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Stamp forming of carbon fibre/PA12 composites – A comparison of a reactive impregnation process and a commingled yarn system

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Abstract

Two forms of carbon fibre reinforced polyamide 12 (PA12) were compared during non-isothermal stamp forming. The first was a stretch broken commingled yarn woven into a fabric, studied at three initial preconsolidation levels. The second was produced by in situ anionic polymerisation of lactam 12 (APLC12) in a carbon fibre textile, using a thermoplastic resin transfer moulding (TP-RTM) process. A processing window was defined for TP-RTM based upon non-isothermal polymerisation kinetics. For each material form, the effects of stamping parameters on flat plaque properties were examined. For commingled materials, the influence of preheat temperature and the initial preconsolidation level dominated, with preconsolidated materials deconsolidating strongly during the preheat cycle. For CF/APLC12 materials, the effect of material temperature and tool temperature dominated and reduced deconsolidation occurred. Hemisphere forming was enabled by stretch-broken yarn but was possible for both material classes. Over-injection moulding of recompounded CF/APLC12 composite onto stamped CF/APLC12 plate was performed, demonstrating a closed-loop recycling process.

Keywords: A: Polymer-matrix composites (PMCs); A: Fabrics/textiles; E: Resin transfer moulding (RTM); Compression moulding

1. Introduction

The use of composites to reduce weight in automotive applications requires specific focus on manufacturing and cost constraints for large series, in additional to material performance [1,2]. Composites use is currently dominated by low fibre volume fractions and planar randomly oriented short fibre architectures (GMT and SMC) and there is hence interest in increased fibre volume fractions and aligned fibre architectures that can be processed within cycle times compatible with high volume industries. This study examines the potential of processing carbon fibre textile reinforced polyamide (PA) by non-isothermal stamping [3–5], as shown in Fig. 1. After heating the material to processing temperature, the primary mechanisms during stamping, which occur simultaneously, are: intraply shearing to facilitate fabric deformation, interply shearing for shape accommodation (for two or more plies), friction between the plies and tool surfaces, pressure application for consolidation, and removal of heat to permit crystallisation and solidification of the matrix [3]. Blank-holders are used to apply a membrane stress to the fabric during stamping, permitting higher shearing angles [5].

This work has considered two carbon fibre reinforced PA materials systems, from both a materials and a process perspective. Specifically, a woven commingled yarn (CF/PA12), and plates produced by in situ anionic polymerisation of Lactam 12 (APLC12) in a carbon fibre

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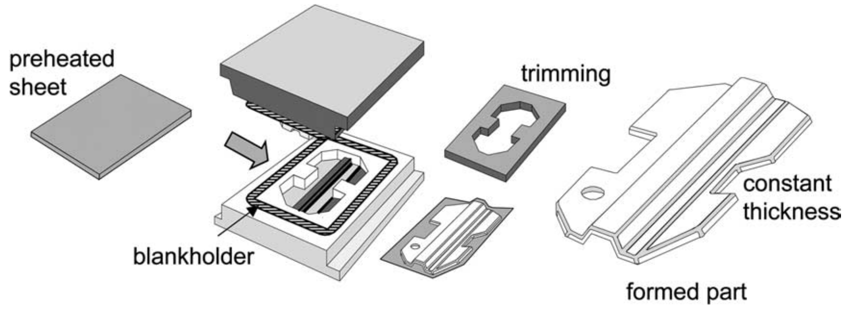

Fig. 1. Non-isothermal stamp-forming process [3].

textile, using a thermoplastic resin transfer moulding (TP-RTM) process, were examined. From a manufacturing perspective, the objectives were to identify the dominating processing parameters before a more detailed study of these factors and the final mechanical properties that could be achieved. From a materials perspective, the objectives were to examine the CF/PA12 material system in three initial degrees of consolidation to determine the effect of any preconsolidation stage on final stamped part quality. With the ability to tailor the molecular weight of the APLC12, the effects of three activator concentrations, with the associated final polymer viscosity, were investigated on stamped part quality. With the trimming required after stamping to remove the blank holder material area, the final study examined the potential of recycling CF/APLC12 scrap by over-injection moulding a ribbed structure onto stamped CF/APLC12 composite plate.

2. Materials and testing

2.1. Impregnation routes

The impregnation of fibre architectures is inherently more difficult with thermoplastics than with equivalent processes for thermosets due to the high viscosity of thermoplastics at melt temperature. Hence impregnation routes have been developed that decrease the impregnation length or the viscosity to reduce the impregnation time, including: hot-melt impregnation [6], solution impregnation [7], reactive impregnation [8–13], powder coating [7,14], fibre commingling [15–25], and textile process hybridisation [26]. Table 1 compares the commingling and reactive impregnation routes studied here.

2.1.1. Commingled material system

The consolidation of commingled CF/PA12 materials has been examined previously [21–24], with experimental trials using comparatively slow isothermal processes [23] or polymeric tools with low heat transfer rates [24]. Bernet et al. [22] examined the effect of dry versus fully preconsolidated materials on the void content of a v-shape component. In order to develop process windows for a rapid (10–30 s) industrial non-isothermal stamping process, and to determine the effect of initial preconsolidation levels on stamped part mechanical properties, this work compared the effect of three initial levels of consolidation on final part mechanical properties, and determined suitable process conditions for each preconsolidation level. The CF/PA12 material consisted of stretch broken 6k carbon fibre (mean fibre length $\approx$ 70 mm, $\varnothing \approx 7$ μm) commingled with staple PA12 fibres ($\varnothing \approx 20$ μm), produced commercially by Schappe Techniques. A carbon fraction of 56% (V_f) resulted, with a matrix mass transfer distance of 10^1–10^2 μm. A low molecular weight PA12 grade ($\overline{M_w} = 26$ kg/mol) minimised the melt viscosity and hence the impregnation time. The commingled yarn (Fig. 2(i)) was processed into a 5-harness satin weave of 760 g/m^2. The three preconsolidation levels studied were:

Table 1
Comparison of two preform production routes for non-isothermal stamping

	Commingled yarn (CF/PA12)	CF/APLC12
Impregnation	Minimise mass transfer distance	Minimise viscosity
Preforms	Dry to consolidated	Consolidated
Reinforcement architecture	Matrix and reinforcement fibres commingled in the same bundle	Full carbon-based textile process freedom
Matrix	Fixed when purchased	Possibility to tailor M_w
Intermediate steps	Polymerisation, formation of polymer filaments, commingling, weaving, and preconsolidation	Fibre weaving, final in situ polymerisation