Composites Science and Technology 117 (2015) 18–25

Contents lists available at ScienceDirect

Composites Science and Technology

journal homepage: http://www.elsevier.com/locate/compscitech

Development and characterization of insert injection moulded polypropylene single-polymer composites with sandwiched woven fabric

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ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form
9 May 2015
Accepted 17 May 2015
Available online 28 May 2015

Keywords:
Polymer-matrix composites (PMCs)
Sandwich
Injection moulding
Mechanical properties
Scanning electron microscopy (SEM)

ABSTRACT

Polypropylene (PP) single-polymer composites (SPCs) with sandwiched woven fabric were successfully produced by insert injection moulding. The woven fabric was set in the middle of the mould cavity and fixed by the clamping force. The injected melt could fill and permeate the fibres from both sides of the woven fabric, so both improved mechanical properties and good appearance could be obtained. A processing temperature window (160–200 °C) with a short cycle time (less than 30 s) could be realized. Orthogonal experimental method was used. The tensile strength of the PP SPCs could reach up to 38.22 MPa, 45% higher than that of the non-reinforced PP. The effects of different processing parameters including nozzle temperature, injection pressure, holding pressure and holding time were discussed. Among the processing parameters, the nozzle temperature is the most important influence factor. The morphological properties were also observed using camera and microscope. It confirmed the processing temperature window and good interfacial adhesion.

1. Introduction

Single-polymer composites (SPCs) are the class of composites with matrix and reinforcement made from the same polymer. They not only offer the promise of superior mechanical properties and reduced weight, but also provide a real world solution for improving recyclability. Different thermoplastic polymers, including polyethylene (PE) [1,2], polypropylene (PP) [3,4], polyethylene terephthalate (PET) [5,6], polyethylene naphthalate (PEN) [7,8], polylactic acid (PLA) [9,10], polyamide (PA) [11,12], polymethylmethacrylate (PMMA) [13] and polytetrafluoroethylene (PTFE) [14], were exploited to manufacture SPCs. Another advantage of SPCs is the missing dispersion step in their production contrasting the common polymer nanocomposites, so the new members of SPC family, the micro- and nanofibrillar SPCs, were developed [15]. Recent development of SPCs is supported by novel preform preparation, consolidation and production possibilities [16]. These different processing methods include hot compaction of fibres or tapes [3–7,9–13,17], film stacking [18–20], combination of hot compaction and film stacking [21,22], co-extrusion [23–26], undercooling melt film stacking [8,27,28], and combination of compression moulding and free sintering [14]. However, these extant methods to prepare SPCs are all limited in compaction technology which has a few disadvantages such as long preparation cycle and products only with simple shapes. There is ongoing research to develop injection-moldable SPCs [29] since the injection moulding can achieve the goals to produce SPCs efficiently with large scales and complex geometry.

Traditional injection moulding process cannot be used to produce SPCs because high temperature and intensive mixing with high-shear will lead to extensive fibre damage. The key issue for injection moulding of SPCs is how to establish a wide processing temperature window. Khondker et al. [30] produced PP SPCs using injection-compression moulding technique. Plain knitted textile fabric was used as the reinforcement. During the injection-compression moulding, the compression process needs a holding time of 40 s which is still longer than that of the injection moulding. Kmetty et al. [31] described the preparation of injection mouldable PP SPCs by using PP-based thermoplastic elastomer as the matrix material and high-tenacity PP fibre as the reinforcement, and reported on their processing-structure-property relationships. A significant wide processing window (about 90 °C) can be obtained. However the thermoplastic elastomer is still not the same with PP, which would also influence the mechanical property. In our previous studies [32,33], the feasibility of preparing PP SPCs by insert

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http://dx.doi.org/10.1016/j.compscitech.2015.05.015
0266-3538/

injection moulding was investigated. PP fabric is preplaced and affixed on the mould cavity wall using double-sided tape, and then PP matrix is injected into the cavity and infiltrates into the fabric by pressure. The mechanical strengths can be improved significantly, and the processing window can be up to 80 °C [33]. However the infiltrating is incomplete because of the very low temperature at the cavity wall, and the remnant adhesive on the sample is difficult to clean. The incomplete infiltrating and the remnant adhesive all affect the appearance of the final sample.

In this study, clamping force instead of double-sided tape was especially used to fix the inserted woven fabric in the middle of the mould cavity so that both improved mechanical properties and good appearance could be obtained. Compared with the compaction technology, a large process window with a short cycle time could still be realized. PP SPCs with sandwiched woven fabric were prepared by this insert injection moulding. Tensile properties of the samples were tested. Orthogonal experimental method was used to determine the influence of different processing parameters. Morphological properties of the PP SPC samples were also observed.

