HYBRID RESIN IMPROVES POSITION AND ALIGNMENT OF CONTINUOUSLY REINFORCED PREPREG DURING COMPRESSION CO-MOLDING WITH SHEET MOLDING COMPOUND

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Abstract

Local continuous-fiber patches could unite the mechanical performance of prepreg materials with the design freedom of chopped fiber materials. However, there is no approved procedure for the reliable co-molding of prepreg compression molding (PCM) material with sheet molding compound (SMC). This paper therefore addresses the influence of the molding conditions and the matrix system on the accuracy of the continuous fiber position and alignment within a molded part. It is shown that the use of a B-staged, hybrid-resin-impregnated PCM material decreases the displacement of a PCM patch during co-molding by more than 700 % compared to a state-of-the-art resin system. This could enable the industry to enhance the quality of compression comolded composites to make them attractive for large-series production.

1. Introduction

Co-molding of prepreg compression molding (PCM) material with sheet molding compound (SMC) allows the fast and cost-effective manufacturing of complex structural composites. The flowability of SMC is needed to form complex geometries like ribs and to integrate inserts, whereas the continuous fiber position and alignment determines the structural integrity of the component. Examples for this new class of thermoset hybrid composites can be found in for example a windshield surround [1], a suspension arm [2] or a subfloor structure [3].
Locking the continuous fiber position and alignment requires the PCM material to withstand the forces applied by the flowing SMC. State-of-the-art PCM resin systems are based on unsaturated polyester (UP), vinyl ester (VE) or epoxy (EP) matrices [4]. All these resin chemistries lack the ability to create a stable, highly viscous B-stage. The viscosity of MgO-thickened UP and VE PCM material drops dramatically when molded under process conditions of 150 °C. The B-staging of EP resins leads to high viscosity levels under compression molding conditions; however, the material shows a narrow process window [5] and short shelf life.

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2. Approach of the current work

These investigations concern the co-molding of SMC with a PCM patch as local reinforcement. The deformation as well as the displacement of the PCM patch due to the flowing SMC is measured after molding and will be reduced by introducing an alternative resin system for the PCM matrix.

2.1. Materials

The PCM material is based on an unsaturated polyester polyurethane hybrid resin (UPPH) and reinforced by a 50k carbon fiber (CF) non-crimp fabric (NCF) in a uni-directional (UD) layout. This stitch-bonded NCF (UD300 by ZOLTEK™) is of high grammage and enables maximized productivity at low material prices. The UPPH resin (Daron41 by Aliancys AG) offers an alternative thickening technology leading to a stable, highly viscous B-stage. This B-stage is achieved in less than five minutes at 80°C.There is consequently no need for a maturing period of several days as for conventional SMC and PCM materials. In addition the high viscosity of the B-stage results in a strong flow resistance under compression molding conditions.

As a reference PCM material with an identical NCF but a UP matrix (Palapreg Premium G22-01 LE by Aliancys AG) is evaluated. This material is MgO-thickened and was thus matured for 7 days at 30 °C after impregnation.

Chopped fiber SMC (type number 6419-01 by Polytec GmbH) is used for co-molding. The SMC is based on a UP resin reinforced with 20 wt.-% of glass fibers (GF), and consists mineral fillers.

2.2. Method

One layer of PCM material with B-staged UPPH matrix, or thickened UP matrix, is cut (Precision-Cutter G3 by Zünd Systemtechnik AG) into 220 x 25 mm patches and comolded with glass fiber SMC. The initial position of the PCM material and of the SMC stack is visualized in Figure 1. While the position of the PCM material was kept constant for all trials, the position as well as the mold coverage of the SMC was changed in three stages:

(M33): For M33 trials a stack of three layers of SMC was placed on top of the PCM material with a mold coverage of 33 %. As this molding condition seems to be the most common in compression molding, the trial was repeated four times to investigate deviations.

(S33): Here the SMC is placed next to the PCM material without overlap.

(S66): For the S66 trial the mold coverage was 66 % with two layers of SMC.

The plate-mold applied has a cavity of 800 x 250 mm in size and is heated to ~145 °C. The closing speed of the hydraulic press (DYL630/500 by Dieffenbacher GmbH) is 1 mm/s, the final pressure reaches 50 bar, the cure time is set to 120 s and the parallelism adjustment control is activated.

