Metal Injection Molding (MIM) Process and Potential Remedies for Its Defects: A Review

Fetene Teshome Teferi(✉) and Assefa Asmare Tsegaw

Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, P.O. Box: 26, Bahir Dar, Ethiopia

Abstract. This review paper focuses on the metal injection molding process and undesirable defects that occur during part manufacturing. In this paper, common types of metals for injection molding, process parameters, and MIM applications are deeply reviewed from recent research works. MIM process merges the high capability of plastic injection molding technology to produce intricate molds with the advantages of a powder route to process metallic, ceramic, or composites materials. The drawbacks of the MIM process come from diverse technical steps involved in the production of the part (feedstock production, injection, debinding, and sintering). The product quality of MIM is depending on feedstock preparation, mold design, process parameters like temperature and pressure, debinding technique, sintering process, etc. However, the advancement of MIM has proven that can produce very small size and large volume production with low cost when we compare to another manufacturing process. Generally, this study has been presented MIM process parameters, existed defects in MIM and possible remedial solutions, and also future research scope.

Keywords: Metal injection molding · Feedstock · Debinder · Sintering · MIM defects

Nomenclature

MIM	Metal injection molding
PIM	Powder injection molding
SEM	Scanning electron microscopy

1 Introduction

1.1 Rationale

Currently, the Metal injection molding method is not yet implemented in developing countries widely, unlike plastic injection molding. However, the MIM process has many advantages over other traditional metal manufacturing processes, it has also drawbacks that need careful analysis and monitoring during operation to manufacture

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defect-free parts. This led the review paper to be more focused on introducing the technology process, equipment, and materials, application, process parameters, and also defect minimizing techniques. The metal injection molding method is a relatively complex process and time taking but the welfares will exceed by applying optimized process parameters. Moreover, the purpose of this review is to create awareness about the production method of MIM in Ethiopia for future implementation to replace expensive manufacturing methods. Generally, the main objective of this review paper is to provide a detailed understanding of the metal injection molding process and its major defect sources. Throughout the review, the emphasis will be directed on MIM process improvements as well as identifying research scopes for further investigation.

1.2 Method

The approach to review this paper is performed primarily through surveys and summarizes of previously published studies of the subject on metal injection molding (MIM). It includes journals, peer-reviewed articles, books, dissertations, and proceedings.

2 Metal Injection Molding (MIM) Process

MIM is the recent newly developed manufacturing method by merging the process parameters of polymer injection molding and powder metallurgy process. Powder injection molding (PIM) is currently replaced the major advantages of powder metallurgy in the production of intricate and near-net-mold parts [1]. This technique combines the advantages of plastic injection molding and the versatility of the conventional powder metallurgy technique. The drawbacks of powder metallurgy now the day overcomes by using powder metal injection. Some of the limitation areas in powder metallurgy are powder compaction, the cost of machining, the productivity limits of isostatic pressing and slip casting, and the defect and tolerance limitations of conventional casting [1, 2]. The assembling cycle of metal injection molding (MIM) is more unpredictable than that of polymer infusion shaping, which emerges from the need to dispose of the folio and to densify and reinforce the part [1]. MIM is compelling as a creation cycle when four primary contemplations are fulfilled. These are minimal expense versus serious manufacture courses, superior with cutthroat properties, high mold intricacy in a more modest segment, and huge creation quantities [1, 2]. The Metal powder infusion forming is prepared by infusing powdered metals and debinders with high pressing factors instead of the ordinary gravity-took care cycles. The powder metal infusion measure has various mixes of powders like covers, shaping strategies, debinding courses, and sintering heaters. Notwithstanding, all varieties share three interaction streams: feed-stock (powders, debinders, blending) readiness, forming (rheology, device configuration, machine drama on), and warm handling (debinding, sintering, and heat treatment) [2].

The MIM cycle is made out of four principal reformist strides as demonstrated in Fig. 1. These are blending of the powder and natural folio, infusion shaping, debinding where all covers are taken out and sintering [1–3].

