Char residues from biomass gasification as low-cost and environmental friendly fillers in polymers

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This study aims at investigating the feasibility of using char derived from biomass gasification as filler in polymers.

Char is the solid residue obtained after the gasification of biomass, i.e. the thermochemical conversion of biomass in an oxygen-deficient atmosphere (Basu, 2010). Currently, char is treated as an industrial waste with high costs associated for its management and disposal. Considering the Italian Region of South Tyrol as benchmark, 1300 tons of biomass gasification char are produced every year with a related disposal cost that ranges from 140 - 150 €/ton (Basso et al., 2018). However, char possesses remarkable properties, such as a high carbon content and well developed porosity, that make it suitable for several applications and thus, it could be valorised lowering its economic, energetic and environmental impacts (Benedetti et al., 2018).

In particular, char potential could be exploited in the field of polymers, as filler. Fillers are the inorganic or organically modified materials that are added into polymers not only to strengthen the composite, but also to reduce the production cost (Hau Hau Xin, 2016).

Recently, the utilization of carbon-based materials as fillers in polymers has attracted the interest of the scientific community. In particular, carbon nanotubes (CNT), carbon black (CB), carbon fibers (CF), graphite and graphene have been used for enhancing the tensile properties, thermal stability and electrical properties of the composites (Byrne and Guin'Ko, 2010; Chen et al., 2018). Nevertheless, the high production-costs, the fossil fuel-based starting feedstock and their chemical synthesis, make them less attractive in the view of minimizing the costs and increasing sustainability.

As alternative, biochar obtained from the pyrolysis of biomass-derived waste has been employed and successful results have been obtained. Indeed, according to the literature, biochar composites showed improved thermal, electrical and mechanical properties (Das et al., 2015, 2016; Hau Hau Xin, 2016; Nan et al., 2016; Peterson et al., 2015). Moreover, the hydrophobic nature of biochar makes it more compatible with polymers, which are also hydrophobic, such as polyolefines (also bio-based).

Due to their characteristics and similarities with pyrolytic biochar, also char residues from biomass gasification could be included in the group of carbon-based fillers. Unlike biochar, char is not produced on purpose, but it is a waste, obtained as a byproduct from wood gasification. Therefore, its properties should be investigated in detail before determining the best features for its utilization, also considering the production process conditions, which can vary significantly among existing gasification technologies.

In order to study the implications of char valorization from and industrial and more practical point of view, char derived from a commercial biomass gasifier, currently operating in South Tyrol, Italy, has been selected for being characterized and used for assessing its potentialities as filler.

Particularly, the selected char was collected from a dual-stage gasifier, designed to operate at 850 °C and atmospheric pressure, using woodchips as feedstock and air as gasifying agent. This gasifier is characterized by a nominal thermal and electrical power output of 540 kW and 280 kW, respectively, from a throughput of about 230 kg/h of dry biomass.

Composites, called Green Polyohm™, were made by melt compounding technology with the use of a lab-scale co-rotating twin-screw extruder installed at Nadir Laboratory (c/o University Ca' Foscari of Venice), with a screw diameter of 11 mm and a length-to-diameter ratio (L/D) of 40 (see Figure 1). The screw profile is composed of 8 zones with three interposed kneading sections. This machine is optimized for the production of polymer composites with fine dispersion of filler inside the polymer bulk (Bastianini et al., 2018).

Polymer pellets together with char, were fed in the main hopper with a volumetric feeder and a double inlet. The screw rotation speed and the barrel temperature were optimized during operation. Green Polyohm™ wires were recovered at the die exit, solidified in a water bath, and finally, pelletized with a pelletizer machine.

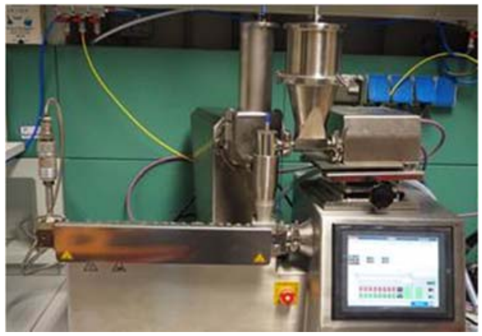

Figure 1*: Lab-scale twin-screw extruder for melt compounding at Nadir Laboratory.*

Char was characterized through elemental analysis, physisorption analysis, thermogravimetric analysis (TGA), scanning electron microscopy (SEM) and X-Ray diffraction (XRD) technique. In comparison to other chars obtained from other biomass gasifiers operating in South Tyrol (Benedetti et al., 2018), the selected char shows a high carbon content (91.4 % wt_{dry}) and a low ash content (4.2 % wt_{dry}), that ensure a reduced brittleness of the material. Its porosity is well developed (S_{BET} = 297 m^2/g, V_{pores} = 0.26 m^3/g, d_{pores} = 4.5 nm), and the presence of crystalline structures is mainly related to calcite ($CaCO_3$).

Also Green Polyohm^{TM} was characterized in detail. In particular, the morphologycal properties were investigated by XRD and SEM/TEM, the thermal stability by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) and the electroconductivity by a Keithley Voltmeter using the four-point method according to ASTM D4496.

According to the results of this study, char improved the properties of Green Polyohm^{TM} and could be employed in polymer manufacturing as filler. Especially, an electrical conductivity of 2.4 10^{-3} S cm^{-1} was measured when nearly 50 % by weight of char was added to the polymeric matrix. Recycling char as filler could enhance its overall value, open up innovative horizons for its valorisation, offer a sustainable way for its management, and mitigate waste generation.

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