The Future of Manufacturing Business: Role of Additive Manufacturing
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Lecture – 32
Metal Powder Manufacturing and Characterisation

Good day. This is Manoj Kabre, Vice President Sales and Marketing from INDO-MIM. We are the world’s largest company engaged into a very unique and emerging technology called metal injection molding and in addition to that over the last few years, we have also started metal powder production and today I am going to discuss with you more related to the metal powders for additive manufacturing which is something which is catching up a lot.

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So, friends, in the content we are going to talk about the introduction, the metal powder production techniques, the facility for metal powder production that is the one which is at INDO-MIM. We are one of the only companies having this kind of unique power production facility. We also talk about INDO-MIM metal powders that is what kind of metal powders are being used at INDO-MIM. So we talk about that.

We talk about qualification and controls at INDO-MIM for metal powders and we talk about metal powders for Mega drivers like what are the main areas where these metal powders for additive manufacturing have been really catching up or what is scenario in the industrial market look like and of course we talk about our core technology metal injection molding before we close for the day. So, I hope this kind of content is aligned to your expectations.

So, let me commence the introduction.

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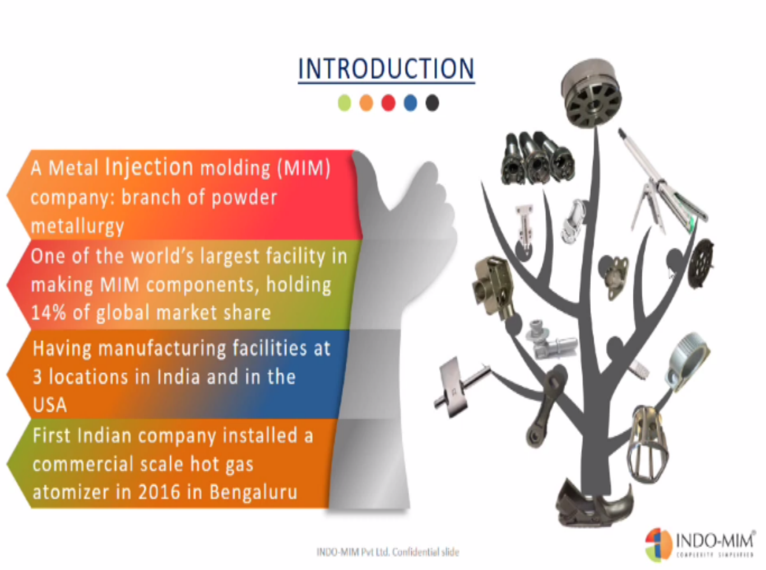

INDO-MIM is a metal injection molding company and metal injection molding is one of the branches of powder metallurgy as few of you might know. We have one of the largest facilities in the world to make MIM components. We have a global market share of roughly about 14%. Actually, this entire market of metal injection molding is very scattered. So it has a very long tail if I may say so and we are of course the world number 1 and the world number 2 is roughly about one third of our size and then of course you have a lot of other companies.

There are roughly about 100 companies in China, there are about 50 odd companies in Japan, similar number in Europe and so on. INDO-MIM has 3 manufacturing location in India, 2 for metal injection molding and 1 for investment casting. We started about 3 years back also green field metal injection molding plant in USA. We as I mentioned earlier are the first Indian company to install a commercial scale hot gas automizer. This was done about 4 years back in 2006 in Bangalore at our Doddaballapur facility.

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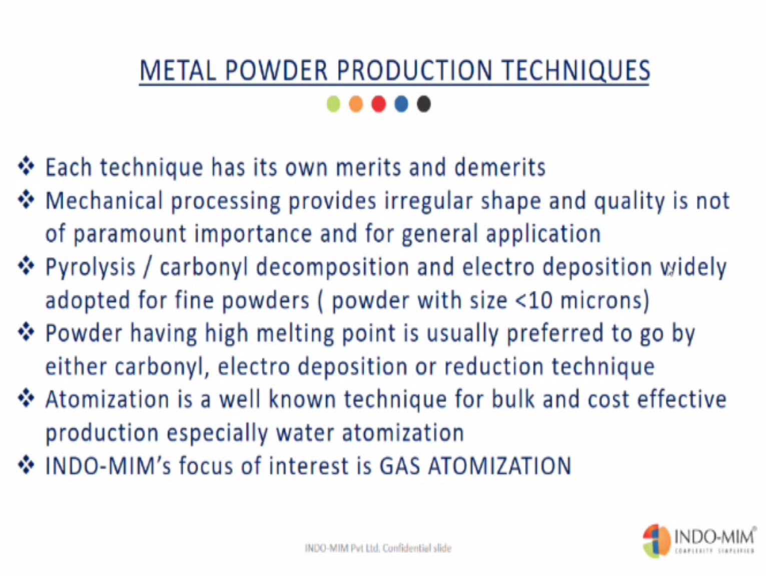

Let us focus some time on metal powder production techniques because I am sure all of you might be curious as to what kind of metal powder production techniques are used, what are their merits? What are their demerits? Why are there multiple metal powder production techniques? So, I mean one thing which all of you probably might be able to visualize or imagine is a mechanical processing or you also call it milling or grinding of powders

Now mechanical processing provides irregular shape and this is something which is used where quality is not of prime importance. Simple example that I could site would be gas cutting or welding application. So, this is something which us used for mechanical application and aluminum powder which is subjected to mechanical milling is also used in tracking application so that is another application for that.

So, predominantly mechanical processing is something which is used where quality is not of paramount importance and where scale is of importance. So, mainly I would say it is mainly for general applications. The second technique which is pretty popular is called pyrolysis or I would say carbonyl decomposition and electro deposition. This is used mainly for powder size less than 10 microns.

So, food industries, iron vitamins industrial application these are some of the application and then you have basically molybdenum which has a melting point of about 2700 degree centigrade, so that is some powder where high melting point is one of the prerequisite for getting into carbonyl or electro deposition or reduction technique. Tungsten might be another example which also has high melting point.

And then the carbonyl route is something which is used for production of sized powders and then the other technique that you do very popular is called atomization, which is mainly for bulk or cost-effective production and within atomization there are 2 types. One is water atomization and another one is gas atomization. So, water atomization is something which is pretty popular and again simple example could be iron powder.

Iron powder which is usually made by water atomization, where you get irregular shape in water atomization. You have to do additional operation like dewatering, like drying which of course consumes some time, but ultimately you end up spending a lot less amount of expenditure as compared to gas atomization. Water atomization is a technique that produces a bit of irregular shape.

It again can be used for areas where oxygen content or nitrogen content is not very important. So, what is happening here is that there is a pick up of oxygen and nitrogen content from water or even hydrogen content from water and that something which remains in the powder when you use a water atomization technique. So, these basically I can call these as impurities, presence of oxygen and nitrogen.

The application of water atomization typically iron are areas where you may not want these impurities to be below a threshold level of a few ppm. The technique which INDO-MIM has been focusing on is called gas atomization and gas atomization is predominantly a technique where you would have these ppm of all hydrogen, oxygen, nitrogen to be below something like 100 ppm.

I mean there are techniques available where you can even control them below 100 ppm and there are various applications starting from aerospace or starting from medical devices or even oil and gas sectors where these kinds of gas atomization techniques or production methodology is used because you have a very clear focus on controlling the ppm levels of these impurities, because these are going to affect the end product quality in a direct way.

At INDO-MIM we have been focusing on utilizing this gas atomization process as well as further perfecting it such that we are able to give the product of quality as required by these demanding industries.

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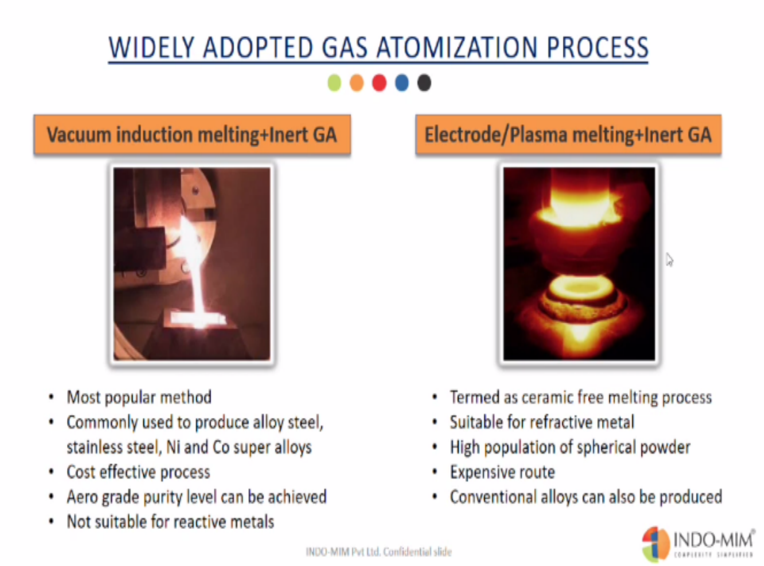

Delvin Littlebird further on gas atomization process which is widely adopted. The gas atomization process can be implemented or the production can be done using two specific methods, one is called vacuum induction melting plus inert gas and the electrode or plasma melting as it is also called plus inert gas atmosphere. So basically, we have inert gas as an important element in both these processes.

But the specific discrimination as you can see on this slide between these two processes is that one is using a crucible whereas second is not using a crucible. Vacuum induction melting is something which is one of the most popular method that is used for producing most of the alloy steels, stainless steels, nickel and cobalt super alloys. It is basically a process whereby you have a crucible into which this particular molten metal is poured.