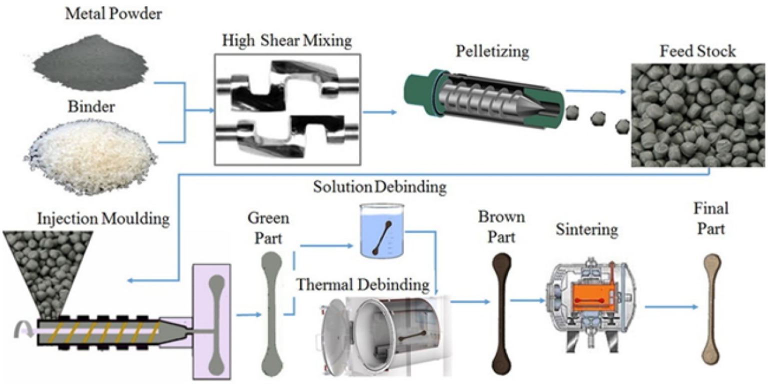


Fig. 1. Process flow of Metal Injection Molding (MIM) [3]

2.1 Steps of the Metal Injection Molding Process

2.1.1 Feedstock Preparation

Making a powder combination of metal and polymer for MIM is the essential action. The size of the metal particles utilized here is ordinarily under 20 µm than those utilized in acclimated powder metallurgy measures. Hot thermoplastic debinders are blended in with the better particles metals and afterward granulated into a uniform feedstock as pellets. The regular proportion of metal particles and polymer in the feedstock is ordinarily 60% and 40% by volume separately [1]. The fine metal particles are completely blended in with different waxes, thermoplastics, and different fixings, and the mix is granulated to frame a feedstock. The feedstock is then taken care of into a normally utilized polymer infusion shaping machine, with trim temperatures, for the most part, going from (149 °C–260 °C). When the feedstock has qualities of a toothpaste-like consistency, it tends to shoot up into openings to mold precise segments. The feedstock is the crude material of MIM that includes the accompanying two fundamental constituents [1, 2, 4].

a. Powders. The MIM powders have a state of little, round if not circular, and deagglomerated. Presently, MIM has utilized more than 1000 assorted combinations, yet a couple is ahead like 17-4 PH treated steel (AISI 630), 316L hardened steel, and a few other spotless sheets of steel, cobalt-chromium, copper, and titanium structures [4]. To get an ideal pressing thickness, circular metal particles are picked, and stream highlights of MIM feedstock; nonetheless, some benefit fit as fiddle retention has been seen with to some degree lopsided formed particles [4].

MIM powder fabrication techniques. Powder grouping for particles size and size conveyance is a significant advance in the creation of powders for MIM since numerous MIM powders are taken from a bigger parcel of powders that have diverse particles estimates and should be painstakingly taken out to guarantee that the MIM powders are consistent on a great deal to-part premise [10, p. 50]. The procedures utilized for the creation of MIM powder comprise gas atomization, water atomization, warm deterioration, and synthetic decrease (Table 1).

Table 1. Common MIM powder fabrication techniques [4, 5, 10, pp. 50–61].

No.	Fabrication techniques	Characteristics	Sample image
1.	Gas atomization	• Produced by liquefying the metal or amalgam by enlistment or another technique for warming and therefore constraining the soften through a spout • It is applied for its round mold, high surface virtue, and high pressing thickness	See Fig. 2
2.	Water atomization	• Typically somewhat unpredictably formed and show more noteworthy surface oxidation than gas atomization particles • The creation rate utilizing water is a lot higher than that of gas • Powder cost is lower than gas atomized powder	See Fig. 3
3.	Thermal decomposition	• This strategy produces powders that have purity greater than 99% and particle sizes in the 0.2–20 μm range • The metal of interest is responded with carbon monoxide at high pressing factor and temperature to deliver a metal carbonyl. This metal carbonyl fluid is purged, cooled, and consequently warmed within the sight of an impetus, which brings about fume deterioration into a powder	See Fig. 4
4.	Chemical reduction	• The measure uses a cleaned oxide which is therefore diminished utilizing a decreasing specialist like carbon to frame carbon monoxide or carbon dioxide • Particle size can be decreased utilizing a lower response temperature; in any case, the response energy is moderate	See Fig. 5

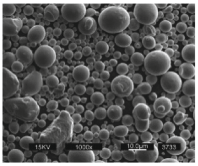


Fig. 2. A gas atomized stainless steel powder imaged by SEM.

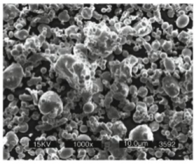


Fig. 3. Water atomized stainless steel powder imaged by SEM.

b. Binders. The principal reason for covers in the MIM interaction is to allow the development of the particles into the form kick the bucket cavity, the fastener should wet the metal particles surface, to help to join together and shaping, so a few synthetic wonders that change wetting conduct are broadly utilized. The three significant pieces

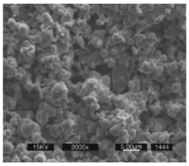


Fig. 4. A thermally decomposed iron carbonyl powder imaged by SEM.