2. Experimental

2.1. Materials

PP granules (random copolymer, model number: ST868M, LCY Chemical Corp.) with a density of 0.896 g/cm^3 at room temperature and a high melt flow index (MFI) of 18 g/10 min at 230 °C were used as the matrix. A plain woven fabric with an areal density of 0.136 kg/m^2 was selected as the reinforcement, each bundle of fibres in warp and weft directions consisted of 70 individual fibres respectively. The thickness of the woven fabric was about 0.5 mm. The fibre with a diameter of 48 μm was supplied by Innegrity LLC (Simpsonville, SC). The tensile strength and modulus of the fibre was 560 MPa and 6.6 GPa respectively, which were measured by a universal tensile test machine (5166 Series, Instron Corp.) with a load of 30 kN and test speed of 5 mm/min. There was no surface treatment of the fibres.

2.2. Differential scanning calorimetry (DSC)

A differential scanning calorimeter (DSC-60, Shimadzu) was applied to study the melting and crystallizing process of PP granules and PP fabric. They were heated from 40 °C to 200 °C at a rate of 10 °C/min and held for 10 min at 200 °C in order to erase thermal and mechanical history, and then cooled to 40 °C at the cooling rate of 10 °C/min. The flow rate of Nitrogen here was 60 ml/min.

2.3. Composites preparation

The PP SPCs with sandwiched woven fabric were prepared at different processing conditions using an injection moulding machine manufactured by GSK CNC Co., Ltd. PP granules were melted under the effects of heat and shear force provided by the screw and barrel, then the melt was injected forward. The temperature of the barrel frontier was 5 °C higher than the nozzle temperature (T_n). The nozzle temperature was changed from 160 to 200 °C. According to the insert injection moulding, the woven fabric was pre-placed like an insert on the half cavity of the moving mould plate. After mould closing the woven fabric was fixed in the middle of the whole mould cavity, and the clamping force could press the sandwiched woven fabric tightly (see Fig. 1). The gate thickness of the mould cavity was 3 mm which is a little smaller than 3.2 mm (the thickness of the tensile sample), so it could reduce the shear effect on temperature. During the injection moulding process, the PP melt was injected into the cavity within 2 s under an injection pressure, following by the packing phase for a holding time (t_h) under a holding pressure (p_h). The holding pressure was 80% of the injection pressure. The back pressure was 2 MPa and the mould was at room temperature (around 25 °C). Finally the material in the cavity was cooled for a cooling time (t_c) and solidified, then the SPCs products could be removed by opening mould. The unnecessary woven fabric was cut off by knife. Table 1 shows the injection moulding parameters. In order to determine the influence of different processing parameters, orthogonal experimental method was used, and nine groups of PP SPC samples (Sample No. 1–9) were produced. The influence of nozzle temperature was especially investigated. Five groups of PP SPC samples (Sample No. T1 to T5) were produced at different nozzle temperature. Non-reinforced PP samples were also produced under each group of process conditions for comparison. At least five samples were prepared for each group.

2.4. Tensile tests

The samples of PP SPCs were standard transects for tensile test in accordance with ASTM-D638. Tensile tests were carried out on a universal testing machine (XWW-20Kn, Beijing Jinshengxin Testing Machine Co., Ltd.) at room temperature with a crosshead speed of 5 mm/min. Five samples were tested for each group.

2.5. Morphological observation

Sample pictures were taken by a camera (Cannon Powershot SX20 IS). In virtue of the semitransparent property of PP, the textile

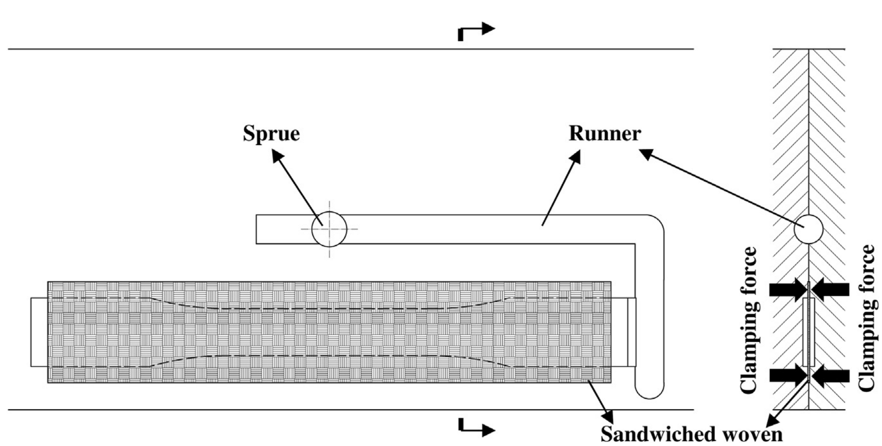

Fig. 1. Schematic of the mould for insert injection moulding of SPCs.