Abstract

This thesis aims to study the structural properties of innovative composite green materials aimed at reducing the CO_2 emissions for new passenger cars and light commercial vehicles, according to EU regulations. The criteria for materials selection have been discussed with the company (Centro Ricerche Fiat, Stellantis, Turin, Italy), following the industrial interests. Within the context of this thesis, the problem of sustainability of composites has been addressed by considering ready-to-use solutions to increase the bio-content of biocomposites and by providing tools and data to promote the diffusion of recycled short fiber reinforced polymers for automotive applications.

To increase the sustainability of the matrix of flax fiber composite materials, different cardanol-bio-based epoxy systems available in the market have been selected and characterized, considering the effect of increasing the total bio-content. In particular, two high bio-content (65% and 84% bio-mass) cardanol-based epoxy (C) and novolac (N) resins were mixed with the two neat epoxy resin systems (M1 and M2) in different weight loadings to reach higher total bio-contents of the final epoxy resin blend. Quasi-static tensile tests were run to assess the tensile behavior of different resin blends at increasing bio-contents. The tensile moduli of the blends obtained by adding 40 wt.% of the 65% bio-content resin showed a reduction from the corresponding neat formulations of about 25-45% for the two neat formulations. The reduction was even more significant for epoxy blends obtained by adding 40 wt.% of the 84% bio-content epoxy novolac resin. Test results showed that resin blends containing up to 40% bio-based content exhibited tensile properties comparable to those of traditional epoxy resin. Further, the glass transition temperatures of epoxy blends, with up to 40% bio-content, were compatible with the requests of the automotive sector. The results showed that adding bio-content resins enhances flexibility and leads to more pronounced viscoelastic behavior than conventional resin. The results were useful to identify new cardanol-based epoxy formulations and compare them to other bio-based systems already present in the market and suitable for automotive applications.

The resin blends used as matrices to produce flax fiber/cardanol-based epoxy composites were selected considering the company specifications and the balancing of high bio-content and high mechanical properties. The production of these composites has been carried out considering two different manufacturing

techniques: vacuum-assisted resin infusion (VARI) and compression molding (CM). In case of CM, two different fiber volume fractions (Vf) were considered: low Vf (LVF) and high Vf (HVF). These composites were mechanically characterized in tension, compression, shear and bending to provide reliable data for the mass use of this bio-based material in next-generation vehicles. In tension, LVF and VARI laminates tended to exhibit more comparable mechanical properties, while HVF consistently yielded superior performance. In shear, both shear modulus and shear strength values remained relatively stable between the laminates made of the same neat epoxy systems (M1 and M2), when evaluated under identical manufacturing conditions (HVF, LVF, and VARI), highlighting the dominant role of processing configuration over matrix type in determining these mechanical properties. In compression, laminates produced through CM with the M2 epoxy system displayed consistent compressive performance across both HVF and LVF configurations, yielding higher values of compressive modulus and ultimate compressive strength compared to VARI. In three-point bending tests, the flexural response of composites produced via the CM process (HVF and LVF) appeared to be significantly influenced by the matrix type. Composites formulated with the M1 epoxy system demonstrated lower flexural modulus and strength compared to those incorporating the M2 matrix.

In order to meet the EU Community regulations and promoting the use of sustainable and green materials to lower the overall carbon footprint in the automotive sector, the present thesis also aims to assess the mechanical properties of a recycled 30 wt.% talc-filled polypropylene (PP65.40) and a recycled 30 wt.% short-glass-fiber reinforced polypropylene (PP140.80) used in the automotive industry, obtained by injection molding employing post-industrial mechanical shredding using recycled and virgin materials. Indeed, the use of recycled composite polymer materials, and so the knowledge of their mechanical properties, has become a fundamental aspect for the automotive industry to save raw materials and reach sustainable goals. In particular, tensile tests at three different operating temperatures (- 40 °C, 23 °C and 80 °C) have been performed in quasi-static (0.1 mm/s) and dynamic (10 and 100 mm/s) strain rate conditions. Shear tests have been conducted across a range of temperatures (- 40 °C, 23 °C and 80 °C) and at a constant strain rate. The mechanical properties have been assessed considering specimens in the longitudinal (in-flow, 0°) direction with respect to the injection flow. The strain has been acquired by using a Digital Image Correlation system to determine the map of the strain in the area of interest before failure. The values of tensile modulus (E) and ultimate tensile strength (UTS) obtained for PP140.80 are higher than PP65.40 material, for all the strain rates considered. Moreover, for E values, the difference was larger as the temperature increased. For both E and UTS values, the difference was not very evident considering the same material at different strain rates and constant temperature. The shear modulus (G) and the ultimate shear strength (USS) values obtained from the shear tests of PP65.40 and PP140.80 showed a similar trend across the considered operating temperatures. Indeed, the peak stress decreased with temperature and the yielding behavior occured at higher strain by increasing the operating temperature, for both materials. Even for the shear behavior, the values of G and USS obtained for PP140.80 were higher compared to PP65.40 material, for all the temperatures considered, and the gap was larger as the temperature increased.

To provide tools for design using this kind of recycled polymer composites, an accurate phenomenological model (ICP model) was developed and validated with literature data for tensile and compression behavior. The ICP model was proposed for the prediction of the tensile and compressive behavior of semi-crystalline and amorphous polymers. The new model modifies the phenomenological model previously proposed by Zhou and Mallick (ZM model) to correctly predict the complex behavior of thermoplastic materials, including the linear viscoelastic deformation, the non-linear viscoelastic deformation, the yielding, the post-yield strain softening and the post-yield strain hardening. A validation activity based on literature data was carried out for polyether-ether-ketone and polycarbonate materials. The new model proved effective in fitting with high accuracy all the phases of the flow stress behavior for the considered materials, across a wide range of strain rates and temperature conditions. In the validation process with literature data, the comparison with other literature models showed the better fitting performance of the ICP model. Moreover, the validation of this model was also carried out for the tensile and shear behavior of the materials provided by the company and tested within the context of this thesis. The ICP model proved to be suitable and accurate also for the prediction of the tensile and shear behavior of 30wt.% SGFPP and 30wt.% TFPP, across different operating temperatures and, in case of tensile behavior, also at different strain rate conditions.