METAL INJECTION MOULDING

A Manufacturing Process for Precision Engineering Components

Process Properties & Testing Technical Guidelines MIM Design Case Studies

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**Metal Injection Moulding (MIM)**

MIM 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. It is capable of producing in both large and small volumes complex shapes from almost all types of materials including metals, ceramics, intermetallic compounds, and composites. Components made by MIM technology are finding applications in industry sectors such as automotive, chemical, aerospace, business equipment, computer hardware, bio-medical and armaments.

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INTRODUCTION

Powder Metallurgy

Metal injection moulding (MIM) is a development of the traditional powder metallurgy (PM) process and is rightly regarded as a branch of that technology. The standard PM process is to compact a lubricated powder mix in a rigid die by uniaxial pressure, eject the compact from the die, and sinter it.

Quite complicated shapes can be and are regularly being produced by the million, but there is one significant limitation as regards shape. After compaction in the die the part must be ejected, i.e. pushed out of the die cavity. It will be obvious, therefore, that parts with undercuts or projections at right angles to the pressing direction cannot be made directly. That limitation is substantially removed by the metal injection moulding process.

Metal Injection Moulding

The use of injection moulding for the production of quite intricate parts in a number of plastic materials has been known for many years, and most of us come into contact with them in some form or other every day. One important feature of such parts is that they are relatively cheap. However, for many engineering applications these thermo-plastic materials have quite inadequate mechanical properties. They are relatively soft, have limited strength and do not resist elevated temperatures.

Some improvement is made possible by the use of solid fillers - ceramic or metal powders - but the real breakthrough occurred when it was found possible to incorporate a very high volume fraction of metal powder in a mix so that, instead of a filled plastic part, a plastic-bonded metal or ceramic part is produced. Careful removal of the plastic binder leaves a skeleton of metal or ceramic which, although fragile, can be handled safely and sintered in much the same way as traditional die compacted parts. After sintering densities of 95% or more are reached and the mechanical properties are, for that reason, generally superior or equivalent to those of traditional PM parts.
RAW MATERIALS USED IN MIM

In the traditional PM process it is normal to produce after sintering a part having dimensions very close to those of the original compact. In this way it is not difficult to ensure close dimensional tolerances. With injection moulding, however, the situation is quite different. The ‘green’ compact, as the as-moulded part is called, contains a high volume percentage of binder - as much as 50% - and during sintering a large shrinkage occurs. It is, therefore, a major requirement of the sintering process to ensure that this shrinkage is controlled. In this regard, MIM has an advantage over conventional PM in so far as the density of the metal in the compact is uniform if the mix has been made correctly. The shrinkage, though large, is also uniform in this case. This eliminates the possibility of warpage that can result from non-uniform density in a die-compacted part.

The rheological properties of the feedstock, that is the powder/binder mix, are of major importance. The viscosity at the moulding temperature must be such that the mix flows smoothly into the die without any segregation, and the viscosity should be as constant as possible over a range of temperature. However, the mix must become rigid on cooling. These requirements dictate the properties of the binders used, and to some extent, the granulometry of the powder. Let us look first at the powders.

### 2.1 Metal Powders

Almost any metal that can be produced in a suitable powder form can be processed by MIM. Aluminium and magnesium are exceptions because the adherent oxide film that is always present on the surface of powder particles inhibits sintering. The list of metals that have been used in metal injection moulding includes many common and several less common metals and their alloys - plain and low alloy steels, stainless steels, high speed steels, copper base alloys, nickel and cobalt base superalloys, titanium, intermetallics, magnetic alloys, refractory metals and hardmetals (cemented carbides). The most promising candidates from the economic point of view are the more expensive materials. This is accounted for by the fact that, unlike alternative processes that involve machining, there is practically no scrap which helps to offset the high cost of producing the powder in the required form. Scrap is of lesser significance in the case of inexpensive metals.

The term 'suitable powder form' deserves clarification, and it can be seen that the issue is not clear cut - there are conflicting requirements. Particle shape is important for a number of reasons. It is desirable to incorporate as high a proportion of metal as possible, which means that powders having a high packing density are indicated. Spherical or near spherical shape should, therefore, be preferred, but the risk of the skeleton going out of shape during the debinding process is increased (there is no metallurgical bonding between the particles as happens in a die pressed compact).

Average particle size and particle size distribution are also important. As is well known, fine powders sinter more readily than coarser powders. Therefore, they are the best choice for MIM, but there are a number of limiting factors. The following table compares the different powder production techniques and their relative cost for MIM powders.

**Fig.2.1:** Iron and steel powders used in MIM

<table>
<thead>
<tr>
<th>Powder Type</th>
<th>Example</th>
<th>Courtesy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonyl Iron Powder</td>
<td><a href="#">Image</a></td>
<td>BASF</td>
</tr>
<tr>
<td>Gas atomized 17-4 PH powder</td>
<td><a href="#">Image</a></td>
<td>IFAM</td>
</tr>
<tr>
<td>Water atomized 17-4 PH Powder</td>
<td><a href="#">Image</a></td>
<td>IFAM</td>
</tr>
</tbody>
</table>
Comparison of Small Particle Production Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Size [µm]</th>
<th>Shape</th>
<th>Materials</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Atomisation</td>
<td>5 to 40</td>
<td>Spherical</td>
<td>Metals, Alloys</td>
<td>Moderate to High</td>
</tr>
<tr>
<td>Water Atomisation</td>
<td>6 to 40</td>
<td>Rounded, Ligamental</td>
<td>Metal, Alloys</td>
<td>Moderate</td>
</tr>
<tr>
<td>Carbonyl</td>
<td>0.2 to 10</td>
<td>Rounded to Spiky</td>
<td>Metals</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

From ‘Injection Moulding of Metals and Ceramics’ by RM German & A Bose, published by MPIF, Princeton, USA

The Ideal MIM Powder is said to be as follows:
- Tailored particle size distribution, for high packing density and low cost (mixture of lower cost large particles and higher cost small particles)
- no agglomeration
- predominantly spherical (or equiaxed) particle shape
- sufficient interparticle friction to avoid distortion after binder removal
- small mean particle size for rapid sintering, below 20 micrometer
- dense particles free of internal voids
- minimized explosion and toxic hazards
- clean particle surface for predictable interaction with the binder.

In reality, of course, the choice is restricted to what is available, but growing demand has stimulated a major effort by powder manufacturers to produce powders that meet the special requirements of MIM.

2.2 Characterisation of MIM Powders

The test methods commonly applied in powder metallurgy to characterize powders such as sieve analysis, flow rate or compressibility are not applicable to MIM powders as their particle size is at least an order of magnitude smaller than of powders used in die compaction. Applicable test methods are the determination of the envelope-specific area (ISO 10070) and gravitational sedimentation (ISO 10076). These tests give an indication of the particle size and shape.

The test method recommended for characterizing the particle size distribution of MIM powders is laser diffractometry/scattering (Fig. 2.2). The technique has a large dynamic range (between 1 and 1000µm) that covers well the size range of interest in MIM technology. A typical plot of the volumetric particle size distribution of a gas atomized 316L powder for the manufacture of MIM parts exhibiting the accumulative and differential curve is shown in Fig. 2.3. The mean particle size D(50) and the 10% and 90% values D(10) and D(90) are given as the intersections of the accumulative curve with the respective percentages.
2.3 Binders

The binder is critical - some would say the most critical factor in the successful production of injection moulded components. To some extent the exact compositions and procedures are still proprietary secrets; however, for the most part binders are mixtures of organic compounds, the main ingredients being natural waxes or synthetic polymers. Other substances may be added to modify the properties. The table below shows the main binder systems in use today for MIM.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Main Ingredients</th>
<th>Polymer Backbone</th>
<th>Additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Binders</td>
<td>paraffin / microcrystalline / carnauba / beeswax / vegetable / peanut oil / acetanilide / antipyrine / naphthalene / PEG</td>
<td>PE, PP, PS, PA PE-VA, PE-A, PP-A, PMBA-E-VA</td>
<td>stearic / oleic acid and esters thereof, phthalic acid esters</td>
</tr>
<tr>
<td>Polycetal Binder</td>
<td>Polyoxymethylene</td>
<td></td>
<td>proprietary</td>
</tr>
<tr>
<td>Gellatin Binders</td>
<td>Water</td>
<td>Methyl cellulose / agar</td>
<td>glycerine / boric acid</td>
</tr>
</tbody>
</table>

Mixing is carried out at an elevated temperature at which the binder is liquid, and in this condition it must ‘wet’ the powder particles producing a homogeneous mix without any clusters of particles. It is in this connection that surfactants are frequently included in the composition. However, there must be no chemical reaction between the binder and the metal.

