Influence of injection temperatures and fiberglass compositions on mechanical properties of polypropylene

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Abstract. Injection molding process appears to be one of the most suitable mass and cost efficiency manufacturing processes for polymeric parts nowadays due to its high efficiency of large scale production. When down-scaling the products and components, the limits of conventional injection molding process are reached. These constraints had initiated the development of conventional injection molding process into a new era of micro injection molding technology. In this study, fiberglass reinforced polypropylenes (PP) with various glass fiber percentage materials were used. The study start with fabrication of micro tensile specimens at three different injection temperature, 260°C, 270°C and 280°C for different percentage by weight of fiberglass reinforced PP. Then evaluate the effects of various injection temperatures on the tensile properties of micro tensile specimens. Different percentage by weight of fiberglass reinforced PP were tested as well and it was found that 20% fiberglass reinforced PP possessed the greatest percentage increase of tensile strength with increasing temperatures.

1. Introduction
Injection molding (IM) process is one of the conventional manufacturing techniques used widely nowadays due to its high efficiency of large scale production of polymeric parts. In this process, raw plastic materials are melted and formed in a cavity known as mold in order to produce three dimensional parts. Large quantities of small to medium size objects can be produced from low melting point materials through this process. Nowadays, many products that we use are manufactured by this injection molding process. Raw materials normally melted polymer is injected into a mold through injection nozzle and the melted polymer solidifies within a cavity and retains the shape of the mold. After the part has cooled, the mold opens up and the part is ejected.

The development of micro injection molding technology started in the middle of 80s and has become one of the most important technologies to the population nowadays. When down-scaling the products and components, the limits of conventional injection molding process are reached and these constraints had initiated the development of conventional injection molding into a new era of micro injection molding technology. Tosello and Hansen (2010) [1] said that a new micro injection molding machine with a screw extruder and a plunger injection unit has been developed over the last ten years. The main difference between the micro injection molding machine and the conventional macro machine with the conventional reciprocating screw injection system is by separating melt plastification and injection. A small injection plunger of a few millimeters in diameter is used for melt injection to control metering accuracy. This micro injection molding machine consists of the splitting of the four
functions of the reciprocating screw which are plasticisation, metering, locking and injecting into different components.

Chang et al. (2007) [2] presented a concept of external module of micro injection molding system in 2007. This external module equipped with a hot runner plunger module can apply about 30-100 tonnes reciprocating screw hydraulic or fully electric injection molding machines. This external module was designed similar to an injection mold to fit the geometry of the general injection molding machine. This external module could be applied to most reciprocating injection molding machines where a precise metering for micro injection molding can be achieved.

Ultimate tensile strength (UTS) is defined as a stress measured as force per unit area. In another words, it is the maximum stress a material can withstand before breaking when it is being stretched. UTS can be determined by performing tensile test to the samples. Tensile testing, also known as tensile test is most commonly used mechanical test to determine the mechanical characteristics of a material. In tensile testing, a sample is subjected to tension until breaking (Czichos et al. 2006) [3]. In 1997, Ilzhofer et al. [4] developed a micro tensile testing machine in order to investigate the mechanical properties of micro specimens. In 2010, Zridda et al. [5] conducted dynamic high-speed tensile tests on a polypropylene (PP) with a servo-hydraulic tensile machine with an original grip system. The purpose of this study was to investigate the effects of strain rate on mechanical behaviour of polypropylene. Experimental results showed that Young’s modulus increased with strain rate and the surface becomes rougher.

Arabi et al. [6] also conducted an experimental study on investigating effects of specimen shape on residual mechanical properties of polypropylene (PP) fiber self-compacting concrete (SCC) exposed to elevated temperatures from 200°C to 600°C. The experimental results revealed that PP fiber can enhance residual strength of concrete subjected to thermal shock induced by air cooling from high temperatures up to 600°C to room temperature. Al-Maadeed et al. 2014 [7] also conducted a study on polypropylene/fiberglass with concentration on processing, characterization and modelling

It can be summarized that injection molding process plays a vital role in mass production of micro parts nowadays. However, to identify the suitability of micro tensile specimen for micro sizes are challenging issues. The mechanical behaviour of materials is described by their deformation and fracture characteristics under applied stresses. Tensile test is the most commonly used mechanical testing method to investigate the mechanical characteristics of micro tensile specimens. In my study, tensile test is performed in order to determine the tensile behaviour of the micro tensile specimens of fiberglass reinforced polypropylene with various glass fiber percentages.

2. Experimental Design

This section explains the material, mold, machine and testing method used in this work. This was done to evaluate performance of micro tensile specimens by conducting tensile test. Experimental details such as equipment/instruments, materials and setting of parameters are further explained in the following sections.

