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A cleaner production of rice husk-blended polypropylene eco-composite by gas-assisted injection moulding

R.C.M. Yam*, D.M.T. Mak

Department of System Engineering and Engineering Management, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong

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ABSTRACT

Gas-assisted injection moulding processes are widely applied in the plastics industry to improve moulding quality by using fewer polymers. This process is achieved by hollowing out the internal section of the mould to reduce the usage for conventional polymers and is particularly good for thick, moulded products. The eco-composites polymers, such as rice husk-filled polymers are environmental friendly materials to replace polymers. A cleaner production can be achieved by using rice husk-blended polypropylene RH/PP eco-composite in the gas-assisted injection moulding process. No successful case is reported in literature, as the increased shear viscosity of the non-petrochemical and natural-based polymers make it difficult for the eco-composite to flow inside the moulds. In this study, gas-assisted injection moulding technology was successfully applied to the rice husk-filled polypropylene eco-composites polymers in different compositions.

Different stages of injection pressure and delays of gas pressure were applied in order to improve the flow characteristics. In addition, the internal wall surface of the mould must be polished to 'Mold-Tech' SPI A2, an industry standard textured finishes. The new approach uses fewer petrochemical polymers with improved moulding quality, especially for thick, moulded parts. The new method is also an environmentally-friendly approach as it uses less injection pressure and clamping force. This has created a good foundation for further research in cleaner production of different kinds of eco-composites material by gas-assisted injection moulding.

1. Introduction

The continued consumption of petrochemical-based polymers together with the unappropriated disposal of the huge amount of rice husk, mostly by burning, have caused significant concerns to the environment (Bevilaqua et al., 2013). Thus, there is an immediate need to develop environmentally-friendly eco-composite materials through innovative moulding processes to reduce the demand on conventional, petrochemical-based polymers. However, rice husk-blended polypropylene eco-composite, has several weaknesses including: low melt-flow indexes, which do not flow effectively inside the moulds in conventional injection moulding, weak interfacing bonding between the hydrophilic natural filler and hydrophobic polymer (Fung et al., 2002) and increased shear viscosity with an increase in natural and agricultural filler content (Fung et al., 2003), such as rice husks, and the relatively lower thermal degradation temperature of natural fillers compared with polymer resins (Albano et al., 1999). The worldwide annual output of rice husk is 800,000 million tons in which 50% are coming from China (Liu et al., 2012). Rice husks are inexpensive, biodegradable, environmentally friendly. The main component of the rice husk is silica (52%) (Liu et al., 2012) which has made rice husk possess good mechanical and fire retardancy properties (Zhao et al., 2009). Furthermore, rice husks are natural waste materials that need to be disposed of without causing damage to the environment. Hence this natural filler has attracted significant research interest for eco-composite developments (Zhao et al., 2008). While there are a number of findings and research reports on the injection moulding process, studies on gas-assisted injection moulding of eco-composite are rarely reported. Serrano (Serrano et al., 2013) reports the cleaner use of the old recycled newspaper to replace glass fibres by conventional injection moulding process. The major focus of Serrano's work is on old newspaper through the convention method which is different from the rice husk and the gas-assisted process used in the current study.

Gas-assisted injection moulding process is a cleaner production moulding technology. The principle of gas-assisted injection moulding is to hollow out the internal, thick sectional area by

* Corresponding author.
E-mail address: mery@cityu.edu.hk (R.C.M. Yam).

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injecting gas at high pressure during injection moulding to further reduce the use of polymers than the conventional method. The gas forces the molten resin forward and then holds it at high pressure during cooling. The resin begins to shrink, thus leaving a hollow section inside the moulded parts. The process is capable of introducing empty space. This is basically an injection moulding process in which the moulded part is first partly filled with molten polymer and then gas is injected into the cavities by filling up 75%–98% of the space through gas pins or nozzles designed and positioned separately from the injection gating of the mould.

After a short time delay, compressed nitrogen hollows the internal section of the molten polymeric material, thus pushing the material towards the inner wall surface of the cavity of the mould. Based on the heat exchange through the mould and circulating water flowing through the cooling channels inside the moulds, heat is transferred from the molten plastic to the mould, the resin nearest to the mould surface is actually cooler than the inner section, and the injected gas stays in the middle section of the plastic forming cavities. The conventional injection moulding technology has difficulties to mould thick products causing defects such as warping and sink marks, which are basically the result of shrinkage.