A further requirement is that the binder does not deteriorate during the process. For economic reasons it is required that the sprues (runners) and any reject green parts are returned to the granulation stage for re-use. A further factor of considerable importance is the ease with which the binder can be removed from the moulded part. This part of the process is time consuming and therefore a major item in the cost equation.

2.4 Mixing

Tumbler mixers - such as double cone mixers for example - which are widely used for the dry blending or mixing of powders - are of little use for MIM mixtures. For these it is necessary that a shearing action takes place. Several different types are available: Z blade and planetary mixers are examples. When a large amount of work is needed to secure feedstock homogeneity, twin-screw extruders can be used for the final feedstock preparation. A major objective is to ensure that the whole of the surface of each particle is coated with binder. Sometimes the powder is pre-processed in order to facilitate and intensify the contact between particle surface and binder. As has been indicated earlier, the least possible amount of binder should be used, but the appropriate volume fraction of powder depends on the powder characteristics. In industrial practice, the volume fraction of powder varies from about 0.5 to 0.7. It is usual to convert the powder-binder mix, the so-called feedstock, into solid pellets by a granulation process. These feedstock pellets can be stored and fed into the moulding machine as required.

2.5 Characterisation of MIM Feedstock

Many MIM parts manufacturers buy their ready-to-use feedstock from specialized suppliers. A consistent feedstock quality must be maintained in order to provide a high quality of the end product, both in terms of material properties and dimensional accuracy. Test methods for feedstock characterization should be agreed between the supplier and the parts manufacturer.

The test methods proposed here have been agreed by the European MIM industry and are commonly used because they are simple and inexpensive. They should be preferred wherever appropriate. However, they do not provide a thorough knowledge of the feedstock, but rather a set of characteristic values that allow to compare different batches of feedstock of the same composition. As feedstock characterization is still a relatively young field of research, new and better test methods may be developed in the future.
Shrinkage

The shrinkage from the mould dimensions to the final dimensions of the MIM component can be regarded as a property of the feedstock. Fig. 2.5 shows a test sample for the determination of the shrinkage of which two diameters are measured perpendicular to each other.

![Sample for shrinkage measurement](image_url)

**Fig. 2.5:** Sample for shrinkage measurement, Courtesy of BASF

Feedstock Rheology

The feedstock viscosity is a very important property in MIM technology, which determines how well the material can be transported and fed into the die cavity. When the flow behaviour is considered, one should bear in mind that the term viscosity can have different meanings depending on the actual conditions of testing.

Regarding the flow through a channel or orifice, which is encountered in capillary rheometer techniques, low viscosity is associated with easy flow of the feedstock. Ideally this flow would reflect the inherent properties of the feedstock. This is the case if the flow is laminar as for a homogeneous feedstock showing no wall-slip behaviour. Capillary rheometry is, therefore, an important tool if the effect of a wide range variation of the (apparent) shear rate on the (apparent) viscosity is of interest.

Of particular importance for a proper formulation of the feedstock is the so-called critical loading. This is the limit of the powder content above which the relative viscosity increases significantly. The critical loading can be determined from the viscosity measured as a function of the powder load at a fixed shear rate.

In polymer science, there are various other techniques employed to study the rheological behaviour, e.g. by controlled stress and controlled strain rheometers. However, their applicability to MIM feedstock testing remains to be validated. It should be noted that these more sophisticated methods can provide a deeper insight in the state of dispersion of the powder in the feedstock, i.e. how well the powder is dispersed in the binder.

For the communication between a feedstock supplier and a parts manufacturer the most crucial need is actually the quality assurance of MIM feedstock with specified properties. This requires a reliable, standardised measure for an easy assessment of such quality assurance. For this purpose, the Melt Flow Index (MFI) test, i.e. melt mass-flow rate (MFR) or melt volume-flow rate (MVR) testing of thermoplastics as described in ISO 1133, is available. This characteristic is derived by means of passing a certain amount of feedstock through a channel during a fixed period of time. MVR is measured in cm³/10 min, MFR in g/10 min. An automatic distance-time-measurement can be monitored (procedure, type B). The test temperature and load applied depend on the polymeric material tested, i.e. the binder in the case of MIM feedstock. For MIM applications, reported MFI values should be encompassed with information on the load or weight that is used, the temperature and test procedure.
3. MIM PROCESSING

3.1 Injection Moulding

The machines normally used for this part of the MIM process are substantially the same as those in use in the plastics industry (Fig.3.1). There are only some special features for injection moulding machines for MIM like wear resistance, screw geometry or a special control of the injection and the ejection process. These features depend on the feedstock to be processed.

The screw from which the feedstock is extruded into the die cavity is located in a heated cylinder. The temperature of the cylinder and the nozzle is carefully controlled to ensure constant processing conditions. The die temperature also is controlled - it must be low enough to ensure that the compact is rigid when it is removed.

In addition to this process called high pressure injection moulding there are also medium and low pressure injection moulding processes in use. The advantages of lower injection pressures are lower investment costs for equipment and tooling. The main disadvantage of lower injection pressure is less reproducibility of dimensions.

A method of reducing the unit cost of parts is to use a mould with multiple cavities so that several parts are produced at each injection. This is particularly relevant when very large quantities of a particular part are required.

Fig. 3.1: Injection moulding machine, Courtesy of Arburg

3.2 Binder Removal

The removal of the binder from the green part is a key step of the process and one that requires most careful control. There are several basic processes:

1. Heating of the green compact to cause the polymer binder to melt, decompose, and ultimately evaporate. This must be done with great care in order to avoid disruption of the as-moulded part, and in this connection the use of binders with several ingredients which decompose or evaporate at different temperatures is advantageous. The process normally takes many hours. Therefore debinding is conducted in a batch process. The time required for binder removal depends on the wall thickness of the part.

2. The catalytic decomposition of POM feedstock using gaseous nitric acid or oxalic acid has greatly reduced the time for binder removal and the risk of part disruption. Catalytic binder removal and sintering can either be done in batch or continuous equipment (Fig.3.2).

3. An alternative binder removal process is to dissolve out the binder with suitable solvents such as acetone, ethanol or hexane. Some binder constituents are even water soluble. Normally heating is required as a final step to complete the removal by evaporation.

4. During the binder removal process, the strength of the compact decreases markedly and great care is necessary in handling the ‘brown’ parts as they are called.

Fig. 3.2: Continuous binder removal and sintering furnace, Courtesy of BASF
3.3 Sintering

Sintering is the heating process in which the separate particles weld together and provide the necessary strength in the finished product. The process is carried out in controlled atmosphere furnaces - sometimes in a vacuum - at a temperature below the melting point of the metal.

Sintering in MIM is substantially the same as that used for traditional PM parts. It can be carried out either in a gaseous atmosphere or in a vacuum. Because it is essential to avoid oxidation of the metal, the atmospheres used are generally reducing. Apart from protecting the metal, such atmospheres have the further advantage of reducing the oxide on the surfaces of the powder particles. This surface oxide increases with decreasing particle size. As MIM uses finer powders, this is, of course, of greater significance in MIM than it is with traditional PM.

The composition of the sintering atmosphere used depends on the metal being sintered. For many metals a straightforward atmosphere containing hydrogen is all that is required, but in the case of steels which have carbon as an essential alloying element, the atmosphere must be either inert or contain a carbon compound or compounds so that it is in equilibrium with the steel, i.e. it must neither carburise nor de-carburise the steel.

