CHAPTER 1

INTRODUCTION

1.1 Foreword

The consumption of plastic foams in recent technology continues to grow rapidly throughout the world. The reasons for this growth include the lightweight, excellent strength/weight ratio, superior insulating abilities, energy absorbing performance and compatible feature to other materials. Foam can be prepared from any polymer, by introducing a gas within a polymer matrix. Selection of polymers for industrial foam applications depends on their properties such as cellular morphology, and resistance to the mechanical performance under the various conditions. Polymeric foams comprise a wide variety of materials, with a wide range of densities. They are usually classified as flexible, semi-flexible, or rigid, and can be fabricated to any desired density and degree of hardness. They can be manufactured by a variety of processes, depending on the application. Typical processing methods include extrusion, injection molding, blow molding, rotational molding, thermoforming, etc [1].

Amongst the lowest densities for all plastics, polypropylene (PP) has good characteristics and properties; therefore it has a huge variety of applications such as vehicle and mechanical engineering, electrical engineering, medicine, and packaging [2]. PP is a polymer of the modern world. It was discovered as late as in 1954 by

Professor Giulio Natta. Till this time polyethylene was already discovered and the catalysts that were used in the polyethylene industry were used by the professor to propylene gas to produce PP. The commercial production of PP initiated in the year 1957 as it can also be produced at room temperature and low pressure. For his work, Natta along with Karl Ziegler, the discoverer of the catalysts, got the Nobel Prize in the year 1963. With its production, it was readily accepted by various industries as it is economical and possesses exclusive physical properties. With time and the introduction of new technologies of production, improvements were done relating to the types of catalysts used and controlling the structure of the product. The world production of the polymer crossed the 14 million tons mark. PP is a versatile polymer as it can be used in a vast number of applications and today the polymer has become non-substitutable [3]. It has been found that the world PP market is growing 3% a year, with global consumption expected to rise to 32.9 billion tons by 2006. The largest manufacturer of PP is USA, where remains about 7.8 million tons in each year. The largest consuming region of PP is found in Asia, accounting for 39% of world consumption [4]. It means that PP went through such a dynamic industrial development that it is today one of the most widely consumed polymeric materials, and still has a bright future. Such tremendous growth is due to the outstanding combination of cost performance, excellent physical properties, strong and continuous expansion of process versatility, environmental friendly processes and materials during manufacturing, and use and recycling stages [5]. Since the use of this polymer is raised in mass, there is a challenge for several manufacturers to sought ways to reduce material cost and to improve processing efficiency for their products. In response to industrial needs, the idea of cellular plastic or plastic foam production is conducted in order to reduce the amount of PP on processing while retain the mechanical properties of any specific product.

Although the outstanding functional characteristics and low materials cost, PP foams have been considered as a substitute for other thermoplastic foams in industrial applications. However, the limitations for PP foam production are due to the weak melt strength and melt elasticity, especially when it is foamed by the continuous processes [6]. Therefore, PP has not been used much in the foaming industry. Because of this inferiority, the cell walls between the cells may not be strong enough to bear the extensional force and may rupture very easily during the foaming. When cells coalescence, not only are the cell density and cell size uniformity deteriorated, but also the volume expansion ratio is greatly sacrifice due to accelerated gas loss through opened cell walls [7]. Therefore, it is very difficult to obtain a low-density foam with a desired expansion ratio.

Moreover, PP is classified as a member of semicrystalline polyolefin family, and a high crystalline fraction of this polymer results in the difficulty of foaming using a solid-state batch foaming process, unlike the amorphous thermoplastics [8-9]. The morphology of semicrystalline polymers has a great influence on the solubility and diffusivity of the blowing agent as well as the cellular structure of plastic foams [10]. In the foaming processing, the crystalline structure and the stiffness of polymer matrix play a critical role. There is a scientific report which shows a strong function of the crystallinity of semicrystalline polymers on the solubility and diffusivity reduction of the blowing agent as the increment of crystalline fraction due to the decreasing of the cooling rate [9]. However, the effect of crystallinity of polymer can be overcome by reducing the shear viscosity of the polymer melt or enhancement of the amorphous region in the polymer matrix. When a blowing gas such as carbon dioxide (CO_2) is dissolved into a polymer, the shear viscosity is reduced, the glass transition temperature is lowered, crystallization rate is changed, and surface tension is also reduced. This is because the polymer is swollen and the free volume of the polymer is modified by the plasticization of CO_2 and the diffusion coefficient becomes larger as the dissolved CO_2 concentration is increased [11]. But in the continuous process for production of a desired volume expansion ratio foam, the change in the free volume due to the concentration of CO_2 is a minor factor compared with the effect of processing temperature at the exiting die, namely when the experiment is done at low temperature then the crystallization of PP foams is a critical factor that affects the maximum expansion ratio. The polymer melt solidifies at the moment of crystallization during cooling. Therefore, in the PP foam processing, the foam structure freezes at the crystallization temperature during the foaming process. In order to achieve the maximum volume expansion ratio on PP, the crystallization should not occur before all the dissolved gas diffuses into the nucleated cells [12]. Furthermore, since the foamed products are made from linear PP, the process usually has a limited expansion capability due to its weak melt strength but using the modified materials or new resin developments can facilitate the foamability improvement [13].

Therefore, it is the challenge to produce the desired foams with the semicrystalline polymer such as PP using the different foaming methods. In this research, the effect of crystallinity of the polymer on the cellular morphology and its properties is investigated through a solid-state batch foaming process and it is expected to generate the microcellular structure into the polymer matrix by our research approach.

