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Formability analyses of uni-directional and textile reinforced thermoplastics

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ABSTRACT

The formability of two different composite materials used in aerospace industry has been investigated for a representative product geometry. The deformations during forming of carbon UD/PEEK and glass 8HS/PPS blanks with a quasi-isotropic lay-up were analysed. The UD/PEEK product showed severe wrinkling in doubly curved areas, whereas the 8HS/PPS product showed better formability in those areas. This can be explained by the relatively high resistance against intra-ply shear for the UD/PEEK material. Moreover, the predictive capability of a finite element based simulation tool was shown. For both materials, the prediction of intra-ply shear and large wrinkles showed good agreement with those observed in the actual product. The smaller wrinkles in the products cannot be accurately represented with the element size used. However, predicted waviness at the corresponding locations could indicate critical areas in the product. The presented modelling approach shows great potential for application in the composite product design process.

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1. Introduction

The re-melting capability of fibre reinforced thermoplastic laminates allows for high volume production of thin-walled complex shaped parts for automotive and aerospace industry. This paper considers the process of stamp forming a pre-heated laminate into the desired geometry. The potential of this process was already shown in the 80s by Krone and Walker [1], and Okine [2] for high-performance composites. Such composites are currently used in aerospace industry, where this process is applied to the production of stiffeners that appear in the wing and fuselage assemblies. The process also shows a high potential for use in the automotive industry due to the high production rates that can be achieved. Product examples are car doors, hoods, and car construction pillars.

Two composite materials used in aerospace industry are considered in this study. One material is the CETEX® TC1200 PEEK/AS4, which consists of a polyetheretherketone (PEEK) thermoplastic matrix and uni-directional AS4 carbon fibres. The other material is the CETEX® PPS glass fabric US style 7781. These are respectively referred to as UD/PEEK and 8HS/PPS throughout this paper. The reinforcement architecture of these materials is shown in Fig. A.1 at the meso- and micro-level. The industry encounters large formability differences between these materials. Defects such as wrinkling occur frequently. Such defects lead to a knock-down of the product's in-service performance. The local thickness increments caused by the wrinkle also results in poorly consolidated spots elsewhere in the product and possibly damage of the matched-metal tooling.

Comparative studies of materials with different reinforcement architectures are scarcely available in the literature. De Luca et al. [3] investigated the forming behaviour of uni-directional (APC2-AS4) and textile (PEI-CETEX) reinforced thermoplastic laminates. A product was selected with a bead that consists of single and double curvature areas. Experiments with these materials were shown to have very different drapability characteristics, especially in terms of wrinkling. Formability analyses of textile reinforced laminates are conducted by many other researchers. The most recent review on this topic is given by Gereke et al. [4]. Well documented practical formability analyses were already given by Hou [5], who studied the stamp forming of glass 8HS/PEI laminates into hemispherical moulds. Here, the effects of blank size, blank holder pressure, and mould geometry on the formability were investigated experimentally. A more recent practical analysis of textile reinforcement forming was given by Allaoui et al. [6], which included an extensive numerical analyses as well. For the formability analyses of laminates with a UD fibre reinforcement, the reader is referred to the work of Mallon et al. [7], Ó Brádaigh et al. [8], and the more recent work of Larberg [9], Haanappel et al. [10,11], and Hallander et al. [12].

Product development times can be reduced when the effects of material parameters and process variables on the forming behaviour

