Spritzgiessautomaten

Metal – Injection – moulding

Metal Injection Moulding
As hard as steel - as flexible as plastic

The electronics and mechanics of modern information technology, especially consumer and medical devices need smaller, more precise but also more highly solid components. Production processes have to be developed to meet this demands. Frequently these new processes originate in the combination of two or more processes and unite the advantages of the original techniques.

The process of metal injection moulding offers this features, the economic production of parts that are as hard as metal powder products yet also offering the freedom in design formerly available only from injection moulding of plastic is now at option

The information following will explain this process and it’s possibilities to you.

In short - the process

For the user the initial product is a completely compounded granulate similar to the well-known plastic granule. It consists
of metal powder and a „binder“ which can be processed to so called green parts on any BOY injection moulding machine. This piece is very sensitive to any mechanical impact.

The share of binder is „burned“ out in the debinding furnace. Now this porous intermediate product is called a „brown part“.

During the finishing process of sintering the part attains it’s final shape and structure (figure 1).

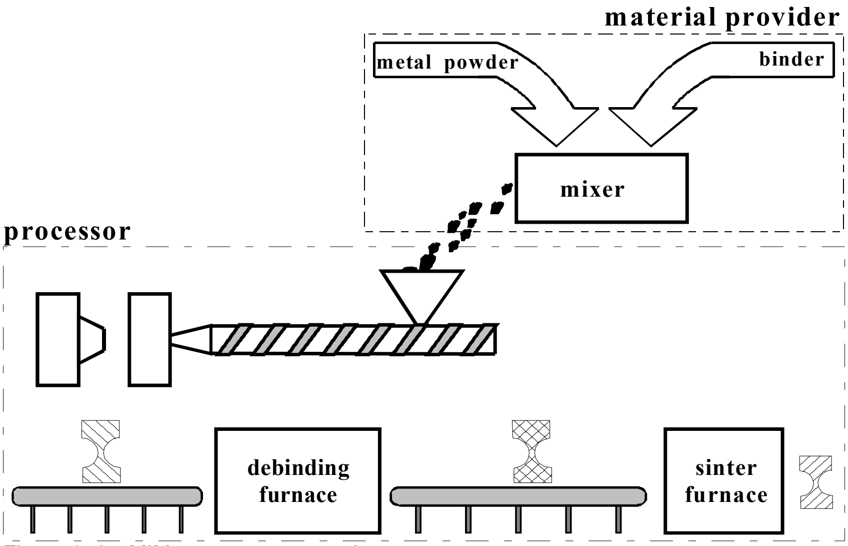


Figure 1: the MIM-process - an overview

Subsequently:

Hard and solid - the metal powder

Basically every metal is suitable as the powder for metal injection moulding material. From hard metal over high-grade steel to supra alloys everything is possible. Though special attention should be paid to the particle size.

Smaller grains tend to agglomerate hindering the later removal of the binder. To achieve higher porosity higher percentages of binder become necessary. Though higher proportions of binder result in removal phases and a less solid brown part. On the other hand finer particles shorten the heating cycle due to their increased activity in sintering.

An average grain size that is too high can lead to wear on the screw, the back flow valve and in the mould.

Therefore the average particle should be between four and twenty µm.
The metal particles shape and consistency have to ensure a high packing density and a good adhesion between the particles.

Nowadays some material suppliers offer complete powder-binder compounds which means the user can reap the benefits of the existing know-how and the uncertainty concerning material selection can be avoided.

Typical metal powders are:

- carbonyl
- carbonyl iron with 50% nickel
- tungsten carbide with 12% cobalt
- high-grade steels
- less alloyed steels
- supra alloys

Adhesion or non-adhesion - the binder

The binders main tasks are contradictory to a high extent in that to fulfil it's job while being processed on the injection moulding machine, it should stick to the metal powder as well as possible to stop the two components from being separated by the centrifugal force developed by the rotation of the screw. On the other hand the removal of the binder during the following debinding process should happen quickly and thoroughly. Some thermoplast-based binders have proved especially suitable in this aspect. There are also systems that are based on water. Here the material is processed at low temperature and injected into the hot cavity.

