The Future of Manufacturing Business:
Role of Additive Manufacturing
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Lecture-26
Additive Manufacturing Application for Prototype, Tooling and Part Repair

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Good afternoon, my name is Vaman Kulkarni. I was ex director of mechanical systems in Honeywell technology solutions. I just took an early retirement a couple of months back from Honeywell. As part of the mechanical systems group at Honeywell, I was responsible for additive manufacturing initiative, we set up a state of a art lab in Bangalore for metal printing. That has been my involvement in additive manufacturing for the last 6 years.

And we make the significant progress in developing the additive manufacturing technology. Before joining Honeywell, I was with DRDO gas turbine research establishment for 21 years involved in developing the gas turbine engine Cauvery engine for LC applications, that is my brief background. Today's topic is additive manufacturing applications for prototype, tooling and part repair.

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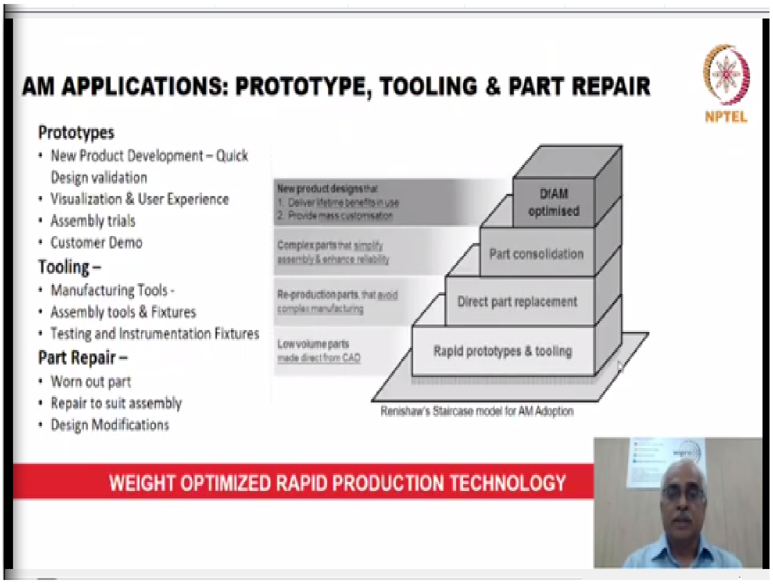

This has been one of the key areas where additive manufacturing has been widely used. In fact, that is what I like this staircase model from Renishaw which shows that at the bottom we have the rapid prototyping tooling. That is where the application of additive manufacturing started way back and with the lot of improvements which are happened in the metal printing.

It has taken a much different shape in taking advantage of the functional prototypes, the tooling and then the part repair applications. It is across the industry. It could be in the aerospace automobile or in the medical. So, it is across the field it has been a significant part of it. Additive is also today used for a lot of production applications whether it could be a direct part replacement or consolidating the parts or in a new product development as part of the as a design for additive manufacturing benefits what additive are brings in. As part of the prototypes typically if their main rapid prototype has been very widely used for last 20-25 years. But rapid prototype need not be always with additive manufacturing. So, the rapid prototype means that how quickly we can make the prototype and then quickly do some of the functional checks and say which helps to finalize the design very quickly or do some design iterations.

That is when the prototype has been very widely used. So, additive plays a very big role as part of this new product development to do the quick design validations and it reduces the overall product cycle time. Prototypes are also used for a lot of visualization, checks, and especially from the assembly and maintenance point of view, the user experience, how it is easy to assemble and maintain it.

So, that is the other thing which you can verify. It is also used to provide the early customer demo of parts, so that he can use it for the next assemblies as well as a lot of functional tests. Today in fact it is also used for a lot of field trials. As far as the tooling is concerned especially with metal additive manufacturing, it is been playing a big role in developing manufacturing tools especially the casting and forging moulds and dyes.

