Searching for a Compromise Formula

Study on the Influence of Process Parameters on the Quality of MIM-Parts

Compared to conventional metal working MIM is a fairly new technology. Comprehensive process knowledge on effects which have an influence on the part quality is missing. MIM specialists from injection molding machine manufacturer Arburg carried out several specific tests with various parameters to enhance the knowledge about the process effects on the characteristics of metal injection molded parts. The results will facilitate a faster process optimization in the future.

During production of such metal test bars different injection molding parameters were varied in order to find the compromise formula for the best setting (© Arburg)

Metal parts are irreplaceable today, since they are widely used in the automotive, electronic, IT, medical and consumer sector. Metal injection molding (MIM) is a promising technology for these industries, not only for economic reasons. As for the diversity of metal materials [1] MIM enables the processing of materials which cannot be used with common techniques.

In order to provide better process knowledge the MIM specialists at Arburg GmbH + Co KG, Lossburg, Germany, investigated the influence of different injection molding parameters on the final part quality. Investigated parameters were

- injection speed,
- holding pressure,
- mold temperature,
- evacuation of cavity, and
- gate geometry.

The investigated attributes green part weight, dimensional accuracy, microstructure and surface property show diverging reactions on the processed adjustments.

A weighting of process parameters in terms of the quality of the components was carried out using statistical methods. For the statistical evaluation the analysis of variance is used as it is described in [2]. The method uses the total sum of squares to show changes of the command variable. With this method it is possible to distinguish true changes from random ones. Three values are resulting from this analysis:

- First, the influence value which shows the parameter's influence on the part quality.
- Second, the F value which is an auxiliary quantity to get to the third one, the p value.
- Finally, the p value shows the probability of error and exposes changes caused by chance.

To separate the true parameters from the random ones a p value level of 10 % is set. This means that every parameter with a p value higher than 10 % is statistically irrelevant. Values with a level between 0.1 % and 5 % are highly relevant and parameters with a p value lower than 0.1 % are extremely relevant. Since the investigated parameters can have interactions with each other that alter the influence every possible combination of parameter setting is applied which requires a wide ranged experimental design.

From Green Part to the Measurement of the Sintered Part

An Allrounder 270 S 400-70 (manufacturer: Arburg) was used for the injection molding tests. The machine has a clamping force of 400 kN and was equipped with a MIM cylinder assembly with screw diameter of 18 mm. It produced test bars (**Title figure**) whose geometric properties i. e. holes, surface roughness, gate geometry or part design can vary.

A detailed design of experiments was used for this investigation as shown in **Table 1**. All test parts were molded with the feedstock Catamold 17-4 PH A (manufacturer: BASF SE, Ludwigshafen, Germany). Debinding and sintering, the latter at 1380 °C under hydrogen, was done in a catalytic debindering plant (type: Elnik CD3045) and sinter oven (type: MIM 3045) respectively at DSH Technologies LLC, an affiliate of Elnik.

After debinding and sintering the sintered parts were measured according to the defined quality parameters. The measuring positions for the length, width 1 (near gate), width 2 (rear gate) and shape distortion (round markings) are shown in **Figure 1**. The surface properties are defined by the surface roughness, sink marks and by failures on the surface such as notches, air pockets and demixing zones. The microstructure was examined at two defined positions (in the cen- »

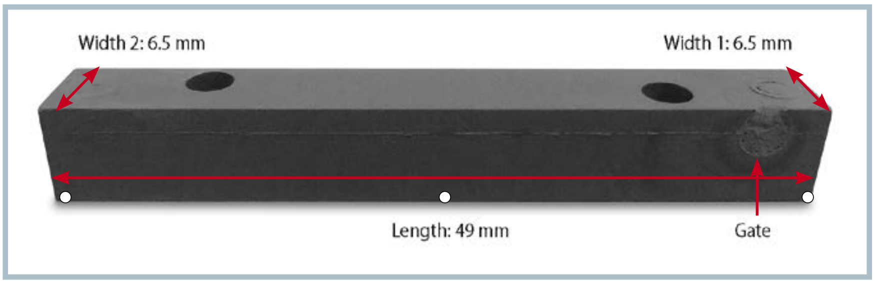

Fig. 1. Green part of a test bar produced via MIM, with different measuring points for length, width and shape distortion used for measuring the sintered part (© Arburg)