The fact that the powders used are very much finer in MIM than those used in PM means that sintering takes place more readily by reason of the higher surface energy of the particles.

As the 'brown' part is extremely porous, a very large shrinkage occurs during sintering (Fig.3.3) and the sintering temperature must be very closely controlled in order to retain the shape and prevent 'slumping'. The final part has a density closely approaching theoretical, usually greater than 95%, and the mechanical properties are similar to those of wrought metal of the same composition.

3.4 Post-Sintering Operations

The properties of MIM components can be improved by many of the standard processes that are applicable to wrought metals and/or PM components, e.g. case hardening, electroplating, etc.

Often, the surface region of a MIM part is fully densified (Fig. 3.5s), so that the residual internal porosity does not negatively affect post-sintering operations.
4. MECHANICAL PROPERTIES OF MIM PRODUCTS

4.1 Tensile Properties - Tensile test samples

Due to the specific rules for shape design in MIM it is obvious that tensile test samples which can be manufactured without additional machining operations have distinct advantages both in terms of cost savings and technically. As MIM is usually a net-shape or near-net-shape manufacturing process, the technical advantage is that the surface condition of the test samples is the same as that of the MIM component. This is why the MIM industry, at an early stage already, has developed its own tensile test sample geometries. These so-called MIMA samples, designated after the American Metal Injection Molding Association by which they have first been proposed, were adopted by the ISO 2740 standard defining tensile test samples in powder metallurgy. European MIM manufacturers found that these test samples which have been designed with holes in their clamping heads in order to facilitate clamping tend to fracture outside the gauge length if weld lines or cracks are formed due to irregular mould filling. In order to avoid this problem, an additional shape was proposed which is almost identical to the MIMA shape, but where the holes at the clamping heads are missing (Fig. 4.1).

The mould dimensions (diameter at the gauge length: 5.0 mm) are between the large MIMA sample (diameter at the gauge length: 5.82 mm) and the small MIMA sample (diameter at the gauge length: 3.8 mm). All three sample geometries have been admitted and integrated in ISO 2740.

![Fig. 4.1: Tensile test sample proposed by the European MIM Industry](image)

<table>
<thead>
<tr>
<th>Mould Dimensions</th>
<th>a (mm)</th>
<th>b (mm)</th>
<th>c (mm)</th>
<th>d (mm)</th>
<th>R1 (mm)</th>
<th>R2 (mm)</th>
<th>R3 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure [mm]</td>
<td>37.6</td>
<td>5.0</td>
<td>75.0</td>
<td>5.0</td>
<td>30.0</td>
<td>7.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Tolerance [mm]</td>
<td>+0.4</td>
<td>± 0.02</td>
<td>+0.5</td>
<td>± 0.02</td>
<td>± 0.1</td>
<td>± 0.1</td>
<td>V0.01</td>
</tr>
</tbody>
</table>

Table 4.1: Mould Dimensions according to ISO 2740.

4.2 Fatigue Strength of MIM Materials

The European MIM industry is undertaking great efforts to provide design engineers with comprehensive material property data as is required by finite element analysis (FEA) and other design software. The determination of these characteristics, in particular fatigue properties, is costly and time consuming. So far, only a few data are available, but these demonstrate that heat-treated MIM steels have a high potential of fatigue properties.

Mechanical Properties Achieved by Tensile Testing

One of the strengths of metal injection moulding is the wide range of materials that can be manufactured in this technology. Many ferrous alloys are produced in MIM, the most widely used being stainless steel. Heat treatable alloy steels are used for high strength requirements. Soft magnetic alloys are also available. Non-ferrous materials include cobalt and nickel base alloys, niobium, titanium, tungsten, copper and even aluminium.

Table 4.1 lists mechanical property data that have been determined for a range of materials processed by MIM. More mechanical and physical properties are given in the Global PM Property database an independent online resource which can be found at [www.pmdatabase.com](http://www.pmdatabase.com)
<table>
<thead>
<tr>
<th>Material</th>
<th>Compositio, wt. %</th>
<th>Density %</th>
<th>Yield Strength Rp0. UTS Mpa</th>
<th>Elongation %</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020 steel</td>
<td>Fe-0.2C</td>
<td>96</td>
<td>185</td>
<td>380</td>
<td>23</td>
</tr>
<tr>
<td>2208 (HT)</td>
<td>Fe-2Ni-0.8C</td>
<td>97</td>
<td>1370</td>
<td>1780</td>
<td>3</td>
</tr>
<tr>
<td>2700</td>
<td>Fe-7Ni</td>
<td>99</td>
<td>310</td>
<td>420</td>
<td>34</td>
</tr>
<tr>
<td>2705</td>
<td>Fe-7Ni-0.5C</td>
<td>98</td>
<td>495</td>
<td>860</td>
<td>12</td>
</tr>
<tr>
<td>4120</td>
<td>Fe-1Cr-0.2C</td>
<td>97</td>
<td>241</td>
<td>483</td>
<td>17</td>
</tr>
<tr>
<td>4140</td>
<td>Fe-1Cr-0.4C</td>
<td>97</td>
<td>400</td>
<td>719</td>
<td>3</td>
</tr>
<tr>
<td>4140 (HT)</td>
<td>Fe-1Cr-0.4C</td>
<td>93</td>
<td>1240</td>
<td>1380</td>
<td>2</td>
</tr>
<tr>
<td>4340</td>
<td>Fe-2Cr-1Ni-1Mn-0.4C</td>
<td>96</td>
<td>700</td>
<td>945</td>
<td>9</td>
</tr>
<tr>
<td>4340 steel (HT)</td>
<td>Fe-2Cr-1Ni-1Mn-0.4C</td>
<td>95</td>
<td>1410</td>
<td>1780</td>
<td>3</td>
</tr>
<tr>
<td>4640 steel (HT)</td>
<td>Fe-2Ni-1Mo-0.4C</td>
<td>97</td>
<td>1400</td>
<td>2000</td>
<td>3</td>
</tr>
<tr>
<td>Fe50Co</td>
<td>Fe-50Co</td>
<td>99</td>
<td>284</td>
<td>485</td>
<td>4</td>
</tr>
<tr>
<td>FL-02N2C (HT)</td>
<td>Fe-2Ni-0.5Cr-0.2C</td>
<td>97</td>
<td>887</td>
<td>1000</td>
<td>1</td>
</tr>
<tr>
<td>gold, 18 ct.</td>
<td>75Au-12.5Ag-12.5Cu</td>
<td>75</td>
<td>108</td>
<td>147</td>
<td>1</td>
</tr>
<tr>
<td>hastelloy</td>
<td>Ni-28Mo-2Fe</td>
<td>97</td>
<td>350</td>
<td>800</td>
<td>40</td>
</tr>
<tr>
<td>inconel 718 (HT)</td>
<td>Ni-19Cr-18Fe-5Nb</td>
<td>100</td>
<td>1100</td>
<td>1330</td>
<td>14</td>
</tr>
</tbody>
</table>

| Table 4.2: From Global PM Property Database and ‘Injection Molding of Metals and Ceramics’ by RM German & A Bose published by MPIF, Princeton, USA 1997. Reprinted with permission |
4.3 Global Powder Metallurgy Property Database

In 2004 the EPMA, together with the similar associations MPIF and JPMA, launched a website: http://www.pmdatabase.com that has become a standard reference for designers willing to understand the properties of candidate PM materials for their projects. A thorough collection of properties of materials, including since 2007 also MIM materials, is available at no cost for registered users. The materials are fully searchable using many different criteria and information on suppliers is also available.

4.4 MIM Materials for High Loading Applications

Two steels have been selected as representatives of heat treatable high strength materials: the precipitation hardening MIM-17-4 PH stainless steel and the low alloy MIM-4340 steel. The latter is representative of conventional quench-and-temper heat treatments. The high strength potential of these steels as produced by MIM technology has been demonstrated and the results could be the basis for the development of new MIM products for high loading applications.