The crucible is mainly having some amount of silica or aluminium oxide, which probably would get mixed up with molten metal thereby because of it there is some gas which gets eroded and mixed and these are some of the inclusions which may be present inside the molten metal while it is getting atomized and it can certainly achieve aero-grade purity level but not to there, I mean I would say about 70% of the application of aerospace would be utilizing this kind of vacuum induction melted gas atomization process.

Whereas some of the demanding application probably 25 to 30% might not be able to use the product out of vacuum induction melting and also it is not suitable for reactive metals. So, in summary, vacuum induction melting has a crucible, it enables some of the impurities or material of the crucible to be mixed along with the molten metals while the melted metal is being poured and it is used for about 70% of the aerospace application.

Coming to electrode or plasma melting, again here as I said it has inert gas and it is termed as a ceramic free melting process. It is used mainly for refractive metals. The simplest thing here is that the inclusions which normally come because of the presence of crucible are going to be absent here and that clearly indicate that you would not have impurities and hence the population of spherical powder is going to be more. Certainly, this is an expensive route.

But then if you have any conventional alloys also to be produced here because of this purity content or because of this higher population of spherical powders, it is definitely preferred. The highlight here is that the electrode that itself acts as a crucible here. So, there is no formal ceramic crucible that is used here since it is a ceramic free melting process, but the electrode itself acts as a crucible and the melting process takes place using this plasma.

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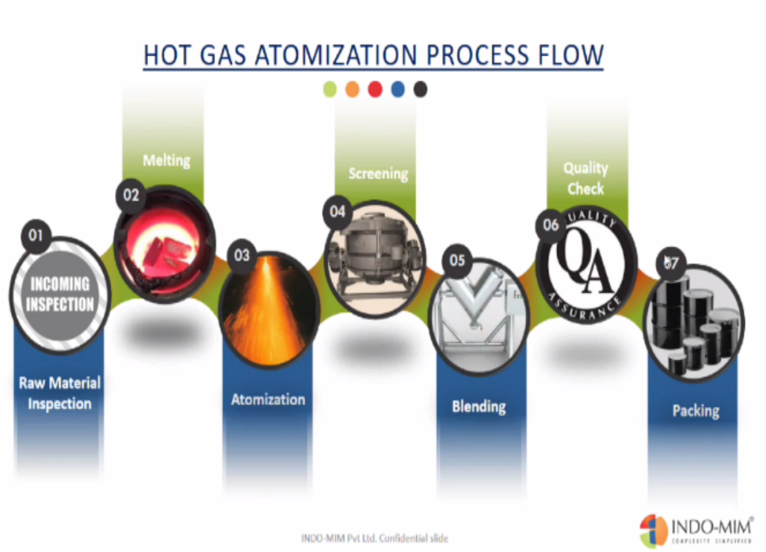

So let us come to the hot gas atomization process flow as this slide briefly explains you the process flow that is being implemented at INDO-MIM. We have basically the 7-step process which is given in this flow chart. The first as you would obviously understand or appreciate is incoming inspection. The raw material is coming into the plant. There is a formal way of incoming inspection which is done. The second process is melting.

Melting is where the molten metal is poured and this we have something called a tundish process, whereby there is a large vessel in which there is small orifice at the end. It will be poured from the crucible into this tundish and this allows the flowability of the molten metal through this small orifice about 6 mm or so before it goes for the atomization process. Now friends what happens in atomization process is that there is a gas which flows at a velocity of something like 1 one or 1.5 mac, 300 meters per second or something.

And under that high pressure when this 6 mm orifice is leading some hot molten metal into the large vessel that is where this atomization takes place. The facilitation of atomization is taken place through the high velocity of the inert gas and once the atomization is done, what you have as a result of it is probably particles less than 5 microns going up to about 150-200 microns. So, it is a very wide array of particles that would come as a result of atomization.

So, necessarily what we need to do is we need to screen them. The next process is screening. What do you mean by screening? Screening is basically classification of these powders into different size levels. We have for instance less than 20 microns which is used for metal injection molding, 20 to 50 microns is used for some of these additive manufacturing processes. The most popular band for additive manufacturing is 50 to 150 microns and beyond 150 microns is used for other processes.

So the major powder which is used is between this 0 to 150 microns and that is something which is done through this screening process. Subsequent to that we have blending process, again where our team has done some wonderful work of establishing fine processes that enables us to have very good blending, which subsequently goes to the quality check. So quality assurance is the area where we do this quality check.

We have various in process inspection stages while we go through these processes, but quality check at the end of the completion of blending is something which is done before we pack these products into pre-determined boxes or predetermined packaging sizes.

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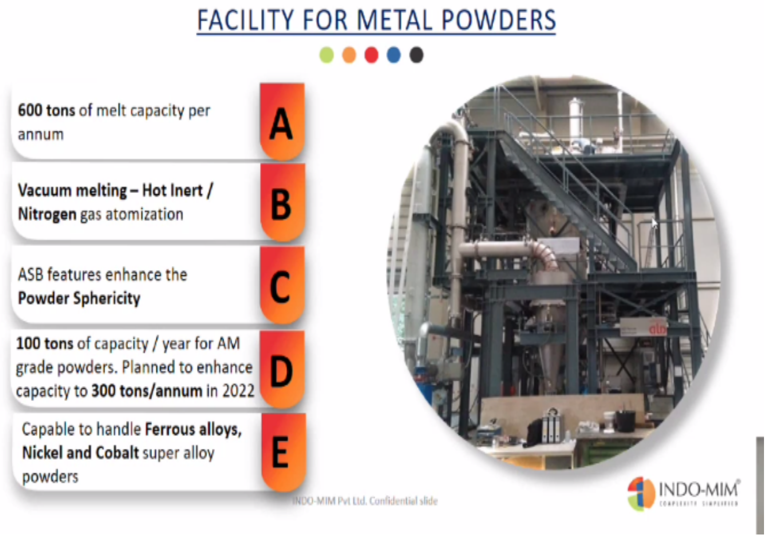

So here is an image of the large-scale hot gas atomizer that is available at INDO-MIM. We have a melt capacity of about 600 tons per annum and this is vacuum melting or hot inert nitrogen gas atomization process. I will talk about ASB features, anti-satellite features, that that our team has wonderfully worked along with the supplier to have this kind of feature that is mainly helping us to have very good powder sphericity.

On additive manufacturing, we are focusing a lot, currently we have about 100 tons of capacity dedicated for additive manufacturing out of these 600 tons that we have and we are planning to enhance this capacity to roughly about 300 tons per annum by the year 2022. Currently we are able to handle ferrous alloy, nickel and cobalt super alloy powders and we certainly plan to get into new and new varieties of powder based on the demands from our additive manufacturing folks across the country as well as internationally.

I am very pleased to say at this stage that majority of additive manufacturing shops in the country today have switched over to INDO-MIM powders and they are pretty happy and pleased with the performance of our teams, both the technical as well as the commercial team. I mean, just to say that the pricing wise we are competitive and we are also able to support most of these additive manufacturing jobs.

With respect to specific powders that they need, with respect to R& D efforts that they need. Many times they need specific controls on flow rate at their end. So, to enhance the print quality we have been able to do a good work with respect to providing them right technical support in terms of a powder manufacturer.

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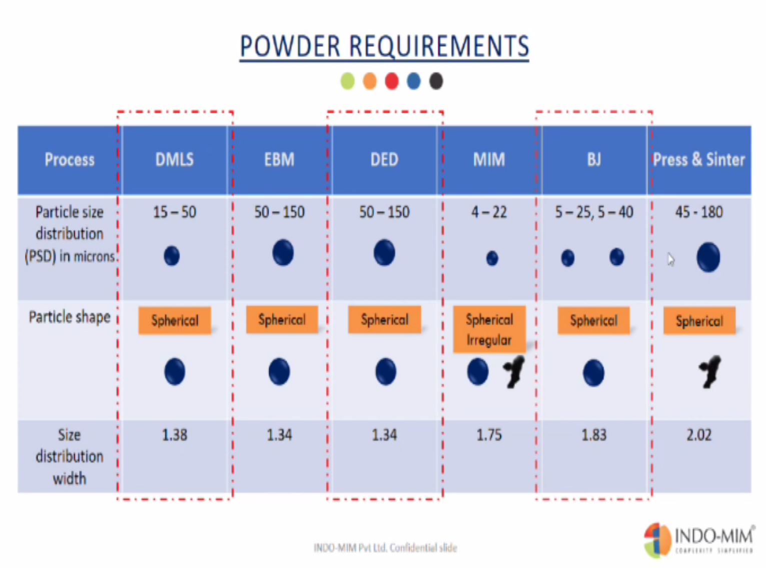

So, expanding further when we talk about the powder requirements, as you all know there are multiple additive manufacturing processes starting from DMLS, EBM, DED, majority of them and then of course we make powders for metal injection molding as well as binder jetting and press and sinter. Press and sinter is the routine powder metallurgy age old process. So, in the second row you can see the particle size distribution in microns that is given for all these different kinds of processes.

For instance, DMLS, direct metal laser sintering uses 15 to 50 microns. EBM, electron beam uses 50 to 150 microns, same is the range of particle size distribution used for DED. Metal injection molding as I said earlier uses less than 20 microns, so roughly about 4 to 22 microns. Binder jetting is another very interesting process that INDO-MIM has gotten to in the last 18 months or so, where again the powder size that is used is about 5 to 25 microns or going up to 40 microns in critical cases, beyond 40 microns. That is from 45 to 180 microns is something which is used for press and sinter.

