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Procedia CIRP 66 (2017) 137 – 142

www.elsevier.com/locate/procedia

1st Cirp Conference on Composite Materials Parts Manufacturing, cirp-ccmpm2017

Advanced molds and methods for the fundamental analysis of process induced interface bonding properties of hybrid, thermoplastic composites

T. Joppich[a,*], A. Menrath[a], F. Henning[a,b]

[a]Fraunhofer Institute for Chemical Technology, Polymer Engineering Department, Joseph-von-Fraunhofer-Str. 7, 76327 Pfinztal
[b]Karlsruhe Institute of Technology, Institute for Vehicle System Technology, Chair of Light-Weight Technology

* Corresponding author. Tel.: +49 -721-4640-529; fax: +49 -721-4640800-529. *E-mail address:* tobias.joppich@ict.fraunhofer.de

Abstract

Hybrid thermoplastic composites play an increasingly important role in lightweight applications. One key challenge in the intrinsic hybridization is to achieve an adequate interface bonding strength. In order to optimize the interface strength specific methods for characterization and process monitoring need to be developed. Thus, within this paper two advanced mold concepts are presented allowing online monitoring of the welding conditions at the spot and time of interest. The resulting part geometries are optimized for characterization of interface properties in a defined and reliable manner. Regarding this, adopted characterization setups are presented and validated allowing the characterization of three stress states.

Keywords: hybrid thermoplastic composites, intrinsic hybridization, injection molding, overmolding, online process monitoring, interface bonding strength, warpage

1. Introduction

Forming and overmolding of continuous fiber reinforced semi-finished products with technical thermoplastic matrices like PP and PA6 currently evolves from niche products to serial automotive applications [1]. The main reason for this is the possibility to take advantage of material and structure related weight savings, while these hybrid parts can be manufactured in highly automated and integrated processes leading to low cycle times and economic feasibility. Due to these advantages, increasing lot sizes and the need for simplified integration as well as recyclability, these production processes will become also of higher interest in aerospace applications in the near future [2,3]. Here, especially flame retardant, high temperature thermoplastics like PPS, PEI or PEEK will be used. Depending on the type of material and the processing sequence it might be challenging to achieve an adequate interface bonding strength. Thereby, the temperatures within the welding zone [3-5] as well as in-mold pressures are most determining for the interface bonding properties. Additionally, the cooling behavior leads to the development of mechanical properties during solidification and thus influences dimensional part stability [6]. However, the determination of the product temperature at the time and spot of interest is quite challenging in closed-mold processes. Thus, in this study two advanced mold concepts are presented in section 2 allowing precise online monitoring of the welding conditions at the spot and time of interest. Along the flow path contact-free temperature sensors as well as contact-based mold temperature and cavity pressure sensors are utilized. Both molds are designed for processing a variety of thermoplastics like PP, PA6, PA66 as well as for high-temperature matrices like PPS, PEI or PEEK. The resulting part geometries are optimized for characterization of interface properties in a defined and reliable manner. Regarding this, detailed information is given in section 3 about the developed characterization methods allowing the characterization of the failure modes: pure shear, pure tension and mixed mode (peel). The presented methods are compared and validated using samples of PEI/CF organo sheets overmolded with

doi:10.1016/j.procir.2017.03.275

PEI/GF short fiber reinforced granulate. The developed molds and methods can be additionally used for the validation of advanced process simulation models predicting welding temperatures and pressures which lead to specific interface properties and final dimensions.

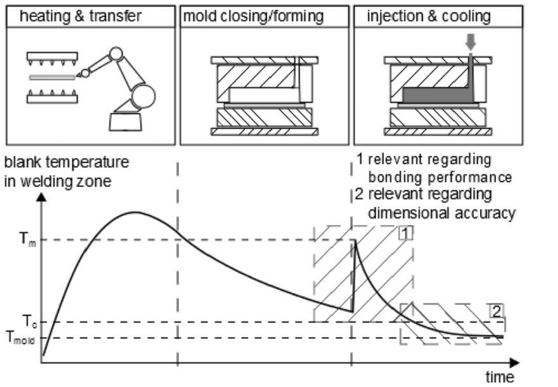

Fig. 1. General process chain illustration for the manufacturing of hybrid thermoplastic composites with exemplary temperature profile of the overmolded blank (T_m: Melting temperature; T_c: crystallization temperature; T_{mold}: mold temperature)

To validate the developed molds and corresponding part geometries as well as the testing procedures and setups, the results of online monitoring and testing are discussed in section 4.

