MECHANICAL PROPERTIES AND CHARACTERIZATION OF INJECTION MOLDED MICROCELLULAR POLYPROPYLENE (PP)/CARBON FIBER COMPOSITE

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ABSTRACT

This article describes the mechanical properties and characterization of polypropylene (PP)/carbon fiber composite through microcellular injection molding system. In microcellular injection molding, nitrogen (N_2) gas at super critical level is used as a physical blowing agent into the molten polymer and thereby injected into the mold to produce microcellular-foamed samples. Carbon fiber filled PP was injection molded into ASTM test bar samples with both conventional and microcellular injection molding system. These samples were then subjected to scanning electron microscope (SEM) as well as tensile testing to study how the process conditions and presence of fibers affect the cell structure and mechanical properties of the microcellular injection molded samples. The detailed discussion leads to the effect of fibers on cell size as well as cell distribution. The orientation of fibers also affects the mechanical properties as well as cell growth in the vicinity of fibers.

1. INTRODUCTION

Microcellular plastics are characterized by cell densities of the order of 10^9 – 10^{15} cells/cm^3 and cell sizes in the order of 0.1-10 μm in diameter depending on the material and application [1-3]. These innovative materials have superior thermal, mechanical properties such as toughness, strength-to-weight ratio [4-5], impact strength [6] and fatigue life [7-8], electrical and acoustic insulation properties when compared to the solid plastics and also have improved performance comparative to conventional structural foam plastics. In addition, microcellular processing technology has advantages over many conventional foam processes because it uses inert gases such as nitrogen (N_2) or carbon dioxide (CO_2) to create cells with evenly distributed and uniformly sized microscopic cells, rather than hydrocarbons, chlorofluorocarbons (CFCs), or toxic chemical blowing agents. These potential advantages led to the expansion of various microcellular foaming techniques such as batch processing, thermoforming, extrusion, injection molding and blow molding [1]. Among all, injection molding of microcellular plastics is an attractive and potential process, because of its flexibility to produce complex plastic parts that have widespread demand in industry.

In the microcellular injection molding process, supercritical fluid (SCF) such as carbon dioxide or nitrogen is injected into the machine barrel and injected into the mold to produce microcellular foamed products. The addition of high-pressure SCF into the polymer melt effectively reduces the viscosity, therefore, a lower injection pressure is required and hence smaller machines may be used for this variant process. The clamp tonnage requirement is further reduced due to elimination of packing/holding stage to

pack the mold. The major benefits of this process are excellent dimensional stability, shorter cycle time, less material consumption and reduction of shrinkage and warpage.

Extensive research and development have been carried out on the processing and characterization of several different microcellular plastics and composites using microcellular injection molding [9-13]. In most of the above research, combining the microcellular molding process with PP/carbon fiber composite was never explored. Also, the mechanical properties of fiber filled plastic composites and the effect of fillers and processing conditions on cell morphology were not investigated. The present work aims to investigate the mechanical properties and cell morphology of carbon fiber reinforced PP through microcellular injection molding.

2. Experimental

2.1 Materials

The polypropylene (PP) used in this study is REPOL H020EG (Reliance India Ltd). Its melt flow index (MFI) is 2 g/10 min as per ASTM D-1238. The chopped carbon fiber of grade Zoltek PANEX33® CF was used as filler for PP/carbon fiber composite preparation. Nitrogen (> 99.5% pure) was supplied by Laser Gases (New Delhi).

2.2 Preparation of PP/carbon Fiber Composite

The micro composite material was prepared by using a Haake type, co-rotating and intermeshing twin-screw extruder. Pellets of polypropylene and 30% by weight of carbon fiber were tumble mixed and simultaneously introduced into the hopper. Barrel temperature (190^0 C) and screw speed (280 rpm) were set for the manufacture of raw extrudate of the composite material. The extrudate were then cut into pellets and then over dried before being injection molded.

2.3 Microcellular foaming of PP/carbon fiber composite

A PP/carbon fiber composite was injection molded using a 40-ton Battenfled® injection molding machine equipped with foam mould package. A schematic of the microcellular injection molding machine with typical microstructure of molded specimen is shown in Figure 1. The gas was injected during metering stage and gas injection pressure was automatically controlled with respect to melt pressure using a foam mould controller. The experimental conditions used for molded samples are shown in Table 1. The key processing parameters like melt temperature, injection speed, shot size were taken into account to study the cell morphology and mechanical properties of molded samples. In addition, some trials were conducted for solid molding for the purpose of property comparison.