2.1. Fiberglass Reinforced Polypropylene (PP)

Glass fiber or more commonly known as fiberglass are made from numerous fine fibers of glass and normally lightweight. Fiberglass reinforced PP is the modified plastics with good mechanical properties, good resistance towards heat and chemical. Fiberglass reinforced PP is normally used for structure and function parts as well as industry of centrifuge and axial fans for its strong resistance against heat and chemical. The Fiberglass reinforced PP used in this study was supply by Ferro Corporation, USA (http://www.ferro.com/). Percentage glass fiber use in the experiment was 10%, 20%, 25% and 30%. The properties of Fiberglass Reinforced Polypropylene (PP) are shown in table 1
Table 1. Properties of Fiberglass Reinforced Polypropylene (PP)

| Properties | 10% Fiberglass-Reinforced Polypropylene | 20% Fiberglass-Reinforced Polypropylene | 25% Fiberglass-Reinforced Polypropylene | 30% Fiberglass-Reinforced Polypropylene |
|------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| Physical Properties | Density, g/cc | 0.930 - 1.45 | 0.970 - 1.46 | 1.00 - 1.51 | 1.09 - 1.56 |
| | Melt Flow, g/10 min | 1.00 - 15.0 | 0.500 - 34.0 | 0.400 - 25.0 | 1.00 - 25.0 |
| Mechanical Properties | Hardness, Rockwell R | 76.0 - 110 | 53.0 - 105 | 57.0 - 107 | 58.0 - 72.0 |
| | Tensile Strength, Ultimate, MPa | 20.0 - 55.8 | 22.0 - 115 | 6.89 - 130 | 30.0 - 150 |
| | Elongation at Break, % | 1.50 - 34.0 | 1.00 - 100 | 0.900 - 30.0 | 1.00 - 10.0 |
| | Modulus of Elasticity, GPa | 1.70 - 5.17 | 1.03 - 6.55 | 2.25 - 15.0 | 3.59 - 12.4 |
| | Izod Impact, Notched, J/cm | 0.267 - 3.74 | 0.135 - 4.50 | 0.320 - 3.26 | 0.427 - 7.52 |
| Thermal Properties | Thermal Conductivity, W/m-K | 0.159 - 0.187 | 0.288 - 1.21 | 0.270 - 0.331 | 0.346 - 0.360 |
| Processing Properties | Melt Temperature, °C | 180 - 260 | 145 - 302 | 145 - 302 | 190 - 290 |
| | Mold Temperature, °C | 20.0 - 80.0 | 18.0 - 100 | 4.00 - 100 | 15.0 - 100 |

2.2. Mold for Microtensile Specimen

The mold cavity used will be fixed and the same dimensions as the test specimen by following the standard of the microtensile specimen, D1708-02a (Standard Test Method for Tensile Properties of Plastics By Use of Microtensile Specimens) as shown in figure 1. Figure 2 shows the mold used to produce microtensile specimen.

![Figure 1. The dimensions of microtensile specimen in mm](image-url)
2.3. Injection Molding Apparatus
The test specimens produced in this study is produced by a vertical injection molding machine as shown in figure 3 (Azuddin et. al, 2015) [8]. The machine use pneumatic system to generate plunger injection motion. The machine also include temperature controller to control various melt temperature. Figure 3 shows the vertical injection molding machine.

2.4. Procedure to Prepare Micro Tensile Specimens
1) Start with injection molding process. Heat up the hopper of vertical injection molding machine.
2) Put materials into heated hopper and allow for melting.
3) Inject pressure to push the plunger down in order to inject molten material into micro tensile cavity.
4) Produce five samples or more of micro tensile specimens for three different injection temperatures.
5) Repeat steps 1 - 4 with different percentage by weight of glass reinforced PP.
2.5. Evaluation of Micro tensile specimens

Tensile test is conducted to evaluate the performance of micro tensile specimens. Tensile strength is the output parameter of experiments to evaluate the performance of micro tensile specimens. The INSTRON 3369 universal testing machine was used to perform tensile test and measure the tensile strength. Five micro tensile samples named A, B, C, D and E was tested.

3. Result and Discussion

3.1. Tensile strength of 10% fiberglass reinforced PP

Figure 4 shows a 10% fiberglass reinforced PP strength at various injection temperatures. At injection temperature of 260°C, highest tensile stress value recorded is 55.55MPa for sample B and lowest value is 51.83MPa. Tensile strength at injection temperature of 270°C shows unstable tensile behaviour where it fluctuates in the range from 52MPa to 55MPa. At 280°C, tensile strength values show less fluctuation of tensile behaviour compared to 260°C and 270°C.