**Heat Treatments**

The heat treatments recommended for MIM-17-4PH and MIM-4340 were chosen in order to achieve a compromise between high strength and hardness as well as sufficient toughness and ductility.

**MIM-17-4 PH**

Solution treatment: 1h/ 1050°C in vacuum  |  Ageing: 4h/ 480°C in air

**MIM-4340**

Normalising: 20 min/870°C in vacuum  |  Hardening: 15 min /840°C in nitrogen, then oil quench  |  Tempering: 2h/425°C in air

**Fatigue Strength**

Test specimens from several parts manufacturers were investigated in order to have a representative data base. Axial fatigue tests were performed in the R = 0 loading mode (pull-pull test) at a frequency of 20 Hz. Tensile test specimens according to ISO 2740 were used as moulded, i.e. without machining, grinding or polishing the sample surface in the gauge length. The fatigue limit was determined at 2x106 cycles. The test results obtained for MIM-17-4 PH are shown in Fig. 4.2. The plot shows that the samples of some manufacturers have longer fatigue life than others. Improvement of the fatigue life can be expected with optimized manufacturing, surface quality and heat treatment. The lower limit of the fatigue strength was determined at 280 MPa.

![Graph: Example of plotted chart from GPMD](image)

**Fig. 4.2:** Axial fatigue test plot for MIM-17-4 PH (R = 0), Courtesy of LNEG
The MIM-4340 material specimens exhibited a high surface quality with very little pores at the surface or underneath, although the total porosity was about 4%. From literature, for a wrought SAE 4340 material, similar heat treatment and tested by plane bending, fatigue strength at 10^6 cycles of about 660 MPa was reported. The results obtained for the MIM-4340 material are at a fatigue limit of approximately 500 MPa (Fig. 4.3). These results demonstrate that MIM materials can have a promising fatigue strength if particular care is taken in the manufacture of MIM parts. Particular attention is recommended on mould preparation, e.g. mould parting lines (as the majority of failures occurred along this line) and a high surface quality in order to achieve appropriate fatigue properties.

Fig. 4.3: Axial fatigue plot for MIM-4340 (R = 0), Courtesy of LNEG

European Metal Injection Moulding Group (EUROMIM)

Objectives
The EuroMIM was formed out of the successful three year MIM Thematic Network "MIMNet" which finished in October 2000. EuroMIM had its inaugural meeting in January 2001. The group’s objectives are to:
- Develop the potential and capabilities of MIM
- To promote MIM to end users in particular to promote EuroMIM Group members specialities
- Provide a united European voice to the outside world

Membership and Structure
The EuroMIM Group covers over 70 companies from across Europe and from all parts of the MIM supply chain.

Activities and results
The group has been involved in a range of activities and has achieved several successes.

Promotion of European MIM
- Global PM Property Database - MIM Section
  www.pmdatabase.com
- Design for PM
  www.designforpm.net
- Promotion at Exhibitions

Standards and Legislation
- ISO Standards
- EPMA and REACH

Technology and Quality Development
- Benchmarking of European MIM Companies
- FP7 and Opportunities for MIM
- Workshops at the EuroPM Event

For further details contact the EPMA Secretariat info@epma.com
5. DESIGNING FOR MIM

5.1 MIM Part Design Guidelines
Generally speaking, any shape that can be produced in thermoplastics by injection moulding can be produced in metal by MIM, but there are certain limitations to this general rule in both cases.

A collection of MIM parts is shown in Fig. 5.1. These are examples of the shape complexity of MIM components. The case studies at the end of this brochure provide further illustrations of the complexity of parts designed for MIM.

5.2 Mould Design

Uniform Wall Thickness, Coring and Holes
Uniform wall thickness is desirable in order to avoid distortion, internal stresses, voids, cracking and sink marks. Variations in wall thickness can also cause variations in shrinkage during sintering making dimensional control difficult. Examples of designing for uniform and minimised wall thickness are shown in Fig. 5.2. One method used to attain uniform wall thickness is coring (see examples in Fig. 5.2), and coring / minimised wall thickness can also reduce cost by reducing material and processing times. In some parts coring can easily be achieved by adding holes that are formed by pins protruding into the mould cavity. Through holes are easier to mould than blind holes, because the core pin can be supported at both ends.

Blind holes formed by pins supported at only one end can be off centre due to deflection of the pin by the flow of feedstock into the cavity. Therefore the depth of a blind hole is generally limited to twice the diameter of the core pin. Holes perpendicular to one another cause special problems of sealing-off or closing-off in the mould. By redesigning one hole to a 'D' shape, the tooling will function better; be stronger; and minimise flashing. An example of this construction is shown in Fig. 5.3.

Reinforcing ribs are another effective way to improve rigidity and strength in parts with thin walls. The thickness or width of a rib should not exceed the thickness of the wall to which it is joined, with the principle of uniform wall thickness being maintained whenever possible. However, while ribs can increase part strength, improve material flow, and prevent distortion during processing, they may also produce warpage, sink marks, and stress concentrations. Ribs should be added to a part design cautiously, and it is often better to wait for an evaluation of the initial tool samples.

In some parts, different wall thicknesses cannot be avoided. A gradual transition from one thickness to another reduces stress concentrations and poor surface appearance (flow lines). The recommended ratio for transitions is shown in Fig. 5.4. In addition, the mould should be gated at the heavier section to ensure proper packing of the feedstock.

### MIM Compact Design Guidelines

<table>
<thead>
<tr>
<th>Restrictions</th>
<th>Desirable Features</th>
<th>Allowed Design Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>• no inside closed cavities</td>
<td>• gradual section thickness changes</td>
<td>• holes at angles to one another</td>
</tr>
<tr>
<td>• no undercuts on internal bores</td>
<td>• largest dimension below 100mm</td>
<td>• hexagonal, square, blind and flat bottom holes</td>
</tr>
<tr>
<td>• corner radius greater than 0.075mm</td>
<td>• weight under 100g</td>
<td>• stiffening ribs</td>
</tr>
<tr>
<td>• 2° draft on long parts</td>
<td>• wall thickness less than 10mm</td>
<td>• knurled and waffle surfaces</td>
</tr>
<tr>
<td>• smallest hole diameter 0.1mm</td>
<td>• assemblies in one piece</td>
<td>• protrusions and studs</td>
</tr>
<tr>
<td>• minimum thickness 0.2mm</td>
<td>• flat surfaces for support</td>
<td>• external or internal threads</td>
</tr>
<tr>
<td>• range weight 0.02 g to 20 kg</td>
<td>• small aspect ratio geometries</td>
<td>• &quot;D&quot; shaped and keyed holes</td>
</tr>
</tbody>
</table>

Table 5.1: (From 'Injection Moulding of Metals and Ceramics' by RM German & A Bose, Published by MPIF, Reprinted with permission)
MIM - Metal Injection Moulding

Gating
Feedstock enters the mould cavity through an opening called a 'gate'. In general, gate locations should permit the feedstock to flow from thick to thin sections as it enters the mould cavity. Ideally, the flow path from the gate should impinge on the wall of the cavity or a pin as shown in Fig. 5.5. A flow path of thin to thick, generally, will cause voids, sink marks, stress concentrations and flow lines on the part surface.

Many MIM components are produced using multiple cavity tooling, where each cavity must be identical to the others. To ensure part reproducibility, the gate and runner system to each cavity must be carefully sized and located so that each cavity will be filled with the identical amount of feedstock at a balanced fill rate. Since the gate will leave a mark or impression, its location must be carefully selected with regard to part function and appearance.

Reducing Stress Concentrations
Sharp internal corners and notches should be avoided because they cause stress concentrations. Thus generous fillets or radii, which will also improve feedstock flow during moulding and assist in the ejection of the part, should be considered. Both inside and outside corners should have radii as large as possible, typically not less than 0.4 to 0.8 mm.

Design of Threads
When required, external and internal threads can be automatically moulded into the part, thereby eliminating the need for mechanical thread-forming operations (Fig. 5.6). Internal threads are typically moulded by using automatic unscrewing devices, but this route is often not cost-effective and tapping should be considered.