Over the years, gas-assisted injection moulding research focused on filling simulations (Chen et al., 2008), gas channel design (Marcilla et al., 2006), as well as faster cooling (Gao et al., 1997). Research also compared the advantages of gas-assisted injection moulding over the conventional moulding processes in terms of material usage (Parvez et al., 2002) and moulding quality (Castany et al., 2003), e.g. improving warping and sink marks. However, all these previous studies on gas-assisted injection moulding were based on conventional plastic resins (Chen et al., 1996). This study is the first attempt to extend the gas-assisted injection moulding technology to the eco-composite material. Farmers commonly burn agricultural waste, such as rice husks, and this has adversely polluted the environment. Collecting agriculture wastes and blending them with petrochemical polymers in different compositions to produce moulded parts for various industries, can make the environment cleaner.

Several gas-assisted injection moulding methods were involved in this study:

SHORT SHOT PROCESS is a standard, internal gas pressure process in which the cavity is pre-filled partially with molten plastic, and then the gas is injected into the cavity of the mould, displacing the melt until the cavity is completely filled. The gas pressure is then maintained as the holding process.

FULL SHOT PROCESS, also known as the shrinkage compensation process, is a process in which the cavity of the mould is completely filled with molten plastic. The gas is then injected as the holding process to prevent shrinkage. The gas inside the cavity forms gas channels in the moulded section to provide holding pressure during the cooling cycle, and the plastic begins to solidify. Meanwhile, the gas pressure inhibits sink marks and the gas releases through a valve, thus relieving gas pressure before the mould opens.

In the **OVER FLOW PROCESS**, the cavity is filled completely with molten plastic and then holding pressure is applied to the melt. The gas is then injected into the cavity, displacing the plastic from the cavity into the overflow. The gas pressure is maintained as the holding pressure throughout the entire cooling cycle in order to inhibit shrinkage. The gas pressure is then released before the mould opens.

There are many advantages of gas-assisted injection moulding technology over the conventional approach. Some of them are listed as follows (www.ua.es):

- For thick products, the gas-assisted approach only requires one moulding process instead of two in the conventional approach. This will reduce energy consumption.
- Due to the packing out of the pressured gas, lower injection pressure is needed;
- Less warping and shrinkage leading to less sink marks
- Reduced cycle time; and
- High strength to weight ratio

There are different cleaner production processes for rice husk reported in literature recently. Liu (Liu et al., 2012) reports the simultaneous production of silica and activated carbon from rice husk ash through a simple, environmental-friendly and economical-effective synthetic procedure. This has provided an alternative means to use the rice husk through an enhanced green, less toxic and sustainable chemical process. Liu has found that substantial amount of silica could be extracted from the rice husk ash. This is why the rice husk eco-composite in our study has good mechanical and fire retardancy properties. Bevilaqua (Bevilaqua et al., 2013) suggests another method to use the residual rice husk for producing levulinic acid which is important for the pharmaceutical and food industries. At present, levulinic acid is mostly produced via an environmentally unfriendly petrochemical synthetic route from fossil oil. Replacing it by a renewable biomass, i,e rice husk, through a cleaner production could save the use of the fossil resources. These two studies emphasize the importance of the clean use of the rice husk by different cleaner production methods. The current study supplements their findings by using the gas-assisted injection moulding process.

2. Experimental

2.1. Materials and preparation of composites

Rice husk particles (in the form of powder: 80 mesh size) was selected and purchased from Tengzhou City, Shandong Province, People's Republic of China (PRC), Fig. 1a. Smaller particle sizes of rice husk were selected to minimize air bubble defects in the eco-composites (Mullin, 1993). Mesh sizes 80 to 100 are the appropriate particle sizes for blending. Before blending with PP, the selected rice husks were filtered through a Mesh 80 Filter to make sure they were close to an 80-mesh size.

2.2. Preparation of eco-composites

Polypropylene (PP), commercial product code PP PP332K from Samsung, with a melt flow index of 5g/10 min was purchased. Coupling agents and additives, such as inorganic fillers, maleic anhydride grafted polypropylene, dispersion oil and pigments (provided by Plastique Aveu Maize Limited) were mixed together.

The cell wall structure of agricultural wastes, such as rice husks, contains many micropores. These micropores trap moisture that could cause manufacturing defects in the eco-composites, such as interfacial failure and air pockets (Allan et al., 1991). In order to remove moisture, rice husk particles were pre-dried in a 50 kg (kg) hopper at 110 °C for 4 h. Applying the design of experiment approach (Douglas, 2005), the pre-dried husks were mixed with PP in various ratios of 10%, 20% and 30%, i.e., with a 10% increase in rice husk content for each composition. In order to determine the appropriate ratio of coupling agents, different weight percentage of coupling agent and a fixed ratio of various additives (recommended by suppliers) were mixed with the rice husks and PP accordingly, until quality pellets were produced. Tables 1–3 show the designation of coupling agent, additives and polypropylene for different weight percentage of rice husks content.