The third row as you can see is about the particle shape. Majority of additive manufacturing requires a spherical shape that is one of the important requirements for having a better printing quality, whereas metal injection molding uses spherical or irregular shape. You need to have a combination of these shapes. That is something which enables you to have a better packing in metal injection molding. Binder jetting also requires spherical shape and of course in coming to press and sinter you have combination of spherical and irregular shapes.

Size distribution width is something which I would like to draw attention from all of you that is the fourth row, which clearly highlights what kind of size distribution width is something which is used for various additive manufacturing processes as well as metal injection molding, binder jetting and press and sinter process. So, you would see that typically additive manufacturing oscillates between about 1.34 to 1.38 as far as the size distribution width is concerned, whereas when we go to metal injection molding**,** it is going to be higher one point seven five 1.75.

Binder jetting again going higher to 1.83 and of course the press and sinter uses about 2.02 as the processing or the size of distribution width as 2.02. I would draw your attention to this size distribution width because this is something which additive manufacturing focuses on. So typically for additive manufacturing, we need a little, I would say narrow distribution that directly affects the print quality. You can see in this chart that 1.34 to 1.38 is the size institution width that has been used for additive manufacturing. Again, to highlight little further in case of metal injection molding, you have a higher size distribution width.

Again, there is a reason for it because by having this you are able to have a better packing in terms of holding process and other things and binder jetting if you would know is also very similar to metal injection molding, just that molding element of metal injection molding gets replaced with printing in case of binder jetting. Whereas the debinding and sintering defining processes that I will explain a little further when I go to metal injection molding is also present in binder jetting.

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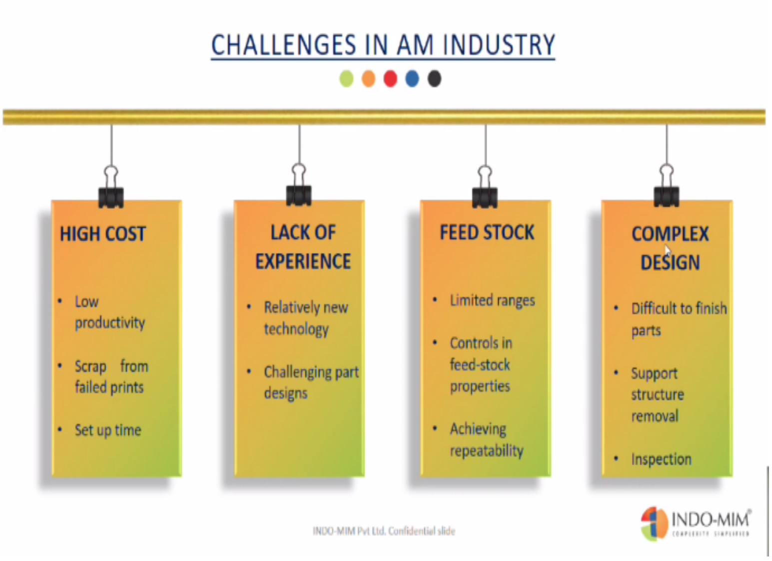

Challenges in the AM industry, I think all of you probably are aware that additive manufacturing is certainly going through a lot of difficult times. I mean there was a definitely a hype about additive manufacturing catching up really quick, but then there are mainly these 4 challenges, which are mainly affecting most of the job shops or 3D printing shops. High cost, lack of experience, feedstock, and complex design.

So, these are the main 4 things which are going to be affecting the growth of additive manufacturing industry. When we say high cost, it is basically because of low productivity as you would know or probably imagine. The other reason also for high cost is scrap from failed prints. So basically, yield that is coming out of additive manufacturing process is not very good, going to be failed prints and the second important thing is the setup time.

These are the 3 main elements which are contributing to high cost in the additive manufacturing process. I mean, it is a relatively new technology. I am sure all of you know that additive manufacturing is not very old in terms of technology, although there has been a lot of research going on, especially in the West and the second important area why additive manufacturing is struggling or in the factor of lack of experience is the challenging part.

I mean, I am sure you know that aerospace is something or oil and gases are industries which are trying to utilize or I would say exploit the additive manufacturing technology to a very large extent, and hence most of the designers are being allowed to make as much challenging part design as possible and most of the additive manufacturing jobs are having difficulty in producing these part designs. So, these challenging part designs are one of the reasons that is causing the additive manufacturing jobs not to be quite successful that is of course acting as a challenge.

Feed stock, this is another area which is an important challenge, but mainly being focused by INDO-MIM our company. There are limited ranges as you would know in terms of feedstock. The controls in feedstock properties is something which is critical, mainly with respect to achieving reproducibility. I would come a little further on talking more about how INDO-MIM has really focused more on getting this feedstock thing done and we have been able to support our own captive requirement as well as most of the customers. The fourth and final challenge named is of complex design.

So basically, we have difficulty in finishing the parts. Most of you would know that additive manufacturing does not give a very good surface finish. So, we need to necessarily have a post additive manufacturing finishing process. The support structure removal is an element which has to be necessarily done irrespective of what kind of additive manufacturing process we do and inspection is an important element that takes up a lot of time. So, these are the 3 parameters under the complex design category that is acting as a challenge to the AM industry.

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So having briefly discussed about these points, let me now talk about INDO-MIM metal powders as to what kind of metal powders INDO-MIM is specifically focusing on, what are the powders that we have included in our basket. We have basically four categories or four basic heads under which we are manufacturing powders and supplying to the additive manufacturing industry. One is stainless steel where we have almost all the major fast-moving stainless-steel items under this particular group SS 316L, 17-4 PH, 15-5 PH, SS 304, SS 321, SS 310 and martensitic stainless-steel SS 420.

These are the main fast moving stainless steel that we are producing regularly and we have stocks of these orders at all points of time. When we come to the alloy steel, we have been making MA 300, H13, tool steels like M2 and D2. We make bearing steel 52100 and we also make 4240. So, these are the alloy steels. Again, based on the research that our sales and marketing team has done with respect to what kind of powders are required in the market, these kinds of items have been used.

Nickel alloys is something which is one of the fast-moving product categories at INDO-MIM, mainly used by aerospace applications as well as some of the oil and gas applications. Inconel 718, Inconel 713C, Inconel 625 and one of the very popular method popular powder that we made is called NIMONIC 90. These are the four categories of nickel alloys that we are making. Coming to Cobalt alloys, T400, T800 these are the commercial names that we are doing is high cobalt powders mainly used for high temperature applications.

We are using F75 also as one of the powders high cobalt chromium which is used for military grade. We do produce Stellite 6 and of course we are producing Haynes 25 also. So, these are the 4 broad categories of powders that we are making and I also narrated all the specific names of the powders. This is something which will help you to remember the variety of these powders.

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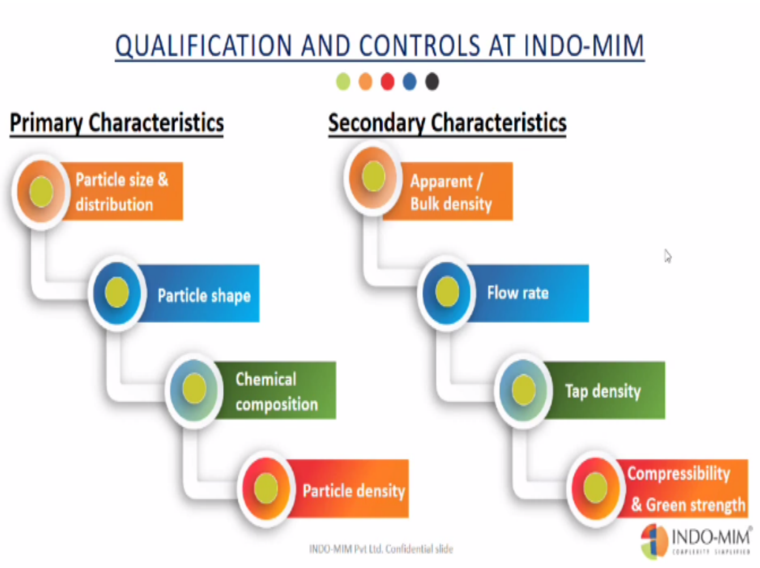

But of course, producing powders is just not enough, what is important is qualification and controls. So, let me take some time and explain to you what kind of qualifications and controls are available at INDO-MIM. In brief, these are the 4 primary characteristics as well as the 4 secondary characteristics that are being controlled at INDO-MIM. What you would see is that the primary characteristics are particle sizes and distribution, particle shape, chemical composition, and particle density.

These are the 4 primary characteristics that INDO-MIM focuses on, which in turn helps is to control the apparent or bulk density, flow rate, tap density as well as compressibility and green strength. So as you would appreciate that the quality control is something which is important for us to get the powder to the additive manufacturing folks whereby they are able to utilize them in a better way and the properties which are listed down here these are something which have the minimum for these additive manufacturing folks to be able to use this powder and have lower field print rates.

Now, what we are doing at INDO-MIM is that we are fine tuning our process design. We are continuously iterating the process and having better controls so as to have all these particle shapes and distribution, particle density that enables us to have mainly better tap density and flow rate. Flow rate is something which is an important secondary characteristic that directly affects the printer and the inhouse process capability measures that we have adopted that is something which is helping us bring a better control in terms of powder consistency.