Mould Parting Lines
Mould parting lines are formed by the opposing faces of the mould, in the plane where the mould halves are separated to permit removal of the part, as was shown in Fig. 5.6. With moulds of normal construction this feature is transferred as lines or witness marks onto the surface of the part.

Undercuts
Undercuts, classified as internal and external are often required for part function. Undercuts may increase tooling costs and lengthen cycles, but this is dependent on the type and location of the undercuts on the part. External undercuts, often specified on MIM parts for ‘o’-ring seating, can be formed by using a split cavity mould. As with the threaded components, there will be two parting lines 180° apart on the surface of the undercut, which may be objectionable in an ‘o’-ring groove. Internal undercuts can be formed by using collapsible cores. Most MIM parts are relatively small and cannot accommodate this approach, but other possibilities may prove viable, like using special plastic cores that are destroyed before sintering, or even sinter joining two or more MIM parts together. Thus, designing MIM parts with internal undercuts or recesses is not recommended but not unfeasible.

Part Ejection from Mould Cavity
Draft, or a slight taper, may be required for the ejection of parts from the mould cavity. This is particularly true for core pins, and the need increases with the depth of the hole or recess being formed. When draft is required, an angle from 0.5° to 2° is generally sufficient. Knock-out ejector pins are usually required for removing parts from the mould, and good design of these pins is critical to minimise flash marking of the parts. Especially for softer feedstocks the contact area of ejector pin and part (related to the diameter of the ejector pin) should be large enough to avoid local destructions of the part.
**Mould Fill Design**

Fig. 5.7 and Fig. 5.8 demonstrate the usefulness of mould design by computer simulation of the injection moulding process. Software packages are e.g. SIGMASOFT® or MOLDFLOW®. The part in Fig. 5.7 exhibits a weld line in a critical position of high stress. This weld line can be moved to an uncritical position by re-design. The gate position was shifted and a flow deflection was achieved by reducing the wall thickness (Fig. 5.8). The mould design software system is suitable to optimize part design, mould filling and gating in single and multicavity moulds. Work on modelling software is continuously progressing and models will eventually predict also other facts like, for instance, distortion due to powder-binder segregation effects.

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**Fig. 5.5**: Gate location  
Courtesy of Metal Powder Report

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**Fig. 5.6**: Moulding External Threads,  
Courtesy of Metal Powder Report

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**Fig. 5.7**: Moldflow® simulation of mould filling with critical position of weld line, Courtesy of IFAM

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**Fig. 5.8**: Moldflow® simulation of mould filling with critical position of weld line, Courtesy of IFAM

---

**5.3 Size of MIM Parts**

There is, theoretically, no limit to the maximum size of part that could be produced, but economic considerations restrict the sizes that are currently viable.

There are two important factors in this connection:

1. The larger the part the greater is the proportion of the overall cost that is attributable to the raw material which is costly. The total cost of the powder is a linear function of the weight of the part, but in the case of parts produced by machining from solid bar stock, for example, the machining costs increase with increasing part size at a much lower rate.

2. The thicker the section the longer the debinding time, and thus the higher the cost of that part of the process. At the present time, the limiting thickness seems to be about 30mm.
5.4 Dimensional Accuracy of MIM Parts

One of the most frequently asked questions when a new application is considered refers to the dimensional tolerances that can be achieved by MIM processing. In order to provide background input data for the assessment of the dimensional accuracy of MIM parts, real part data has been collected from several European manufacturers.

For dimensional tolerances (critical measures) the limits according to the table (next page) have been proposed.

<table>
<thead>
<tr>
<th>TYPICAL DIMENSIONAL TOLERANCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Injection Moulding Components</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>[mm]</td>
</tr>
<tr>
<td>&lt;3</td>
</tr>
<tr>
<td>3 - 6</td>
</tr>
<tr>
<td>6 - 15</td>
</tr>
<tr>
<td>15 - 30</td>
</tr>
<tr>
<td>30 - 60</td>
</tr>
<tr>
<td>&gt;60</td>
</tr>
</tbody>
</table>

Table 5.2: The MIM data has been obtained in accordance with Standard DIN ISO 2768. Better tolerances for some critical dimensions can be achieved in MIM after optimising design and process.

These dimensional tolerances can only be achieved on critical dimensions under favourable moulding conditions. Mould parting lines, varying wall thickness and other factors can adversely affect the dimensional accuracy of a part.

In Fig. 5.9, the tolerances of MIM parts are compared to the ISO tolerance classes IT 7 to IT 12. Although not identical, the tolerances of MIM parts are very similar to the IT 10 class between 3 and 35 mm. Below 3 mm, MIM is better than IT 10 and above 35 mm it is somewhat worse than IT 10. Besides the dimensional accuracy, it is also necessary to consider:

- angular tolerances
- surface finish
- radii

Here, angular tolerances are identified to be ±40’ or for improved performance criteria ±30’. The surface finish may be Ra = 4 - 20 µm depending on the type of material. MIM materials on the basis of carbonyl iron with a powder particle size of less than 10 µm tend to have a smoother surface than materials made from atomized steel powders which are considerably coarser (e.g. stainless steels). Surface finish of MIM parts is appreciably better than most investment castings. However, profiometer readings may be affected by residual porosity and are subject to interpretation. The method of measuring surface finish should be agreed upon by both the customer and the vendor. The surface finish of MIM parts can be improved by conventional processes such as grinding, lapping or burnishing. Radii should generally be at least 0.3 mm. Further details related to radii are given in the guidelines for MIM design. The following general rules should always be observed when dimensional tolerances of a MIM part are specified:

- Tolerances specified should be no closer than absolutely required for satisfactory performance and to avoid secondary operations.
- Close tolerances should not be specified for parts having major wall thickness variations.
- Close tolerances on several dimensions of a part usually result in increased part cost (secondary operations).
- Close tolerances should not be specified across a parting line or for dimensions controlled by movable cores or sliding caps.
5.5 Comparison with Competing Technologies

MIM is essentially a technology for producing complex shape parts in high quantities. If the shape allows the production of the part by, for example, conventional pressing and sintering (and mechanical properties are adequate), then MIM would in most cases be too expensive. However, if the required number of complex parts is higher than a certain amount, MIM is cheaper than machining.

Then there is the influence of part size on cost the bigger the part the smaller is the gap between the cost of say 250,000 and 3 million pieces. A typical competing process to MIM is investment casting and the table below compares the characteristics of parts produced by the two processes. In regard to many features MIM comes out on top. However, this does not tell the whole story, and many shapes that are possible by MIM cannot be produced by other routes. MIM certainly has advantages compared with investment casting in the case of high numbers of small parts, and of course in noncastable alloys.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Investment Casting</th>
<th>MIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. bore diameter</td>
<td>2mm</td>
<td>0.4mm</td>
</tr>
<tr>
<td>Max. depth of a 2mm dia. blind hole</td>
<td>2mm</td>
<td>20mm</td>
</tr>
<tr>
<td>Min. wall thickness</td>
<td>2mm</td>
<td>&gt; 0.3mm</td>
</tr>
<tr>
<td>Max. wall thickness</td>
<td>unlimited</td>
<td>~ 30mm</td>
</tr>
<tr>
<td>Tolerance at 14mm dimension</td>
<td>+/- 0.2mm</td>
<td>+/- 0.075mm</td>
</tr>
<tr>
<td>Surface roughness R&lt;sub&gt;a&lt;/sub&gt;</td>
<td>5µm</td>
<td>4-20µm</td>
</tr>
</tbody>
</table>
6. CORROSION RESISTANCE OF MIM STAINLESS STEEL

6.1 Objective
The present guidelines are intended to provide manufacturers and end users of stainless steel parts manufactured by metal injection moulding (MIM) with a basic understanding of the interrelations between corrosion resistance, microstructure and manufacturing conditions.
Recommendations are given how to define and test the corrosion resistance of MIM parts made from MIM-316L stainless steel.