It helps to come out with a more optimum design of dyes and moulds which will have better cooling. It will help in having a better quality of the part as well as in increasing the life of the tool itself. It also reduces the downtime because the tools can be quickly made with additive manufacturing. Lot of tools which are required for assembly and assembly requirements could also be done through the additive.

In quite a few instances, when the part is being tested lot of test tools or test fixtures needs to be developed in a very short period of time. So, I think definitely have the advantage of supporting that. The part repair has been in existence for last 20 years, but most of that because of the direct energy deposition using the laser technique.

But with DMLS coming up in a big way in last 5 to 6 years. It is been very widely used across the industry to repair the worn-out parts as well as last minute any design changes could be incorporated very quickly onto the part which is already manufacture. So, those are the benefits which additive brings as part of part repair. So, we will be looked into the in all these 3 areas based this additive technology is, and then how it is being applied and there are some good examples which we have deployed additive manufacturing in all these three areas.

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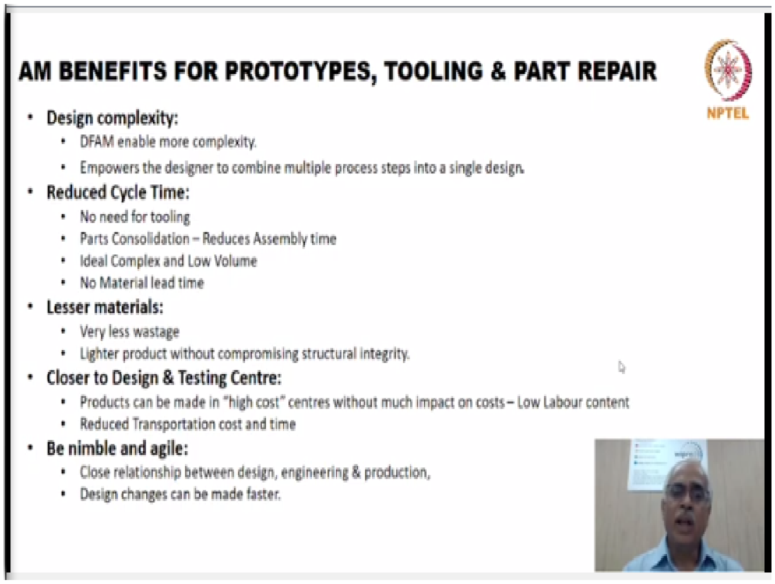

So, before we get into that what benefits additive manufacturing brings, when I talk about additive manufacturing mainly, we are focus is on metal printing, that is been our main focus. So, definitely the advent of metal printing, we are able to design a very complex parts with additive which helps in improving the performance, life and it could be lightweight. So, those are the things which additive manufacturing enables whether it is part of prototype or it is part of the tooling or the part repair.

It also empowers the designers to consolidate the parts into a single design. It removes the lot of constraints which used to be there while designing a part keeping the manufacturing constraint. So, most of that is eliminated because of the process of additive manufacturing itself which is building the part layer by layer. Additive definitely reduces the cycle time because there is no need for the tooling.

Assembly time is also reduced because we can consolidate all the parts. It is ideal solution for very complex parts and which where there is a low volume which is the case with prototypes. There is no lead time involved to get the materials because the powder which is used is already either in stock or we can get the powder very quickly. Because of the process itself there is no wastage of material as far as additive manufacturing is concerned.

It can come out with the very light designs; the lighter designs could be because of using the thinner materials or it could be because of the lattice structures. So, we can come out with a very light part from additive manufacturing. Typically, when you want to get the prototype manufactured, we always go to our suppliers who can do this at a low cost and with additive manufacturing we can have this done very close to the either the internal customer or the external customer where it will get into the next assembly or testing.

Because there is very less content, labour content involved as part of this and it also reduces the transportation cost and time. If the additive manufacturing process itself is very agile, very late design changes could be incorporated easily. The part can be produced, so we can be more responsive to the customer changes and customer request and we can incorporate that into the designs. So, all these benefits will definitely help when you as you get in to the prototypes or for tooling or for the part repair.