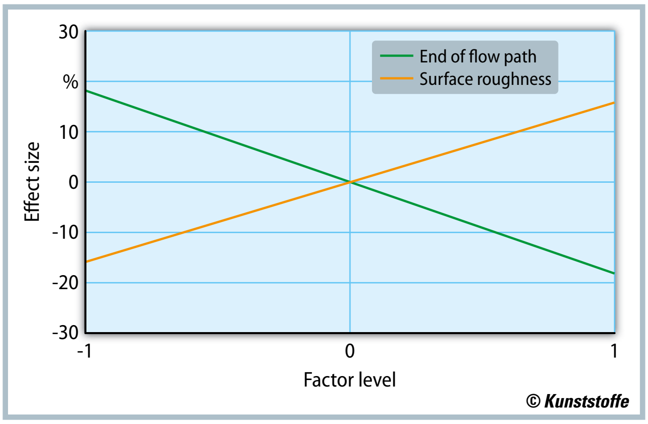

Fig. 2. Influence of the injection speed on joint line appearance and surface roughness (source: Arburg)

ter of the part and at the end of the flow path) under the microscope. After measuring the values were analyzed via variance analysis.

Statistically Relevant Influencing Factors

Table 2 shows the influence of the five investigated parameters and their interaction on the surface roughness of the part. The parameters injection speed, gate geometry and the interaction ACD are the only true parameters which have influence on the part quality (p value lower than 10 %). The other parameter influences are statistically irrelevant which means that they show no effect on the part.

The gate geometry (34.84 %) shows the highest influence on the surface roughness followed by the injection speed (15.68 %). These effects are caused by different shear ratios. The higher the injection speed the higher the shear ratio. High shear ratios lead to high stress on the feedstock and therefore to large demixing areas [3]. Also, it is shown that the mold temperature as a single factor has no statistical relevance. However, in combination with the injection speed and the gate geometry (ACD, 12.72 %) the mold temperature does have influence on the part quality.

Examination of the sintered parts reveals brighter zones that indicate the demixing areas where powder was separated from binder. The appearance of these zones depends on the geometry of the gate, their position gets shifted by changing the gate.

Based on these results and the variance analysis charts for each varied process parameter can be created to show its influence on the quality parameter. In these charts only the significant quality changes are considered. For example, for the factor injection speed the joint line on the rear of the testing part and the surface roughness are the only attributes that show statistical significance (**Fig. 2**).

The value of the x-coordinate shows the parameter setting, e.g. low (-1) and high (1) value. The value of the ordinate shows the influence of the varied parameter in percent of the total variance of the current quality parameter. Higher values have higher influence on the part quality. The gradient of the curve shows in which direction the quality variable is influenced by the parameter. A positive gradient shows that if the parameter value increases the quality value also increases and in contrary if the gradient is negative the quality value decreases with a growing parameter value.

As it is shown in **Figure 2** the joint line appearance on the rear of the part can be reduced by changing the injection speed to lower levels with an influence of 19 %. Coontrary to this, the surface roughness and therefore the demixing increases with higher speeds with an influence of 15 %. The interaction between two parameters is illustrated in a 3D chart as it is shown in **Figure 3**.