6.2 Corrosion Testing
The test method recommended for stainless steel MIM components is neutral salt spray (NSS), carried out in agreement with ISO 9227. Experience shows that a 200 hours NSS test is long enough to characterise the corrosion resistance of 316L MIM parts. For a better understanding of the corrosion phenomena, the samples can be examined after 24, 48 and 100 hours. The admissible corrosion, however, should be agreed between manufacturer and customer. The normal requirement is a maximum corrosion of less than 10% of the surface. The following corrosion test methods have been critically evaluated:
- Neutral salt spray test
- Synthetic sweat test
- Artificial saliva test
- Stress corrosion test
- Susceptibility to intergranular attack
- Passivation potential measurement
- Pitting potential measurement

Stress corrosion and intergranular corrosion of MIM materials are not significantly different from wrought steels. In addition, the test samples required are very specific and the test is not easy to apply to finished products. Information about these specific corrosion conditions is also generally of low interest. Therefore, these corrosion tests are not very well suited for the characterisation of the corrosion resistance of MIM parts.

Passivation current measurements are performed on samples with a defined geometry and are not suitable for testing finished products. Pitting potential measurements are a little easier to carry out, but the values found are not always in good agreement with the salt spray results. The synthetic sweat test is a very fast and effective test when applied for 24 hours according to NF S 80-772. This test is only qualitative, but it is in quite good agreement with the salt spray test within a 10 times shorter period.

Corrosion Resistance of MIM Stainless Steels
This test can be useful for the evaluation of the performance in a very short time. The information is especially relevant when comparative tests are performed. The neutral salt spray test does not require a specific sample geometry. It can be performed on any component shape and is the most widely used and accepted corrosion test in industry. It is recommended for MIM parts. The results can best be compared with each other.

6.3 Interrelation between Corrosion Resistance and Other Properties
On the basis of more than 300 samples of 316L stainless steel MIM parts, the results of salt spray testing have been evaluated. Most of these tests have been conducted for 200 or 600 hours. Observation of the evolution of the corrosion phenomena (stain, pitting, rust, rust drips) and of the percentage of the surface affected by corrosion together with a metallographic analysis allows one to interpret the results.
The corrosion behaviour of MIM parts depends largely on the manufacturing conditions. In many cases it is possible to find interrelations between the corrosion resistance and other properties such as porosity, density, phases in the microstructure, grain size, or mechanical properties. Corrosion resistance and other properties have been compared in order to understand the reasons for differences in the corrosion behaviour and to modify the manufacturing process in order to improve the results of corrosion testing if necessary.

Mechanical properties
No clear relationship exists between tensile strength and porosity or microstructure of the material. Too many parameters affecting the tensile strength have differing effects on the corrosion resistance. Considerable differences have been found in the strength of tensile test specimens supplied from different sources, but they cannot be related to the corrosion resistance.

Porosity
A clear relationship exists between the density and the measured porosity. The bulk porosity itself has no noticeable influence on the corrosion resistance. However, the presence of open surface porosity and significant surface roughness can lead to an increase of the corrosion of the material, mainly due to crevice corrosion. Surface recesses can also be preferential sites for adhering impurities that can produce local corrosion.
Grain size
The best corrosion resistance is connected with the smallest grain size. This small grain structure is also of great importance for machining and polishing of the materials. The conditions of sintering and cooling are very important as far as the grain size is concerned.

Delta ferrite
The percentage of austenite transformed into delta ferrite during sintering is directly connected to the thermal cycle applied for sintering, and then to the grain size. Most samples having a good or very good corrosion resistance contain some delta ferrite and have a fine grain size (no. 5 or more). However, a too large quantity of ferrite is detrimental when high quality finishing is required. Heterogeneity on the surface due to delta ferrite can also have a detrimental effect on corrosion.

Carbon content
The effect of the carbon content on the corrosion resistance of 316L is well known. Low or very low carbon austenitic stainless steels are required for a good corrosion resistance. Even with powder of good quality, if the material is contaminated by carbon coming from the binder, its corrosion resistance can deteriorate.

Chromium content and chromium distribution
Chromium is essential for the formation of the passive film on the steel surface. If some chromium is evaporated, concentration of chromium can fall down below 12%. The material is then easier to corrode. During cooling, chromium can also react with carbon in order to form chromium carbides which precipitate at the grain boundaries. They form the discontinuities which allow corrosion to start. As the carbides precipitate more easily at the interfaces of ferrite and austenite, a too large quantity of ferrite can be harmful. The temperature should be reduced very quickly from 900 to 600°C in order to limit the chromium carbide formation.

Other effects
Different metallurgical problems have been discovered on some samples and can be the cause of poor corrosion resistance. The presence of impurities or inclusions, for example iron contamination of the metallic powder in the feedstock, leads to localised pitting. Intermetallic phases or mixed carbides (Cr + Mo for example) can be produced in some particular conditions, especially when a high temperature is maintained for a long time.
7.1 Two Component MIM

The two-component MIM process has been developed as a manufacturing route for the fabrication of bi-material parts. The major advantage of two component MIM is the direct combination of two materials with different properties in a single production step, therefore eliminating the need for a subsequent joining process. The range of parts that can be manufactured extends from hollow items with complex internal structures right through to flexible, non-detachable joints.

The objective in all cases is to manufacture industrial parts with enhanced functionality at a favourable cost. Parts that are subject to wear can be strengthened by using, for example, a harder or more resistant material at only critical areas and thus having a tailor-made component for an individual application.

There are a number of important material and processing requirements to be considered to produce satisfactory parts by this route, it is simply not enough to understand the injection moulding behaviour of the two feedstocks. Critically the two materials must be able to be sintered in the same furnace under the same sintering atmosphere. This is because during sintering the two parts shrink with different rates that may lead to delamination and cracking. Also diffusion of alloying elements along the boundary can take place when unwanted phases are formed which can reduce material properties.

By tuning the processing factors the quality of two component MIM parts can be optimised and as a result, due to its unique capability to enable different material properties within one part without any assembling operation, two component MIM will certainly expand the potential market for the MIM industry.

7.2 Micro MIM

The trend towards miniaturization of products and systems means that structural and functional components in complex systems are becoming smaller and smaller. The integration of an increasing number of functions can be achieved by the use of advanced materials with suitable physical properties but also by miniaturized geometrical features. Therefore highly efficient and reliable methods for the mass production of micro components or micro structured components need to be developed. Micromechanical components made by micro-MIM can be used to replace plastic parts especially to benefit from metallic material properties like mechanical strength, corrosion resistance or high temperature performance.

The success of this new manufacturing process is based on a lack of alternatives to micro-MIM. The so called LIGA technique (a combination of lithography and galvanic processes) is usually only suitable for 2D geometries and limited in the choice of materials by the galvanic process. Other technologies like electrochemical micro-fabrication methods, micro-milling and micro-grinding techniques are adapted from the silicon-based microelectronics industry having feature resolution capabilities of down to 1µm. But they are not ideally suited for the mass production of 3D components.

Indeed most of these manufacturing processes are too expensive to become cost-effective for mass production in the near future. Today micro-MIM can be used to produce micro components with feature sizes down to 5µm.

However for optimum performance, for example in terms of flow behaviour or component shape retention, tailor-made feed-stocks of submicron or nano-powders need to be developed to utilize the full potential of micro-MIM.

The general rule is that features in the order of ten times the mean particle size can be reproduced by MIM is especially valid for micro parts. If smaller features shall be produced even finer powders need to be used. The availability of metallic powders with a particle size of less than 1µm is currently limited. Some of the powders are too reactive to be produced in that size distribution range (e.g. Ti) while others can be produced more easily by a special gas atomization process (e.g. stainless steel).
If the powders are in the size range below 1 \( \mu \)m a special feedstock composition should be used to accommodate the high surface area of the powder and the problems during injection moulding and debinding.

Today micro-MIM is still in its incubation phase developing more or less in parallel with the two component MIM process. First applications for both technologies are already in production today but the situation is characterized by technology push and feasibility studies for a large variety of micro parts or micro structured components.