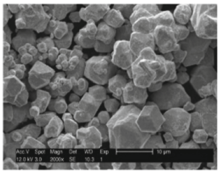


Fig. 5. A chemically reduced tungsten powder imaged by SEM.

of covers are polymers that offer strength, a filler stage that is effortlessly eliminated in the main period of debinding, and a surfactant to the connection between the folio and powder [4, 5]. As of now, there are numerous potential outcomes to pick the folio, yet no cover is great. Two fundamental prerequisites are needed for the folio: the first is to give a simple progression of the particles into the kick the bucket hole during trim, wax polymers which by and large have low thickness well satisfy this need; the subsequent one is to limit the detachment of the metal particles during the readiness of feedstock and forming, and new waxes are not satisfactory with this detail [1, 4, 5].

2.1.2 Injection Molding

The result of MIM can be formed utilizing similar hardware and tooling that are utilized in plastic infusion shaping. Nonetheless, the mold openings are planned about 20% higher to represent the segment constriction during sintering. In the MIM cycle, the feedstock is warmed, liquefied, and infused into the form opening, where it cools and solidifies into the state of the segment. The formed green part is projected out and afterward cleaned to eliminate all undesirable highlights [1, 4, 7] (Fig. 6).

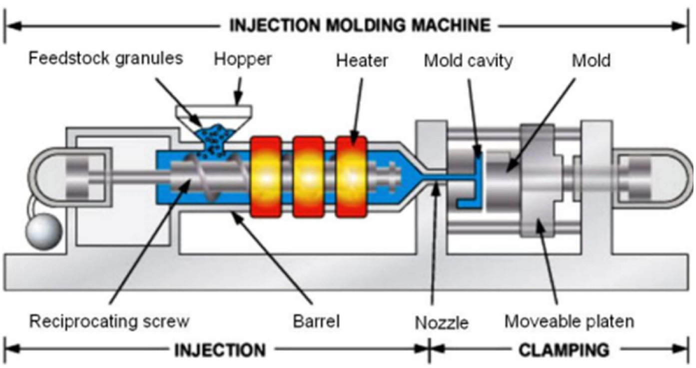


Fig. 6. Principle sketch of the injection molding equipment [7]

2.1.3 Debinding

The debinding phase of the MIM interaction dispenses with the polymer cover from the powder metal by warming it to roughly 400 °C. The outcome is known as the earthy colored part that holds its unique mathematical mold and size [1, 4, 5, 7]. The metal particles are fortified together by the remaining polymer before sintering. MIM utilizes a few variable folio evacuation strategies like warm, solvent, and synergist debinding. A bit by bit high temperature is needed in warm debinding cycles to eliminate the cover. Debinders can be additionally eliminated from the green part utilizing the solvent debinding method by dissolving it in synthetic substances or water.

The recently created debinding technique (synergist strategy) produces leaves behind the incredible mold and great dimensional control because the cycle stays beneath the conditioning point of the folio. The reactant debinding technique is tentatively demonstrated that can dispose of debinders from green parts five to multiple times faster than acclimated warm debinding measures. The temperatures needed for reactant debinding are gone from 120 to 130 °C [4, 5, 8].

2.1.4 Sintering

The last advance is to sinter the brown part in a high-temperature heater (up to 1371 °C) to little space to roughly 1–5%, bringing about a high thickness (95–99%) metal part [4, 8]. The inactive gases for the heater can be gotten from the environment and accomplish temperatures near 85% of the metal's dissolving point. Be that as it may, this withdrawal of the segment happens homogeneously and can be precisely anticipated. The sintered part saves the first formed mold with high resistances yet is present of a lot more prominent thickness. The warming temperature of the earthy-colored part is roughly 85% of the material's dissolving point during sintering, permitting densification and compression of the metal particles with the disposal of the pores [4, 5]. A net mold or close net-mold metal segment found at the last stage is comparative in properties to that of bar stock or billet. Toward the finish of the MIM cycle stage, the segments are warmed with a gum-based paint and climate profile explicit to the composite being prepared. The lingering cover is taken out at the lower temperatures of the sintering cycle (300 to 400 °C). At the point when the temperature expands, particles meld, pore volume therapists, and grain limits structure at particle contacts. The grain size and part thickness rely upon sintering time and temperature [4, 5].

