Metal Injection Moulding: A Review of Material Properties and Testing Standards

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ABSTRACT

The Metal Powder Industries Federation (MPIF) was established to advance the powder metallurgy industry, providing foundational benchmarks for material characterization, including metal injection moulding (MIM). The MIM process involves sprues, runners, and gates, which are considered waste material; therefore, compression moulding is an alternative process to produce metal parts. However, characterization standards, especially for compression moulding, should be selected based on the MIM process framework. Over the decades, the MPIF has published a comprehensive suite of standards specifically concerning terminology, testing methods, and material specifications required to ensure quality control in MIM production. However, due to the coexistence of various standards, selecting the most appropriate protocol poses a significant challenge for researchers and manufacturers alike, as careful and precise selection requires thorough investigation. Therefore, this paper aims to review the appropriate standards for material characterization, focusing primarily on tensile testing. Given the multiple standard systems currently available in the metallurgical field, this review narrows its focus to three predominant standard frameworks for detailed comparative discussion: MPIF, ASTM, and ISO. Literature analysis indicates that evaluation of MIM components relies heavily on three primary material properties, namely mechanical, physical, and rheological properties. For the assessment of mechanical performance, specifically regarding tensile testing, the standard methodologies predominantly utilized are MPIF Standard 50, ISO 2740, and ASTM E8/E8M. Consequently, ASTM E8/E8M was selected as the tensile testing standard to be implemented for compression moulding due to its requirement for flat parallel surfaces on the specimen, which is consistent with compression moulded parts.

Keywords: Metal injection moulding; compression moulding; material characterization; tensile testing standards; standard selection

INTRODUCTION

Metal Injection Moulding (MIM) is a premier manufacturing technology for net-shape production, utilizing the injection of a mixture comprising metallic powders and polymeric binders to fabricate components with complex shapes and intricate geometries. The production of intricate metal components is often constrained by traditional metal fabrication processes; thus, MIM serves as a highly viable alternative for producing near-net-shape metal products. Consequently, a significant surge in demand for MIM products has been observed across various application sectors, including aerospace, automotive, sensors, medical instruments, and energy devices [1].

For decades, conventional MIM materials such as stainless steels, titanium and its alloys, cobalt-based alloys, and nickel-based alloys have proven indispensable for these diverse high-tech applications. However, as the geometric complexity and precision requirements of a component escalate, the tooling and mould design become substantially more complex and cost-prohibitive. For instance, in the conventional injection moulding

process, the feed system, specifically runners and sprues have generated substantial material waste, which directly inflates production costs. Furthermore, the procurement of fine powders incurs premium pricing. A prime example is the prohibitive cost associated with high-purity, spherical titanium alloy powders synthesized via gas atomization. The excessive cost of low-oxygen, fine (≤45 μm) spherical titanium powders remains a major barrier for widespread industrial applications, serving as the primary bottleneck for the MIM-titanium market compared to the well-established MIM-stainless steel sector [2].

According to Hamidi et al. (2017), [3] MIM has gained prominent recognition over the past few years for fabricating high-performance components across numerous industries. Notably, this technique has also been extensively exploited in the biomedical sector as an effective alternative for fabricating surgical and dental implants. While the injection moulding process remains the dominant paradigm for producing metal-composite parts, alternative methodologies like compression moulding emerge as highly promising, cost effective options [4].

To date, the fabrication of metal parts using metal powders combined with polymeric binders via MIM has proven highly significant in the production of complex metal components. However, conventional compression moulding has emerged as a promising alternative process due to its lower cost and the elimination of waste material such as sprues, runners, and gates. Therefore, implementing compression moulding as a cost-effective alternative for fabricating metal powder products presents significant future opportunities. Thus, the objective of this paper is to comprehensively review the material properties, material characterization techniques, and testing standards associated with MIM, with particular emphasis on identifying those that can be appropriately adopted for material characterization in the compression moulding process.

Metal Injection Moulding Properties

Mechanical Properties

Investigation of mechanical properties of MIM products has received a lot of attention for the past few years. One of the most popular tests to determine the mechanical properties of MIM is the tensile test. There are lots of tensile test of MIM parts has been conducted previously [5]. Zhang et al. [6] investigated the effect of sintering temperature on microstructure mechanical properties such as compressive strength, ultimate tensile strength and elongation of MIM parts. Sintering temperature also has affected the performance of mechanical properties due to grain growth and pore coarsening.

Some researchers studied the factors that affect the mechanical properties of MIM parts. For example, Obasi et al. [7] found that sintering, cooling rates and maximum temperature were crucial to determining the tensile strength of MIM parts. Effects of solid loading and cooling rate on the mechanical properties such as tensile strength and elongation were studied. Besides from the tensile test, stiffness of materials is very important and Young's modulus is often evaluated to determine part stiffness. In 2015, Zhang et al. [8] investigated the mechanical properties of MIM213 superalloy to fabricate turbine wheel that has a hollow internal structure and complex blade geometry in the MIM process. They found MIM is suitable for the near-net-shape forming of a turbine wheel and low tensile strength and ductility are related to the grain size formation of the semi-continuous grain boundary.