Pre-competitive research and development projects are key activities to develop the technology on its way to market success but a real breakthrough can only be achieved through the development of materials and process plus the education of engineers in the industry about the possibilities of micro-MIM.

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**8. SUMMARY**

**International Standards for MIM**

The European MIM industry has long recognised the need for the development of international standards. A draft European standard was produced as one output from the MIMNET project and subsequent work by the EuroMIM group has focussed on the development of an ISO standard for MIM materials. The outcome of a series of meetings and discussions with the North American and Japanese trade associations as well as the relevant ISO sub committee has been the production of such an ISO standard published in 2012 ISO 22068 Sintered Metal Injection Moulded Materials - Specifications. This covers the requirements for the chemical composition and the mechanical and physical properties of sintered Metal injection Moulded Materials. It is intended to provide design and materials engineers with necessary information for specifying materials in components manufactured by means of the Metal Injection Moulding (MIM) process only. It does not apply to structural parts manufactured by other powder metallurgy routes, such as press-and-sinter or powder-forging technologies.

There are a number of existing ISO and EN standards which are also relevant to MIM these include:

- ISO 2740: Sintered metal materials (excluding hardmetal) - Tensile testpieces
- ISO 3369: Impermeable sintered metal materials and hardmetals - Determination of density
- ISO 6892: Metallic Materials - Tensile testing at ambient temperatures
- EN 23 954, Powders for powder metallurgical purposes - Sampling
- EN 23 369, Impermeable sintered metal materials and hardmetals - Determination of density

**What next?**

This guide is intended to give an overview of the benefits and capabilities of the MIM process however before a particular grade of material is selected, a careful analysis of the part design and its end use is required, including dimensional tolerances and an analysis of part design versus tool design. The final property requirements of the finished part should be stipulated between the manufacturer and the purchaser. Issues such as static and dynamic loading, wear resistance, machinability and corrosion resistance may also be specified.

To select a material optimum in both properties and cost effectiveness, it is essential that the part design and the application be discussed with the MIM parts manufacturer, a list of such manufacturers can be found online at the EPMA website www.epma.com. Further useful information concerning the MIM process, MIM materials and the design of MIM components can be found at www.designforpm.net or www.pmdatabase.com
9. CASE STUDIES

BASE AND JAW FOR ORTHOPEDIC APPLICATIONS
(MIMEST SPA, Italy)
Originally designed for machining. Switch to MIM for economical reasons.
Redesigned in some parts for a new restyling. It has a sandblasted finish to it and it’s final weight is 922 - 968 grams.

GUIDES FOR AUTOMATIC ASSEMBLY LINE
(ITB, Netherlands)
This set of 3 parts is used in an automatic assembly line to mount electric connectors.
Weighting between 4.63 and 7.25 grams, they replace conventional parts machined out of solid material. For the material a 100Cr6 alloy was selected, sintered to a density of > 7.5 g/cm³. After heat treatment a hardness of 62 HRC was obtained.
The metal injection moulding route allowed for a light, thin wall and more complex design, introducing rectangular and square holes. Compared to conventional machining operations production cost per part was reduced by a factor 40! Due to this substantial cost reduction the MIM production route is preferred even for small quantities (several 1000 sets per year).

UNDERBAREL
(MIMECRISA, Spain)
Designed for MIM with know-How interchange between Final User and MIM maker.
Big saving in cost compared to if the part would be machined.
MIM design rules as Uniform wall thickness was needed to avoid deformation after sintering

NOZZLE
(Iscar, Israel)
This part is used for generation a powerful, quiet and laminar air stream.
The part is made from MIM 17-4PH stainless steel with precise narrow trapezium slots and customer’s logo.

COMPONENTS FOR PROSTHETIC LIMB
(GKN Sinter Metals, Germany)
Three MIM components; a blocking plate, blocking hook and a twin connecting plate are used in a new prosthetic knee produced by Otto Bock. The blocking plate and blocking hook are assembled together in the knee joint as a unit. They are used to prevent accidental variable knee flexion when necessary as a protection of the knee joint. In this case the blocking hook which is rotatable, snaps in on the blocking plate in the extended position and blocks the flexion of the prosthesis. When the blocking hook is lifted in the extended position of the prosthesis by means of a lifting device, the flexion of the knee prosthesis is activated and the patient can sit down, for example.

BOLT
(Iscar, Israel)
This part is used in medical device and made from MIM 17-4-PH stainless steel.
As a rule in conventional manufacture process such kind of articles are assembled from two parts- pin and body -that are made by machining. MIM technology allows production the part as one article, saves the material and decreases the cost of the parts for customer.

SPORTS GOODS AND HAND TOOLS
(Mimecrisa, Ecrimesa Group, Spain)
These parts for personal and professional hand tools and sports goods are made from case hardened steel like MIM-8620 with a surface hardness of 700 HV10 and fully hardened steel (arrow tip) MIM-Fe8Ni0.6C with a hardness of 50 - 55 HRC. A traditional costly manufacturing route of bending, welding and machining has been replaced by MIM. Close tolerances of ± 0.3 % are achieved, thin walls of 1mm ending in sharp corners and an external thread are possible directly by using MIM technology (see arrow tip).
ACTUATER VALVE POINT
(Iscar, Israel)
The application of this part is associated with manually actuated valves for controlling fluids such as liquid paint. The part is made from WC-12.5%Co hard metal. The mechanical properties are: hardness of 1320-1390HV, Transverse Rupture Strength of 3240 MPa minimum, toughness Klc of 17.5-19.0 MPa/m\(^{1/2}\).

SAW BLADE FASTENER
(Parmaco AG, Switzerland)
This part is used to mount the blade of an electric handheld keyhole saw. It connects the blade to the oscillating drive. The material is MIM-316L stainless steel at a density of 7.75 g/cm\(^3\). Overall dimensions are 19x12x9mm and the weight is 11.7 g. Two gates are used in moulding to ensure a good filling of the die. Tolerances on parallelism and the flatness of the slot surface are better than 0.05 mm. This MIM part was previously made by investment casting, but the tolerances were not good enough to ensure trouble-free functioning. MIM offers closer dimensional tolerances, a better surface finish (Ra 3.2 µm) and a considerable cost reduction.

LOCKING LEVER
(Iscar, Israel)
This part is used in cutting tools locking mechanism and provides locking force to clamping insert into different types of turning cutting tools. The parts is designed specifically for MIM technology and produced from MIM 4340 low alloy steel with heat treatment to the hardness of 45-48 HRC.

GEARS FOR ELECTRIC TOOTHBRUSH
(Schunk Sintermetaltechnik, Germany)
A set of two gears is used to transmit the oscillating motion of the toothbrush drive to the rotating bristles. The gears are manufactured from MIM-316L stainless steel. Corrosion resistance against water and tooth paste having pH values ranging from 4 to 10 is required as well as sufficient strength and resistance to abrasion by the polishing ingredients of tooth pastes. Dimensional tolerances met are between ISO 9 and 10. The production rate is up to 30,000 parts per day.

PISTON COOLING NOZZLE
(GKN Sinter Metals, Germany)
A MIM part and a tube are assembled and brazed to form this nozzle which cools the piston in a V8 engine. The nozzle is built into the engine block and directs a defined oil jet stream onto the bottom side of the piston. The close dimensional tolerances and the slot required for brazing can best be produced by MIM. The material is MIM-Fe2Ni at a minimum density of 7.5 g/cm\(^3\), the part weight is 11g.

CAM
(Comotec, France)
The overall dimensions of this MIM part are 6.90 x 3.20 x 2.50 mm. Diameters of the holes are 1.05 mm with tolerances of ± 0.015 mm. The weight is 0.22 g and its density is 7.88 g/cm\(^3\). No machining is needed after sintering. This part, made of MIM-316L stainless steel, is welded to a stainless steel wire. The picture shows the 3 stages of MIM process: green part, part after debinding and finished part after sintering.

DRIVING BUSH – SEAT BACKREST ADJUSTMENT
(Schunk Sintermetaltechnik, Germany)
This part is a central element of seat backrest adjustment in automotive applications made of MECO12 (1.0618) with a weight of 21.2g. The part is injected to be ready to use and will be assembled with a rubber part for limit stop damping.


