METAL INJECTION MOULDING PROCESS SIMULATION FOR ORTHODONTIC BRACKET APPLICATION

SIMULASI PROSES *METAL INJECTION MOULDING* DALAM APLIKASI *BRAKET ORTODONTIK*

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Diterima : 4 Juli 2017 Direvisi : 26 Juli 2017 Disetujui : 9 Agustus 2017

ABSTRAK

Proses Metal Injection Moulding (MIM) merupakan salah satu proses yang efektif untuk pembuatan produk logam yang memiliki bentuk yang rumit dan skala produksi massal. Proses MIM telah digunakan pada banyak aplikasi seperti produk rumah tangga, otomotif, biomedikal dan lain-lain. Dalam penelitian ini, braket ortodontik dibuat melalui proses MIM. Sebelum proses manufaktur, simulasi injeksi dilakukan dengan menggunakan *software* komersial Sigmasoft untuk mengevaluasi desain dan optimasi parameter proses. Beberapa parameter proses dimasukkan ke dalam simulasi untuk mendapatkan kondisi proses yang optimum, antara lain temperatur injeksi,temperatur *mold,* waktu proses, dan tekanan selama proses injeksi. Dalam simulasi ini, temperatur injeksi 190 °C dan temperatur *mold* divariasikan 90-150 °C dan waktu pengisian dari 0,5-3 detik. Hasil simulasi menunjukkan temperatur *mold* optimum pada 90 °C dan *feedstock* masih bisa mengisi rongga dengan waktu pengisian 2,5 detik. Dari hasil simulasi aliran menunjukkan desain yang ada dapat dioptimalkan dengan mengurangi ukuran *runner* dan bentuk yang tajam.

Kata kunci: braket ortodontik, *metal injection moulding*, simulasi, *software* Sigmasoft

ABSTRACT

Metal Injection Moulding (MIM) process is one of effective process to produce complex shape product in the mass production scale. MIM process had been applied in many applications such as consumer product, automotive, biomedical etc. In this work, an orthodontic bracket is manufactured using MIM process. Before manufacturing process, simulation using commercial software Sigmasoft is done to evaluate the design and optimize the process parameters. Some parameters are inserted to run simulations in order to get optimum process condition for MIM process. Parameters to be optimized include the mold and feedstock temperature, cycle time and pressure during the injection process. In this simulation, the melt temperature is 190 °C and mold temperature is varied from 90-150 °C based on the reference from Catamold. The optimum mold temperature is 90 °C and filling simulation shows that the melt can still fill the cavity in that temperature with optimum filling time 2.5 s. From the simulation, the existing design can be improved by reducing the size of the runner and removing the sharp corner.

***Keywords**: orthodontic bracket, metal injection moulding, simulation, Sigmasoft software*

INTRODUCTION

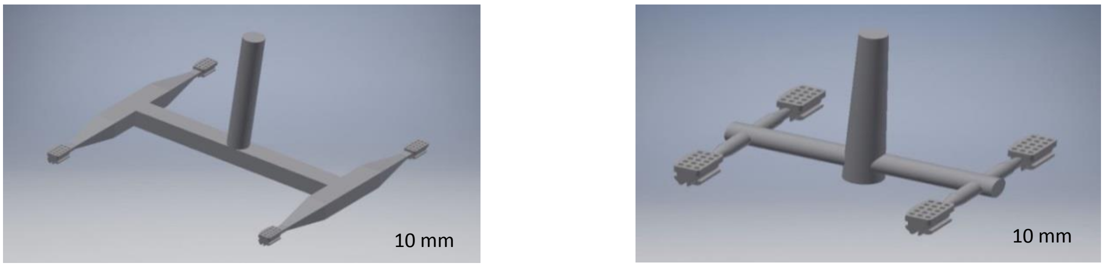
Along with the growing awareness for maintaining dental health and for the cosmetic purpose, the demand of orthodontic bracket is increasing as well. Dental bracket is used to correct misaligned teeth. It aims to increase self-confidence that can affect personal and social life. Based on the Ministry of Health, Republic of Indonesia data, all the orthodontic bracket is imported, which means that the design itself is not adapted to the dental characteristics of Indonesian people. The results of previous study have succeeded in making orthodontic bracket by investment casting process with acceptable geometric tolerance [1]. However, the results show that the quality of the surface must be improved. The alternative fabrication process to make orthodontic bracket is Metal Injection Moulding (MIM) process. MIM process has over the past decades established itself as a competitive manufacturing process for small precision components which would be costly to produce by alternative methods. MIM is one of the effective processes to produce complex shape part in the mass production. Some of the characteristics of MIM parts are high density (96-99%), high mechanical properties due to homogeneous structure, good tolerance, high surface finish (0.4 - 0.8 µm), high design flexibility and wall thickness (0.1 - 10 mm) [2,3].