Well-known injection moulding materials consist of 40 % by volume of binder. This equates to between 6 and 8 % by weight.

BINDER	SUPPLIER
Bayerceram	Bayer AG
Catamold	BASF AG
Hostaform	Hoechst AG

Table 1: MIM-binder

From the granules to the green part -
the injection moulding process

This process is quite similar to the moulding of thermoplastics.

Nevertheless the processor should concentrate on some process parameters and machine set-values.

Firstly, process temperatures are very important; low temperatures result in increasing wear, on the other hand high temperatures lead to separation symptoms of the metal powder. These signs of separation are due to the low adhesion between binder and powder, the binder's low viscosity and the huge difference in the components' densities. Unevenness in the brown part's shrinkage behaviour is the result of these separation and can lead to cracks during sintering. A breakage of the part during the production can be the consequence.

Some additional differences to the processing of thermoplastic materials are given by the improved heat transmission of the of the metal-binder mixture (factor 12-15). An advantageous result is the clearly shorter dosage times when plasticising the material in the cylinder.

However the considerably shorter gate seal-off times are also a disadvantage. In the cavity temperature-caused shrinkage can hardly be levelled out during cooling phase. The holding pressure doesn’t reach the part. This fact must be considered as well during the moulds construction by short and stocky runners as during the processing by an exact and speedy filling with high injection pressures. The possibility of the procan-microprocessor control to define multistage injection speed and holding pressure profiles proves to be particularly valuable for MIM.

Use of a hot runner system should be actively taken into consideration in order to reduce the loss of pressure. Nevertheless runner waste that is produced can be granulated and reprocessed.

We want to emphasize that errors resulting from the injection process cannot be reduced or even eliminated during the following steps. They are rather intensified and become more evident.
On the whole an as-regular-as-possible process has to be striven for. Thus separation and the resulting shrinkage differences in the MIM part can be reduced to a minimum.

Table 2 contains some clues for the main adjusting parameters.

PARAMETER	VALUES (AREAS)
circumferential screw velocity	1-3 m/min
back pressure	average values
cylinder temperature	170-210 °C
injection volume	10-20 ccm/s
injection pressure	up to 1800 bar
mould temperature (depending on the binder type)	20-50 °C or 120-135 °C
cycle time	proportional to t^2 (t = max. wall thickness)

Table 2: areas for parameters

Handle carefully - the green part and its debinding

When demoulding the product as a green part it has to be handled very carefully. A handling device to transport the parts from the injection moulding machine to the debindering furnace is absolutely essential for an automatic production process.

Depending on the system initially used, the binder is dissolved or thermally or catalytically removed from the green part in the debinding furnace.

Nevertheless a proper temperature and pressure profile in the oven has to reassure a certain debinding velocity and reduce internal pressures to a minimum. This is the only possible way to avoid disruption of the moulded part. Exact process parameters strongly depend on the chosen feedstock and the part's geometry. To figure out the exact debinding process and the resulting parameters one has to carry out tests for each new product.

Table 3 contains some typical types of binder and the corresponding debinding parameters.

BINDER BASIS	DEBIND. PROCESS	-TEMPERATURE/ -TIME	DISADVANTAGE
polyacetal	catalytic cat.: nitric acid	110-140 °C/ very fast 1-2 mm/h	costs
other thermoplastics (i.e. LDPE)	therm. debinding	above TP- melt temperature/ slow	debindering time
(Krupp-process)	dissolve (with organic solvents)	slow	ecology MAK-values
PVAL	dissolve (with water)	fast	binder chose

Table 3: binder and debindering conditions

The binder system used also fixes the size, the volume and the type of the debinding furnace that has to be assembled to the production line.