2. Mold Concepts & Part Geometries

Hybrid thermoplastic components usually contain areas where the substrate is planar overmolded as well as areas were the substrate is locally overmolded (e.g. ribs). To accomplish for both cases two molds were developed.

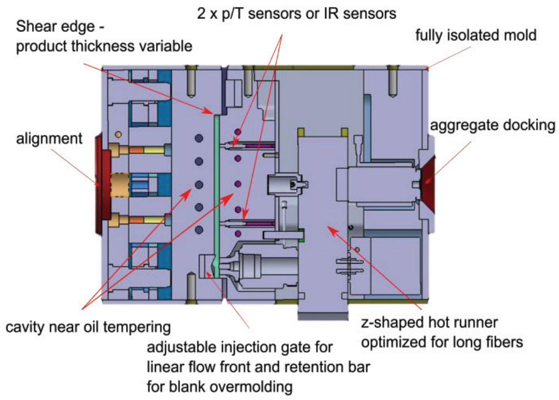

Fig. 2. Mold 1 for hybrid plate manufacturing – Visualized is a section profile of the mold

Figure 2 illustrates the mold for hybrid plate manufacturing with a size of 180 mm x 180 mm. Due to the shearing edge design, plate thickness can be adjusted as needed up to 8 mm in total. By utilizing the retention bar in the gate zone frontal injection to the substrate is prevented which could lead to substrate damage. Substrates with a thickness of up to 2 mm can be inserted. For homogeneous tempering of the mold, cavity near oil cooling as well as water heating of the mold platens are integrated. The z-shaped hot-runner is optimized for long fiber thermoplastic materials and includes an 8 mm needle valve nozzle.

Mold 2 for local rib overmolding of substrates is illustrated in Fig. 3 In a vertical closing injection molding machine the substrate can be placed on the lower part of the mold. The cavity needs to be sealed by the substrate. Thus the clamping force is applied onto the substrate. Due to a small projected area of the rib ground, necessary closing forces are rather small and no substrate damages takes place. Additionally, spacer blocks can be used for sensitive or softened substrates. The hydraulically activated sliders are necessary to allow product release before mold opening, since the rib is designed with an undercut (cf. Fig. 4). The rib thickness is 3 mm and is reduced to 2 mm in the rib ground. During testing this design leads to a defined failure zone within the welding zone of the hybrid structure. It is not intended to test an optimized rib design, but rather the bonding interface strength in a defined and reliable manner. For an optimized gripping in the testing procedure no draft angle is introduced to the rib geometry.

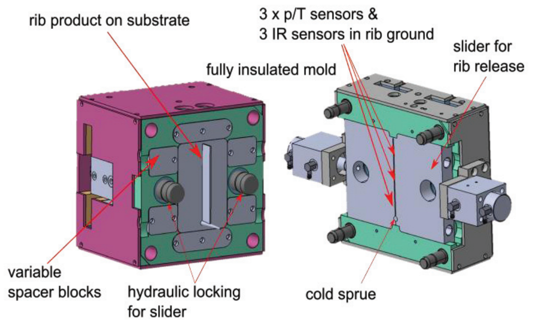

Fig. 3. Mold 2 for hybrid rib-substrate manufacturing – left: lower part of the mold, right: upper part of the mold

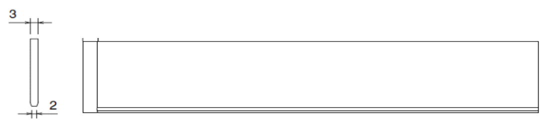

Fig. 4. Rib geometry illustrating the undercut – rib height is 30 mm and length approx. 160 mm – optimal substrate length is 180 mm

2.1. Online Process Monitoring

In mold cavity sensors have been applied in order to determine the process conditions during overmolding. The integration of IR sensors enables to measure the substrate surface temperature at the time and spot of overmolding. Within the rib mold additionally thermocouples can be