Injection process parameter analysis of metal injection molding for green part orthopedic implants

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Abstract. Based on Permenkes RI No. 86 of 2013 the need for orthopedic implants in the jaw / face is increasing. In orthopedics, implants are devices that are placed in place of bone to support fractures. Referring to the statement, Balai Besar Logam dan Mesin (BBLM) conducted research on the manufacture of orthopedic implant products for the face using Metal Injection Molding (MIM) technology. MIM is a combination of the characteristics of Powder Metallurgy and Plastic Injection Molding for the production of complex metal components. The injection process is a major factor that needs to be considered to prevent injection defects including incomplete fill defects in order to proceed to the post-molding process. Based on this, it is necessary to simulate and analyze process parameters to find the maximum process parameters in order to prevent incomplete fill defects. The analysis was carried out using injection molding simulation software, namely Sigmasoft, to the previously obtained design, with a variation setting of the filling temperature value of 170°C-190°C and filling time of 0.5s-2.5s. Variations in values are processed to obtain a combination of parameter settings analyzed. The simulation software generates filling pressure values and filling percentages in the mold cavity. Demonstrate optimal parameters for green part orthopedic implants with Catamold 316L feedstock. The optimal injection operating parameters are at a melting temperature of 180°C, filling time of 1s and filling pressure of 700 bar.

Keywords: metal injection molding, incomplete fill, sigmasoft, parameter analysis

1. Introduction
Based on the vision and mission of national industrial development, Indonesia will become a strong medical equipment industrial country by 2035. To support this, the Minister of Health issued Permenkes No. 86 of 2013 concerning the Roadmap for the Medical Device Industry which is prepared based on priority needs, the ability of existing production facilities and available natural resources as shown in Figure 1.

Bone fracture is an occurrence that is often experienced by people, one of which is a fracture in the face and jawbone / skull. Referring to the road map for the medical device industry, orthopedic implants are one of the priority medical devices to be developed until 2035. So that the
need for orthopedic implants in the jaw / face part increases. In addition, the relatively expensive price makes it a driving factor for producing cheaper implants so that they are more affordable to the public. Implant is a medical device to replace the construction and function of a biological part. In orthopedics, implants are devices that are placed in place of bone to support fractures.

![Figure 1. Roadmap for the Medical Device Industry](image1.png)

Referring to the above statement, Balai Besar Logam dan Mesin (BBLM) conducted research on the manufacture of orthopedic implant products for the face using Metal Injection Molding (MIM) technology. The raw material used for orthopedic implant products is Catamold 316L. The shape of orthopedic implants for the facial and jaw bones can be seen in Figure 2. Metal Injection Molding combines the characteristics of Powder Metallurgy and Plastic Injection Molding for the production of small metal parts with complex shapes with outstanding mechanical properties. Broadly speaking, the production process for this MIM component consists of the preparation of feedstock, printing, debinding, and sintering.

![Figure 2. Orthopedic Implants for Facial and Jaw Bones](image2.png)

The injection molding process at MIM is strongly influenced by the parameters of filling time, packing pressure, cooling time, holding time, melt temperature and mold temperature. Based on this statement, it can be said that the injection process is a major factor that needs to be considered to
prevent injection defects including incomplete fill defects in order to proceed to the post-molding process. From the description above, this study conducted an analysis of operating parameters to find the maximum operating parameters in order to prevent incomplete fill defects. The analysis used injection molding simulation software, namely Sigmasoft, to the previously obtained designs, with various settings for the injection pressure and injection temperature values. These value variations will be processed to obtain a combination of parameter setting values under study. The results of the simulation are then selected parameters which are considered to produce the most optimum parameter values.