Factor	Value		
	–	0	+
Injection speed [cm³/s]	5	10	20
Holding pressure [bar]	100	800	1200
Mold temperature [°C]	125		135
Gate geometry	Film		Round
Vacuum	Off		On

Table 1. Factor definition: The experimental design for the examination of the test bar varies five parameters (source: Arburg)

Factor/interaction	Influence [%]	F value	p value [%]
A: Injection speed	15.68	5,58	2
B: Holding pressure	1.28	0,39	54
C: Mold temperature	1.65	0.50	48
D: Gate geometry	34.84	16.04	0
E: Evacuation	0.07	0.02	89
AC	7.52	2.44	13
AD	6.42	2.06	16
ACD	12.72	4.37	5

Table 2. Variance analysis: The results show the influence of the five examined parameters and their interactions on the surface roughness of the part (source: Arburg)

The chart shows how the surface roughness is influenced by the interaction of mold temperature and injection speed. It is shown that there is a zone where low levels of the roughness can be reached. To get to the lowest point both parameters have to be set to a certain level. In this case the lowest roughness levels are reached with the lowest mold temperature and with high injection speeds. However, it can be seen that the highest speed causes a higher roughness which indicates higher separations of binder and powder.

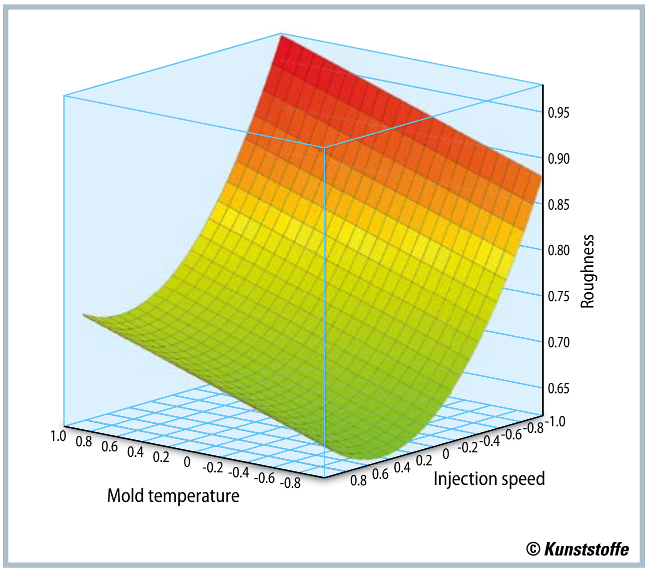

Fig. 3. Influence of mold temperature and injection speed on surface roughness (relative values, respectively). In order to get to the lowest point, i. e. the smoothest surface, both parameters have to be set to a certain level (source: Arburg)

Air Pockets, Joint Lines and Shape Distortion

Due to the flow behavior of the melt during injection notches can create at the end of the flow path (**Fig. 4**). At first the melt takes off from the wall and flows to the end of the part. After the melt reaches the wall the part is filling back and air is trapped between the take off and the end of the flow path (**Fig. 5**). Due to the fact that here no ventilation can be installed the only way to solve the problem is evacuating the mold (**Fig. 4**).

Another quality parameter is the shape distortion which influences the dimensional accuracy. This quality parameter is affected by the holding pressure and the interactions of holding pressure and mold temperature as well as of injection speed, holding pressure and gate geometry.

Also the appearance of joint lines can be influenced by varying parameter »

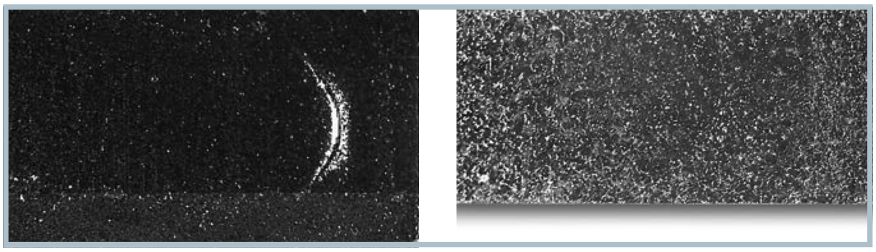

Fig. 4. The notch that forms in the part (left) can be eliminated by evacuating the mold (right) (© Arburg)

