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Effects of injection Moulding Parameters on the Produced Parts

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Abstract

The publication deals with an innovative technology called powder-based metal injection moulding, which is a combination of traditional polymer injection moulding and powder metallurgy. With the technology, it is possible to produce metal components with complex geometry in large series. There is an extremely large selection of materials that can be used, mostly steel, copper, titanium or nickel-based alloys. In this research, the material used is type 17-4PH, martensitic corrosion-resistant steel, and since it is a widely used material, it is examined in many international articles and research studies, and it is also common in industry, so it is advisable to use this type of material for further comparability. Little information can be found in the literature about spraying parameters and their effects, which is why this research focusses on this. On the other hand, these data can also serve as useful information for the industry. During the production of so-called green products, the effects of product shrinkage were measured by changing the most important parameters and comparing the effects of these parameters to traditional polymer injection moulding.

Keywords: *metal injection moulding, shrinkage, stainless steel.*

1. Introduction

In industry, an increasingly widely used process is metal injection moulding (MIM), which allows for the production of complex geometry metal components with high precision and in large quantities. One of the major application areas of this process is the automotive industry, where it is employed for the production of relatively small-sized products. There is a wide range of materials that can be used, but iron-based alloys, titanium alloys, and copper alloys are predominantly used. A literature review reveals very limited information regarding the impact of moulding parameters on the properties of the product. Therefore, the first step in the research is to investigate how the moulding parameters affect the shrinkage of the product and to what extent this resembles what is observed in plastic injection moulding **[1]**.

1.1. Metal injection moulding technology

Metal injection moulding can be described as a combination of traditional injection moulding and powder metallurgy. It involves using a granular feedstock with high metal powder content (95% by weight) and a binder consisting of 5% thermoplastic material. This feedstock is injected into a mould using an injection moulding machine. The resulting product is called a „green part." To create a porous structure throughout the entire cross-section of the product, the amount of binder needs to be reduced. There are various methods for removing the binder, depending on the specific binder system **[2]**. It is important for the binder to create a porous product while still providing enough binding strength to hold the powder particles together. The product with reduced binder content is referred to as a „brown part." The next step in the process is the sintering phase. The part is heated in a high-temperature furnace below the melting point until it reaches the desired density characteristic of the material. At this stage, the component acquires its metallic properties and sound [1]. The overall process can be seen in Figure 1.

So it can be seen that I am examining a narrow range of the MIM process, namely the injection moulding phase.

1.2. Effect of parameters on shrinkage

By changing the moulding parameters, it is possible to modify the dimensions of the injection-moulded product, which is directly related to shrinkage. The melt temperature, mould temperature, and post-injection pressure are among the main influencing factors. In the case of MIM, we may not observe the same processes as in plastic injection moulding, as the processed feedstock contains only a small percentage of polymer materials and is three-component due to the two-stage binder removal. Increasing the mould and melt temperature generally increases the shrinkage value. Increasing the post-injection pressure achieves a decreasing effect on shrinkage [4, 5].

2. Experiment and methodology

In this chapter, we present the tools used for measuring moulding parameters, the materials used, the mould, and the parameters of the experiment.

2.1. The raw material of the experiment

The selected material is martensitic corrosion-resistant steel, commercially known as 17-4PH, and its main components are listed in Table 1. [6]. This material is commonly used in both MIM and additive manufacturing processes, which is why it is advantageous to use it [7]. Apart from its corrosion resistance, it exhibits excellent mechanical properties, making it widely utilized in various industrial applications. It is frequently employed in aerospace and space technology, as well as in the oil and gas industry. It is used for the production of screws, springs, nails, gears, and also finds applications in the medical field for manufacturing surgical instruments. The binder used in the process consists of two main components: polypropylene and wax, which are mixed with the metal powder at a ratio of 6% by weight [8].

