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Injection moulding simulation analysis of natural fiber composite window frame

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ABSTRACT

Study of window frame fabrication by injection moulding process was carried out with the aid of Moldflow® software. Rice husk filled high-density polyethylene was used as the raw material. Solid and hollow designs (A001 and A002) were created to compare the pros and cons of each design. The investigations were carried out on flowing, packing, cooling and costing of injection moulded window frame. At the end of the analysis, the most feasible design was selected to be further undergone stress analysis according to BS EN 14608:2004 and BS EN 14609:2004. Eventually, the mechanical properties were classified according to BS EN 13115:2001. The actual processing conditions of rice husk composite were approximated to softwood at Cross-WLF viscosity model due to unavailability of rice husk plastic composite (RHPC) rheology property. RHPC melt is generally shear thinning, meanings that the viscosity decreases with increasing of shear rates. From the analysis, window frame with hollow design is preferable, since hollow design has advantage of filling, packing, and cooling properties. The hollow design also costs less than solid design of window frame. However, high injection pressure and clamping tonnage are unfavourable for hollow design. A002 hollow design was selected as the most feasible window frame to be fabricated. Stress analysis was done to classify the window frame. The analyses were carried out to determine racking and static torsion resistance. A002 window frame mechanical strength is classified as Class 2 according to BS EN 13115:2001.

1. Introduction

Doors and windows are the most common parts of fittings in houses. The design of doors and windows also varies depending on the requirements of house owners. Some are well designed in terms of good looking for indoor and outdoor decorations, and some are simple and cheap designs for affordability of budget buyers. However, nowadays especially the energy prices jump drastically, people prefer to invest in energy saving design of doors and windows. By controlling the amount of energy losses from the doors and windows, eventually it helps to save cost in maintaining the indoor temperature.

Many types of materials are used to manufacture the window frame. The most popular materials are timber, polymer and metal. Out of these materials, polymer plays an important role in the energy saving design of windows frame (Vetter and Doors, 2004). Polymer materials are known to be low heat transfer materials. This property helps to decrease the heat losses to the outside environment of houses (Kansas State University, 2000).

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Injection moulding processing technique is the most commonly used method in plastic industry. The injection process is a conformation process of thermoplastic polymeric material that has been great economic and technologic significance (Reig et al., 2005). The technique is suitable to process many types of polymeric material and the product shapes are sharp. In order to build a low cost and processable mould for thermoplastic product, it requires depth knowledge in polymer processing field particularly in rheology studies. Thus, many polymer product manufacturers take easier approaches by undergoing trial and error method in the early stages of manufacturing new product design. Most of the time the results are quite satisfied, but it is time consuming. Consequently, small and medium scale manufacturers unlikely to introduce new products in short time. Some commercial computer aided engineering (CAE) software designers have taken the opportunity to develop injection moulding flow analysis simulation software to help to predict and overcome the problems. Mould design plays the most important roles to produce good quality products either in mechanical properties or appearance. Several professional CAE softwares in injection moulding are available in the market such as Moldflow® and Moldex3D®. The injection moulding simulation software helps to study the flow patterns of polymer melt inside the mould during injection, packing and cooling processes (Moldflow Corporation, 2004). The output results can be used as guidance to design mould with correct operating parameters and the most important is the cost expenses in building a mould. Imihezri et al. (2006) has done Moldflow® flow and component design analysis of polymeric based composite automotive clutch pedals with polyamide 6.6 with 30% glass fiber reinforcement. The finding helps to evaluate automotive clutch pedals ribbings' designs in cost and ease of manufacturing.

Nowadays, researchers focus on developing natural fiber or cellulose fibers to use as reinforcing agents for composites. Compare to inorganic fillers that are commonly added into thermoplastic resins, natural fibers are able to withstand higher weathering exposure to deteriorate. Moreover, the natural fibers those are recovered from natural waste such as rice husk, coconut fiber, waste paper and wood flour are able to reduce burden of local waste treatment plants. A research was done by Panthapulakkal et al. (2006) used wheat straw fibers as reinforcing additives for thermoplastics. The wheat straw was obtained from local farmers in Canada. The particle size of the chemical solvent treated wheat straw is 500 μm. Filler (30 wt%), compatibilizer, and polypropylene were granulated using a brabender. The wheat straw fiber filled polypropylene composite tensile modulus is 2.99 GPa with compared to virgin polypropylene tensile modulus is 1.21 GPa. It shows that incorporation of natural fiber can improve the mechanical properties of the injection-moulded composite. Beside that, according to Herrera-Franco et al. (1997), chemically treated henequen natural fiber of particles size 200 μm has also been used as fillers to form composite material. Tensile modulus of 25 wt% henequen fiber in the composite is 1.35 GPa. In France, researchers have been investigated the application of sunflower oil cake as the natural filler for injection moulding composite material. The detailed research was done by Rouilly et al. (2006). Sunflower oil cake is the residue of the oil extraction of the seed, consists of approximately 40% highly lignified husk lignocellulosic fibers. Similar to other natural composite, chemical treatment was done to sunflower oil cake before being used as the filler for plastic composite. After that, a twin screw extruder was used to blend the all the ingredients. Injection moulding product of sunflower oil cake has average density 1.20 g/ml and tensile modulus 2.0 GPa. In this study, rice husk plastic composite (RHPC) is used to manufacture the window frame. According to the information obtained from Naurah (2006), the mass flow rate of RHPC is 3.28 g/10 min. The test was done using 1.05 kg load at 190 °C. RHPC is used because the composite material possesses excellent mechanical properties, low cost reinforcing fiber and good weathering resistance. RHPC has results of tensile strength and tensile modulus of 17.39 and 1317.40 MPa, respectively. Meanwhile, the melting point of RHPC still remains similar to matrix polymer which is 130 °C.

Lack of the information about thermal properties leads to difficulty in flow analysis simulation (Cichocki and Thomason, 2002) especially when dealing with natural fiber plastic composite. In contrast, many CAE program require thermal properties of the material such as linear thermal expansion coefficient, heat capacity, pressure–volume–temperature (PVT) relationship and thermal conductivity properties to accurately simulate the melt flow behaviour. In the case lack of thermal properties data, approximation can be done to the nearest natural fiber composite material under control conditions to ensure the simulation results do not deviate far away from the real processing conditions. Preliminary study of injection moulding flow analysis is undertaken by using Moldflow® simulation software. For the window frame three dimension (3D) geometrical drawing, it was initially done in SolidWorks® and further imported to Moldflow® for injection moulding analysis simulation. Finally, the processing parameters and mechanical properties were obtained. In future, these results would be used to manufacture RHPC window frame.

2. Methodology

SolidWorks® was used to draw window frame geometrical layout as well as Moldflow® software was utilized for injection moulding simulation analysis. The window frames designs which are compliant to National Fenestration Rating Council (NFRC) ratings was used. Two window frame designs A001 and A002 were created as shown in Figs. 1 and 2, respectively. A001 window frame is a solid frame design; meanwhile A002 is a hollow frame design. Both of window frame designs were further separated into two parts—main frame part and side cover part. The length, width, and thickness of the composite window frames are 1150, 560 and 40 mm. The composite window frame is designed to glaze with 2 mm thickness glasses to minimize energy losses as shown in Fig. 3. The objective of creating two window frame designs is to compare which design would be more feasible to be fabricated in large scale. The simulation was done on filling, packing, cooling, warping and stress on the window frames. Economic analysis was also undertaken to ensure the design is profitable. The cost of energy was further determined according to Peninsular Malaysia electricity supplier, Tenaga Nasional Berhad (TNB) tariff rates E1 for medium voltage general industries which