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DISCREPANCIES IN DESIGN DETERMINATION OF METAL INJECTION MOLDED TENSILE TEST SPECIMENS

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Abstract: *The paper describes the discrepancies among tensile test specimens for determination of mechanical properties of Metal Injection Molding (MIM) materials. A standard used in Europe - "Sintered metal materials, excluding hardmetals – Tensile test pieces" differs from that proposed by American Metal Powder Industries Federation (MPIF) - "Preparing and Evaluating Metal Injection Molded (MIM) Sintered/Heat Treated Tension Test Specimens". While American standard prefers specimens with holes in a T-bone shape, the European specimens are flat, without holes. Cores in a mold cavity, which form the holes in test pieces, are barrier for the flow front, but also the created weld line might be a critical place for powder/binder separation of the feedstock.*

Keywords: *Metal Injection Molding, Tensile Test, Standard*

Introduction

Technology of injection molding of plastic material has been experienced during 20th century. With this technology it is possible to produce parts in large quantities in a short time, with precise details, good surface quality and textures, with high repeatability and low cost. Although it is widely accepted that any shape that can be produced by thermoplastic injection molding can be produced also with Metal Injection Molding [1], there are certain specifics and limitations of MIM, which have to be taken into account.

MIM process is essentially a three-step and involves (Fig. 1):

- formulation of a feedstock from appropriate metal powders and polymers;
- molding of a feedstock into tooling that is designed for the final part and includes dilation of the size in anticipation of sintering shrinkage;
- thermal processing of the shaped part to remove a polymer binder (debinding) and sinter remaining powder structure into the final density.

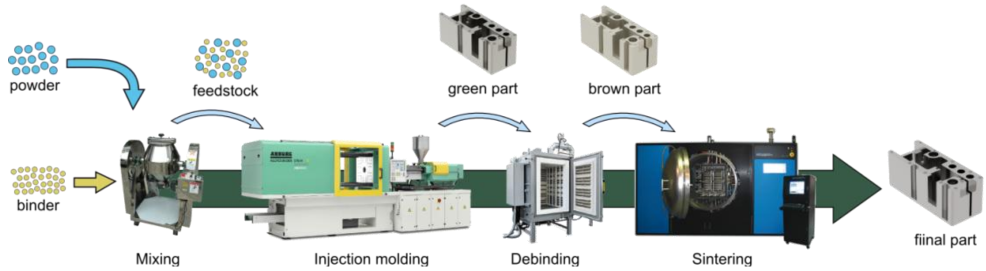


Fig. 1 - Processing steps of Metal Injection Molding

In most cases MIM technology replaces conventional machining and casting. The main benefit is the possibility to create complex shapes in one cycle. In contrast to machining, where there is almost 90 % of waste in extreme cases, MIM is no waste technology. Also with MIM the cost of the product is exponentially decreasing with the production volume.

A fundamental data of mechanical properties expressed as a tensile strength R_p for various polymers and metallic materials is shown in Table 1.

Table 1 - Strength Rp comparision of plastic and metal materials

Plastic materials				Metallic materials	
Matrix	Fibre Filler	*Rp* [MPa]		Powder	*Rp* [MPa]
LDPE		11		Cobalt – chromium F75	880
HDPE		22		Stainless 17-4 PH	900
PP		31		Stainless 440 C	620
ABS		38		Stainless 440 C (HT)	1600
PC		65		Titanium	620
PC	30 % glass	115		Toolsteel M2 (HT)	1100
PA 6		70		Hastelloy X (HT)	675
PA 6	30 % glass	140		Kovar F15	460
PA 6	50 % glass	190		Iron – Nickel FE - 42Ni	490

Geometry and dimensions of tensile test specimens depend on processing technology. Further, standard test specimens made with injection molding are different for plastic and metallic material. The standards available for MIM lack of the clarification of important issues, which are discussed in this paper.

American MPIF Standard

MPIF standard describes one shape of tensile test specimens of two optional sizes. The main difference consists in gauge diameters. While for the larger specimen the gauge diameter is 5.82 mm, at the smaller test piece it has a value of 3.81 mm. Gauge length is the same in both cases [2].