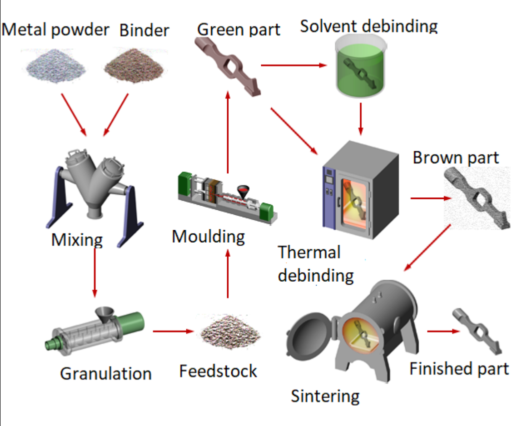

Figure 1. *The process flowchart of metal injection moulding* [3]

2.2. Test tool

To conduct the tests, we used a production mould specifically designed for creating a test specimen that weighed approximately 36 grams. This mould is capable of facilitating various types of tests. It is equipped with cooling channels on each side and features a central inlet from which a short runner feeds the mould cavity. The mould used for the experiment is illustrated in Figure 2. AFT Hungary Ltd provided us with the tool and the possibility to test the tool.

Table 1. *A 17-4 PH corrosion-resistant steel main components 1.4542* [7]

%	Cr	Mn	Si	Ni	Cu
Min.	15,0	–	–	3,50	3,00
Max.	17,5	1,00	0,70	5,00	5,00

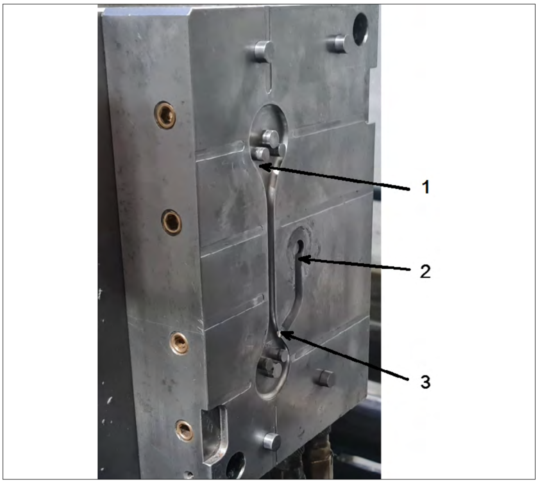

Figure 2. *The tool used for the test. 1- Cavity, 2-Runner, 3-Gate*

2.3. Technological parameters

To determine the precise moulding parameters, we conducted preliminary injection moulding trials. In order to examine the effects of the parameters, it was necessary to establish an optimal set of technological settings within the processing limits. The switching point was set at 99% cavity filling (**Figure 3**) with the dosing quantity continuously increasing.

The melt temperature was selected as the average processing temperature of the polyethylene (PE) component of the binder, and the value of the holding pressure was set to the midpoint between the two extremes of the processing limits. The optimal mould temperature was determined empirically through experimental observations.

Table 2. *The defined processing parameters*

Parameter	Value
Injection volume	6.56 cm^3/s
Injection pressure	903 bar
Postpress time	2 s
Post pressure	827 bar
Cooling time	15 s
Tool temperature	45°
Melt temperature	205 °C

Figure 3. *Fill sequence to define the switching point.*

2.4. Changed parameters

During the experiment design, the primary objective was to vary the key parameters, namely melt temperature, mould temperature, and holding pressure, individually in each case. As a result, 16 different technological settings were generated. The first 5 shots were disregarded to allow the process to stabilize and reach thermal equilibrium. Subsequently, for each configuration, 10 test specimens were produced, with 5 of them left as green parts, while the other 5 underwent additional steps (binder removal, sintering).

Table 3. *The changed parameters and corresponding values*

Variable	Back press.	Tool temp.	Melt temp.
Deviation -	550 bar	25°C	195°C
Deviation -	690 bar	35°C	200°C
Average alue	827 bar	45°C	205°C
Deviation +	965 bar	55°C	210°C
Deviation +	1103 bar	65°C	215°C
Deviation +	1241 bar	75°C	220°C

3. Results

After completing the trial injections, we proceeded with the evaluation of the results. Initially, we examined the samples that had not undergone sintering or binder removal. However, due to the variation in injection moulding parameters, the products exhibited flash along the parting line (**Figure 4**) which would have affected the measurement of hole distances. To obtain more accurate measurement results, we manually deburred all the holes in the fabricated samples. As a result, the distances between the holes could be precisely measured.