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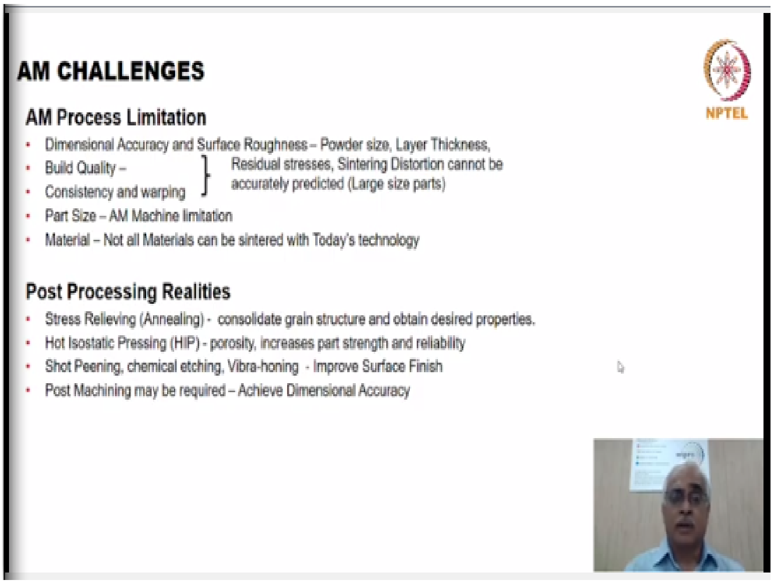

There are quite still a few challenges with additive manufacturing technology. These challenges could be in terms of achieving the final accuracy, dimensional accuracies, geometrical tolerances, the surface roughness. All this is decided by the powder size, the quality of the powder, the layer thickness. So, it still needs some sort of a post processing to address the final finish. But still it could be done much faster than the conventional but there are with these limitations still exist.

Similarly, the quality of the part which is built that still needs to be consistent and reliable with the quality of part is affected because of the residual stresses or because of the distortions which could happen while printing. So, these things cannot be accurately printed, so it needs to be validated especially when you are building a larger overhang part. So, there could be some warping issues which needs to be addressed and needs to be adopted and supports need to be optimized.

So, there is still a manual intervention and some sort of trial which needs to be carried out. There is still limitation on the size of the part what can be printed. 400 millimeters by 400 millimeter is now very well established. But there are machines which are now available which can build up to 1-meter length, breadth, and height but it is still being validated. So, as time progresses, I think the size will grow a part of additive manufacturing, not all materials can be sintered with today's technology.

So, we still have some limitations, we may not be able to print magnetic materials or the hard tool steel. So, there is still a constraint as far as the material is concerned. So, as I mentioned earlier there are, we still need to do a lot of post processing. The minimum post processing or any part which is built on a is to go for the stress relieving and then some sort of a surface finish process either it could be shot peening or chemical etching to improve the surface finish.

On need basis depending on the criticality of the part you may have to do the heaping; heaping is the hot isostatic pressing process which will remove the porosities and then it increases the density of the part and enhance the better material properties. Depending on the dimensional accuracies, we may have to do some post machining. So, those are the aim challenges, I have just wanted to keep it up front before we get on to the details of applications of prototype tooling and then the part repair.