2.4 Characterization of Microcellular Foamed PP

Scanning electron microscope (SEM) analysis was performed to characterize the cell morphology of microcellular injection molded samples. The samples were fractured at middle of gage portion with liquid nitrogen to make sure that the microstructure remains unaltered, and then sputtered with silver for enhanced conductivity. The micrographs were observed in ZEISS EVO 50 VP type SEM instrument with the accelerating voltage of 20 kV. Quantitative measurement such as cell size and cell density was performed using Image analysis software (Image J). The cell density (N_f), which characterizes the number of cells per cm^3 of foam, was determined using the following relation [9]:

$$N_f = \left(\frac{N}{A}\right)^{3/2} \qquad (1)$$

where N is the number of cell in the micrograph and A is the area of the micrograph (cm^2).

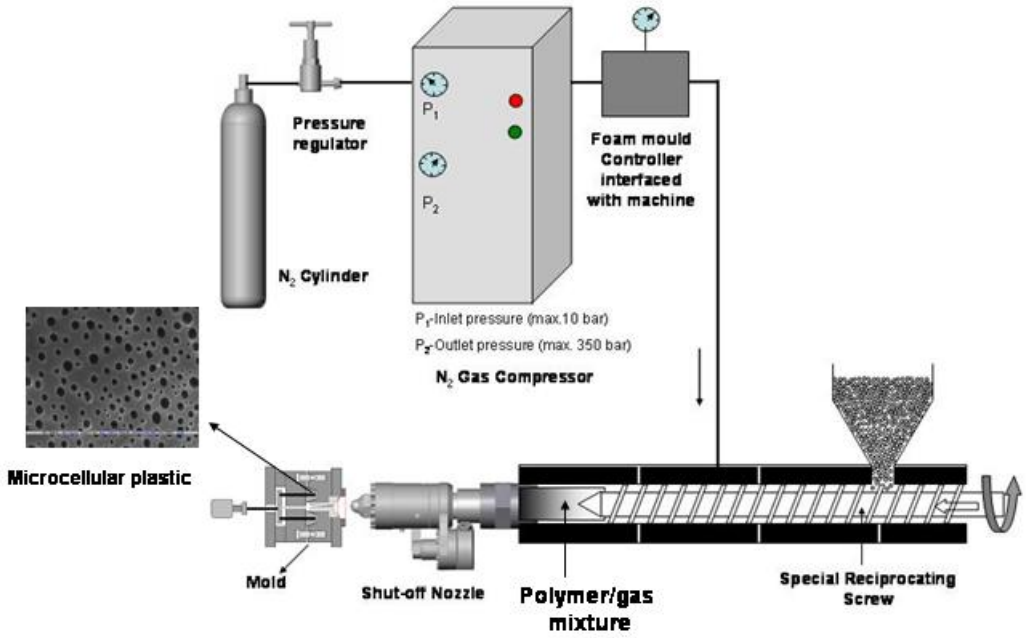


Figure 1: Schematic of microcellular injection molding machine

Table 1: Experimental conditions

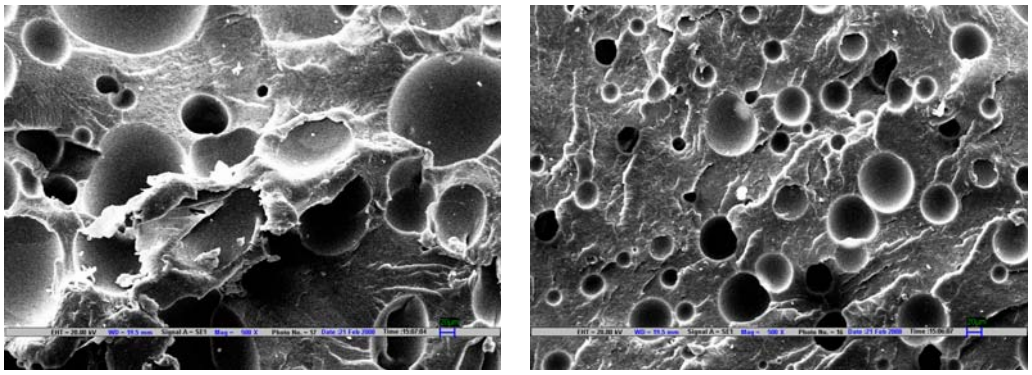
Variable	Condition 1	Condition 2
Melt temperature	210 ^{0}C	210 ^{0}C
Injection pressure	40 MPa	40 MPa
Injection speed	25 cm^3/s	50 cm^3/s
Shot size	50 cm^3	40 cm^3
Cooling time	40 s	40 s
Gas injection time	3 s	3 s
Gas volume	50% of metering volume	50% metering volume