Following the removal of flash, we measured the distances between the holes (**Figure 5**) using an optical measuring machine. Therefore, the values of linear shrinkage correspond to these distances.

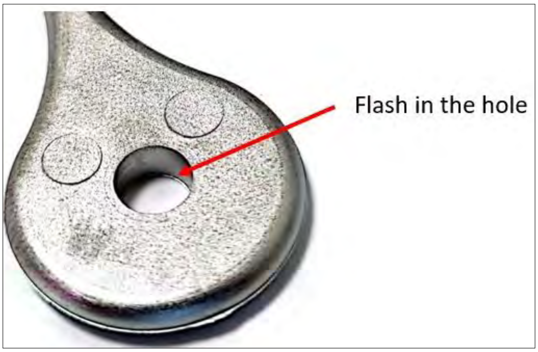

Figure 4. *Burring of the test specimen's hole.*

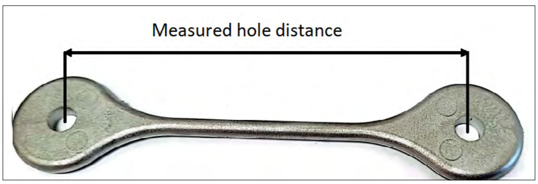

Figure 5. *Measured value of linear shrinkage.*

The obtained results were plotted on a diagram, illustrating the relationship between the variable property and shrinkage. The data represents the average of samples taken after 5 shots from the new material.

Shrinkage was determined using the following equation:

$$Shrinkage = \left(\frac{tool\ distance}{part\ distance} - 1\right) \cdot 100$$

The parameter that mostly influences the product size is the tool temperature (**Figure 6**). The shrinkage ranged from 0.34% to 0.72%, which can be considered a significant deviation, resulting in a dimensional difference of approximately 0.4 mm over a test length of 100 mm.

The curve shows an increasing trend similar to plastic injection moulding but only up to a temperature of 55°C. Beyond this temperature, the shrinkage value starts to decrease again. During the trials, it was observed that at higher tool temperatures, the products would come out of the mould with a „wet" appearance. This could potentially be attributed to wax exudation from the binder (**Figure 7**) As a result, metal particles could replace the exuded wax, resulting in a smaller shrinkage factor. It is hypothesized that this could be measured based on the percentage composition of the components.

The relationship between shrinkage and the variation of applied pressure differs from that of polymers. Based on the results, shrinkage reaches its maximum around 900 bar (**Figure 8**), leading to less shrinkage at higher or lower pressure values. It should be emphasized that the impact of applied pressure on shrinkage is significantly smaller compared to that of tool temperature.

The deviations from plastic processing parameters can be attributed to several factors; however, further research is required to fully understand them.

Among the parameters studied, the variation in melt temperature had the least effect on product dimensions, and the scatter of the curve was significant compared to the deviations (**Figure 9**).