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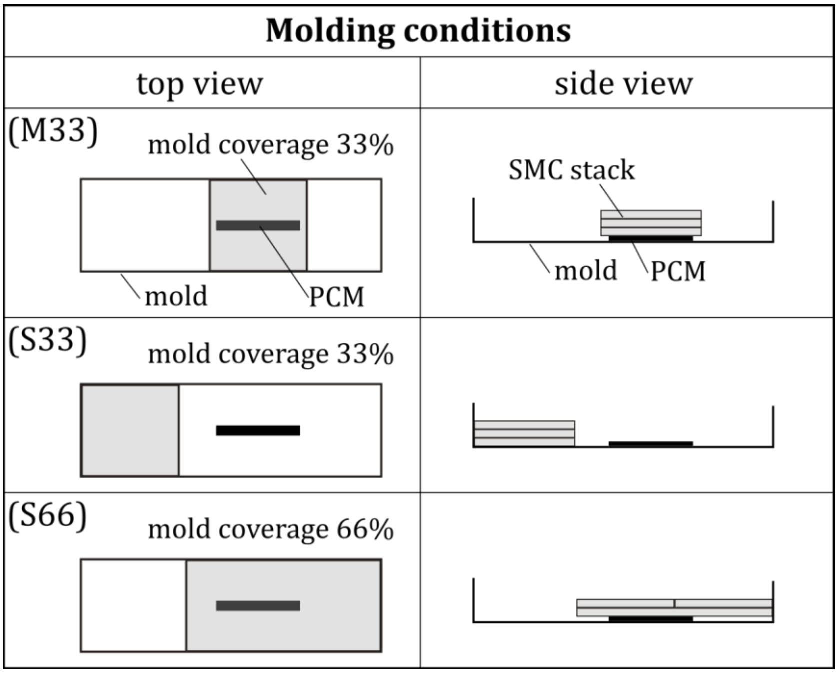

Figure 1. Mold coverage and material position for the M33, S33 and S66 trials.

After demolding the position and geometry of the PCM patch is measured in relation to its initial position and shape. The total failure is analyzed in terms of two failure mechanisms: displacement and deformation of the patch (compare Figure 2). For this purpose the software ImageJ provides diverse algorithms which are applicable to pictures taken of the surface of the molded plates. To subtract the smooth change in brightness of the SMC over the total plate length in the picture, a so-called "rolling ball" algorithm [6] is used. Afterwards the PCM material can be separated from the SMC by defining a threshold for the grey value. In a next step the centroid of the patch is determined in relation to its initial position before molding. This delivers the vectorial displacement (d in mm) of the patch. Furthermore a bounding rectangle is drawn around the PCM material, providing the key figures rotation (φ in deg), change of length (Δl in %) and change of width (Δw in %).

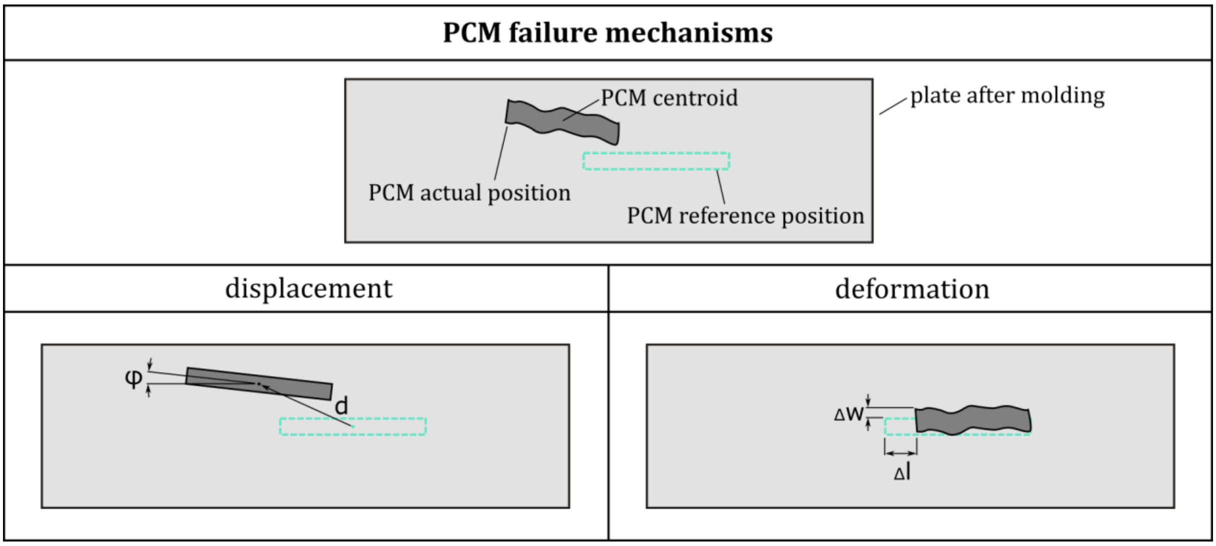

Figure 2. Superposition of the failure mechanisms displacement and deformation.

