. Almost the entire spectrum of natural fiber colors could be investigated by selecting fibers with minimum and maximum retting degrees. The results show that the change of absorption in the interesting region of wavelengths for different retting degrees is minimum and does not affect the heating time and the surface temperature of specimens significantly. Also, different chemical compositions were tested by chemical separation of individual constituents of natural fibers. Again, there is no significant change in infrared heating behavior of natural fibers with diverse chemical compositions. For the heating concept, this means that the absorption cannot be optimized by using a specific natural fiber type. However, there is also no risk and no need for restrictions concerning the raw material selection.

The organic sheet condition, that is the area weight and the compaction, has the greatest influence on the heating behavior. A greater compaction of organic sheets is more expensive and difficult than a light compaction of nonwovens to low densities and high porosities. However, a low density and high porosity may adversely influence the infrared heating behavior of the sheets, since the entrapped air has a very low thermal conductivity and leads to self-insulation. Comprehensive infrared heating investigations were performed with natural fiber organic sheets with area weights between 1000 g/m^2 and 1700 g/m^2, which were compacted to thicknesses between 2 mm and 4 mm. It could be shown that the area weight of the sheets significantly influences the heating time, whereas the thickness of the sheets determines the surface temperature. Both factors could be described mathematically for a development of processing guidelines.

The examination of the process result showed that the selection of the forming temperature does not influence the mechanical performance, so that the forming temperature can be selected according to the degree of deformation to avoid wrinkling. The mechanical performance is mainly determined by the final part density. Also the odor of the heated organic sheets is not worse than the odor of calibrated nonwovens, although the organic sheets are exposed to high temperatures twice. All in all, it could also be shown that the emissions of the finished parts made of natural fiber organic sheets are on average as high as the emissions of conventional natural fiber materials.

At the end of this work, the results are summarized in guidelines for the processing of natural fiber organic sheets. The guidelines offer the possibility to select an appropriate natural fiber organic sheet according to the desired heating and emission properties.

The development of a material selective IR heating method is a basis for the automation and further weight reduction of natural fiber parts. The research results are a first major step towards the improvement of the competitiveness of natural fiber parts compared to glass fiber composites. This can lead to new applications and markets for thermoplastic based natural fiber composites.