I have also included in the presentation some of the control charts which will have you proof of the pudding is an eating kind of concept whereby you are able to see what kind of controls are actually being given out at INDO-MIM batch after batch. The particle size distribution and morphology indirectly control the apparent density and flow rate as I was mentioning earlier. So just to kind of give you a kind of thumb rule, so if there is a good powder what would happen is you pick up 50 grams of powder, pass it through an orifice of say 1 inch, it should take less than 20 seconds to flow.

So this is one of the easiest or benchmark kind of a method by which you are able to understand if the flow rate of the powder is good and if it is going to be helpful for the printing platform.

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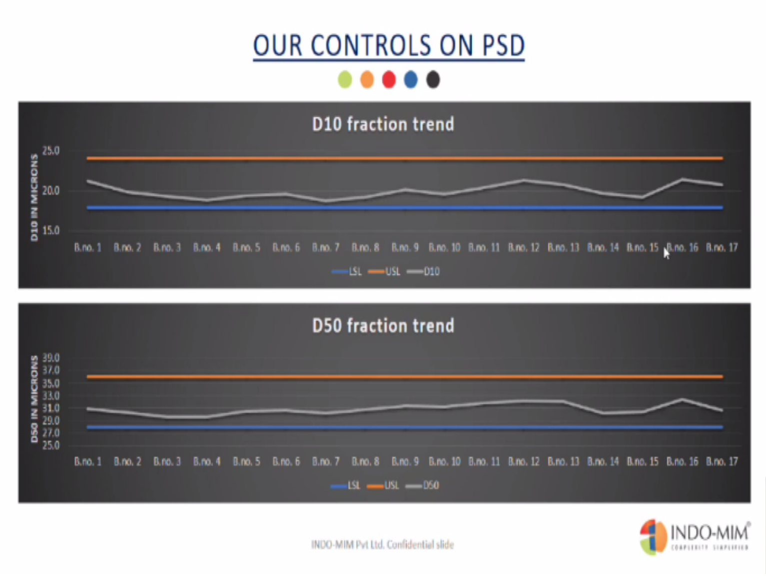

I was mentioning about these controls. So here are some of the particle size distribution control charts. In the upper chart, you see D10 in microns and what you are seeing there is the blue one, which is the lower specification limit, the orange one is the upper specification limit and at the center is the D10 control on particle size distribution, starting from batch number 1 to batch number 17. So, what is controlled at INDO-MIM in terms of the process parameters is what is reflecting here in terms of results.

So, well within the upper and lower specification limit. Same thing you can see in the D50 fraction trend. Again, the blue is the lower specification limit, orange is the upper specification limit and the D50 line as you can see or trend as you can see from batch 1 to batch 17. We have just taken some example here that shows you that the output is very much in control within the upper and the lower limit.

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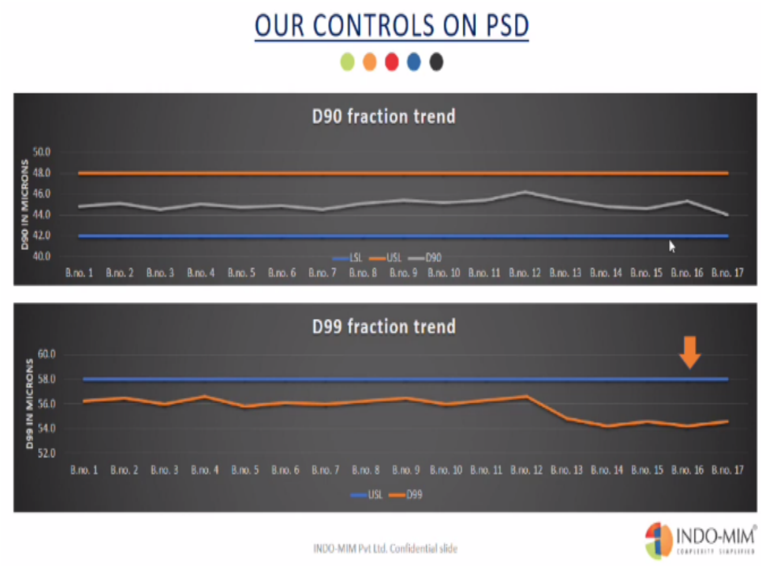

Here, you have the controls on PSD for D90 fraction trend. So again, you can see between the lower and upper specification limit, D90 is pretty consistent, pretty low in terms of the variation and the last one is D99 where of course there is only upper specification limit and again D99 is pretty much controlled.

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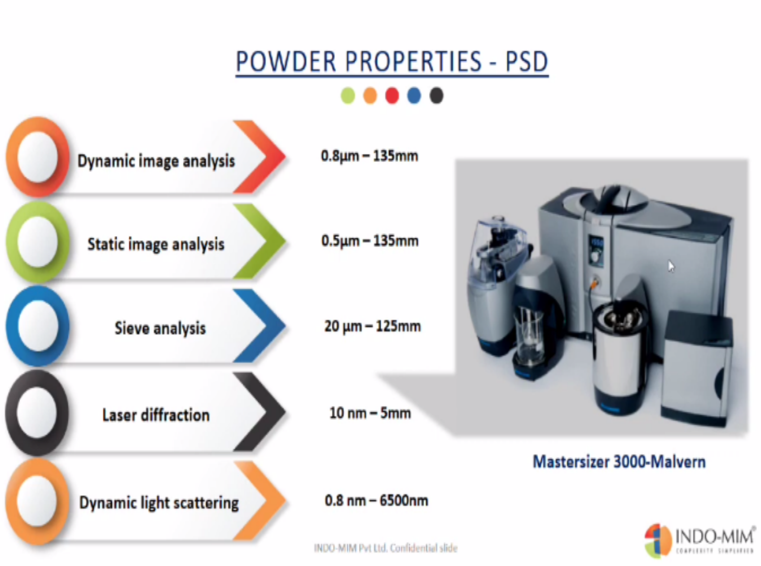

When we talk about powder's particle size distribution trends, it is important to have these checked, the powder properties to be checked. So, these are some of the popular methods that are being used by the industry starting from dynamic image analysis, static image analysis, sieve analysis, diffraction and dynamic light scattering. So you can see on the right-side against each of these methods we also given the range for this particle size distribution. For instance, for dynamic image analysis, it is 0.8 microns to 135 microns.

For laser diffraction it is about 10 nanometers to 5 mm. I mean we at INDO-MIM of course use laser diffraction. On the right-side you can see the Mastersizer 3000-Malvern that is the instrument that we use. We control from 1 micron, starting from 1 micron upwards using this laser diffraction method, but just out of academic perspective, I thought we should include these different methodologies as well as the range that they can qualify or that we can check.

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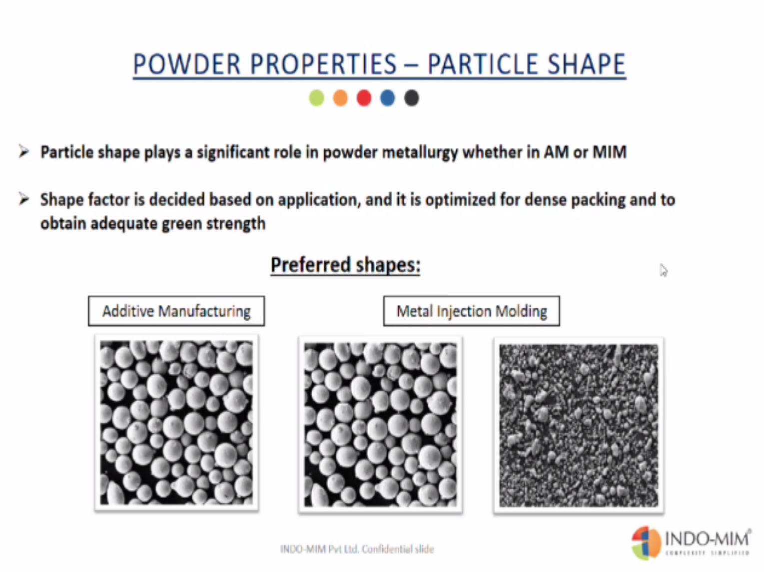

So having talked about the particle size distribution or methodologies to check them powder properties and all, I think it is time for us to switch over the gears to particle shape. This is another important parameter that needs to be controlled when we come to additive manufacturing and what does particle shape play in terms of role? So, it has a very significant role in powder methodology whether it is additive manufacturing or metal injection molding and shape is basically decided based on the application.

If you remember early on I just mentioned briefly that additive manufacturing needs spherical shape for having a better printing quality, whereas metal injection molding wherein you mix the powders along with the binders and you need something called green strength, there you need a very good combination of irregular shape as well as the spherical shape. So, the particle shape is going to be one of the main parameters I would say, which is going to affect the process and in case of metal injection molding, the way it would be optimized is that it would enable dense packing to be done by having this kind of combination.