After the removal of the organic ingredients the part is very porous and is called a brown part. It still has roughly the same geometry as the green part.

Get rid of the air - the process of sintering

The finishing heat process makes the brown part become the actual physical size of the actual product by shrinking it to it's final size. If the previous process stages have been conducted properly it can be precisely determined that isotropic, i.e. direction independent shrinkage during the sintering will occur. This is approximately 33 % by volume (equating 15 % linear shrinkage).

Since this process is the same as while sintering pressed parts, one can use the same parameters established from this method. The maximum values for the temperature profiles are, depending on the used powder, around 1200-1300°C, but always below it's melting temperature. To save the metal from oxidation the heating process usually takes place in a nitrogen or hydrogen atmosphere. In a very few cases it is necessary to add a vacuum system to the oven.

Due to the much finer powders, compared to the ones used in the common powder processes, remarkable shorter sintering phases are achieve able.

Afterwards - the refinishing

After the sinter process the final product has emerged. Very seldom threads and edges have to be refinished. Usually this operation can be avoided.

The hardware

Nearly as known - the injection moulding machine

As already mentioned nearly every BOY-injection moulding machine can process metal powder feedstock's.

BOY offers MIM-screws, especially developed for the high requirements of this process:
In spite of the increased abrasion of the MIM-materials a costly hard metal lining is usually not necessary. Only when processing hard metal powders do the cylinder, the screw and the check ring need to be specially protected.

The diameter of the screw has to be chosen such that the high injection pressures needed can be achieved. Smaller screws result in higher specific injection pressures.

To reduce the mechanical stresses to a minimum in the melt, one should avoid mixing elements in the screw.

The relatively high viscosity of the melt leads to high flow resistances therefore an open nozzle is preferred to a shut-off nozzle. Additional pressure losses caused by the small flow areas can be avoided. Since the material usually is not ropy or pouring out of the nozzle no dangers for the automaticised process are resulting.
As already mentioned, it is very important to fill the cavities exactly and fast, since the holding phase hardly exists. Therefore its absolutely important to be able to fix injection speed as well as holding pressure in different stages in a closed loop at the injection moulding machines. The PROCAN-control offers this facilities, and because of this is eminently suitable for this processing method.

An additional reason to use BOY injection moulding machines for the MIM-process is their compact design. Since the whole production unit consists of three elements, namely the injection moulding machine and the two furnaces, it is important to shorten transport distances to a minimum. On the one hand, investment for transport elements like handling devices and conveyor belts are reduced. On the other hand, the danger of damage to the green or brown parts are minimized.

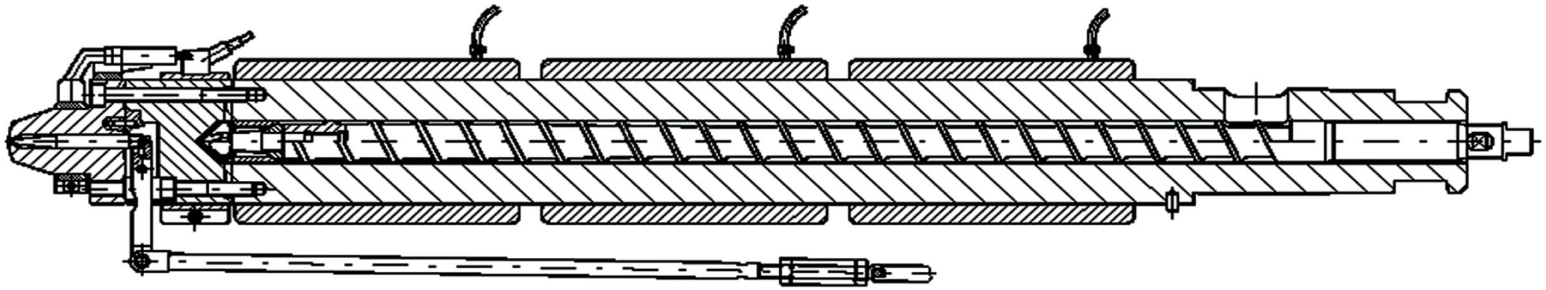
Particularly the MIM parts' kind and style speak well for the suitability of machines in the lower clamping force area. Usually these parts are small and geometrically complicated, therefore, the high demands for pressure makes the use of moulds with several cavities on larger machines difficult to obtain.