3. RESULTS AND DISCUSSION

3.1 Effect of processing parameters on cell morphology

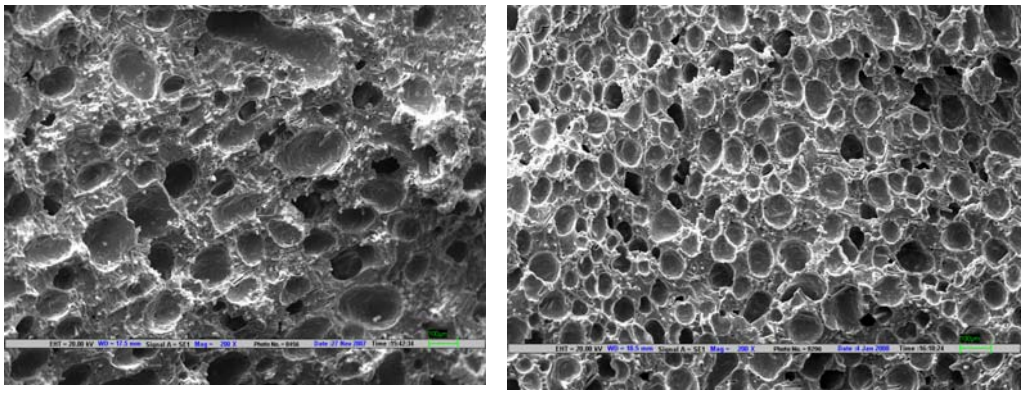
The cell morphology of foamed composite was studied at two different process conditions for molded samples. Mainly, the effect of injection speed and shot size on cell size and cell distribution was focused in this study. Figures 2 and 3 are SEM micrographs of foamed composite samples. The well-defined and uniform cellular structures were observed from the micrographs for both the molding conditions, which

indicate that microcellular thermoplastic composites can be successfully developed by microcellular injection molding system. From the micrographs, one can see that the average cell size decreased with increasing injection speed. When the injection speed was increased, the rate of pressure drop across the nozzle greatly increases, which leads to change in solubility of gas concentration in polymer/gas solution. The mean cell diameter and cell density for molded composite samples at condition 1 was calculated to be around 100 μm and 0.24×10^6 cells/cm^3. For condition 2, the mean cell diameter and cell density was calculated to be approximately 60 μm and 1.3×10^6 cells/cm^3. A large size and non-uniform cells result from a low injection speed due to slow rate of nucleation i.e. heterogeneous nucleation. Hence, the pressure drop rate should be sufficiently large to achieve a high rate cell nucleation that leads to uniformly spaced microscopic cells. Based on the results, it can be presumed that shot size is also important processing parameter which affects cell size and cell density. Higher shot size tends to take longer solidification time and provide additional time for cells to grow. This could be one of the reason for reducing the cell density and large cell size.



a) b)

Figure 2: SEM micrograph of microcellular PP: (a) condition 1, (b) Condition 2



a) b)

Figure 3: SEM micrograph of microcellular PP/30%carbon fiber composite: (a) condition 1, (b) Condition 2

3.2 Tensile properties of foamed PP/carbon fiber composite

The engineering stress-strain curves of solid and foamed PP/30%carbon fiber composite samples obtained from tensile test are shown in Figure 4. From the stress-strain curve, it is clearly observed that foamed samples show a lower strain and stress value than the

solid counterparts. The tensile properties of solid and foam molded composite samples in two different molding conditions are summarized in Table 2. Foaming significantly reduces the ultimate strength, maximum strain and toughness of the samples. However, by increasing an injection speed, the tensile strength and toughness increases considerably due to decrease in cell size and increase in cell density. It is conjectured that further reduction of micron size bubbles, significant improvements can be achieved in both the tensile strength as well as in toughness. The results validate that increase in injection speed improves the maximum strain at break of foamed samples [13]. At a low injection speed, the cell sizes were large and non-uniform in structure like voids due to a slow rate of nucleation. Hence, the foamed samples behaved like brittle materials.