To produce orthodontic bracket by MIM process, we must consider many aspects such as product design, gating system, and production process parameters. The advantages of MIM process simulation software are to shorten development times and minimize risks. Developers and designers can distinguish possible problems or critical behavior in the parts before developing a prototype. The mold maker can find ideal production parameters to realize the desired part quality and productivity. Although the plastic injection mold process had been established for decades, the knowledge can not be applied directly to the MIM process because of the MIM feedstock [4,5]. In this study, a commercial MIM Computer Aided Engineering (CAE) simulation software, SIGMASOFT (Sigma Engineering GmbH) is used to analyze the design and process parameters during injection moulding process. Some parameters are inserted to run simulations in order to get optimum process condition for MIM process. Parameters to be optimized include the mold and feedstock temperature, while the cycle time and pressure during the injection process are set in the constant value. In the simulation, the possibility of defect such as weld line can be predicted. The weld line is detrimental for the MIM part because after sintering, the weld line may become the weak area in the part which can cause the breakage when the part is under the stress [6,7]. Besides that, the powder binder segregation which occurs during the moulding stage can be also simulated [8,9]. Segregation defect can be found after sintering process, where aesthetic or failure may occur in the application.

The aim of the study is to optimize the mold design and injection moulding process parameters before manufacturing the orthodontic bracket. Some parameters are inserted to run simulations in order to get optimum process condition for MIM process. Parameters to be optimized include the mold and feedstock temperature, while the cycle time and pressure during the injection process are set in the constant value. In the simulation, the possibility of defect such as weld line or particle concentration can be predicted.

METHODS

In this paper, the orthodontic bracket that specially designed for the teeth structure of the Indonesian people by T. Prasetyadi [10] is simulated by using SIGMASOFT MIM Simulation Analysis Software. The 3D drawing of orthodontic brackets together with the gating system can be seen in Figure 1a (A), while the improved design of mold is shown in Figure 1b (B). The design of the initial mold was describe elsewhere [1]. Feedstock material used in this simulation is Catamold 17-4 PHA from BASF, using Stainless Steel 17-4 PH powder. The parameters put into simulation can be seen in Table 1.



(a) (b)

Figure 1. 3D Drawing of Bracket and Gating System, a) Initial Design (A), b) Improved Design (B)

Table 1. Simulation Parameters Used in This Study

No.	Parameter	Remarks
1	Feedstock Material	Catamold 17-4PHA
2	Mold Material	Steel
3	Melt Temperature	190 °C
4	Mold Temperature	90-150 °C
5	Filling Time	2.5-4 s
6	Filling Pressure	900 bar
7	Packing Pressure	80 % of Filling Pressure
8	Holding Time	2 s
9	Solidification time	10 s

The SIGMASOFT Simulation software calculates the filling, packing and solidification proses during injection moulding proses. The results can visualized the 3D melt flow, flow tracers, heat distribution in the mold or the parts and particle concentration of the green parts. The simulations are performed to analyze the influence of melt temperature and mold temperature to the filling behavior of the melt to the cavity and analyze the existing mold design to optimize the injection moulding process.