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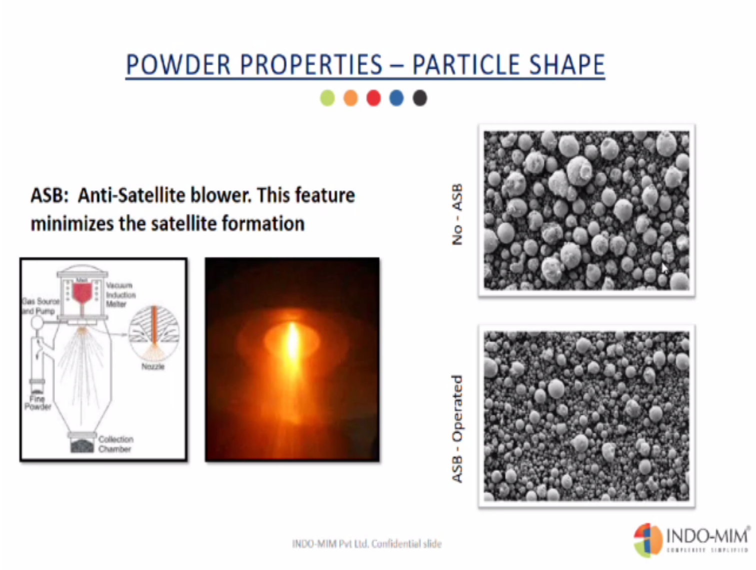

Powder properties again now focusing on this ASB that is a feature that INDO-MIM has jointly developed with our suppliers, anti-satellite blower. So, what does this mean? This basically means that it is a feature that minimizes the satellite formation. What is a satellite formation? As the word says it is basically small particles which are kind of clung on the large particles, so this is what is called satellite. So obviously you would be able to visualize that these small particles which are clung onto the large particles, they would act as friction.

So, because of friction what would happen is that it would become a deterrent to the flowability during the printing. So, anti-satellite blower is a feature available in the manufacturing process that allows you to make the printing quality better. You would not have friction on these smaller particles that are clung onto the major particles and that is how you would have a better flow rate and hence a better printing quality. So, the properties that are going to be affected in ASB, anti-satellite blower kind of are going to be superior as compared to the no ASB kind of or material.

On the right-side in the screen you can see on top we have given micrograph of no ASB and on the bottom, you can see a micrograph of ASB operated powder and the schematic of this ASB, anti-satellite blower is shown on the left-side. We have also taken a small photograph of the actual anti-satellite blower happening inside the atomization process just to make you understand what exactly is this particular feature.

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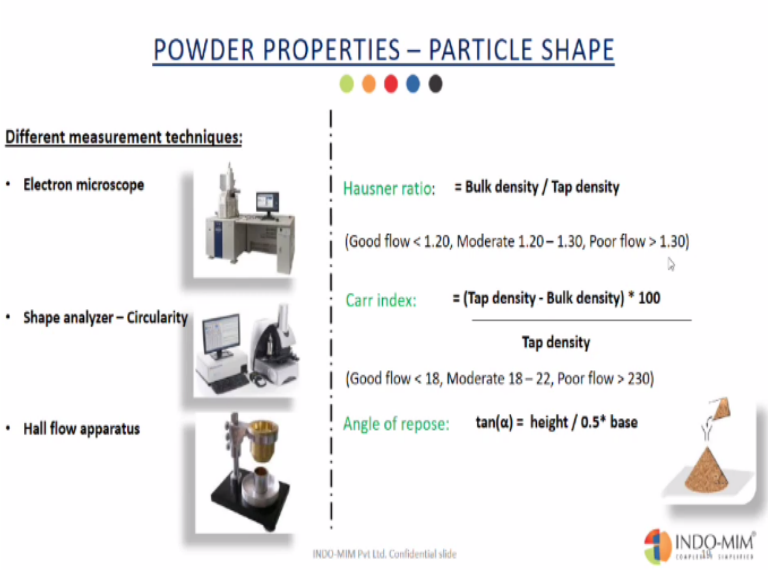

Coming to different measurement techniques when we talk about the power particle shape, electron microscope, shape analyzer for circularity and hall flow apparatus for checking the flow. These are the 3 different measurement techniques that have been used. Hausner ratio and Carr index, I am sure most of you would be familiar by these parameters, and this is something which are the parameters that are used to basically designate the flowability of the powder.

So good flow would be less than 1.2 Hausner ratio, moderate would be 1.2 to 1.3 and poor flow will be more than 1.3. Again, on the Carr index you would have good flow less than 18, moderate would be 18 to 22, and poor flow would be more than 23, sorry for the small typo there. Coming to angle of repose, this is another parameter that is being used for the particle shape. I hope everyone is able to follow this particular thing as of now and we will try to go to little more details as we go into the next slides.

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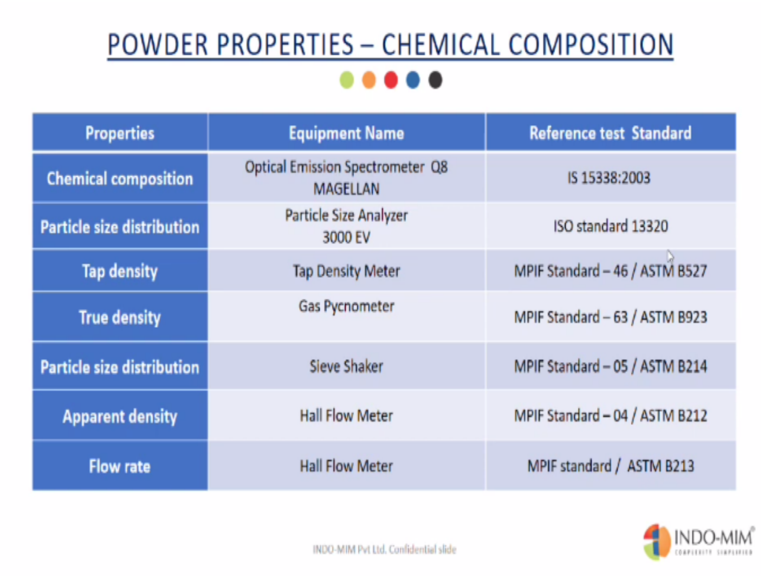

POWDER PROPERTIES – CHEMICAL COMPOSITION

Properties	Equipment Name	Reference test Standard
Chemical composition	Optical Emission Spectrometer Q8 MAGELLAN	IS 15338:2003
Particle size distribution	Particle Size Analyzer 3000 EV	ISO standard 13320
Tap density	Tap Density Meter	MPIF Standard – 46 / ASTM B527
True density	Gas Pycnometer	MPIF Standard – 63 / ASTM B923
Particle size distribution	Sieve Shaker	MPIF Standard – 05 / ASTM B214
Apparent density	Hall Flow Meter	MPIF Standard – 04 / ASTM B212
Flow rate	Hall Flow Meter	MPIF standard / ASTM B213

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Powder properties, chemical composition. This is a slide which gives you details about the equipment that we are using for checking the particle size distribution, for checking the tap density, for true density as well as the particle size distribution and apparent density. These are the instruments that we are using and the reference test standards are given there. So, as you know that MPIF, metal powder industries federation that has a standard and aligning with ASTM and these ASTM and MPIF standard is something which we are using as a reference for checking all these properties using the equipment that you are seeing on the slide

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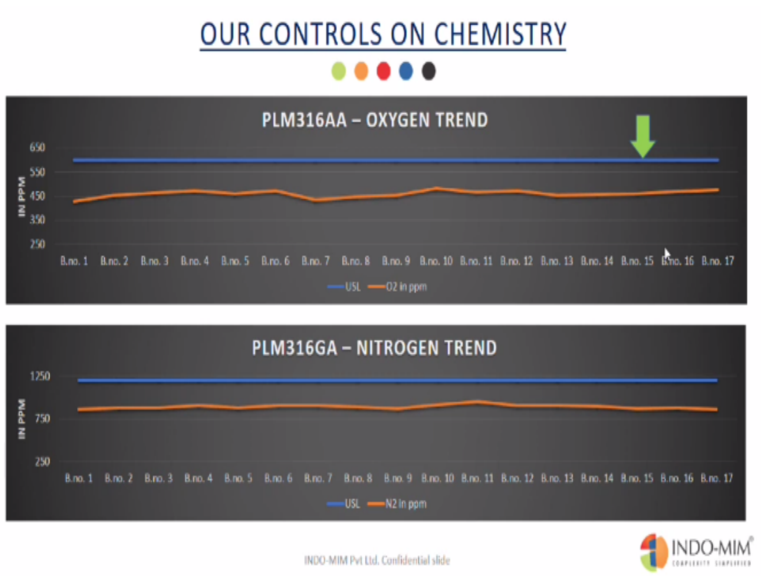

Here are some reports or some trend charts to highlight the controls established at INDO-MIM on chemistry. So, these are the results in PPM as you can see and we are giving the O2 in PPM on the top chart and the bottom chart shows you the nitrogen in PPM. So very good controls on the O2 and nitrogen and you have the upper specification limits for both oxygen and nitrogen. At INDO-MIM we are able to sufficiently control these well below the upper specification limit. I mean needless to say the lower the better, but again if you want to have a better control on oxygen and nitrogen, certainly you need to have higher manufacturing cost.

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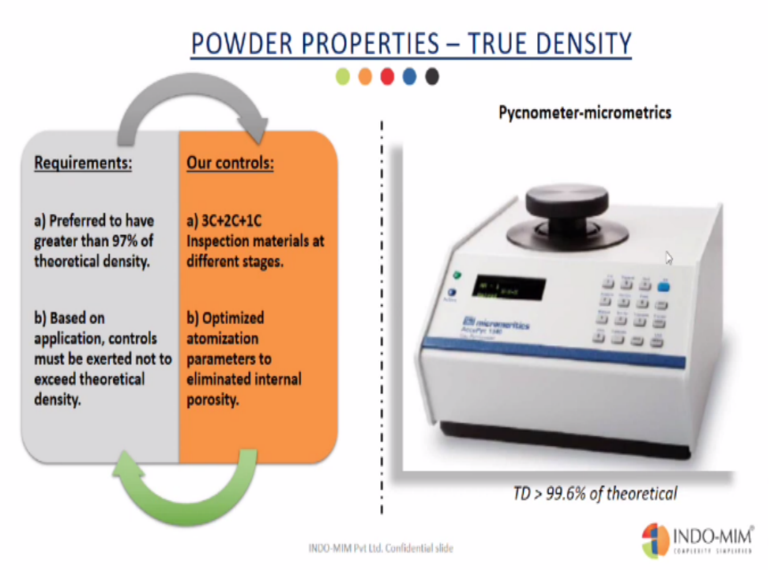

That brings us to the next important topic that is true density, so which is also measure of the porosity present in the powder. True density is something which we measure using instrument called pycnometer and on the left-side you can see the requirements. Usually it is preferred to have greater than 97% of theoretical density and for that what the controls that are available at INDO-MIM are 3C+2C+1C that is an inspection of materials at different stages.