2. Research method
The research method can be described in the flow chart as shown in the Figure 3.

![Flow Chart of Research Methods](image)

**Figure 3. Flow Chart of Research Methods**

3. Research Result

3.1 Simulation Results
The result is a simulation image that is visualized in 3 dimensions. From 15 analysis data, one analysis data will be displayed from the input data 1 second filling time and 190°C filling temperature for feedstock material. The simulation results generated from the Sigmasoft software are as follows:

1. **Filling**
   From the data input, Filling time of 1 second, the filling temperature of the feedstock material is 190°C and the molding temperature is 25°C and it is obtained 100% filling. The filling simulation shows the flow of the feedstock against the filling time of the print cavity. Filling simulation produces 3D visualization as shown in Figure 4.
2. **Temperature**

Temperature simulation shows the initial flow temperature of the feedstock when filling the print cavity. As shown in Figure 5, the temperature results are visualized using various colors to show the lowest temperature region indicated in blue and the highest temperature indicated in red.

3. **Pressure**

Pressure simulation shows the pressure in the feedstock during the filling process. Pressure is visualized using various colors to show the lowest pressure area indicated in blue and the highest pressure area indicated in red. As shown in Figure 6, the filling pressure of small implant products is greater than that of large implants.
3.2 Results of process parameters study

Making green parts for implant products using an injection molding machine requires process parameters for the injection molding machine. The process parameters are divided into three, namely:

- **Fixed parameters:**
  - Mold Temperature: 25°C
  - Packing pressure: 80% of filling pressure
  - Holding time: 2 s
  - Cooling time: 20 s

- **Free parameters:**
  - Melt Temperature: 170°C - 190°C
  - Filling time: 1 s - 2.5 s

- **Bound parameters:**
  - Filling pressure
  - Percentage of filling

![Figure 7. Inlet pressure at 170 °C filling temperature and 0.5s filling time](image)

Input parameter experiments on Sigmasoft software were carried out at melting temperatures of 170°C, 180°C, and 190°C with variations in mold filling time, namely 0.5s, 1 s, 1.5 s, and 2.5s. Of the three process parameters, fixed parameters and free parameters were input into the simulation software and 15 experiments were carried out which resulted in bound parameters in the form of graphs and 3D visualization. The results of bound parameters in graphic form can be seen in Figure 7. The results of bound parameters in the form of 3D visualization will be discussed in the next section. The simulation results are then loaded into the table. Experiments on input parameters on Sigmasoft software were carried out at melting temperatures of 170°C, 180°C, and 190°C with variations in mold filling time, namely 0.5s, 1 s, 1.5 s, and 2.5s. Of the three process parameters, fixed parameters and free parameters were input into the simulation software and 15 experiments were carried out which resulted in bound parameters in the form of graphs and 3D visualization. The results of bound parameters in graphic form can be
seen in Figure 7. The results of bound parameters in the form of 3D visualization will be discussed in the next section. The simulation results are then loaded into the table.

Table 1 Parameter data of simulation results at a melt temperature of 170 °C

| No. | Filling time | Filling pressure | Percentage of filling |
|-----|--------------|------------------|-----------------------|
| 1   | 0.5 s        | 975 bar          | 100%                  |
| 2   | 1 s          | 825 bar          | 100%                  |
| 3   | 1.5 s        | 900 bar          | 92.60%                |
| 4   | 2 s          | 1424 bar         | 88.33%                |
| 5   | 2.5 s        | 1284 bar         | 74.22%                |

Table 2. Parameter data of simulation results at a melt temperature of 180 °C

| No. | Filling time | Filling pressure | Percentage of filling |
|-----|--------------|------------------|-----------------------|
| 1   | 0.5 s        | 850 bar          | 100%                  |
| 2   | 1 s          | 700 bar          | 100%                  |
| 3   | 1.5 s        | 728 bar          | 96.23%                |
| 4   | 2 s          | 861 bar          | 90.83%                |
| 5   | 2.5 s        | 738 bar          | 87.76%                |

Table 3. Parameter data of simulation results at a melt temperature of 190 °C

| No. | Filling time | Filling pressure | Percentage of filling |
|-----|--------------|------------------|-----------------------|
| 1   | 0.5 s        | 775 bar          | 100%                  |
| 2   | 1 s          | 637.5 bar        | 100%                  |
| 3   | 1.5 s        | 613 bar          | 98.61%                |
| 4   | 2 s          | 671 bar          | 92.72%                |
| 5   | 2.5 s        | 547 bar          | 88.75%                |