RESULTS AND DISCUSSIONS

Mold Filling Analysis

In this study, the mold filling analysis is carried out to analyze the flow of the feedstock in to mold cavity. The mold A has a rectangular cross section for the runner and gate, while mold B has a cylinder cross section and smaller dimension than mold A. Mold A has sprue dimension dia. 5 mm x height 35 mm, runner dimension 50 x 5 x 5 mm and ingate dimension 1.8 x 2.3 x 1 mm. Mold B has dimension of sprue dia. 4 mm x height 25 mm, runner dia. 3mm x 30 mm and ingate dia. 1mm x 3 mm. Mold A has yield of product 4.24 %, while Mold B has yield of product 33.07%. In the simulation, the 3D flow of the melt is visualized by tracer particles. In the calculation, the tracer particles do not have mass and volume, only to visualize the flow into mold cavity. The flow tracer simulation of both mold designs is shown in the Figure 2. From the flow tracer simulation results, given in the Figure 2, it can be seen that the mold B has better flow than mold A, where in the mold A, the melt flow through the center to bottom part of runner. There is area of runner that is not filled by the flow. This can be caused by not enough pressure to fill the runner cavity or the melt has already solidified in that area. Different flow pattern is shown by mold B which has circular cross section. The flow can fill the cavity in the mold B and the flow is relatively smooth, which lowering the possibility of the air trap or void inside the green part. From this result, it can be conclude that mold B is more suitable design for injection moulding of orthodontic bracket using CATAMOLD 17-4PHA feedstock.

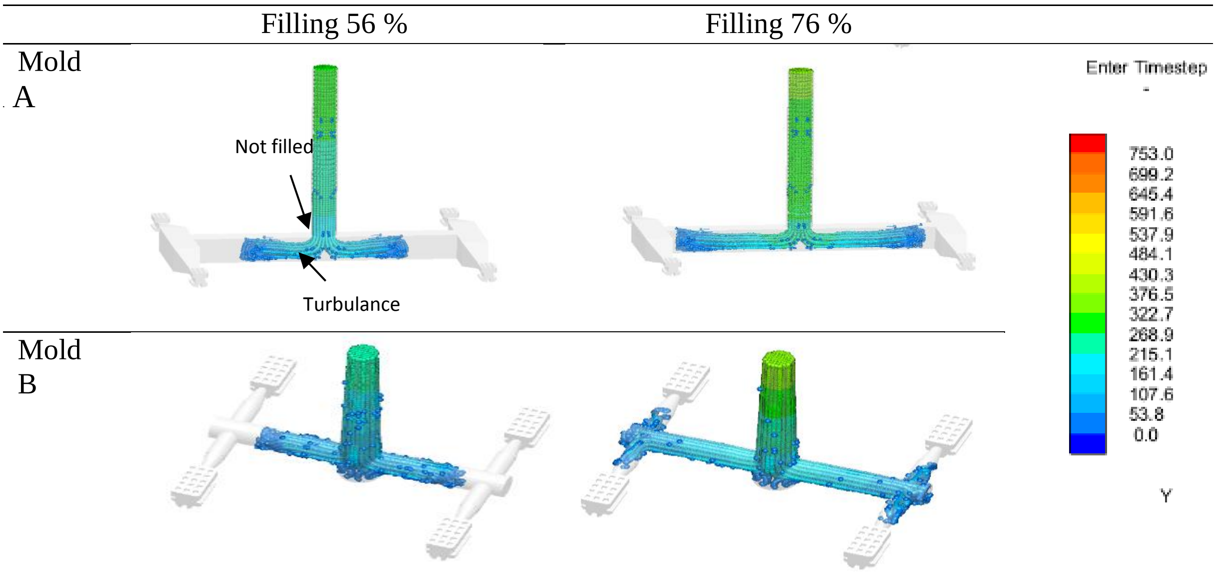


Figure 2. The Filling Stages Corresponding to the Different Mold Design (T_{melt} 190 °C, T_{mold} 150 °C; Filling Time 1 s).