2.2 Materials and Applications of MIM

The regular metal infusion-molded items are little and complex. In the MIM technique, a superior precise item is feasible to accomplish. Powder metal infusion shaping lessens the constraint forced by ordinary powder metallurgy strategies for example the sidewall ought to be equal. MIM has ready to deliver multi-practical parts with slim dividers, sharp corners, and undermines, cross openings, screw strings, molds, gear portions, and comparative highlights without auxiliary operations [4, 6–8].

The principal advantage of the MIM interaction is the creation of high-volume creation of little metal parts. The math of numerous parts made by MIM might be perplexing and have meager dividers and fine subtleties. The use of metal powders empowers a wide assortment of ferrous and nonferrous amalgams to be utilized and for the material properties (strength, hardness, wear opposition, and so forth) to be near those of created metals. The MIM measures don't need the softening of powder metal since high-temperature amalgams can be utilized with no adverse consequence on instrument life. The significant kinds of metals prepared by MIM are incorporate low composite prepares, treated steel, high velocity prepares, irons, cobalt combinations, copper amalgams, nickel compounds, tungsten alloys, titanium alloys, and so forth in various businesses, the results of MIM from metal parts are found like aviation, auto, buyer items, clinical/dental, and broadcast communications. The principal items made by metal powder infusion forming are found in PDAs, power devices, careful instruments, and different electronic and optical gadgets [4, 6, 8].

3 MIM Defects and Remedies

3.1 Problem of Feedstock Preparation

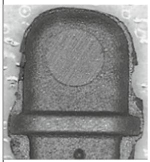
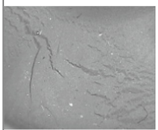
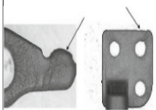
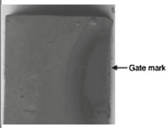
The crude powders utilized for MIM are normally very fine, generally under 20 μm, and subsequently, agglomeration could be not kidding. The solid hard constructions shaping during high-shear-rate manipulating, are remembered for the feedstock, the last sintered item could then contain inhomogeneous miniature designs [9, p. 236]. In the working interaction, a homogenous development is consistently a worry. The metal powders won't be consistently circulated if the manipulating time and shear rate are not satisfactory. Bothersome pockets of natural covers may likewise exist and cause rankling during the resulting warm debinding measure [3, 4, 9]. At the point when the powder diminishes and turns out to be consistent, the feedstock is prepared and ought to contain consistently appropriated powders and debinders. For this situation, a pycnometer thickness meter or a slender rheometer can affirm the uniform dispersion and parcel to-part consistency [4, 9].

Recycled feedstock. The decrease of the production cost of MIM items can be accomplished by reusing the entryway, sprinter, sprue, and faulty green parts. The received strategies by the MIM ventures are available [9]. The primary strategy is to add 30% to half reused feedstock to new materials, while the other is to utilize 100% reused materials. Sadly, these feedstocks debilitate the quantity of reusing emphases increments. Oxidation of the cover segments, especially on account of paraffin wax, brought about by the change of the C–C chain to the C=O chain causes the crumbling of feed-stock [4, 5, 9]. Significantly more breaks and twists of creation parts may result during dissolvable debinding with an additional emphasis on reusing because of more vulnerable holding among powders and debinders [9].

3.2 Molding Defects

MIM forming surrenders are generally equivalent to the ones experienced in conventional plastic infusion shaping. The utilization of ill-advised boundaries like temperature, pressing factor, and shot size are altogether regular reasons for issues in conventional infusion trim and they apply to MIM too. The forming apparatus itself can cause surrenders by comprising of complex math or lacking sufficient air channels. A most minor imperfection can be settled by modifying the temperature-time-pressure connection transport [5, 10, pp. 129–238] (Table 2).

Table 2. Common defects in metal injection molding [10, p. 242, 11, 12].