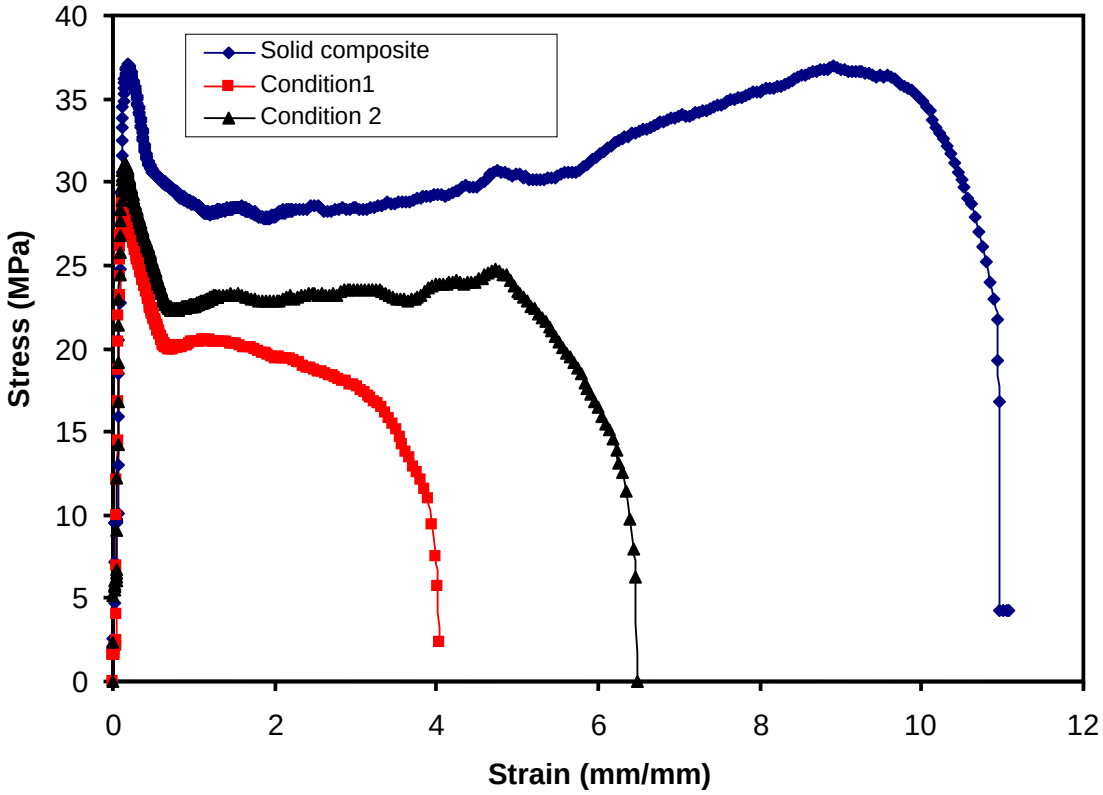


Figure 4: Engineering stress-strain curve for solid and foamed PP/30% carbon fiber composite

Table 2 : Tensile properties of solid and foamed PP/30% carbon fiber composite molded in two different molding conditions

Materials	Tensile Strength (MPa)	Maximum strain (mm/mm)	Toughness (MPa)
Solid PP/30% carbon fiber	39.57	10.75	353.67
Foamed composite at condition 1	23.19	5.99	128.30
Foamed Composite at condition 2	27.28	7.17	152.19

4. CONCLUSIONS

Microcellular foaming have been achieved in PP/30% carbon fiber composite through a microcellular injection molding system. Effect of processing conditions on the cell morphology and tensile properties of foamed PP/30% carbon fiber composite were studied. There was a significant improvement in cell structure and foaming and also reduction of cell size with increasing injection speed and decreasing shot size. Higher injection speed tends to increase the pressure drop rate at the nozzle, which is found to be the most important parameter in microcellular foaming. Foaming reduces the tensile strength, maximum strain at break and toughness of PP/carbon fiber composites, however due to processing conditions significant improvements in the tensile strength and toughness can be achieved in PP/carbon fiber composites resulting into higher specific strength and specific stiffness materials.

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