So, let me explain a bit about the 3C. Our raw metal supplier, they would, we would go and audit them or do a prequalification for them that would be the first C. The second C would be the reports or the samples that they would send us for every melt that they are going to send it to us. We would maintain records for that, that is the second C and the third C is the raw material inspection that we would do upon the arrival of powder.

So, if you recall when I was explaining the process flow of the powder manufacturing, I was showing you that the in-process inspection is something which happens at INDO-MIM for every arriving batch, so that is the third C that is being done. Now when we come to 2C, this is basically the process inspection that is being done, in-process inspection and the final inspection that is being done and 1C is the final inspection that is being done before the dispatch of the powder to our customer.

So, another requirement is that based on the application, the controls must be exerted not to exceed the theoretical density. This is one of the important parameters. So, what we do is we optimize the atomization parameter to ensure that internal porosity is eliminated to a large extent. True density as I said is a measure of how much internal porosity is available. Every powder has certain internal porosity and for us to assess on which of this internal porosity is available, we check the true density using this pycnometer.

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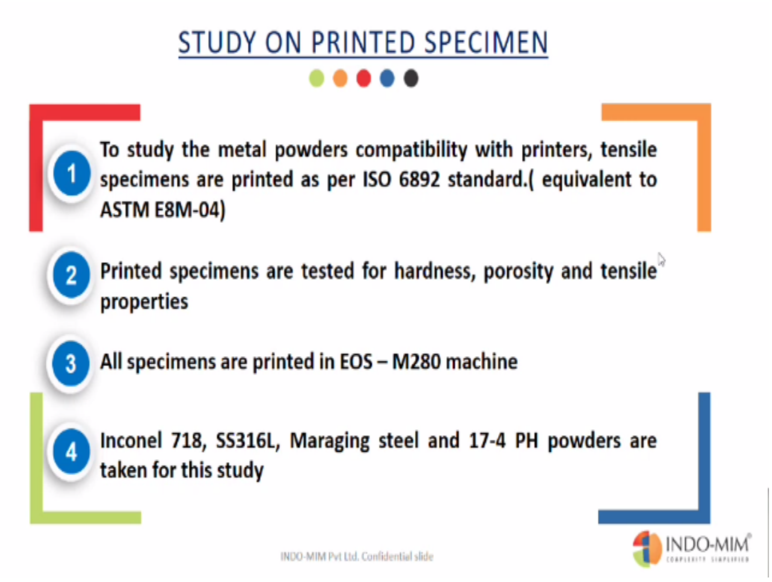

Now coming to the study on the printed specimen, what we do is we study the metal powders compatibility with printers, the tensile specimens are printed as per the ISO 6892 standard, which is equivalent to the ASTMs standard given here. Then these printed specimens are tested for hardness, porosity and tensile properties. All the specimens are printed in EOS and our team has a really taken good lead in having the wonderful collaboration with EOS, which is the world’s largest company for making these printers.

We have identified a specific machine M280 on which all these printed specimens are tested and this kind of collaboration between INDO-MIM and EOS is something which is standardized and that is something which is followed powder verification process. This enables us to have a standardized thing. So, what we have done is we have taken Inconel 718, we have taken SS316L, we have taken maraging steel and 17-4 PH.

These are the 4 powders that we have taken for study and we carried out these studies with the printer basically to assess how good are the mechanical properties compared to conventional processed materials and standard values of the printed specimens from the other manufacturer. So, unless you benchmark, I am sure you would agree that it is very difficult for you to indicate your USP.

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Powders for mega drivers, I think we have talked about the powder, we have talked about the manufacturing process, but it is also important to identify or to correlate these powder productions with respect to the industry. Of course, all of you are from academic background, but there are I am sure some people in the audience who are also from the industry side, so you would be certainly curious to know that what are the materials for the emerging markets.

So, what kind of applications are coming up in the coming years and where exactly is the industry building so as to help people like us like who are powder manufactures to be able to catch up with the upcoming requirements and thereby support. So, when we come to high-temperature applications, these are the ones that you can see are clearly emerging. On the high temperature applications, aerospace that is one of the areas that is certainly demanding for this.

Coming to pharma, food, chemicals and fertilizer industries again there are very specific and niche requirements that are helping us to identify these things and develop the specific powders. And soft magnets, I mean EV as you all know is something which is an emerging application, just catching up very fast both on the two-wheeler as well as four-wheeler side and EV is demanding a lot of support from the powder manufacturers and so we are doing a lot of activity for the EV as well.

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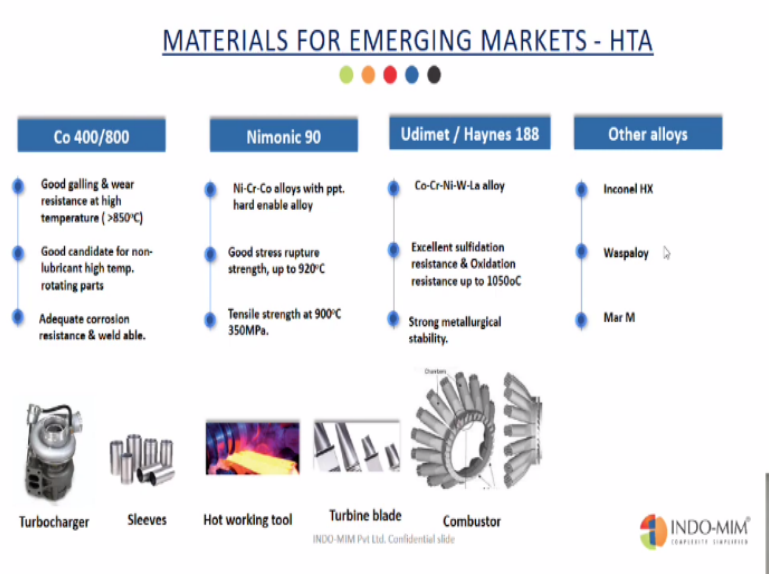

So, let us go into all these specific market applications one by one. So here are the 4 major alloy that we have developed for applications from the HTA, high-temperature applications, which spans across the industries of manufacturers like turbocharger manufacturers, like people who manufacture sleeves, hot working tool, turbine blade, combustor and these kinds of applications. So, when we come to Cobalt 400 and 800, good galling and wear resistance at high temperatures is something which is required more than 850 degrees centigrade.

This order is a good candidate for non-lubricant high-temperature rotating participants and adequate corrosion resistance and weldability is something which is important for this part which is the key characteristics. When we come to Nimonic 90 nickel, chromium and cobalt alloys, this is something which is the hallmark of Nimonic 90. It has a good stress rupture strength up to 920 degree centigrade. So, turbochargers are ones which are using these particular materials to a large extent.

It has a tensile strength of about 350 megapascals at about 900 degree centigrade. So, this is something which is very unique for Nimonic 90. Coming to Udimet or Haynes 188, this is again a cobalt, chromium, nickel, tungsten alloy which has an excellent sulfidation and oxidation resistance up to about 1050 degrees centigrade and it has a very strong metallurgical stability. Some of the other alloys that we have been developing for these markets are Inconel HX, Waspaloy and Mar M.

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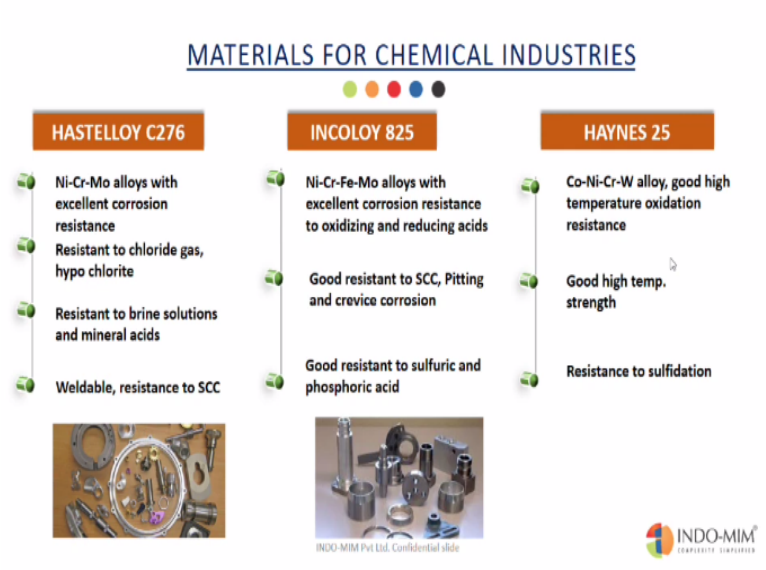

Coming to chemical industries or I would say also pharma industries which can be covered in this category, the three main materials that we are developing here is Hastelloy C276, Incoloy 825 and Haynes 25. Nickel, chromium, molybdenum alloys with excellent corrosion resistance is the hallmark for C 276 of Hastelloy. It is resistant to chloride gas and hypochlorite. So, any application that demands these kinds of resistance can definitely use these kinds of materials.

