Abstract

Over the past few decades, there has been a continuous increase in the global demand for carbon fiber reinforced thermosetting polymers (TS-CFRP). This growth can be attributed to the expanding range of applications of TS-CFRP, which includes not only the primary markets of aerospace, aeronautics, and defense, but also the mass consumer goods industries, particularly in the sports, biomechanics, and automotive sectors. However, mass production involves the use of more standardized, cost-effective, and green production techniques to increase the efficiency of the manufacturing value chain and comply with the circular-economy concerns. Recyclability and reusability are the two main concepts to implement in order to properly apply the waste-management policies. The first imply the reclamation of the composite's main constituents from the end-of-life products; the second instead deals with the in-process cut-offs reuse, generated during the ply cutting operations. In this last case, the prepreg side streams are in an uncured condition, and thus can be used to produce new components without any intermediate reclamation stage.

This thesis work presents a multidisciplinary and applicative approach to accomplish the reuse strategies of the prepreg side streams coming from the ply cut operations. The manufacturing conditions, the structure quality, the mechanical characteristics, and the design requirements are correlated to validate and optimize the performance of the final part produced with the proposed technology. The prepreg cut-outs (called also chops, chips or strands) coming from the ply cut operations are used as raw charge to produce new components with the compression molding process. Each chop keeps the properties and the orthotropic structure of the original prepreg fabric from which it is cut, but the final component presents a discontinuous randomly oriented structure. As the charge is highly inhomogeneous in terms of local density and fiber orientation, the prediction of the final properties of the material results a tricky task. Consequently, a processability study was carried out, in order to analyze the material flow evolution during the compression stages. Furthermore, the mechanical properties of the final structure are strongly affected by the initial charge condition (i.e., the shape of the charge and the size of

the chops). Accordingly, an extensive mechanical characterization was conducted to create a relationship between the performance output of the structure and the initial molding conditions. The results evidenced a high scatter as the material exhibits a variability of the local properties, that are mainly dictated by the presence of voids, rich matrix areas, interface regions between the chops and the local fiber rearrangement that occurs during the viscous flow stages of the manufacturing process.

Compared to the viscoelastic properties of a continuous fiber prepreg, pressing a charge composed of fabric cut-outs induces several phenomena, such as the sliding of a chop over another, the reorientation of the chops and the swirl rearrangement that cause the chops to fold up. These phenomena greatly influence the overall viscoelastic response of the charge, which is not only influenced by the rheological properties of the resin, but also by the interaction between the chops. Consequently, squeeze tests were performed for the characterization of the rheological properties of the material at different temperatures, and rheokinetc analytical models were fitted to predict the viscous behaviour of the material and build up numerical simulations.

The numerical model of the manufacturing process was built with the Moldex3D flow-based simulation software. As the initial charge presents randomly oriented chops, but each chops presents locally orthotropic oriented fibers, a Matlab code was written to generate the initial fiber orientation within the charge. The process results were then mapped with the Digimat multiscale software, and structural simulation were launched, and results compared with the experimental ones.

Finally, a case study was proposed: a Formula SAE accelerator pedal featuring ribs and narrow sections was manufactured to test the applicability of the proposed technology even to complex geometry. The pedal was then mechanically tested, and its production process simulated.

The performance of the produced components not only resulted to be comparable with the once of the most common low-density structural metals (i.e. Aluminum 6061), but can be also enhanced by properly tune the process conditions and the chop shape factors. The result of the investigation confirmed that the reuse of the in-line prepreg cut-outs is an efficient and cheap strategy to re-introduce in the value chain the side streams produced during the ply cutting operations.