Especially if production methods are build of several different processes the user has to direct his attention to the processes reliability. If a MIM-production line would be equipped with only one huge injection moulding machine, any stoppage led to the interruption of the whole production. All the other elements, conveyor devices and furnaces, would still be operable but unused. Several small injection moulding machines offer the opportunity to keep the production line running.

Nearly as it used to be - the mould

The freedom of design has already been mentioned as a main advantage of the MIM process. To realize undercuts and bores, core pulls, chases and the likes can be used. The requirements and restrictions for the mould designer are roughly the same as known from constructing thermoplastic articles. Some of the main construction rules are shown in table 4.

Plasticizing Unit for MIM



	BOY 12		BOY 22							BOY 35				
	129-15	129-18	220-15	220-18	220-52					350-52		350-92		
Screw diameter mm	14	18	14	18	18	22	24	28	32	18	22	24	28	32
Screw-L/D ratio	18	20	18	20	20	17,5	22	18,6	16,3	20	17,5	22	18,6	16,3
Max. stroke volume (theoretical) ccm³	6,1	10,1	6,1	10,1	20	30	36	49	64	20	30	43	58,5	76,5
Max. shot weight in PS	5,6	9,6	5,6	9,6	19,4	28,4	34	47	61,6	19,4	28,4	41	55,8	73,7
max. specific injection pressure	2413	1795	2413	1795	2587	1732	1455	1069	818	2587	1732	2146	1577	1207

	BOY 55								BOY 90					
	550-52		550-79			550-205			900-205			900-370		
Screw diameter mm	18	22	24	28	32	28	32	38	28	32	38	36	42	48
Screw-L/D ratio	20	17,5	22	18,6	16,3	22,7	20	16,7	22,7	20	16,7	23	20	17
Max. stroke volume (theoretical) ccm³	20	30	43	58,5	76,5	73,9	96,5	136,1	73,9	96,5	136,1	157,8	214,7	280,5
Max. shot weight in PS	19,4	28,4	41	55,8	73,7	70,1	91,1	129,7	70,1	91,1	129,7	142	193	252
max. specific injection pressure	2587	1732	1810	1340	1030	2778	2127	1508	2778	2127	1508	2347	1724	1320

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CONSTRUCTION HINTS	REASON
using a hot-runner	reduction of pressure losses
big gates - short runners	reduction of pressure losses
gating in the area of higher wall thickness	fast gate-sealing
injecting against a wall in the cavity	avoiding of filling patterns
avoiding of sharp deflections	danger of demixing processes
polishing the cavity's surfaces	reduction of deforming forces
considering the volume shrinkage	30-35% after sintering
convenient deforming angles 3-5%	reduction of deforming forces

Table 4: construction hints for MIM-moulds

As a result, realizable geometries and surfaces of MIM-parts are less restricted than those produced by investment casting (table 5).

	MIM	INVESTMENT CASTING
minimum bore diameter [mm]	0,4	2
maximum depth of a 2mm blind hole [mm]	20	2
minimum wall thickness [mm]	<1	2
maximum wall thickness [mm]	≤30	∞
toleranz at 14 mm dimension [mm]	±0,06	±0,2
surface roughness [µm]	1	5

Table 5: comparison of MIM and investment casting parts

For different reasons the use of hot runners are highly recommended. On the one hand pressure demands and wasted material from the runner are reduced. Moreover the gate seal-off time is lengthened and gives the possibility to equalize the volume shrinkage for a stretched time period.

