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High toughness hybrid biocomposite process optimization

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ABSTRACT

The process optimization for production of a tough hybrid biocomposite through long fibre thermoplastic direct compounding and moulding process (LFT-D) was investigated with an ultimate goal of high impact strength. High shear mixing – twin screw extrusion – and low shear mixing – single screw extrusion – methods were used for the production of tough hybrid composites. The optimum operating condition was found to be the twin screw extrusion at which feeder to motor speed ratio was 1:10 without breaker and die while feeding the GF before the vent at 100 rpm. The hybrid composite produced accordingly had well dispersed fibres with GF content of 20 wt%, the average length of 2.3 mm, and impact strength of 130 J/m. It can be concluded that toughness was influenced by fibre concentration, length and dispersion.

1. Introduction

Thermoplastic composites are produced by various conventional processing methods such as single screw extrusion, twin screw extrusion, injection and compression moulding. Shear force exerted by the screws in the extruder results in fibre breakage and length variation aside from dispersion of fibres and bonding fibre and matrix. Greater fibre length and better fibre dispersion are crucial for composite performance [1]. Length of fibres is a key parameter for enhancing strength and toughness, while dispersion of fibres improves stiffness [2,3].

Variations in processing conditions were made to vary fibre length, content and dispersion in the composite. The experimental approach here was to use both low shear mixing (single screw extruder), and high shear mixing (twin screw extruder) to develop long fibre thermoplastic direct compounding and moulding process (LFT-D). Hybrid composites (mixture of two or more fibres in a single matrix) have higher strength and stiffness compared to single fibre reinforced polymers. Panthapulakkal et al. showed that hybridization with GF enhanced impact strength by 35% for a hemp–PP composite [4]. In this paper, various parameters such as feeder speed, motor speed, and position of fibre feeding were changed to find the optimum conditions with the least fibre breakage while providing good dispersion and mechanical properties – particularly impact strength. The aim was to find the operating conditions which result in the best impact properties and fibre dispersion while having acceptable glass fibre content. The preliminary way to investigate dispersion of fibres was through mechanical properties. Subsequently SEM was carried out to make a stronger conclusion about the dispersion of fibres. Further validation was carried out by glass fibre (GF) length distribution and the way in which particle size was distributed.

1.1. Composite manufacturing

Matrix, fibre(s) and other additives are compounded through different methods to form a composite. The extruder provides shear force and heating to melt polymer and facilitate dispersion of fibres within. Natural fibres are temperature sensitive and the process temperature should be kept below 200 °C at all times, thus making the control of shear and heat in the system very crucial for Wood Plastic Composites-WPCs. Sain et al. showed the process for manufacturing structural hybrid thermoplastic biocomposites which comprises of defibrillating the natural fibre in resin, followed by impregnation of inorganic fibre in composite and further dispersion of fibres to get mouldable hybrid composites [5].

After compounding, composites are commonly manufactured through injection or compression moulding. The impact resistance of compression moulded parts is 50% higher than injection moulded ones, as shown on tests of large LFT-D body panels [6]. Hence compression moulding is used here for the LFT-D process.

1.2. Long fibre thermoplastic direct compounding and moulding process

Fibre length is governed by the original length and concentration of fibres, equipment design and processing conditions [7]. Long fibre reinforced thermoplastics (LFTs) have a better mechanical

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performance due to their higher aspect ratio, and are very tough due to their energy dissipating mechanisms of fibre debonding and pull-out. However, processing becomes more difficult as the length of fibres increases. Fibre length retention is a hard task to accomplish as fibre length reduces during the mixing process. Fibre length distribution depends on the type of matrix and its rheological properties, fibre content, and their interactions [8,9].

In the LFT-D process, thermoplastic polymer pellets are fed into the resin hopper where they melt in a resin shooter. Continuous glass or other fibres are pulled into the process die by the high pressure flow of molten polymer. An in-line chopper cuts the fibre imbedded in the molten polymer as it exits the viscous entrainment die. Cut lengths of 6–25 mm are possible [10]. Although LFTs have been commercially in use for the automotive industry, little experimental work exists for these materials [11,12].

Natural fibres have numerous advantages including renewability, sustainability, lightweight design, eco-friendliness, low cost, and sound abatement capability [13]. Unfortunately, impact properties of natural fibre reinforced composites cannot compete as well as their other mechanical properties with glass fibre reinforced composites [14]. Hence, hybridization (use of more than one fibre in matrix) can facilitate the achievement of biocomposites with great load-carrying capacity and better impact energy absorption while being environmentally friendly.

2. Materials and methods

2.1. Materials

Hemp fibres used in this study have an original length of 8.2 cm, obtained from Hempline Inc., Ontario. Two different glass fibre rovings with filament diameters of 17 and 22 μm, both excellent for long fibre polypropylene processes such as LFT-D, were used. Polypropylene PP3622 with a density of 0.905 g/cc and melt flow index of 12 g/10 min was obtained from Arkema, Canada, and is good for extrusion. The coupling agent was maleic anhydride polypropylene, MAPP OREVAC-CA100 from Arkema, Canada.