Temperature Analysis

The temperature distribution must be uniform to make sure the quality of the green part. At the end of filling the surface area should have homogeneous temperatures. Large temperature difference will lead to uneven cooling, resulting formation of residual stress [4] in the green part. The residual stress may cause the deformation of the part during sintering. Another temperature dependent parameter is cooling time, the time used for the part cooling before ejected from the mold. The even cooling can reduce the residual stress and dimensional accuracy. In the production line, cooling time is desired as short as possible to increase the productivity, however, too fast cooling time may cause the warpage, sink mark or sticking of the part into mold wall [4]. Figure 3 shows the temperature distribution at the end of filling. The mold temperature is set 90 °C and the filling time from 0.5 s to 2s. From the results it can be seen that too long filling time make the feedstock temperature drop and the cavity can not filled completely. The shorter filling time the better filling condition, however it depends on the machine capability. High melt temperature results in higher final temperature of the part as seen in the Figure 4 and requires longer cooling time, in other word reduce productivity. In terms of temperature distribution, temperature gradient on the part which can lead to residual stress in the part. Increasing mold temperature can reduce the temperature gradient in the green part.

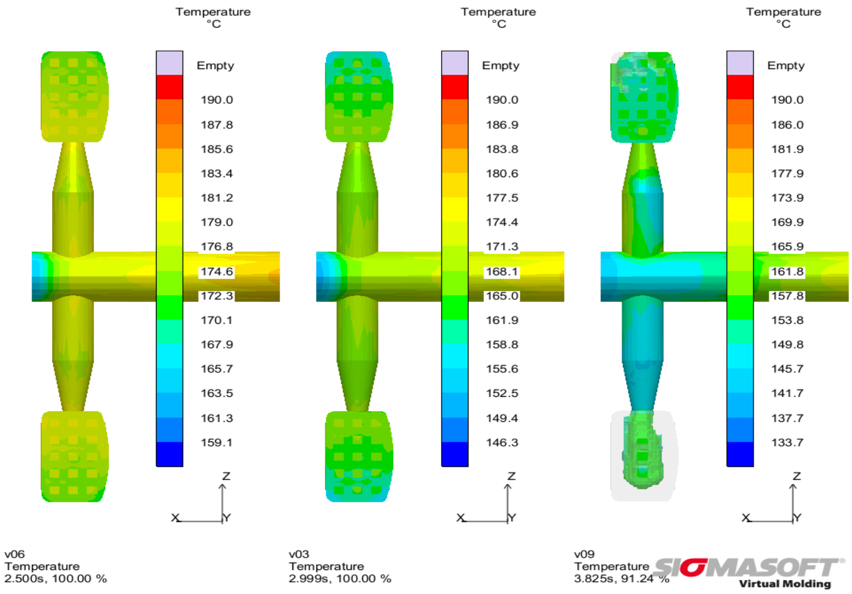


Figure 3. Temperature Distribution at the end of Filling a) 2.5 s, b) 3 s, c) 4 s Filling Time.

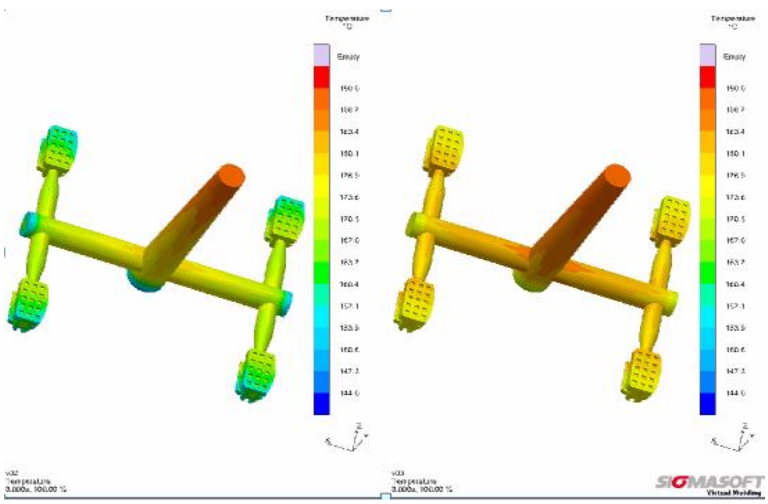


Figure 4. Temperature Distribution at the end of Filling at Different Mold Temperature a) 90 °C; b) 150 °C