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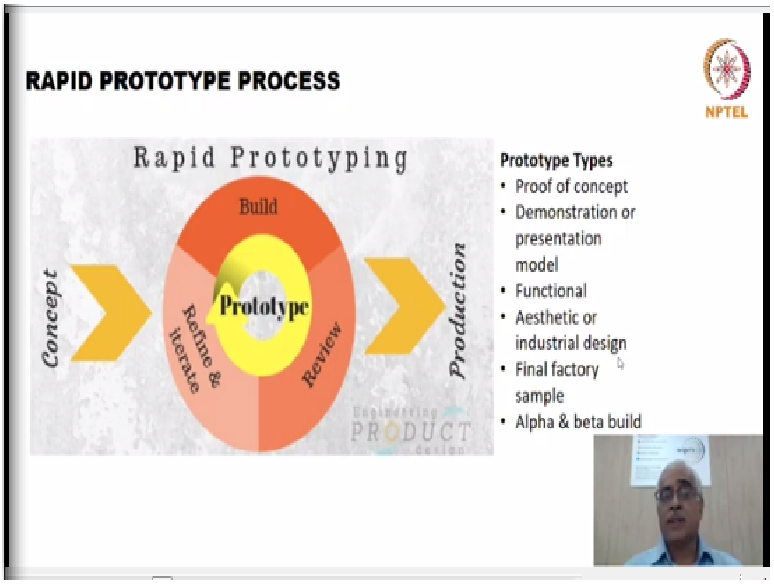

This typical rapid prototyping process is what we shown here. So, we get a concept design then the concept design is converted into a build. The build could be out of additive manufacturing or it could be out of conventional machining or it could be out of casting. That is where we need to identify the right process, so that we can reduce the cycle time and then that is what is review. When you say review it is the design is validated for the performance, for the assembly. So, it will undergo some of those trials as part of the review.

And then you go back and then change the refine the design and then you do some iterations, finally have a build which can get into the production. So, this is where the in nutshell how the rapid prototyping process looks like. A prototype could be for the proof of concept or it could be a demo model for the customers or for the both the internal and external customers and then it also gives a visual feel of the things and then you can also validate all the functionalities for which the product has been developed.

It could be also for the aesthetic purpose, how it looks like. Because that plays a big role when you have to get the product into the market or it could be the initial test builds which you release it like an alpha or beta versions, this could be for the hardware or software the word prototype is applicable across. So, in our scenario we specifically are looking at the mechanical parts as our focus.

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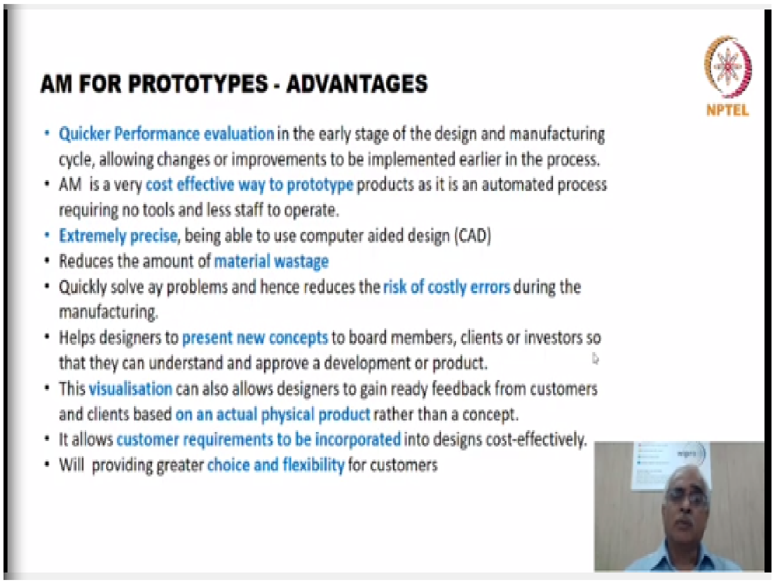

What benefits the AM brings it when you look at for the prototypes? One of the key things what AM enables is the quicker performance evaluation. So, we can have the design converted into a product which we can do all the functional tests whether it could be at a higher pressure or temperature. Even if you are not using the original material, it can still be tested for all those functionalities. It may not withstand the life for which the product needs to be designed but it can still be evaluated for all it is performance.

So, that helps to quickly validate the design and then do the design improvements and then quickly build the parts and test it. I have few examples where you can see that how it is really reduce to the cycle time by more than 70%. AM is definitely a cost-effective solution for building the prototypes because it is a completely automated process, there is less labor involvement in building the part and of course there are no tools are required.