No.	Defects	Possible causes	Remedies
1	 Flash	• Blazes happen when the feedstock is constrained into the clearances between mold parts under high embellishment pressures • Too high a pressing factor inside the die, the helpless evenness of form surface along the splitting line, venting channel excessively enormous • Insufficient clamping force • Viscosity issue	• Utilize a huge weight machine, appropriate instrument making, utilize a lower infusion speed and trim pressing factor, improve the switch point • Minimize infusion pressure in addition to press pressure • Expanding feedstock strong stacking to improve dissolve consistency, acquaint high sub-atomic weight polymers with improving the thickness of the soften
2	 Weld lines	• Cold feedstock in the die • Weld lines form when two cold fronts meet each other	• Speed up injection time, mold temperature, and feedstock temperature, expand gate opening, add venting channels or flood wells close to weld line areas, move entryway area, update parts to stay away from stream segment
3	 Flow mark	• Cold feedstock in the die • Flow marks occur when the feedstock temperature is too low	• Speed up, form temperature, and feedstock temperature, grow gate opening, change entryway area
4	 Incomplete fill	• Misalignment of the splitting line, tooling issue, inadequate of liquid feedstock into the mold cavity • Material feeding problem • The gate gets hardened before the cavity is filled or that the shot size is essentially excessively little	• Ensuring tooling is appropriately positioned and clamped • Increment pack pressure, infusion speed, dissolve temperature, mold temperature, and shoot size • Decrease back pressure and size of the feedstock
5	 Gate mark	• With a high shear rate at the gate, powder/folio separation happens and fastener-rich entryway marks structure	• If the first entryway has a narrow column opening and is situated at a flimsy segment, it very well may be augmented and moved to a thick area. Therefore, the degree of powder partition

(*continued*)

Table 2. (*continued*)

No.	Defects	Possible causes	Remedies
			will be decreased and the stream checks and weld lines will be limited
6	Sticking in cavity	• Too high a trim pressure, insufficient warm shrinkage, early launch, ill-advised form plan or making	• Use a lower infusion speed, forming/holding pressing factor, and mold temperature, increment cooling time, take out undercut and increment the draft point, change discharge region and area, rede-sign the fastener
7	Sink mark	• Thermal shrinkage, low density • Uneven shrinkage during cooling	• Increment forming/holding pressing factor and infusion speed, decline mold temperature, increment gate territory, add venting channels, de-wrinkle speed when passing thick areas
8	Voids	• Trapped gas, absorbed moisture	• Increase holding pressure, decline infusion speed, increment form temperature, increment entryway territory, move the gate to thick sections
9	Burn marks	• Overly heated binders	• Lessening infusion speed and feedstock temperature, increment gate region, change entryway area
10	Shrinkage and/or warpage	• Parts distort during ejection • Pressure gradient in component	• Reduction mold temperature and increment cool time; use im-demonstrated cooling instruments and means • Decrease holds pressure
11	Crack	• Part cracking during ejection	• Lessening pack pressing factor and liquefy temperature, increment form temperature

3.3 Debinding Defects

The stress which is existed during the removal of the binder may cause the product defect. During debinding, gravity and the decreasing amount of binder are not the only defects vulnerable for components. The debinding methods by themselves cause stress inside the parts. The irregular thermal expansion, harsh energy-rich atmosphere accommodates and other problems are the most common debinding defects like cracking and distortion [1, p. 210, 12, pp. 243–244].

3.3.1 Thermal Debinding

The main source for warm debinding imperfection is simply too fast warming. The cycle should be exceptionally delayed to keep away from surrenders, even a few days in length debinding times aren't extraordinary. Warm debinding works by debasement of cover parts into gas. If the gas development is large and legitimate pore channels haven't molded at this point pressure inside the parts will make pressure. The main defects like cracks and blisters are built up by the high pressure of molding. The gas build-up problem will not be solved rapidly by decreasing the heating rate. If the components find themselves distorted or bent the answer is probably going to be an equivalent. The reduction of distortions occurs by utilizing some sort of ceramic support for the parts. The removal of formed gas will be also accelerated by good airflow around the parts and thereby reducing the pressure inside [5, 10, pp. 245–248, 11].

3.3.2 Solvent Debinding

The defect of items in MIM that is helped by dissolvable debinding isn't straightforwardly corresponded to the debinding boundaries. The transcendent reason for abandons in MIM items is feedstock body electorate and trim methods. The elements of folio segments may not be flawlessly appropriate with one another in the dissolvable. The MIM segment can miss its underlying honesty if some folio part gets uncover at an evil fitting time. The inadmissible mix of spine polymer and the dissolvable is additionally a reason for deserts. Entering dissolvable in the fastener causes the polymer to grow, the bigger the development the more noteworthy the pressure. Drooping and breaking are the most regularly experienced deformities in dissolvable debinding. The change of cycle boundaries probably decreases abandons that can't be altered by folio science or high embellishment pressure. Guidelines to the embellishment cycle or exchanging feedstock/dissolvable will tackle these issues [5, p. 211, 10, pp. 244–245, 249].