Particle Concentration

Particle concentration relates with powder binder segregation during injection process. Powder binder segregation will affect the quality of the part. Region with particle concentration may introduce failure or influence the aesthetic of the MIM parts. Usually, the powder binder segregation is found in the final stage after sintering process. In the simulation, the particle concentration is simulated for mold design and process parameter optimization. Figure 5 shows the particle concentration of the part by change the mold temperature. It can be seen that by lowering mold temperature from 150 °C to 90 °C the high particle concentration in the center of the part are reduced. Particle concentration affects the melt viscosity as well: in powder-poor regions the viscosity is low, and as the particle content increases, the viscosity increases following a power-law correlation. Therefore, in areas such as the center of the flow channel, the viscosity can reach very high levels, while the feedstock still flows smoothly at the boundaries. Figure 6 shows the particle concentration with mold temperature from 150 to 90 °C with shorter filling time (2.5 second). It can be seen that homogeneous particle concentration can be obtained by reducing the filling time.

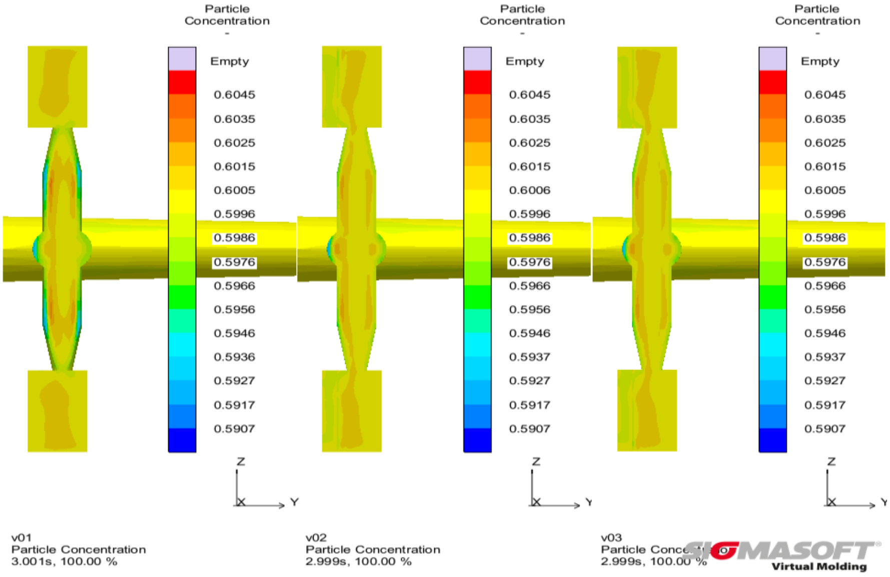


Figure. 5 Particle Concentration Profile of the Part With Mold Temperature a) 150 °C; b) 120 °C, c) 90 °C; Filling Time 3 s.