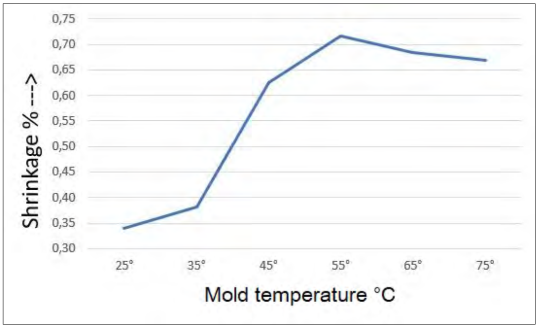

Figure 6. *Effect of tool temperature on shrinkage.*

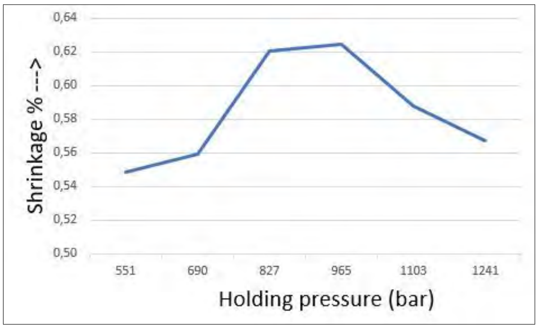

Figure 8. *Effect of holding pressure on shrinkage.*

Figure 7. *Wet product surface, possible wax separation.*

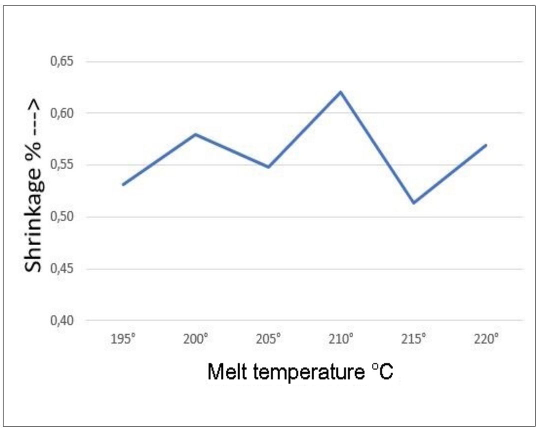

Figure 9. *Effect of melt on shrinkage.*

4. Conclusions

Based on the results of the conducted experiments, it can be summarized that the general principles of polymer injection moulding may not necessarily be applicable to metal powder processing. The physical properties of the materials show significant differences, such as varying density, viscosity, thermal conductivity, and the behaviour of a three-component system needs to be examined.

However, the preliminary measurement results are not sufficient to draw definitive conclusions. Further tests and investigations are necessary to validate the obtained results and ensure their reliability. Therefore, additional examinations are required to apply more effective methods for optimizing the injection moulding process and improving the quality of the final product.

Based on the tests, it can be assumed that other factors also influence shrinkage, especially in the case of pressure and mould temperature. The most significant effect is observed when changing the mould temperature. The influence of melt temperature is not known, and measurement errors may occur, which require further measurements.

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References

[1] Heaney D. F.: *Handbook of Metal Injection Molding*. 2. kiadás Woodhead Publishing Series in Metals and Surface Engineering, Cambridge, (2019) 1–25.

[2] Petzoldt F., Eifert H., Hartwig T., Kramer L., Veltl G., Pest A.: *Broadening the Scope of MIM*. Materials and Manufacturing Processes, 12/4. (1997) 691–711. https://doi.org/10.1080/10426919708935176

[3] Custom Part USA, *Metal Injection Molding* https://www.custompartnet.com/wu/metal-injection-molding (accessed on: 2023. 03. 01.).

[4] Barriere Th., Liu B., Gelin J. C.: *Determination of the optimal process parameters in metal injection molding from experiments and numerical modeling*. Journal of Materials Processing Technology, 143–144. (2003) 636–644. https://doi.org/10.1016/S0924-0136(03)00473-4.

[5] Tseng W. J.: *Statistical analysis of process parameters influencing dimensional control in ceramic injection molding*. Journal of Materials Processing Technology 79/1–3. (1998) 242–250. https://doi.org/10.1016/S0924-0136(98)00019-3

[6] Amatek Specialty Metal Products. *Specialty Powders 17.4 PH Alloy Powder* https://www.powderclad.com/products/specialty-powders/17-4-ph-alloy-powder

[7] Singh G., Missiaen J.-M., Bouvard D., Chaix J.-M: *Additive manufacturing of 17–4 PH steel using metal injection molding feedstock: Analysis of 3D extrusion printing, debinding and sintering*. Additive Manufacturing, 47. (2021) 102287. https://doi.org/10.1016/j.addma.2021.102287.

[8] Hamidi M. F. F. A., Harun W. S. W., Khalil N. Z., Ghani S. A. C., Azir M. Z.: *Study of solvent debinding parameters for metal injection moulded 316L stainless steel.* IOP Conference Series: Materials Science and Engineering, 257. (2017) 012035. https://doi.org/10.1088/1757-899X/257/1/012035.