It is also resistant to brine solutions and mineral acids,, and of course needless to say it is weldable and resistance to SCC. The second alloy is nickel, chromium, iron, molybdenum alloy. It again has excellent corrosion resistance to oxidizing and reducing acids. It has a good resistance to SCC, pitting and crevice corrosion and also good resistance to sulfuric and phosphoric acid. We have also shown some of the images at the bottom of these specific materials.

Haynes 25 is a cobalt, nickel, chromium, tungsten alloy with good high-temperature oxidation resistance, also good high temperature strength and resistance to sulfidation. So, based on these properties for these specific materials, the industries can select and there is a lot of support that INDO-MIM engineers are providing to the industry in terms of understanding the requirements and tailoring our processes to get these kinds of parts the specific industry.

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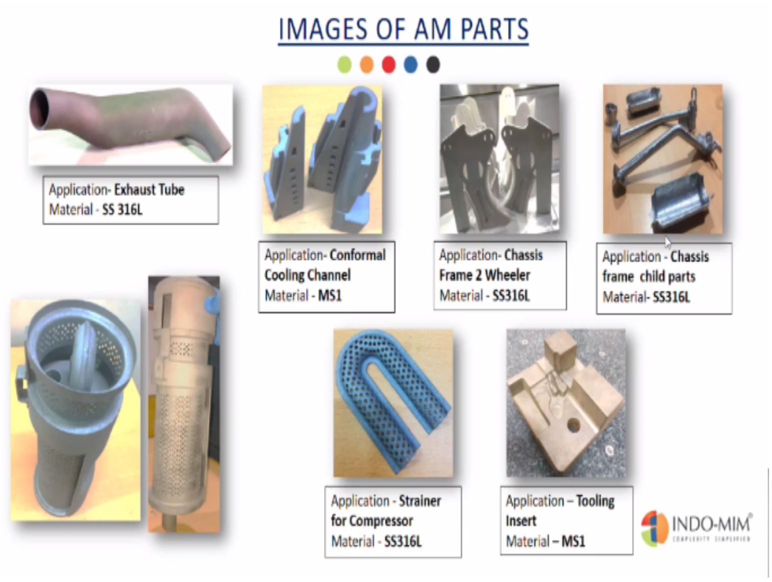

Here are some of the images of additive manufacturing parts. I mean, we have also thanks to our partner industry from the 3D printing who helped us to get these images courtesy. Application is exhaust tube as you see at the top left which is material of SS 316L. There is another application of conformal cooling channel in material MS1 that has been done using 3D printing. The third one you can see in the sequence is chassis frame for a two-wheeler. It is a pretty large competent in 316 that we have made that this we have helped additive manufacturing.

There are other chassis frame child parts which are made on the fourth one and then you have a strainer for compressor and tooling insert, I mean that this particular additive manufacturing company is making for us for our own captive consumption. The reason I thought we should include these images of additive manufacturing parts are these are the kinds of parts that are used by the powder that we are supplying or we have printed by the powder we are supplying.

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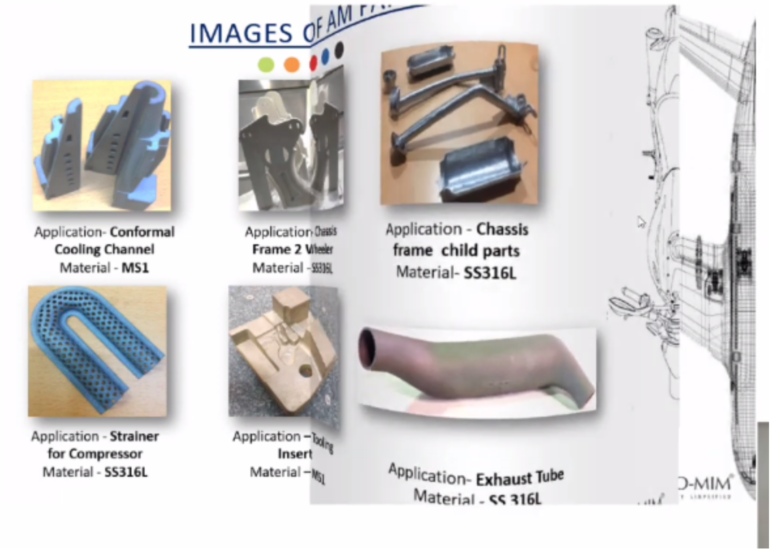

Here are some more classified images as per the industry. These are the images for instance for two-wheeler segment as you can see from the representative images of motorcycles that these are parts which go for specific to two-wheeler industry and again spanning across various materials and spanning across various shapes.

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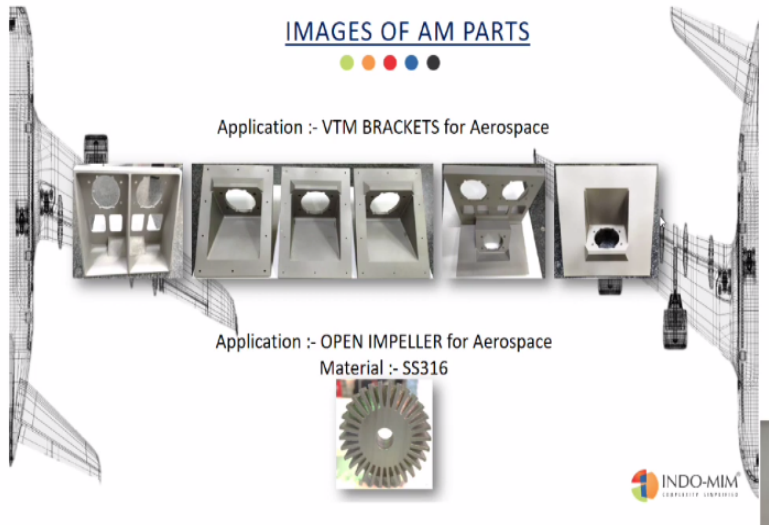

Here are the applications of aerospace. We are making powders which are being used to make VTM brackets as well as the impeller open impeller. As you can see the open impeller material is SS316. The shape is pretty complex, and making such kind of impellers through conventional process is going to be very tough using machining you can take hours and days to make these kinds of products. So additive manufacturing is certainly the best process which is suitable for these kinds of components for aerospace industry and in general aerospace industry as shown very good acceptance for AM parts.

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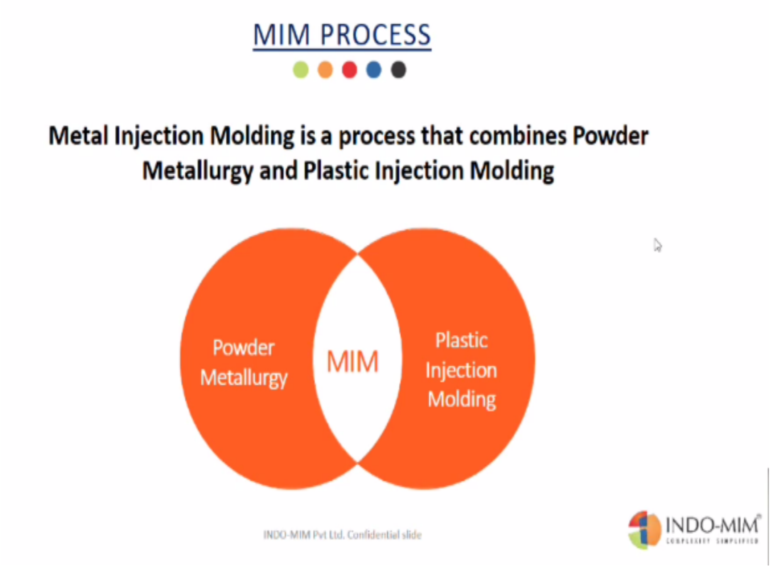

Having talked about additive manufacturing in detail, I think time has come for me to also touch upon metal injection molding. That is one of the process which is at the core of INDO-MIM. As I said we are the world's largest company engaged into making this metal injection molding process. So, friends, metal injection molding is a process that has the best of both worlds, one of the world called powder metallurgy and another world called plastic injection molding.

So, what this process has done metal injection molding is we have picked up the alloying benefits from powder metallurgy and it has picked up the shape making benefits or shape making capability feature of plastic injection molding and it has evolved as a process that has the best of both these words.

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So MIM as we call it as an abbreviation, MIM is a 4-step process starting from compounding, injection molding followed by de-binding and sintering. So, what is compounding? Compounding is basically a process where we mix the metal powders that are produced by atomization process, gas and water atomization, and these are mixed with binders. So, we have 4 different components of binders that we use to mix along with the metal powders and then feedstock is made.

In the image you see white color is the binder representative binder, black color is the powder and farther end you see the feedstock which is very similar to plastic injection molding granules, just that here it has a mixture of metal powders and binders. The feedstock is something which is injected into the mold at the injection molding stage and that is something which gives us the green part. So, you can see an image of the green part. Now this green part has the entire shape or contour of the part that you as a customer intend to have.

However, the part is oversized. The reason I say oversized is it has content of binder in it. So, what would happen necessarily in the next two stages is that we would have de-binding and sintering to the removal of binder. The first major component of binder which is basically called the primary binder is removed at the solvent dividing stage. At this stage we call the output as brown pipe and the remaining component binder, secondary component binder is still with the component holding the metal particles together.