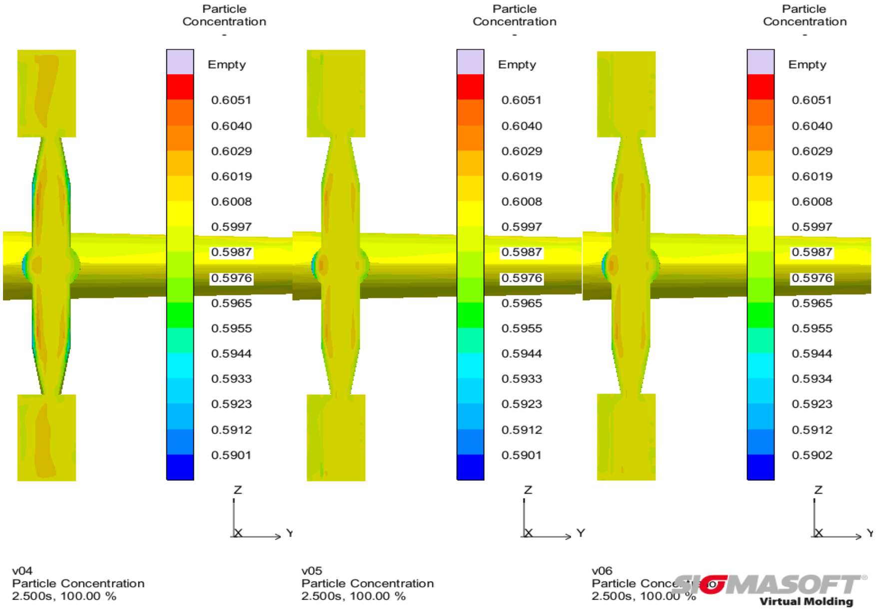


Figure 6. Particle Concentration Profile of the Part with Mold Temperature a) 150 °C; b) 120 °C, c) 90 °C; Filling Time 2.5 s.

CONCLUSION

Injection moulding simulation with Sigmasoft helps to reduce development time and cost significantly and leads to stable process and higher product quality.Flow tracer analysis show smoother flow for cylinder gating than rectangular gating design. Sharp edge must be avoided/limited. The temperature distribution must be uniform to ensure the quality of the green part. In this case the optimum mold temperature about 90-100 °C. Low filling time tend to reduce the particle concentration variation, therefore homogen green part can be obtained.

ACKNOWLEDGMENT

The authors would like to thank to Ministry of Industry, Directorate General of Metal Industry, Machinery, Transportation and Electronic, in Mold and Dies Center Program for facilitating the SIGMASOFT Simulation Software to support this research we would also like to thank to Ministry of Research and Higher Education for Research Grant *Penelitian Unggulan Perguruan Tinggi 2016*.

REFERENCES

[1] Supriadi. S, T.W. Sitanggang, B. Irawan, B. Suharno, G. Kiswanto, T. Prasetyadi, "Orthodontic Bracket Fabrication Using the Investment Casting Process", *International Journal of Technology* vol. 4, pp 613-621. 2014

[2] Heaney. D.F., "Handbook of Metal Injection Moulding", *Woodhead Publishing Limited*, Cambridge, UK, 2012.

[3] R.M. German, Metal Injection Moulding, "A Comprehensive MIM Design Guide", *Metal Powder Industries Federation, Princeton*, New Jersey, 2011.

[4] Lee S, Ahn S, Whang C, Park S, Atre S, Kim J, German R., "Effect of Process Parameters in Plastic, Metal and Ceramic Injection Moulding Process", *Korea-Australia Rheology Journal*, Volume 3 (23), pp 127-138, 2011.

[5] A. Bakar Sulong, N. Muhamad, Amir Arifin K., **"**Optimizing Injection Parameter of Metal Injection Molding Processes Using the Feedstock of 16 µm Stainless Steel Powder (SS316L)", PEG, PMMA and Stearic Acid", *Journal of Applied Sciences Research*, Volume 8(6), pp 2998-3003, 2012.

[6] A. Manonukul, S. Songkuea, p. Moonchaleanporn, M. Tange., "Effect of Weld Line Positions on the Tensile Deformation of Two-Component Metal Injection Moulding", *International Journal of Minerals, Metallurgy and Materials*, December Volume 24, Issue 12, pp 1384–1393, 2017.

[7] M. Miron, Z. Major, T. Adachi., "Fracture Behavior of Weld Lines in Injection Molded Components Loaded under Real Operating Conditions", *Procedia Materials Science*, Volume 3, pp 2048-2053, 2014.

[8] W. Fang, X. He, R. Zhang, S. Yang, X. Qu., "The Effects of Filling Patterns on the Powder–Binder Separation in Powder Injection Molding", *Powder Technology*, Volume 256, April, pp 367-376, 2014.

[9] A. Mannschatz, S. Höhn, T. Moritz., "Powder-Binder Separation in Injection Moulded Green Parts", *Journal of European Ceramic Society*, Volume 30 (14), PP 2827-2832, 2010.

[10] T. Prasetyadi, "Orthodontic Bracket Design Simulation in Race and Mechanical Aspect", *Proceeding of the 9th IDCMR Congress*, Bali, Indonesia, 2014.