Factor such as pore structure of MIM parts is important when the compressive strength of porous titanium depends on the porosity. Hardness test of the metallic component from the MIM process has been investigated such as the effect of backbone polymer and varied volume fraction of PMMA on the hardness of MIM parts. Youhua et al. [9] studied the mechanical properties of Inconel718 alloy in MIM. They found that the effect of the heat treatment on properties of on the hardness of the MIM specimens increases while the elongation decreases. For the flexural test, Contreras et al. [10] determined the mechanical properties of the MIM part through the three-point bending flexural test. Other researchers also have studied the flexural behaviour of MIM products based on binder system and process parameters [11]. Fatigue test also has been chosen to study in the MIM part. During the investigation of the fatigue test, the study believed that the smaller grain size will be beneficial in terms of fatigue behaviour [12].

Physical Properties

In MIM, physical properties of the injected sample can be investigated based on shrinkage, density and porosity. It is reported that the selection of a binder system plays a crucial role to determine the shrinkage, density and porosity of MIM parts. Besides that, the effect of sintering parameter plays an important on the physical behaviour of the sintered part.

It is important to predict the shrinkage and suitable processing parameters to get a good dimensional quality of MIM parts. In term of the density of MIM parts, better properties of MIM parts can be achieved with higher densities. To control shrinkage, powder volume loading is very important and when the brown part is sintered at elevated temperature, the part will experience shrinkage. Hence, the sintering step is crucial in determining the final density as well as mechanical properties of MIM part.

Rheological Properties

Rheological measurements typically mean the measurement of viscosity versus shear rate. Jabir et al [13] investigated the effect of variety binder system on rheological properties of MIM feedstock. Different binder combination also influenced the rheological properties and this is because feedstock is critically important to MIM. In particular, the binders in the feedstock strongly determine MIM quality. Also, rheological or flow behaviour study of feedstock is crucial for powder injection moulding in general and especially for micro powder injection moulding [14].

Mechanical Properties Standards

Various standard systems have been identified to investigate the material characteristics of MIM. Here, three standards that have been identified will be discussed in detail such as MPIF, ASTM and ISO standard.

Metal Powder Industries Federation (MPIF)

The issuing body of this standard by Metal Powder Industries Federation from USA. For, this standard covers some aspects of powder metallurgy (PM) including components made by MIM. This standard includes various types of common MIM materials such as low alloy steel, stainless steel, soft magnetic alloys and copper. It is frequently reviewed and updated with the latest version being published in 2016 [15].

However, earlier in 2019, it is reported that the MPIF has released the 2018 edition of its Standard 35, covering materials standards for metal injection moulded parts. This standard provides the design and materials engineer with engineering property data and information to specify materials for components made using the MIM process. This standard 35 was used to mould tensile bar for various applications [16]. In addition, standard 50 is one of under the standard 35 which cover the tensile standard.

MPIF standard 50 is about the preparation and evaluation of the tensile test specimen to determine the tensile properties of sintered MIM material. It is found that a researcher has conducted testing by following MPIF standard 50 in their research [17]. In 2009, Huang and Hsu [18] performed injection moulding on the MPIF standard tensile flat bar. The tensile flat bar has 108.39 mm in length, 3.81 mm in width and 3.86 mm in thickness. Other researcher used different dimension which the total length of the tensile test specimen is 100 mm while its gauge length is 38.5 mm.

The width and thickness of the tensile test specimen are 6 mm and 3.5 mm respectively [19]. Further, Youhua et al. [9] designed a single cavity mould of the tensile specimen according to MPIF guidelines. The standard dimensions of the tensile samples were 85.25 mm × 3.82 mm, with a gauge length of 9.65 mm. Flexural behaviour of green MIM part also was conducted according to MPIF standard 15 [20]. MPIF standard 43 was used to determine the hardness of the metal part. The mechanical properties of the sintered MIM part also used MPIF standard 41 to analyse its mechanical properties especially for transverse strength [21].

American Society for Testing and Materials (ASTM)

The issuing body of this standard by ASTM International from USA, formerly known as the American Society for Testing and Materials. It has published four MIM standards, with the first being issued in 1997 that focuses on material properties such as titanium and its alloy, steels and cobalt-chromium. ASTM B883-15 has been issued as a standard for MIM materials. The ASTM standard was adapted from MPIF standard 35 but it only covers few data of materials such as stainless steels, low alloy steels and copper. Further, research has conducted a tensile test where the ultimate tensile strength and elongation have fulfilled the ASTM B883-10 specification standard for ferrous materials in MIM. Tensile in ASTM B883 applied ASTM E8 according to the designation in ASTM B883. Besides, ASTM E8 is also used in the test method for tension testing of metallic materials.

ISO Standard

The issuing body of this standard by International Organization for Standardization. According to Mulser [15] during 1996, the International Organization for Standard (ISO) committee founded a working group that was dedicated to MIM. The work then resulted in ISO standard 22068 which it was issued in 2012 and specifying physical and mechanical properties of MIM materials. Furthermore, suitable tensile test specimen for MIM was introduced and has been added to the ISO 2740 standard in the mid-1990s. This standard specifies tensile test pieces for PM technologies. ISO standard 2740 can be applied to all sintered metals and alloys except for hard metals.