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3. Results

Visual inspection of the molded plates reveals a clear dependency of the position and alignment of the PCM patch in relation to the molding conditions as well as the matrix system of the patch:

(M33): For M33 trials the rotation of the PCM material is negligibly small (~1 %) for both UP resin and UPPH resin (Figure 4 right). However, the centroids' total displacement decreases from 23 mm for the UP resin to 3 mm for the UPPH resin (Figure 4 right). The deformation of the patch also decreases, in absolute values and deviation, when impregnated with the UPPH resin (Figure 4 left). In fact the UPPH-resin-impregnated patch stays in shape whereas the UP-resin-impregnated patch shows high waviness and a pullout of single CF rovings (Figure 3 (M33)).

(S33): The flowing SMC leads to high deformation and displacement of the PCM patch for both resin systems. The PCM patch is found at the edge region of the plate (Figure 3 (S33)).

(S66): The uni-directional flow leads to a higher displacement of the UP-resin-impregnated patch compared with the M33 trials. The UPPH patch stays in place and maintains its shape (Figure 3 (S66)).

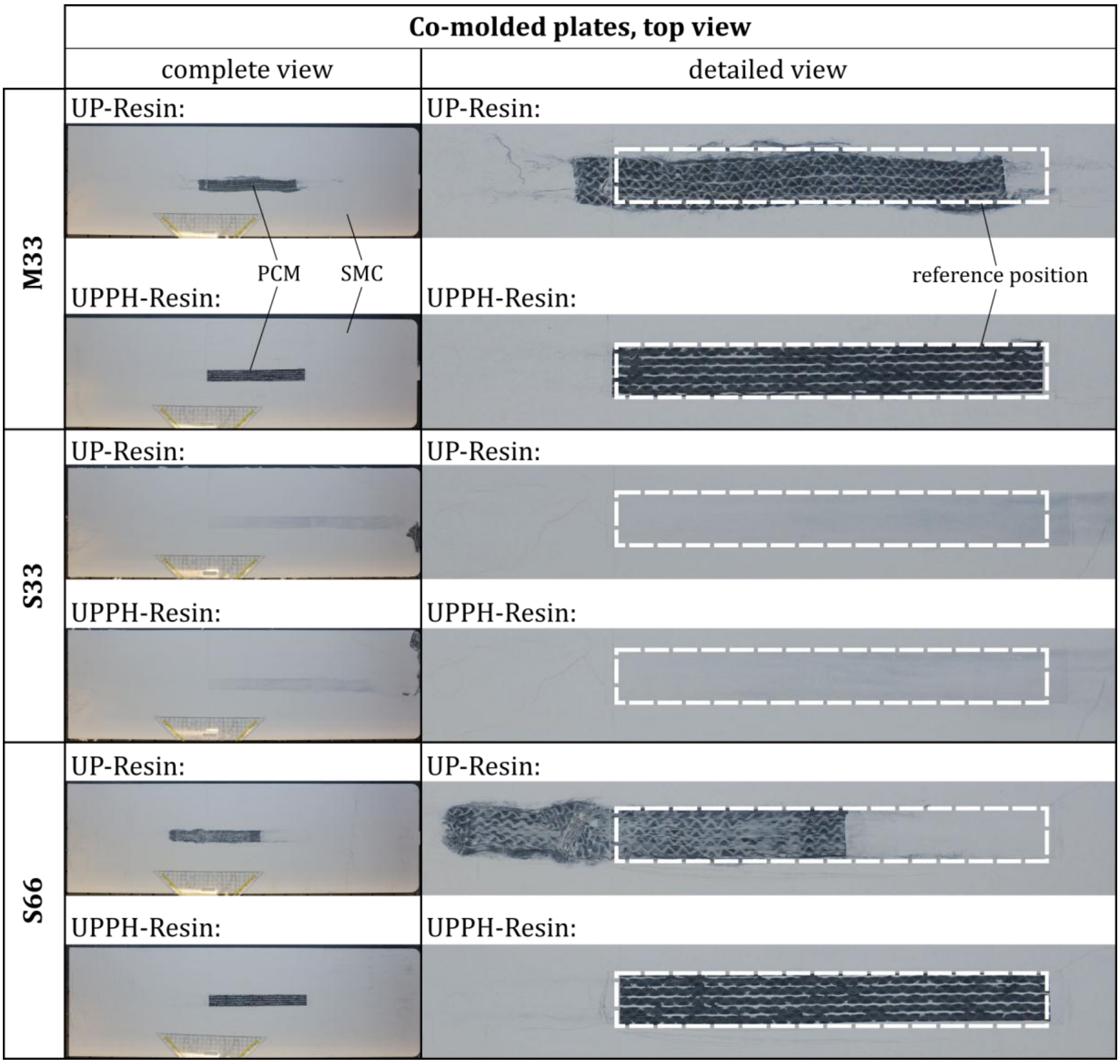

Figure 3. Pictures of the patch reinforced plates after molding for the M33, S33 and S66 trials.

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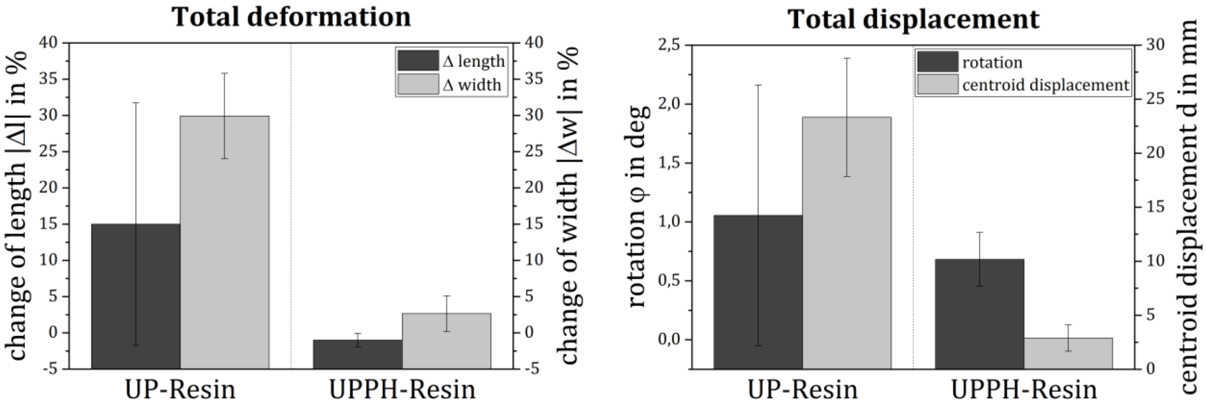

Figure 4. Deformation and displacement of the PCM patch due to co-molding for trial M33.

4. Discussion