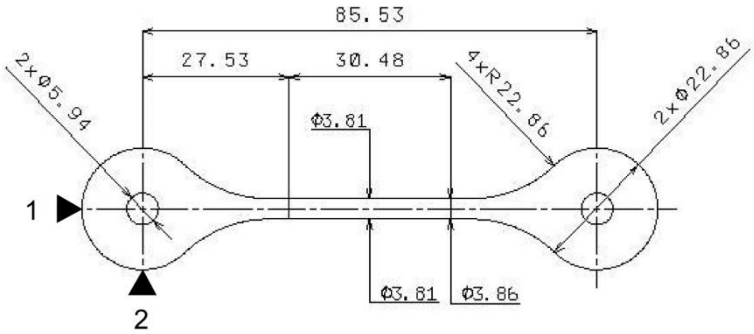


Fig. 2 - Small MIM tensile test specimen drawned from MPIF Standard

The standard does not recommend the gate location, and this might be the source of the non uniformity of this mold design with severe consequences. Usually, the molds in use have the gates located in two positions highlighted in Fig. 2. In the first option a weld line will be created along the gauge length. A sudden change in shape causes the redistribution of a flow front (Fig. 3) which might support a separation of feedstock components caused by shear rate gradients through a flow domain as demonstrated in Fig. 4.

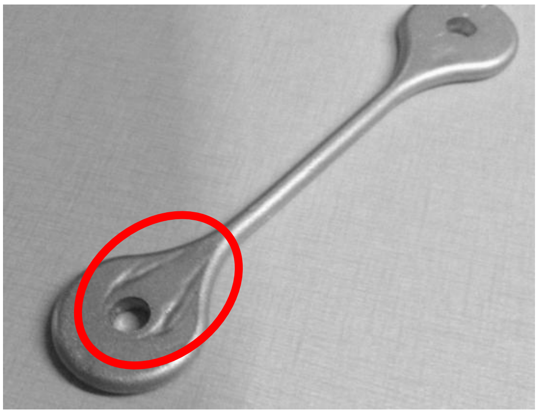


Fig. 3 - Phase separation caused by redistribution of a flow front

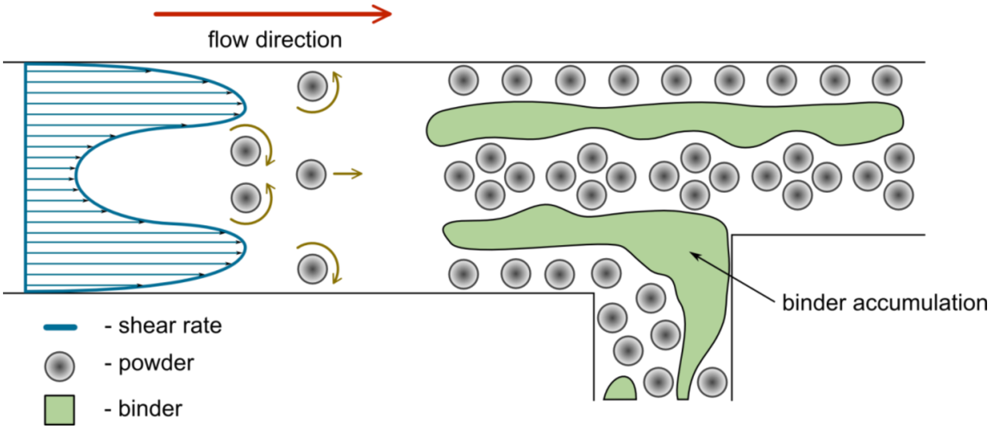


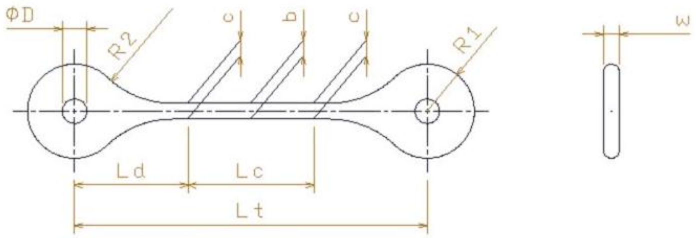
Fig. 4 - Powder/binder separation caused by shear rate gradients occuring near the chanel walls (acc. to Thornagel [3])

When the second gate location is chosen, the phase separation area and weld line are oriented in a grip section, where the negative artifacts do not affect the results of the mechanical tests.