Some studies have followed this ASTM 2740 to inject MIM tensile test specimen with “dog bone” shape by referring to this standard [22]. In 2017, Hnatkova et al. [23] injected MIM feedstock into a tensile bar mould according to ISO 2740. Then this standard also has been implemented in 2018 for biomedical applications where MIM specimen was prepared according to ISO 2740-B [24]. On the other hand, it is found that there are some researchers have not mentioned the standard that they used in MIM studied. However, in their research paper, for example, Santos et al. [25] have shown the dimension of tensile test specimen used.

DISCUSSION

All three standards, MPIF Standard 50, ISO 2740, and ASTM E8/E8M are used to evaluate the tensile properties of sintered MIM materials, but they differ in scope and application. MPIF Standard 50 is the most MIM-specific and widely used in North America, employing a flat dog-bone specimen that is moulded directly without machining, though the inconsistency in reported specimen dimensions across studies limits cross-study comparability. ISO 2740 covers all powder metallurgy technologies and is internationally recognized, referencing ISO 6892-1 for the test method and ISO 22068 for MIM material acceptance values, making it the preferred choice for biomedical and global MIM research.

ASTM E8/E8M is the most procedurally rigorous but is a general metallic materials standard that must be used alongside ASTM B883 when applied to MIM, with narrower material coverage compared to MPIF Standard 35. Overall, the three standards complement one another, and the most appropriate choice depends on the research context, geographic region, and application requirements.

Figure 1 shows the tensile test specimens for MPIF Standard 50, ISO 2740, and ASTM E8/E8M used in MIM. For compression moulding applications, the most suitable tensile testing standard is ASTM E8/E8M, as it specifies a flat unmachined specimen geometry consistent with powder metallurgy materials. This is attributed to the fact that the specimen can be fabricated using a mould with two parting lines located at the top and bottom of the mould plates, which is compatible with the compression moulding process. Furthermore, it was found that ASTM E8/E8M shares similarities with ASTM B925 in terms of specimen geometry. In contrast, MPIF Standard 50 and ISO 2740 incorporate a corner radius in their specimen design, which prevents their direct application in compression mould preparation. Therefore, ASTM E8/E8M is the most suitable standard for preparing tensile test specimens in the compression moulding process.

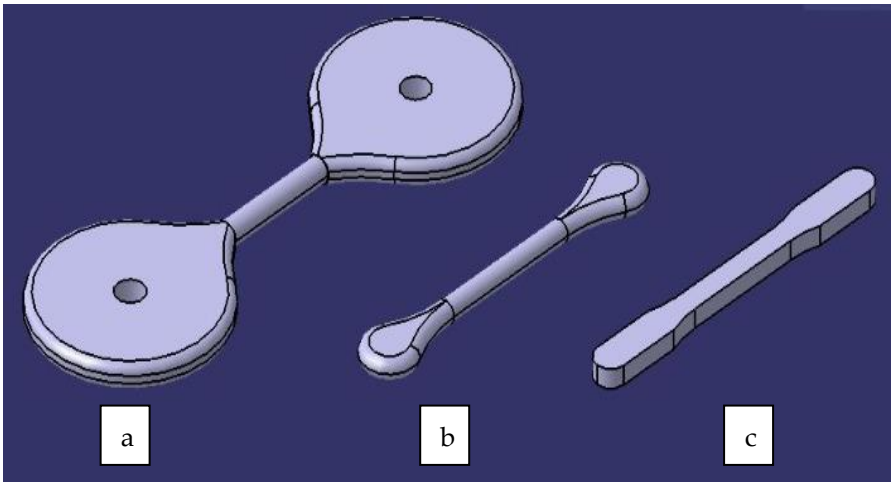

Figure 1: Tensile test standard (a) MPIF Standard 50, (b) ISO 2740 and (c) ASTM E8/E8M

CONCLUSION

Based on this review, numerous studies on the mechanical properties of Metal Injection Moulding (MIM) components have been conducted in accordance with MPIF, ASTM, and ISO standards, with the selection of each standard depending strictly on the specific requirements and objectives of the study. While MIM materials demonstrate significant growth potential owing to their diverse applications, their relatively high production cost remains a persistent challenge. A key contributing factor to this cost is the material waste generated by the feeding system comprising the sprue, runners, and gates which becomes scrap upon completion of the injection process. Consequently, compression moulding has been identified as a promising alternative manufacturing route for producing metallic parts with minimal material waste and at a lower cost. In terms of material characterization, standardized tensile testing protocols, particularly ASTM E8/E8M, are applicable to compression-moulded specimens due to their flat parallel surface geometry, which is consistent with the requirements of this standard. Therefore, the adoption of established MIM characterization standards, with appropriate consideration, presents a viable pathway for advancing the material evaluation of compression-moulded metal powder components.

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