It is we can get a complex part with an extreme precise dimension because it is directly converted from the CAD models. Material wastage as we talked earlier it is very nil and any risk involved in the manufacturing. So, those risks can be very easily addressed and it can be quickly solved using additive manufacturing. Because as I told the last-minute changes can still be included into the design before we start actual printing.

We can take these prototypes quickly to the customers or the board members and then get quick approvals for the full development of the product. It also helps to any inputs which comes from the customers very late in the design phase and then we can incorporate that into the prototypes and then we can validate it. So, it really has that flexibility to produce the parts.

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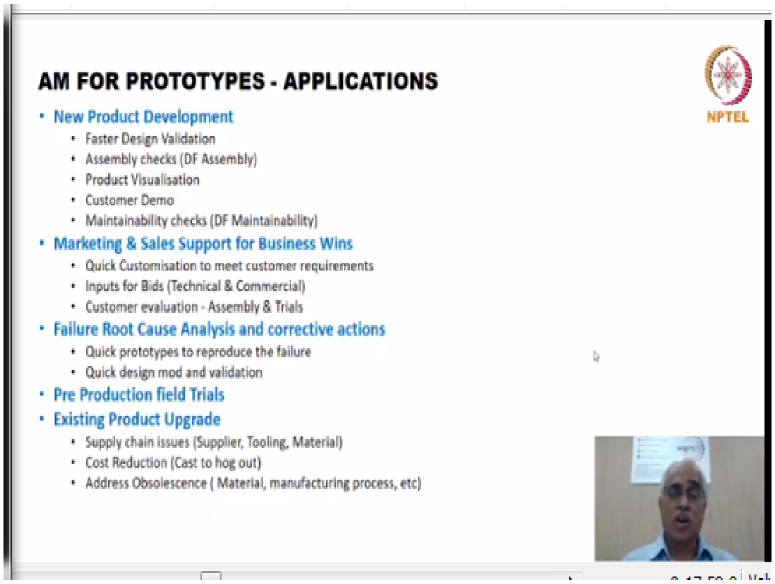

The applications of prototypes talked about the new product development is plays a big role. We can do the very quick design validations. Design for assembly, we can validate this assembly checks, we can take it to the customer demos and any maintainability related things from the user experience point of view. All that can be validated very easily with these additive prototypes. Sometimes we need the prototypes to take it to the customers which helps our marketing and then the sales channel to win the businesses.

So, we can quickly modify the existing product or the new opportunity and then we can quickly engage with the customers. So, that helps in the whole business win process. It also gives a lot of inputs when we start preparing the bits both for the technical as well as the commercial piece of it. We can use these prototypes to have both the technical feasibility as well as the commercial validations.

Even before we engage the final engagement, we can give those demo pieces to the customer. So, that he can evaluate it and then get the confidence of the customers. In many cases whatever field failures which we see in the field we struggle to find out the root cause and then come out with the corrective actions. So, if you are able to reproduce the failure what you see in the field, then we can come up with a design fixer. So, the additive manufacturing prototypes helps to quickly make those prototypes and reproduce those failures.

And then incorporate those design changes, test it and then validate it. We can also use the prototypes for the pre production field trials which helps to make sure that it functions properly in the bigger assembly scenarios. In some cases, there is a need to upgrade the existing part through additive manufacturing because of various concerns and issues. It could be because of the supply chain issues where we have some tough time with the suppliers or the tooling which is involved is gone bad and then there is not tooling drawings available.

Especially this is true in an aerospace scenario where there is a long life for the product. Typically, most of the aircrafts have a life cycle of more than 30 years. In such a situation for the parts which are 20 to 30 years old, we may lose the inventory of the tools to manufacture the part. So, for we can there is may be a requirement to replace those parts with additive manufacturing. In some situation because of the longer life cycle we may want to reduce the cost of the product.