European ISO Standard

European standard EN ISO 2740:2009 – "Sintered metal materials, excluding hardmetals – Tensile test pieces" describes two types of test specimens [4].
The first type probably originated from an inappropriate adoption of the American standard. It contains two optional sizes with the same geometry as described in MPIF standard, with similar dimensions which are differing in the tenths of millimeters, Table 2.
The main difference is in a grip section. While the American standard attributes the dimension of a grip section to diameter, the European standard attaches the same dimension to the radius.
This substitution alters the entire design of the test specimen as shown in Fig.5. To our best knowledge no mold currently used in practice has followed this design.

Table 2 - Dimensions differences between ISO and MPIF Standard



Position	Dimensions [mm]		
	MPIF Standard	ISO Standard	Difference
b	3.81	3.80	- 0.01
c	3.86	3.85	- 0.01
Lc	30.48	30.50	+ 0.02
Ld	27.52	27.50	- 0.02
Lt	85.53	85.50	- 0.03
w	3.86	3.85	- 0.01
R1	11.43	23.00	+ 11.57
R2	22.86	23.00	+ 0.14
D	5.94	6.00	+ 0.06

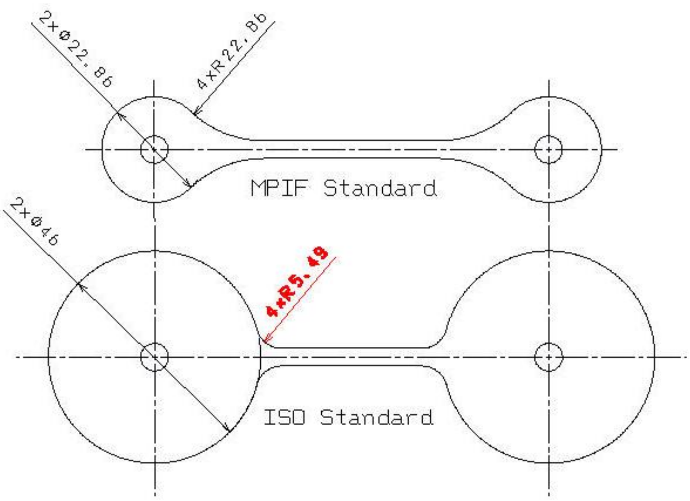


Fig. 5 - Geometry comparison between MPIF and ISO Standard test specimens

The second type included in the ISO standard (Fig. 6) is of a design similar to the previous type with changed dimensions. The geometry of a grip section is changed. In mold design the cores are removed which forms holes in section and the radius is scaled from 23 mm to 7.5 mm. This change has resulted in the increase of the dimension of transition radius of about 7 mm. Overall length is reduced from 108 mm to 90 mm and gauge length exceeds 37 mm.
According to the research published [e.g. 6-8] and personal communication with the leading research institutions in this area, the second type is often used in practice and can be recommended for a tensile tests of MIM materials. During injection molding, there is no potential place, where the weld line is created. Moreover, any position of the gate location ensures fluent flow of a material without any redistributive elements, which minimizes accumulation of individual components in feedstock.

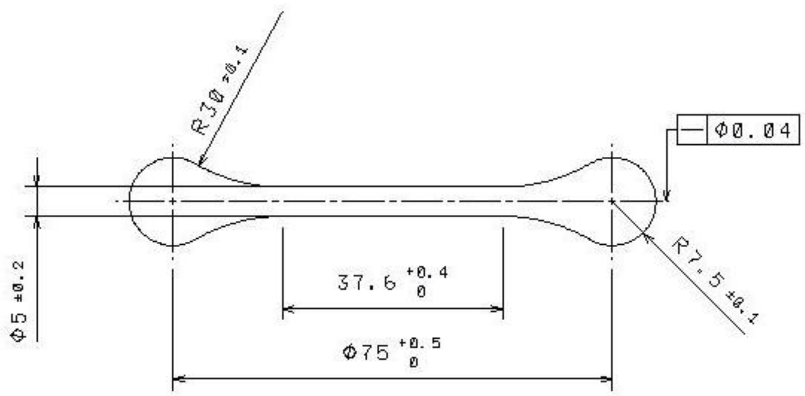


Fig. 6 - Second geometry of a tensile test specimen in ISO standard

Conclusion

Standards for tensile test specimens for MIM materials have been investigated in this work. MPIF standard lacks of the precise definition of the position of the gate to the mold, which may influence the resulting mechanical properties. It is also evident than one type of a specimen in ISO standard originated from inaccurate adoption of MPIF standard. Therefore, only the specimen described in ISO as a second type can be recommended to be followed.

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This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

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