4. Discussion

4.1 Filling pressure parameters
The simulation results then made a graph of the filling pressure parameter that is sought against the filling time and filling temperature. Figure 8 shows the relationship between filling pressure to filling temperature. Temperature 170°C, 180°C, and 190°C, with a filling time of 0.5s will result in filling pressures of 775bar, 850bar and 975bar, respectively. This is because the faster filling time will require greater pressure. When compared with 1s filling time which requires less filling pressure, which is worth 825bar, 700bar and 637.5bar. Meanwhile, during the 1.5s and 2s filling times on the graph, the pressure increased, because the feedstock was frozen more, causing the filling pressure to increase. At 2.5s Filling time the simulation does not reach 2.5s time but stops at 1.84s time. This is because more of the feedstock is frozen in the mold cavity. The 2.5s filling pressure graph in the Sigmasoft simulation can be seen in Figure 9.
Figure 8. Graph of filling pressure versus filling time and filling temperature test

Figure 9. Graph of 2.5s filling pressure at Sigmasoft (1) 170°C, (2) 180°C and (3) 190°C

4.2 Filling Percentage Parameters
Figure 10 shows the relationship between filling percentage and filling time and filling temperature. The percentage of filling can reach 100% at temperatures of 170°C, 180°C, and 190°C, with filling times of 0.5s and 1s. This is because the fast filling times reduce the freezing of the feedstock before the print cavity is fully filled. If the feedstock freezes before the print cavity is fully filled it will result in an incomplete fill as in the experiment at temperatures of 170°C, 180°C, and 190°C with filling times of 1.5s, 2s and 2.5s.
4.3 Optimum parameter analysis

Based on the results of the injection process parameter analysis at Sigmasoft, it is known that there is an effect of changes in the value of the variable value of filling time and melting temperature on the selected dependent parameter. The variable values of filling time and melting temperature of feedstock material were analyzed to produce values for filling pressure and filling percentage. Figure 8 shows the graph of changes in filling pressure on filling temperature and filling time. The filling pressure is the pressure applied to the injection screw when the feedstock material is pushed into the mold. This injection pressure requires pump pressure to achieve injection. The heating temperature of the material affects the given injection pressure. The lower the temperature of the filling material used, the greater the filling pressure required to push the feedstock material into the mold cavity and vice versa. Figure 10 shows a graph of the change in the percentage of filling against filling temperature and filling time. The percentage of filling is the percentage of feedstock material that enters the print cavity. Time of filling material affects the change in filling percentage.

The longer the time the filling material is used, the lower the percentage of filling and vice versa. Filling time that is too long will inhibit the rate of melting of the feedstock material because the melt will freeze before the print cavity is fully filled and vice versa. Based on the explanation of the value of filling pressure and the percentage of filling on the value of filling time and filling temperature. The optimum value of the parameters analyzed for the 316L feedstock material is 180°C filling temperature, 1s filling time and 700bar filling pressure. This parameter was chosen to produce a balanced filling pressure, namely not too big and not too small. Filling pressure greatly affects power usage and electricity costs. The filling time was chosen because it resulted in 100% filling percentage at the not too long filling time. Filling time will also have an impact on increasing production costs if the filling time is used longer.

4.4 Testing the optimum parameters using software

Based on the results of the optimum process parameters for MIM injection with a filling temperature of 180°C, filling time of 1s and filling pressure of 700bar, a simulation was performed to see the percentage of filling and possible defects. None of the parameters are set automatically, unlike the parameter analysis experiment which is automatically set on the filling pressure. The optimum parameter analysis results in Sigmasoft software resulted in 100% filling percentage as shown in Figure 11.
5. Conclusions
The simulation results show that the tendency to be too low for the injection temperature value will cause product defects in the form of incomplete fill. Meanwhile, if the injection time is too fast, it will require a large injection pressure to fill the entire molding cavity and at a longer injection time it will cause incomplete fill defects because the liquid feedstock freezes more. The optimum parameter settings for the implant product injection process are at 700bar injection pressure, 180°C injection temperature, and 1s injection time. The results of the analysis show that these parameters can reach 100% filling in the print cavity.

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