3.3.3 Catalytic Debinding

The further developed and gentler strategy than warm or dissolvable debinding has a higher capacity to bear the boundaries and is more averse to create surrenders. The reactant strategy is created by consolidating the warm and dissolvable debinding strategies. The synergist strategy makes gas from the surface inwards, which means caught gas won't an issue as opposed to warm debinding [10, p. 244] (Table 3).

Table 3. Common defects found in debinding of MIM [9, p. 249, 11, 12].

No.	Defects	Possible causes	Remedies
1	Cracks (solvent debinding)	• Swelling of binder components, poor bonding between binder and powder, low strength of the backbone binder, too high a molding pressure, large differences in section thicknesses	• Change the type and composition of solvent or binder, use a lower injection speed and molding pressure, redesign parts with smaller differences in section

(*continued*)

Table 3. (*continued*)

No.	Defects	Possible causes	Remedies
			thicknesses, use lower debinding temperatures
2	Bending/distortion (solvent debinding)	• Residual stress from molding, lack of support for overhanging sections, entrapped air	• Bake between 50 and 908 °C, use fixtures, adjust molding parameters
3	Corrosion/stain (solvent debinding)	• The high acidity of solvent, humid environment	• Replenish solvents or use new ones, leave parts in a dry atmosphere
4	Cracks/blistering (thermal debinding)	• Overly fast heating absorbed water in feedstock, insufficient binder removal for solvent debinding, poor binder distribution, low solid content	• Use slow heating rates, extend solvent debinding time, use longer kneading time and adjust binder components, keep feedstock dry, use higher gas sweeping rate, and shorter flow path
5	Bending/distortion (thermal debinding)	• Overly fast heating, insufficient binder removal for solvent debinding, lack of support for overhanging sections, insufficient interparticle friction, too much binder	• Use slow heating rates, extend solvent debinding time, use fixtures or sands for the support, use higher gas sweeping rate, use more irregular powders, increase solids loading
6	Exfoliation (thermal debinding)	• Wax separation to the surface, overly high heating rate	• Extend solvent debinding time, use slower heating rate, and bake below 100 °C

3.4 Sintering Defect

Since this is the last cycle there are additionally minor deformities presented during past measures that will appear. The densification and shrinkage will be overseen under the sintering working guideline. Appropriately, the most well-known sintering deformities will likewise be identified with dimensional control. The natural climate is another unmistakable reason for sintering issues. For fruitful sintering, environment control is fundamental. Furthermore, the grouping of the gas chemistry needs to be adjusted. Notwithstanding dimensional and environment-related imperfections, the familiar forming and debinding absconds are breaking, twisting and rankles, and so forth are on the whole regular during sintered also [5, pp. 249–250]. The components' thickness will be expanded by observing dad parameters of sintering. The sintered segment will have great strength when its thickness is higher and compacted. On the off chance that the fastest-warming rate in the sintering cycle may cause the imperfections like breaking and twisting. If the pinnacle temperature isn't sufficiently high the metal particles won't intertwine as expected regardless of how long the sintering continues, leaving the thickness too low bringing about poor properties [10, p. 159]. Over sintering is an imperfection brought about by grain development in the microstructure. The enormous grain size getting in MIM segments causes a decrease in mechanical properties. The refinement of the grain size shows an ideal strength of the part as the thickness to be pretty much as high as could be expected (Table 4).

Table 4. Common defects found in sintering of MIM [9, 11, 12].