Molding conditions appear to be one of the key parameters for a reliable co-molding of PCM material with SMC. An overlap of the SMC stack and the PCM material on placement inside the mold is needed to fixate the PCM material. A mainly symmetrical two-directional flow (M33) leads to less displacement compared to a uni-directional flow (S66) for UP-resin-based PCM materials, even at smaller mold coverage.
A second key parameter is the matrix system of the PCM material. UPPH resin significantly improves the position and alignment of the PCM material while co-molding. The accuracy in displacement improves by more than 700% compared to the reference matrix material. Furthermore the shape of the UPPH patch is left intact whereas the UP resin allows significant deformation. Thus UPPH-based PCM has the ability to enhance the quality of compression comolded composites in combination with increased productivity and reduced component costs.

Acknowledgments

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References

[1] M. Bruderick, D. Denton, M. Shinedling, and M. Kiesel, "Aplications of carbon fiber SMC for the Dodge Viper,"
[2] C. Jansen, "Carbon Fiber Isogrid-Stiffened Automotive Suspension Arm," 2013.
[3] K. Akiyama, "Development of PCM technology," in *11th-Annual Automotive Composites Conference and Exhibition, ACCE 2011*, p. 37p.
[4] H. Schürmann, *Konstruieren mit Faser-Kunststoff-Verbunden,* 2nd ed. Berlin, Heidelberg, New York, NY: Springer, 2007.
[5] K. Akiyama, "Development of preforming process in PCM (Prepreg Compression Molding) technology," in *12th Annual Automotive Composites Conference and Exhibition 2012 (ACCE 2012) ; Troy, Michigan, USA, 11 - 13 September 2012*, pp. 347–362.
[6] S. R. Sternberg, "Biomedical Image Processing," *Computer*, vol. 16, no. 1, pp. 22–34, 1983.

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