**FIREARMS COMPONENTS**  
(Mimecrisa, Ecrimesa Group, Spain)  
These MIM parts weighing between 5 and 65 g are made of low alloy steels like MIM-4140 or MIM-Fe8Ni0.6C. Densities are 7.45 g/cm³ and 7.55 g/cm³ or 96% of full density. Through hardening to 40 HRC is applied. Parts can also be manufactured from stainless steel MIM-17-4 PH (density 7.65 g/cm³) which is age hardened to 40 HRC using the same injection tool. Safety levers and stoppers were tested for fatigue strength under shooting conditions. No machining is needed, simple coining operations are used in some cases. The traditional manufacturing route by investment casting plus machining has been successfully substituted with a high cost reduction and greater freedom of design.

**BURN CHAMBER**  
(GKN Sinter Metals, Germany)  
This part weighing approximately 40 g is the burner chamber of an automotive heater used in cars and trucks. The part is made from MIM-316L stainless steel at a minimum density of 7.3 g/cm³. Besides resistance to heat and oxidation, gas tightness is required. Only the outer diameter is finish machined for a close fit. Special design features include a lateral through hole at a 9º angle and the engravings on the inside which are produced during moulding.

**WATCH COMPONENTS**  
(ETA SA Fabriques d’Ebauches, Switzerland)  
These watch components such as blanks, bracelet segments, buckle parts with part weights between 1 and 2 g are made of stainless steel MIM-316L. The density required is 7.92 to 7.95 g/cm³ to guarantee a very high polishability. All these parts are MIM net shape parts (except surface finishing).

**INTERIOR GEARS**  
(Parmaco Metal Injection Molding AG)  
Our customer is one of the leading manufacturers of planetary gears and stepping motors. He wanted to find a cost effective method to produce a solution. The MIM process is this solution. The annual production quantities are app. 10’000 to 20’000 pcs. The material is AISI 17/4 PH DIN 1.4542, the weight is 10.37 g. Final density of PM product is > 7.65/cm³, hardness HRC 38, surface roughness better than Ra 2.0.

**LATCH FOR DISPENSER**  
(Parmaco Metal Injection Molding AG)  
The component is used in a hand dispenser to dispense accurately measured quantities of all kinds of liquid chemicals. This dispenser is used in laboratories. It can accurately dispense quantities of 1/1000 of 1 ml up to 10 ml. The annual requirement quantities are app. 25’000 pcs. The material is AISI 316L DIN 1.4404, the weight is 1.52 g. Final density of PM product is 7.65/cm³, hardness 85 HV1, surface quality as sintered: Ra < 1.6.

Only proficient MIM producers are capable of reproducing such fine contours as realized in this latch with huge cost advantages over any other manufacturing technique. Therefore after specifically designing for MIM cost savings of 80% compared over machining could be achieved. This gives the end user freedom of design paired with economic benefits and thus outstanding advantages in this market segment.

**GUIDES FOR RETRACTABLE CAR TOP SYSTEM**  
(Schunk Sintermetaltechnik, Germany)  
These parts are made of MECO44 (1.5735). In a CSC-car top they are applied to lock and guide the lift gate. Delivery of these parts is completed with a sliding lacquer coating.
**W-Cu/Mo-Cu-HOUSING FOR HIGH-FREQUENCY MICROELECTRONIC PACKAGING**  
(Fraunhofer Institute IFAM, EADS Deutschland GmbH, H.C. Starck GmbH, GKN Sinter Metals GmbH, Daimler Chrysler AG, Germany)

Advanced high frequency circuits are integrated on highly sensitive gallium arsenide (GaAs) chips. These chips produce a considerable amount of heat. A special housing material is required that drains and dissipates the heat due to a high thermal conductivity. Further, a low thermal expansion coefficient is needed in order to reduce the thermal stresses due to temperature changes. Tungsten and molybdenum pseudoalloys fulfill these requirements. The parts shown here are made from a Mo60/Cu40 alloy. The thermal expansion coefficient is $a = 9.7 \text{ ppm/K}$, the tensile strength is $R_m = 490 \text{ MPa}$. The parts have been developed in the research project BMBF 03 N 1030 and the development is continued with the objective of a dimensional upscaling.

**STEERING LEVER**  
(Schunk Sintermetalltechnik, Germany)

This part is supplied for use in an automotive steering assembly. It is made from MIM-4340 low alloy steel and hardened after sintering. The lever is electroplated with zinc and black chromatized in order to provide the required corrosion resistance.

**WATCHCASES**  
(ETA SA Fabriques d’Ebauches, Switzerland)

ETA turned to metal injection moulding for its range of SWATCH IRONY watchcases because of significant cost savings compared with the traditional manufacturing process. The cases which follow the same basic design as for the plastic SWATCH, are made of stainless steel MIM-316L. Density after sintering is 7.90 to 7.95 g/cm³. Generally, tolerances must be maintained at ± 0.02 mm. All watchcases are polished or brushed to provide the excellent surface finish required by marketing. Particular attention has been paid to health and safety issues, such as the prevention of nickel allergy by avoiding high nickel contents; only 316L is permitted for watchcases and watch components.

**REVERSE GEAR STOP**  
(CM Pulverspritzguss, Germany)

This reverse gear stop is used in the gearbox of passenger cars. The part design was optimized on the basis of FEM analysis in order to guarantee sufficient strength of this thin-walled component. It is made from MIM-Fe8Ni. The part weight is 23 g and dimensional tolerances of ± 0.05 mm are met. The finished component is co-injection moulded with a component made from long fibre reinforced PA. The sandwich structure of this composite part is characterized by excellent strength and stiffness due to the external steel body and a noise-damping and wear resistant inlet.

**PLANET CARRIER WITH SUN GEAR**  
(Parmaco Metal Injection Molding AG)

Planetary gears are widely used to reduce the rotary speed and thus increase the rotary torque of DC motors. There is a shift to ever smaller motors and consequently smaller planetary gears. MIM proved to be the most cost effective manufacturing route for the high production volumes of 12 million Planet-Carriers with Sun Gear per year. Instead of assembling 5 parts, microMIM can produce the Planet Carrier with sun gear in one part. Cost savings are in the range of 40%. This microMIM part weighing 0.076 g. The powder is mixed of carbonyl iron powder, Nickel powder and a 316L master alloy. After sintering the parts are vacuum hardened and polished. Density 7.8 g/cm³, hardness 450-550HV1, surface roughness better than Ra 0.4.
Literature
'Powder Injection Molding - Design & Applications' by R. M German, Metal Powder Industries Federation, 2003
Soft Magnetic Materials – Fundamentals for PM and Metal Injection Moulding – Monograph Lall, Chapman
This literature and much more is available at the EPMA, Shrewsbury, UK.

Acknowledgements
The original text for this brochure was prepared and edited by Dr Georg Schlieper (Consultant), Dr Gordon Dowson (Consultant) Bernard Williams (formerly Executive Director, EPMA) and Prof Frank Petzoldt, IFAM, Bremen

For this revised version the EPMA gratefully acknowledges the assistance in particular of:
Mr Martin Bloemacher (BASF SE)
Prof Marco Actis Grande (Politecnico di Torino)
Dr Bruno Vicenzi, (MIMitalia SrL)
Prof Frank Petzoldt (IFAM Bremen)
Mr Keith Murray (Sandvik Osprey)

The EPMA is indebted to the companies producing MIM parts for their cooperation in contributing the photographs and Case Studies; also to the Metal Powder Industries Federation, Princeton, New Jersey, USA, and to the journal 'Metal Powder Report', for their permission to include much useful information on design and property aspects of metal injection moulding.

The EPMA EuroMIM Group which comprises the majority of European MIM parts producers, raw material and equipment suppliers, and research organisations developed the technical guidelines in this brochure as part of the EU funded MIMNET project.
Jonathan Wroe Executive Director EPMA - September 2013

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