No.	Defects	Possible causes	Remedies
1	Dimensional defects	• Tool design error • Uneven heat exposure • Non-uniform shrinkage	• The size can be changed to some degree by expanding or lessening the sintering temperature • Increasing the sintering time can also be a cure
2	Atmosphere related defects	• Improper chemical reactions between the metal parts and the atmosphere • Oxygen leaking in the sintering furnace	• Using a surplus of carbon of decreasing the oxygen in the atmosphere
3	Low density	• Uneven heating of the furnace • Insufficient heating temperature	• Adjusting the heating rate can alter the densification
4	Low properties	• Incomplete densification • Grain segregation during cooling	• Increasing the sintering temperature • Adjustments to the cooling parameters
5	Large pores	• Feedstock mixing problem or over sintering	• Reducing the heating rate should ease grain growth
6	Cracking	• Too rapid heating	• By diminishing the warming rate at early sintering the segments will have the opportunity to develop fortitude before they get exposed to incredible pressure
7	Distortion	• Gravity and the component support • Uneven heating	• Support that follows the part mold grantees' support for the whole part • The temperature should be uniform as possible thermal gradients are less likely

The excluded abandons which come in metal infusion formed segments ought to be checked to stay away from revamps and cost increases. MIM is a net-mold cycle to deliver generally little metal parts with profoundly complex calculations, especially fit large scale manufacturing as portrayed in Fig. 7 [13]. On account of mold's multifaceted design, added substance fabricating is the lone regular method.

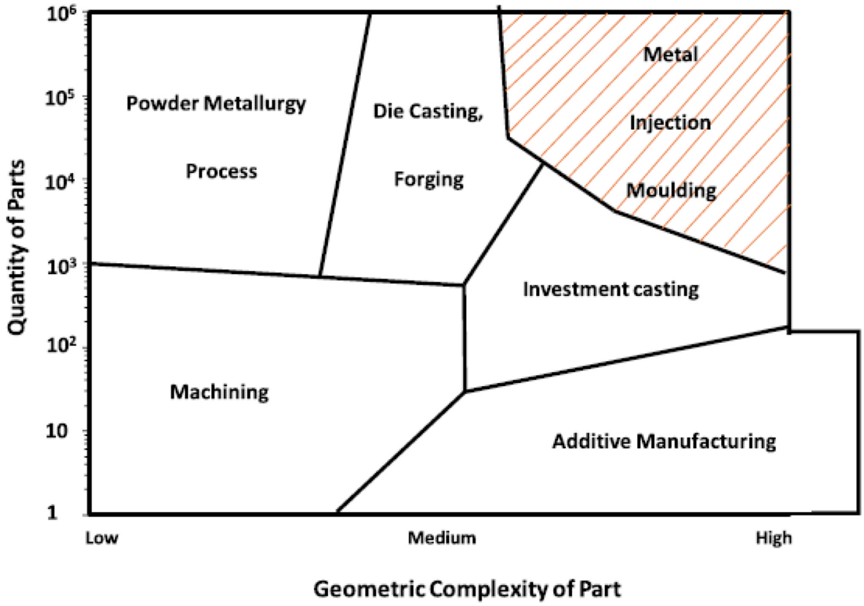


Fig. 7. Suitability of different manufacturing processes as a function of geometric complexity and quantity [13].

MIM items are different and range from buyer items, office gear, clinical instruments, and car segments to mechanical preparing hardware. In light of this wide application and its novel advantages, numerous analysts were included to research the ideal preparing boundaries. A portion of the exploration yields is introduced in Table 5 underneath.

Table 5. Recent research works on metal injection molding (MIM) [14–18]

Authors and years	Methods and materials	Results	Gaps/limitations
Wolff et al. (2016)	•Mg-alloys •Using a novel natural polymer cover, to be specific PPcoPE, material properties coordinating with those of human cortical bone tissue •Polymer content was varied between 5 and 35 m. % of the binder	•The first implant demonstrator parts could be successfully produced by the MIM technique •Dog bone molds tensile test specimens, Young's modulus test specimens, and more complex demonstrator parts, and biomedical implant screw	•Long sintering time •Sublimation of Mg-vapor on the surfaces of specimens holding the lowest temperature

(*continued*)

Table 5. (*continued*)