2.2. Methodologies

2.2.1. Hemp fibre preparation

The 8.2 cm hemp fibres were reduced in size by passing through a refiner. The refiner is composed of two rigid metal plates which crush the material to a smaller size based on the gap setting value between the plates. The refiner plate gap was placed at different settings of 5, 20, 80 and 120 resulting in gap values of 0.125, 0.5, 2, and 3 mm. Consequently hemp fibres with different lengths and diameters were obtained. In order to find the optimum grade of refining, mechanical properties of hemp–PP composites were investigated. The formulation of composites were 30% hemp – refined at different gaps, thus different fibre lengths, 65% PP, and 5% MAPP compounded as described by Sain et al. [15]. Hemp and MAPP were oven dried at 105 °C for 1 h prior to mixing to remove moisture. Afterwards composites were compression moulded to produce approximately 3 mm thick hemp–PP sheets. Rectangle shaped specimen were cut from the sheets with the width and length in accordance to ASTM D638 and ASTM D256. First, impact and then tensile properties of the hemp–PP composites with varying hemp fibre length were investigated. The refining gap resulting in the highest mechanical properties for hemp–PP was selected to refine the hemp required for hybrid compounding.

2.2.2. Composite preparation and process optimization

To achieve long fibre reinforced composites, a LFT-D process consisting of compounding, extrusion, and compression moulding was used. 30% Hemp, 65% polypropylene, and 5% MAPP were compounded based on the patent for manufacturing high performance lignocellulosic fibre composite materials by Sain et al. [15]. The same amount of hemp was compounded in a rotary mixer for all runs. Glass fibre was then added to hemp–PP granulates in the extruder to obtain the long GF–hemp–PP hybrid composite.

The co-rotating twin screw extruder had a length to diameter ratio (L/D) of 40, and a diameter of 25 mm. Parameters that could be changed in the extruder were as follows: the main motor speed – speed of rotation of the screw; the feeder speed – the speed at which the materials from the hopper enter the extruder body; temperature in each of the 11 zones; the feeding position of the glass fibre; and keeping the breaker and die in place or removing them. The temperature in all zones was kept constant at 185 °C for all runs with the twin screw extruder to assure complete melting of the resin and good flow of the composite in the extruder, while avoiding overheating of natural fibres during compounding. Two feeding positions in the extruder were investigated for the glass fibre to arrive at a desired length with acceptable wetting and dispersion: the middle port, and the one before the vent port (Fig. 1).

To find the optimum operating conditions for the twin screw extruder, the mentioned parameters were varied to create different scenarios as shown in Table 1. Initially, pure PP was introduced into the system instead of a hemp–PP composite as it was time-consuming to make large amounts of composite – the batches were limited to 60 g in the plasticorder. Since viscosity is different when hemp is present, optimization of motor and feeder speeds had to be repeated when hemp was introduced into the system. It is important to note that the main motor speed determines the amount of glass fibre that gets pulled into the system, and thus affecting the glass fibre content. On the other hand the feeder speed determines how much polymer enters the system, hence controlling the amount of hemp–PP component of the hybrid composite. The breaker, a square block with a number of holes to direct the fibres in the composite, and the die could be removed from the end of the extruder to reduce the pressure on the composite and breakage of fibres.

To determine GF length, GF was isolated from the composite via pyrolysis in a muffle furnace at 600 °C for 3 h. Feeding the GF before the vent resulted in long and short fibres, while feeding in the middle of the extruder resulted in only short fibres. Eye observation of acquired GF led to the selection of before the vent feeding, as it resulted in longer fibres. Fibres were longer in cases where the breaker and the die were removed from the machine. Hence, based on the runs from GF–PP it was concluded to feed the GF before the vent port, with no breaker and die in the extruder machine. These conditions resulted in GF–PP composite with an average glass fibre content of 18.3 wt%.

For the case of hemp–GF–PP, the optimum operating condition for the twin screw extruder was found to be a motor speed of

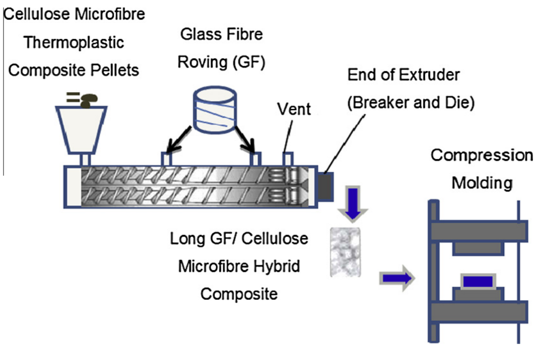

Fig. 1. Schematic of the LFT-D process.