![Graph of tensile strength for 10% fiberglass reinforced PP](image)

**Figure 4.** Graph of tensile strength for 10% fiberglass reinforced PP
3.2. Tensile strength of 20% fiberglass reinforced PP

A tensile performance of 20% fiberglass reinforced PP is shown in figure 5. 20% fiberglass reinforced PP shows uniform tensile behaviour at three different injection temperatures. At injection temperature of 260°C, the tensile strength falls in the range from 57MPa to 65MPa. When injection temperature rises to 270°C, the range gets higher where tensile strength falls between 72MPa and 76MPa. There is a drastic increase in tensile strength. For injection temperature at 280°C, the range falls the same as 270°C.

![Figure 5. Graph of tensile strength for 20% fiberglass reinforced PP](image)

3.3. Tensile strength of 25% fiberglass reinforced PP

Figure 6 shows a 25% fiberglass reinforced PP strength at various injection temperatures. For 25% fiberglass reinforced PP, sample A shows the lowest tensile strength 56.16MPa at injection temperature 260°C. At 270°C, tensile strength falls in the range from 59MPa to 62MPa. A less fluctuation of behaviour at 270°C. When injection temperature rises to 280°C, tensile strength increases with the highest value recorded 63.83MPa for sample E.

![Figure 6. Graph of tensile strength for 25% fiberglass reinforced PP](image)
3.4. Tensile strength of 30% fiberglass reinforced PP

A tensile performance of 30% fiberglass reinforced PP is shown in figure 7. At 260°C, 30% fiberglass reinforced PP shows decrease in tensile strength from sample A to C and increases slightly for sample D before decreasing to 45.88MPa. When injection temperature increases to 270°C, tensile strength shows fluctuation and falls in the range from 49MPa to 52MPa. At 280°C, it shows uniform behaviour at the range from 51MPa to 52MPa.

![Graph of tensile strength for 30% fiberglass reinforced PP](image)

Figure 7. Graph of tensile strength for 30% fiberglass reinforced PP

3.5. Comparison between all Fiberglass reinforced PP

Figure 10 show the comparison of tensile strength of various percentage Fiberglass reinforced PP with melt temperature. Average tensile strength for 10% fiberglass reinforced PP is 53.13MPa at injection temperature of 260°C. When at 270°C, tensile strength increases to 53.35MPa. For injection temperature of 280°C, the tensile strength recorded is 53.60MPa. Overall, 10% fiberglass reinforced PP shows uniform increase in tensile strength with temperatures. Average tensile strength of 20% fiberglass reinforced PP at 260°C is 60.95MPa. When injection temperature rises to 270°C, there is a drastic increase in tensile strength. Tensile strength recorded at 270°C is 74.20MPa, an increase of 22.15% in tensile strength. At injection temperatures of 280°C, tensile strength increases slightly to 74.45MPa. 25% fiberglass reinforced PP shows an average tensile strength of 58.88MPa at 260°C. Then, tensile strength increases to 60.33MPa when injection temperature is raised to 270°C. An increase of 2.46% in tensile strength is recorded. At injection temperature of 280°C, tensile strength shows 62.44MPa which is an increase of 3.50% in tensile strength. Average tensile strength of 30% fiberglass reinforced PP at 260°C is 46.66571MPa. When at 270°C, tensile strength increases to 49.90MPa. An increase of 6.95% in tensile strength is recorded. For injection temperature at 280°C, tensile strength increases 3.23% to 51.52MPa.
4. Conclusion

In this study, fiberglass reinforced PP with various fiberglass percentage are evaluated in terms of tensile strength. The following conclusions are made based on the analysis of the tensile tests:

1) Tensile strength increased with increasing temperatures.
2) Tensile tests for different percentage by weight of fiberglass reinforced PP showed increase in tensile strength.
3) Tensile strength of 10% fiberglass reinforced PP increased from 53.13MPa to 53.60MPa, an increase of 0.87% when injection temperature increased to 280°C.
4) 20% fiberglass reinforced PP showed greatest increase of 22.15% in tensile strength from 60.95MPa to 74.45MPa when injection temperature raised from 260°C to 280°C.
5) An increase of 6.05% in tensile strength was found in 25% fiberglass reinforced PP when temperature increased to 280°C. A uniform increase in tensile strength from 58.88669MPa (260°C) to 60.33 (270°C) and lastly 62.44MPa at 280°C.
6) 30% fiberglass reinforced PP showed uniform increase in tensile strength from 46.66MPa at 260°C to 49.90MPa at 270°C and then 51.52MPa at 280°C. It was found that a total of 10.41% increase in tensile strength.

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