Authors and years	Methods and materials	Results	Gaps/limitations
	system. The powder loading was 64 vol. % for all feedstock batches	demonstrators were produced very successfully	
Veeresh et al. (2018)	•A nickel-based self-fluxing composite NiCrSiB (70% Wt.) was precisely blended in with Cr_3C_2-NiCr (30% Wt.) utilizing a high-energy ball factory •The powder (thickness of 4140 kg/m^3) with a volume part of 56% is blended in with polyethylene glycol (10% wt. Stake), Low-thickness polyethylene (35%wt. LDPE), paraffin wax (52%wt. PW), and stearic corrosive (3%wt. SA) by utilizing sigma Z cutting edge blender •The Feedstock was characterized using Differential Scanning Calorimetry (DSC) •The rheological behavior of the feedstock was determined using a Rotational Viscometer •The microstructure analysis and stage investigations of the ragged surfaces were done utilizing SEM, X-beam diffraction spectrometer (XRD)	•A nickel-based feedstock accomplished great homogeneity, warm and rheological properties, and deformity-free dissolvable debinding was done at 48 °C •The nickel-based composite was effectively evolved and created with various syntheses utilizing the MIM procedure	•Long debinding and sintering time
Askari et al. (2019)	•AISI 4605 MIM feedstock •Paraffin wax (PW) utilized as a filler to improve the rheological property of feedstock,	•The worth of thickness diminished with each additional expulsion step, while expanded the four times expulsion because of the	•If the cooling obliges a quick expansion inconsistency, the outcome might be shaping deformities

(*continued*)

Table 5. (*continued*)

Authors and years	Methods and materials	Results	Gaps/limitations
	Polypropylene (PP) and Polyethylene (PE) are spine polymers to keep the green part fit as a fiddle during the debinding and stearic corrosive (SA) utilized as a surfactant to improve the wettability of powder particles with the fastener framework	debasement of folio segments •By increasing the mixing time, powder particles are more distributed between the binder systems	like distortion and breaking in parts
Lin et al. (2020)	•MIM mold flow simulations with the Taguchi method	•The consistency of the powder particles fixation circulation can be improved by utilizing a more limited occupying time, a higher liquefy temperature, a lower pressing factor, a lower mold temperature, and a more modest gate size	•Formation of black lines •Lack of optimal MIM processing parameters

In general, many researchers have made significant studies on the MIM process by applying experiments and optimization techniques to reduce part defects and also product costs. However, MIM has a unique advantage over another manufacturing process, it is not yet implemented in developing countries like Ethiopia because of a lack of knowledge on the process application. Hence, the reviewer recommends that investors should emphasize their business in this area in the developing countries since it is untapped manufacturing technology for the production of high volume with lower cost.

4 Future Works

MIM is an effective manufacturing method for smaller size, massive in volume, and intricate mold of components from metallic powders. Thus, the debinding method and sintering process further demands scientific guidelines to obtain quality and cost-effective parts. Also, the process parameters need detailed analysis and optimization for valuable outputs using computer simulations and advanced optimization techniques. Moreover, the invention of a new type of feedstock enhances the versatility of product mixes in a specific industry. Researchers should also think about the integration of MIM with 3D printing and other suitable processes to improve the appropriateness of variable material powders.

5 Conclusion

With MIM processing technique micro parts, as well as biomaterial, can be successfully processed/fabricated. The five primary steps required for Metal Injection Molding (MIM) are tooling, mixing, molding, stripping, and sintering. Conventional secondary operations could be added if required. The cost of MIM products becomes higher because of the long time sintering process. The compositions of binders are designed to separate sequentially, without disturbing part geometry. Generally, from this review the following conclusions and suggestions are drawn:

- The drawbacks of the MIM process are commonly observed in molding, debinding, and sintering that require improving through advanced research works, however, it is well suited to the high-volume production of complex mold parts and offers a freedom of design equivalent to that of injection-molded plastic parts or investment castings.
- Removal of debinders is a long cycle that subjects the formed parts to high inward pressure. The decrease of imperfections and chopping down measure term would be the primary focal point of optimization. There is a hostile event while streamlining any debinding strategy is the contention between limiting interaction term as opposed to limiting deformities. During the time spent time reduction, the initial step is to remove any abundance run-time, and the subsequent advance is to increment debinding power and accordingly cutting personal time significantly further. An increment in power will make more noteworthy pressure bringing about an expanded danger of imperfections like breaking, contortion, and others.
- The imperfections of bending become much more genuine when fluid stage sintering or weighty metals, for example, tungsten amalgams are utilized in the sintering interaction. The bending imperfection can be reduced by utilizing high solids stacking and more unpredictable powders. The necessity of installations in the sintering interaction is regularly to forestall twisting, and faker extensions, which are taken out by mechanical techniques after sintering, are frequently planned into the part to forestall opening of the long spaces during sintering.
- The feedstock is what makes the MIM process possible. Hence development and characterization of alternative feedstock are highly demanded and searched.
- Scientific guidelines for molding, debinding, and sintering should be researched. Specifically, computer simulation and parameter optimization techniques are looked into further for process and product improvement.

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