Due to the high rate of flow the abrasion in the cavity is intensified by the metal powder feedstock. One can estimate a 100.000-300.000 cycles life for a MIM-mould.

Debinding and sintering - the furnaces

The size of the ovens is mainly fixed by the production level to be attained. The maximum throughput has to be suitable for both components of the production line, i.e. the debinding and the sintering ovens.

Moreover the capacity and the exact type of debinding furnace depend one the binder system used.

Catalytic-remove able binders give the opportunity to carry out the debinding in a simple oven at a nearly one-stage-temperature-profile. Additionally the oven can be of a smaller design since this kind of takes less time. Though, the oven's waste gases have to be burned off separately; this requires additional investments.

For most of the other binder systems it is necessary to maintain exact temperature profiles. For this a closed-loop control is important. Some suppliers of furnaces can be found below.

- Nabertherm
- Linn
- Kera
- Riedhammer

Is it worth it?- the prospects

For the production of articles using the MIM process investment is relatively high because of the additional production line components:

ADDITIONAL COMPONENTS
- handling devices
- conveyor belts
- debinding furnace

⇒ possibly waste gases burning
- sinter furnace

An estimation of the economy obtained, carried out by BASF, shows that the overhead expenses and personnel costs are neglect able for this part of the process (table 6).

	man power	personnel costs [€/kg]	overhead expenses [€/kg]	total [€/kg]
INJECTION MOULDING	1	7,77	19,71	27,48
DEBINDERING	1/3*3	0,02	0,02	0,04
SINTERING	1/3*3	0,11	0,5	0,6
QUALITY CONTROL	1	0,98	3,49	4,47
TOTAL	**4**	**8,88**	**23,72**	**32,59**

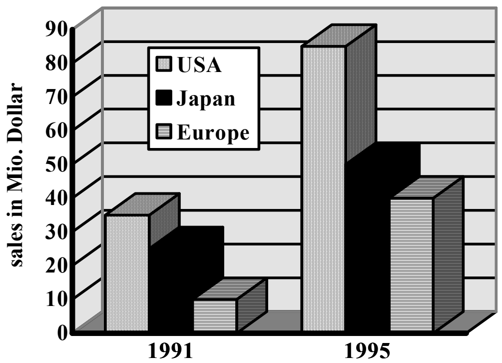
Table 6: overall production costs for a MIM-part (according to BASF)

The total costs are more likely to be fixed by the injection moulding and the, as yet, relatively high material prices.

But, the possibility of producing small, highly presice, complicated parts with nearly any form and surface quality, in a process that offers huge automation potential (table 7, appendix), explains why, especially in the USA, there are growth rates of 20-30 % in MIM (table 8).

MIM-PART'S PROPERTIES	ALREADY REALISED VALUES
maximum weight	≤ 2,5 kg
maximum wall thickness	≤ 30 mm
relative density	≥ 97 %
mechanical properties	as normal casted parts
maximum flow length	100 mm

Table 7: MIM-part's properties



Even if the European processor does not want to speculate over a price reduction, this is quite probable due to the foreseeable developments, lot sizes of 5000 parts can be already produced very economically in MIM. In addition to this, uncertainties concerning the selection or even production of the binder are reduced to a minimum because some raw material producer offer ready-to-use power/binder feedstock's.

Looking at the possible fields of application for MIM-parts, automotive and aeronautic industry, consumer electronics, office machines, electronic devices, jewellery and watch industry together with the construction industry: from this point of view this quantities are definitely realistic. Therefore the MIM process comes next to thermoplastic injection moulding and metal casting. Once the necessary capacities for production are available, many parts for the aforementioned applications will be made by metal injection moulding.

We hope that we have brought this interesting process -Metal Injection Moulding- to your attention and created your interest.
If there are any further questions, our process engineering staff are always at your disposal for a discussion or evaluation. When developing MIM-parts or building a production plant our experience of this interesting process could be very helpful to you.