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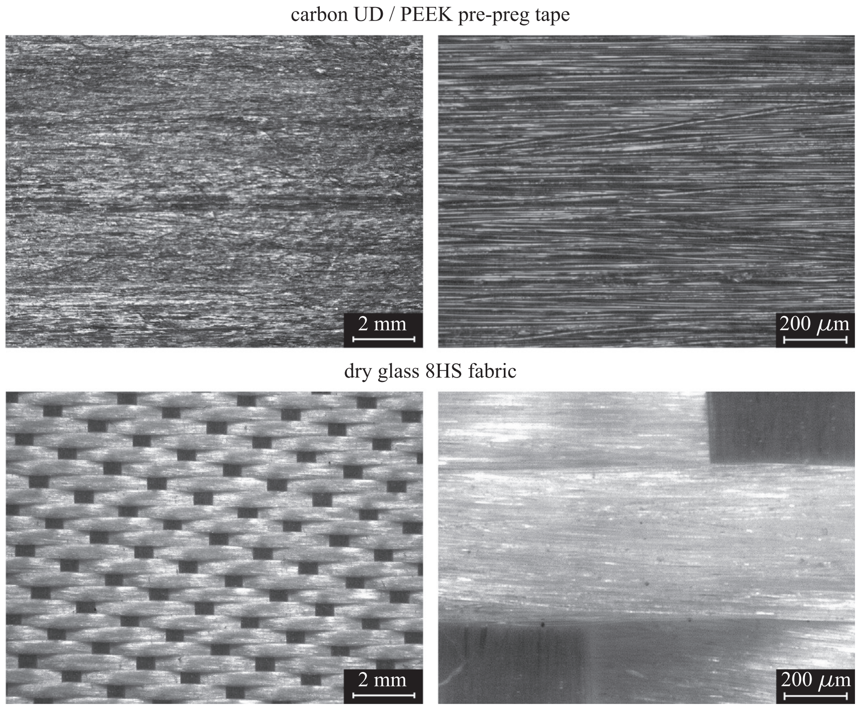

Fig. A.1. Micrographs of the materials considered.

can be predicted. Forming prediction codes become increasingly available, which are categorised as continuous, semi-discrete, and meso-FE model approaches [4]. Validation is mainly performed with relatively simple products, such as domes [13–15]. A more complex geometry referred to as the "double dome" has been and is currently being benchmarked by several research groups [16–19].

In this paper, the differences in forming behaviour between UD/PEEK and 8HS/PPS are investigated in detail for a representative product geometry used in the aerospace industry. Forming experiments are conducted and analysed firstly. Several deformation mechanisms are characterised for both materials. The results are subsequently processed in the finite element forming simulation software AniForm [20], which falls in the category of continuous approaches. The underlying theory has been described by Ten Thije et al. [21]. AniForm uses an implicit solution scheme and it deals with separate constitutive relationships to describe the in-plane, interface, and bending mechanisms of the modelled plies. Forming predictions for the considered geometry are presented and compared with the results of the forming experiments.

2. Forming experiments

Forming experiments were carried out in order to investigate the formability differences between two different composite materials: carbon UD/PEEK and glass 8HS/PPS. A representative product geometry for aerospace applications was selected as shown in Fig. A.2. This stiffening part appears in a wing fixed leading edge, designed and built by Fokker Aerostructures. The product contains a couple of features, such as the flat web and the long straight flange. Two beads and the curved flange are features with double curvature.

Blanks were manufactured from both materials. These were cut from quasi-isotropic laminates with $[0, 45, 90, -45]_S$ and $[(90/0), (-45/45)]_S$ lay-ups, for the UD/PEEK and 8HS/PPS materials, respectively. Such lay-ups are considered for the majority of the stamp formed products in aerospace industry. The laminates were consolidated in a hot press at Ten Cate Advanced Composites. The top-ply fibre direction is indicated in Fig. A.2, which encloses a 45 degree angle with the long straight edge of the blank. The top plies of the blanks were accommodated with a regular grid of dots,

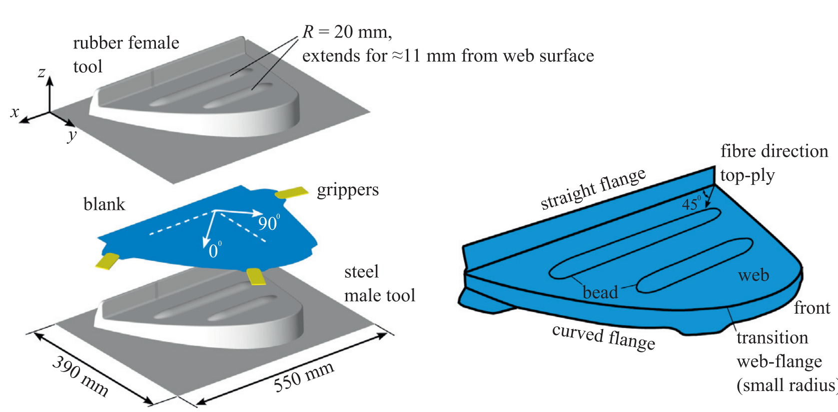

Fig. A.2. Forming set-up and product geometry. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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