A tandem extrusion system; the continuous foaming was also studied in this research, was used to fabricate the low-density and fine-celled PP foams. The relationship between the processing conditions and the characteristics and properties of produced PP foams has been discussed as the following chapters.

1.2 Objectives of the thesis

The experiment of this study were divided into 2 parts; 1) the solid-state batch foaming process experiment and 2) the continuous foaming process experiment, in order to fabricate the microcellular foams and low-density, fine-celled foams with semicrystalline PPs, respectively.

The first foaming process was conducted to improve the understanding of microcellular PP foam manufacturing and the influence of processing conditions on the foaming behavior, cellular morphology, and the properties of the final foam products. An appropriate solvent which has a solubility parameter comparable to that of the polymer material was used to overcome the difficulty of foaming of semicrystalline PP sheets with the different thicknesses (i.e., 0.5 mm, 1.0 mm, and 1.5 mm). Moreover, the designed equipment in the experiment was built and developed to use for the solid-state foam production. The experimental results were expected to lead the innovation of microcellular PP foam production and the understanding of the foam morphology and their properties.

In addition, a tandem extrusion foaming system was selected to use as a continuous process for manufacture of the low-density and fine-celled PP foams. The high-melt-strength (HMS) PP resin was also conducted into the system to bear the extensional force and protect the undesirable cell nucleation and also the advantage of this polymer was the expectation to promote the desired volume expansion ratio in PP foams due to its molecular structure. In addition, this HMS PP resin is recyclable; therefore the final foams can be easily reprocessed compared to the crosslinked PP foams [13]. Although, the crosslinked polymer matrix can contribute the strain hardening into the matrix but the crosslinked foams are not recyclable [14]. Therefore, the most feasible and easiest method for promoting large expansion by increasing the melt strength of PP foams is to use branched PP materials. Utilizing a long-chain branched PP with high melt strength and high melt extensibility was found to prevent cell coalescence much more effectively than using a linear one [15]. This result in HMS branched PP material is regarded a good candidate for low-density, fine-celled foaming. Furthermore, to achieve the low density foams with fine cellular structure, the selection of optimum die geometry is very crucial for generate the suitable pressure and pressure drop rate at the exiting die [16]. Thereby, the effect of different die geometries on the foaming behavior of HMS PP resin was also investigated to obtain the right filament die for extruded PP foam production in the research. In general, the high processing pressure and pressure drop rate are required to produce a large cell density and they are expected to be lowered by using a nucleating agent thus an undesired foam structure (i.e., cell coalescence) can be overcome by adding some nucleating agent. Usually, nucleating agents are finely powdered to serve as nucleation sites and play an important role in determining the cellular structure of thermoplastic foams [17]. In the studied PP foaming process, the addition of nucleating agent is essential in achieving a good nuclei density and talc powder was selected to use as a nucleating agent in the extrusion foaming process experiment. Because of the environmental concerns, all studied foaming process used an environmentally benign CO_2 as a blowing agent to promote PP foams. The cell nucleation and expansion behaviors of extruded PP foams with various contents of CO_2 and talc were studied. The effects of processing conditions on the final foam morphologies had also been examined through the experiments.

1.3 Outline of the thesis

Chapter 2 presents a literature survey and the background on polymer science and plastic foams. The part of polymer science will describe about the general information of polymeric structure (especially the crystalline phase in semicrystalline polymer matrix), thermal and mechanical properties, and the swelling behavior of polymer. The fundamental of foam production and the conceptual design of the studied foaming processes (solid-state batch foaming process and extrusion foaming process) are also described in this chapter. These include the built-up gas saturation equipment for the batch foaming process, the tandem extruder foaming system, and all details of any sections which assembled to the system. Moreover, the theoretical background and strategies of microcellular or low-density, fine-celled PP foam production will be presented. In order to understand the influence of the processing conditions on the foam properties and the impact of cellular morphology on the mechanical properties, the characterization methods will be informed in this chapter as well.

Chapter 3 presents the previous researches which concerned about the making of microcellular foams using the solid-state foaming process. These include the research approaches for batch-foaming process with the semicrystalline polymers by crystallinity modification. In this experiment, the fundamental of solvent plasticization is applied to generate the microcellular structure and facilitate the ease of cell nucleation in the PP matrix with the different thicknesses. The effects of processing conditions, polymer sheet thickness, and solvent performance on the cellular morphology and the mechanical properties will be discussed in this chapter.

Chapter 4 describes the effective strategies and the fundamental mechanism governing the cell growth and volume expansion ratio of extruded PP foams. The basic background on the die design is informed and the investigation of the die geometries (die diameter and length) will be performed in order to select an optimum filament die for contribution the optimum pressure and the pressure drop rate in the system. The production of low-density, fine-celled PP foams and the experimental results are presented to verify the effects of processing parameters such as temperature and pressure at the exiting die, contents of blowing gas and nucleating agent on the final extruded PP foams with a desired volume expansion ratio by utilizing a tandem extrusion foaming process. Moreover, it is expected to see the advantage of using a high-melt-strength PP resin on its foamability through the image analysis of the final cellular characteristics.

Chapter 5 provides the summary and the conclusions of the effective strategies of both foaming processes (microcellular foaming process and low-density, fine-celled PP foam production) based on the experimental results of our research.

Chapter 6 discusses the critical problems based on our experiments and the suggestions and the feasible future work are also presented.