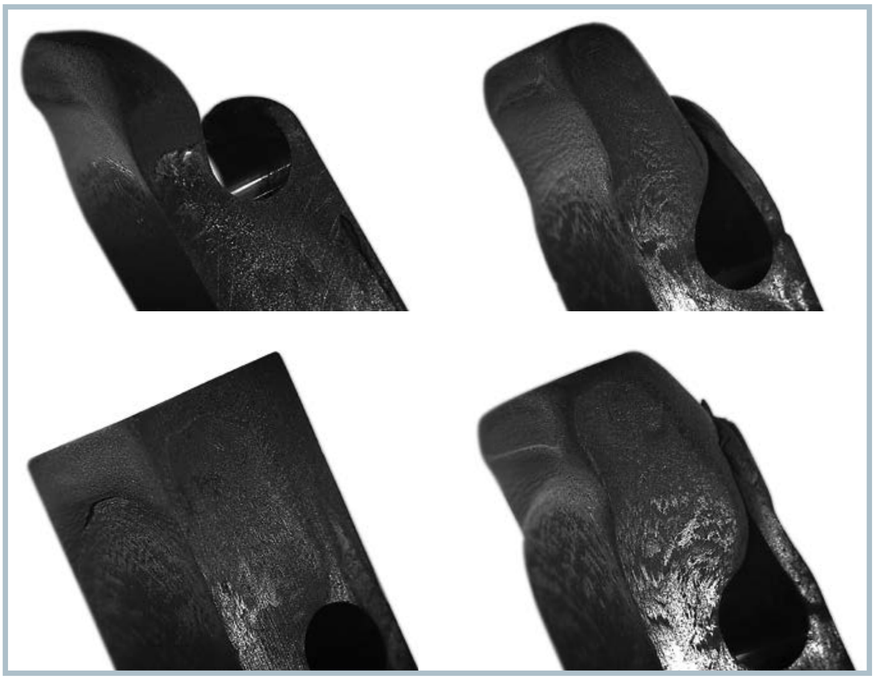

Fig. 5. Filling behavior during formation of a notch (clockwise, from top left): First, the melt detaches from the wall and flows to the end of the part. Then the part fills from the back and air gets trapped inside the cavity (© Arburg)

settings, especially by changing the injection speed and holding pressure. Dimensional parameters such as length and width are mostly affected by the holding pressure. With higher pressure levels the testing bar gets longer as well as wider. The effect is stronger the shorter the distance to the gate is. While the holding pressure has an influence of nearly 90 % on the width near the gate it only has an influence of approx. 17 % at the end of the flow path.

The part length is affected by the holding pressure only: 80 % of the total part change on the length is caused by changing the holding pressure level.

Main Influence Factor: the Holding Pressure

The investigation shows that the holding pressure is the strongest factor of the examined ones. Also, this parameter is partly covering the effect of other parameters. This is important to know for processes with low pressure levels or tiny gates which freeze very fast.

The study also shows that the part quality is widely adjustable to the required properties. The best results regarding part dimensions are achieved with a high holding pressure level. With higher injection speeds the surface roughness is decreased but the joint line appearance is increased. This means for the operator to find a compromise during parameter setting in order to achieve the best part quality. With higher mold temperatures on the other hand, the flow fronts merge better while the appearance of joint lines is reduced.

Another important result: Film gates cause higher demixing than round gates. This effect is due to higher shear ratios. Accordingly, for critical parts round gates should be preferred over film gates for a good part quality.

The last investigated parameter is the evacuation of the mold. As described above, an evacuation can prevent notches caused by trapped air.

Outlook

Based on the results of the study continuing investigations will be done. The Arburg specialists will further investigate different feedstocks, surface roughness of the cavity and different melt temperatures as well as wall thicknesses. Additionally, also rheological investigations shall be carried out to get information about the shear stress during the injection molding and plastification process. ■

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Service

References & Digital Version

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