At this stage, we put the part to sintering. Now, inside the sintering furnace, we have 2 types of furnaces, vacuum furnace as well as continuous furnace. Here, the first stage of the process is called thermal dividing, wherein we allow the secondary binders to evaporate and with the completion of evaporation of these secondary binders starts the intermolecular diffusion or which we also call a sintering.

Now friends, you can see in the image here that the sintered part seems to be far smaller than the green part or the brown part, and this is indicative of the 20% shrinkage that occurs in the sintering process. So, why does 20% shrinkage happen? The intermolecular diffusion that happens inside the sintering furnace is the main reason why 20% shrinkage occurs and this gives the density to the product. What we say usually is that metal injection molding is a process that enables you to get complex shaped parts with full strength.

Which means there is no compromise on strength, but still you are having a metal forming process produce it, you are not doing metal cutting and in simple things if I can tell you metal cutting is something which enables production of burr. MIM process is a metal forming process that eliminates the production of burr itself. So that is one of the very important deterrent that any manufacturing shop floor fellow kind of be worried about that is something which is completely absent here in metal injection molding into the way this process is designed.

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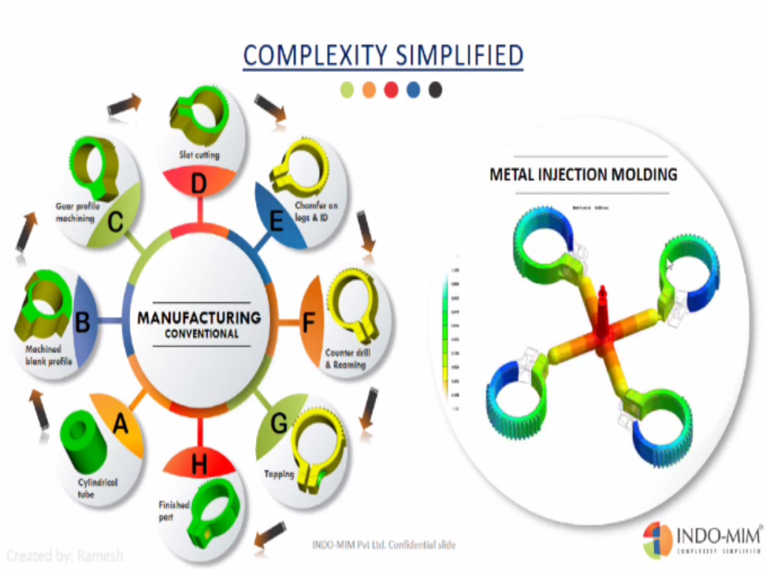

So, here is an example I mean what do you do understand what kind of complexity are we talking? INDO-MIM the guideline is complexity simplify. When we say complexity simplified, what kind of complexity are we talking about? So, on the left-side you can see it is an 8-step process for the component that you see of course, on the last H stage, that is the finished part. So this is basically a steel part used for an automotive application for fuel flow control I would say.

So, starting from A to H are the specific processes that were being used to manufacture this particular component using the conventional manufacturing technology. A is the cylindrical tube, B is the machined blank profile, C is the gear profile machining. Then they are followed by slot cutting, chamfer on the legs and ID, followed by counter drilling and reaming, tapping and finally the finished part. Now to have all these features on the component if you can see on the right-side.

Metal injection molding just uses a very simple molding step, which gives the entire profile, entire form and here you have a single drop of the hot runner that shown we have 8 cavity or 16 cavity mold for this particular component and the beauty is that the entire feedstock flows inside the mold which has been designed in manufacturing ahead of time to get this entire profile incorporated onto them, including internal thread as you can see there.

Then subsequently as I said in the earliest slide, it is taken through de-binding and sintering process where you get the intermolecular diffusion and the densification of the part. You are able to get all these 8 steps eliminated and convert that into a single process called metal injection molding. This specific component is just finished at the metal injection molding without the need of any post MIM secondary process.

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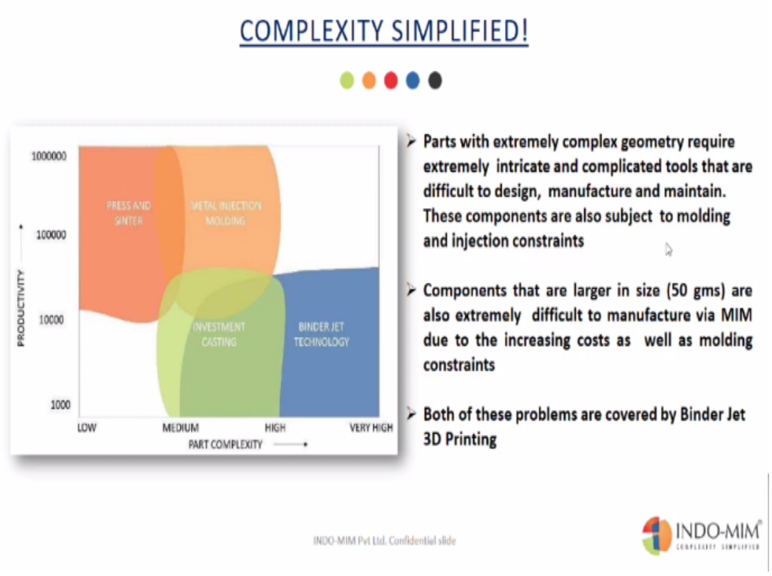

Now, what kind of applications or what kind of windows of opportunities does metal injection molding offer? So here is a slide that gives you the activity on the y-axis, which means the quantity that you need annually and part complexity on the x-axis, where we are spanning the complexity right from low to medium, high and going to very high. So if you can see, low part complexity and high volume is something which is the domain of press and sinter or powder metallurgy.

If the volume is less, that means the quantity is less, whereas the part complexity is medium or high, you would end up using investment casting and if the medium to high complexity is available for the part as well as the productivity is high or the quantity is high that is when you end up using metal injection molding. So basically, we are talking about complexity as the prerequisite for metal injection molding to be favorable.

The yet another new emerging technology called binder jet technology is something which INDO-MIM has really got into and that is for the area of high or very high complexity with low volumes. I have briefly mentioned that bind jet technology also uses more or less similar process flow like metal injection molding, just that the modeling process is replaced by a printing process. So typically, the applications for metal injection molding, I would say 80% applications across the world are less than 50 grams per weight.

So typically, metal injection molded parts are the ones which you can hold in your palm, you know four to five parts you can hold in your palm, very small parts, 10 grams, 15 grams that is the weight range of metal injection molded parts, but most of these parts would have at least about 25 to 30 measurement dimensions or critical dimensions on the component drawing. So that is a very easier way of identifying part favorable for metal injection molding.

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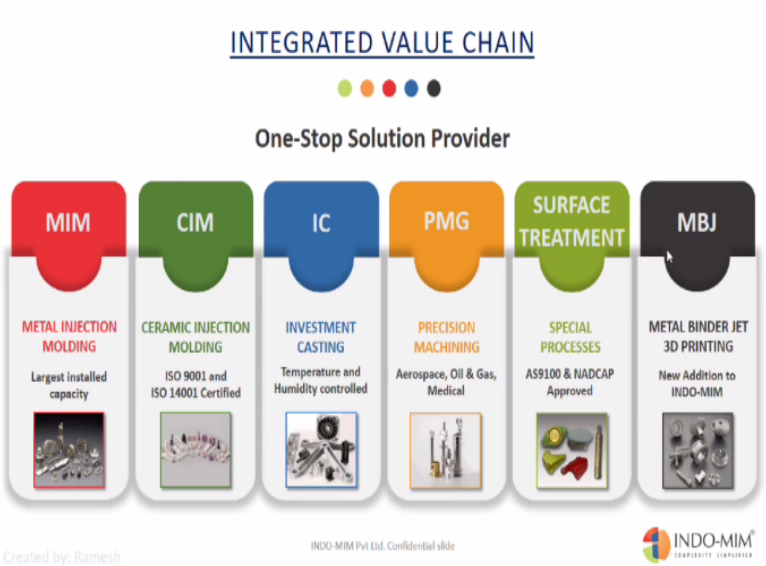

INDO-MIM offers an integrated value chain starting from metal injection molding to ceramic injection molding, investment casting, precision machining, special processes, and metal binder jet 3D printing. We are basically a one-stop solution provider who is able to offer all these solutions for all our global customers. The 92% of our sales is exports and INDO-MIM is a very popular and very credible name reckoned across the globe in the manufacturing space, whereby we are able to cover a very wide scope of industries through these particular technologies.

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Customer is God for INDO-MIM and that is the reason you can see on this slide the global presence. In addition to our manufacturing footprints which are shown through arrows, we also have sales offices as well as sales representatives all over the world. We have sales offices in USA, in Germany and in China. In addition to that, we have sales representatives in majority of the non-English-speaking regions where we need people who are native to those countries were able to converse or interact with the customers and get them to service. So, the whole objective here is that we should be able to take the technology to the customer's doorsteps that is objective of INDO-MIM having such wide kind of skill.

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So that all from my side. Our whole objective is partnering our skill with your innovative minds to engineer value. This is a prerecorded session. So, I am not sure if we are able to have any questions or interactions here, but nevertheless you can definitely post your questions to the organizing team and we can certainly get you the answers. If you have any suggestions for us, any ideas, any areas where you want INDO-MIM additive manufacturing powder plant to partner with you or to give you additional expertise, always welcome. Thank you.