Because that design which is old design is gone through a costly manufacturing process of maybe casting or forging. So, it may be in the present technology is easy to either do it through the additive or do it for the hog out. So, we can do those design validations with these prototypes. In some cases, the part could become obsolete either because of the material itself or because of the older manufacturing process.

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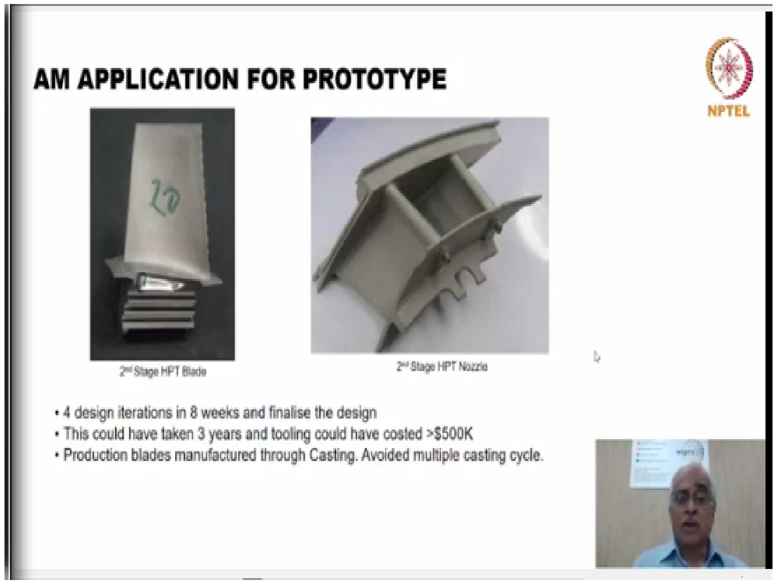

So, those are the areas where additive brings lot of benefits and advantages. So, in the next few slides, we will see few examples of prototypes and how it is benefiting the industry. You can see here high-pressure turbine blade, typically most of these high-pressure turbine blades have a complex airfoil. As well as they need to be internally cooled to withstand the very high temperatures.

So, when we use the design process for these things, doing all the thermal analysis, the flow analysis, the CFD analysis and come out with the design and to manufacture these blades it could take anywhere from 6 to 9 months to manufacture these plates. And then we had to test it and that could take another 4 to 6 months for the testing then we further if you have to modify any design changes, it is a cycle of one to one and half years what we were talking about.

Typically to finalize this type of a design, it takes about 3 to 4 years to finalize a design. But with additive manufacturing we can have this part available in less than 8 weeks. This one was specifically with Honeywell went through 4 design iterations and in those 4 iterations we could validate the design and then finally, the final production is not done through additive but it is the prototypes are done through additive.

And then all the validations are done and then it is released for production. So, it has reduced this cycle time from 3 years to about 6 months the entire whole design iterations what you are talking about. The cost savings is also more than 500,000 dollars as part of this product development. So, same thing with should be high pressure turbine nozzles. You can see the complexity of the part which is involved, so additive is used for prototyping. It can finally be processed for even for the production version but that also depends on a lot of validations and the certifications which is involved.

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The next one is the TOBI nozzles. TOBI nozzles are the tangential injection of the cooling flow on the turbine blades to at the right pressure and temperatures, so that is a criticality of these TOBI nozzle designs. We could quickly get these things manufactured through the additive and we can take it to the testing. So, the one which is printed through additive may not have the life what we are looking at. But we can take it to the next assembly like engine testing.

So, we can do those validations even at the engine level. That way the overall cycle time for the overall engine development we could reduce it. If we had gone through the conventional approach to make these parts available, it could have taken around 9 months. So, all in all there are quite a few other models what you can see here as part of the prototyping. The typical cycle time in an industry what we can reduce is closed about 70% and can have a cost reduction of about 65% and then we can do more design iterations and have a different thing completely addressed through additive manufacturing.

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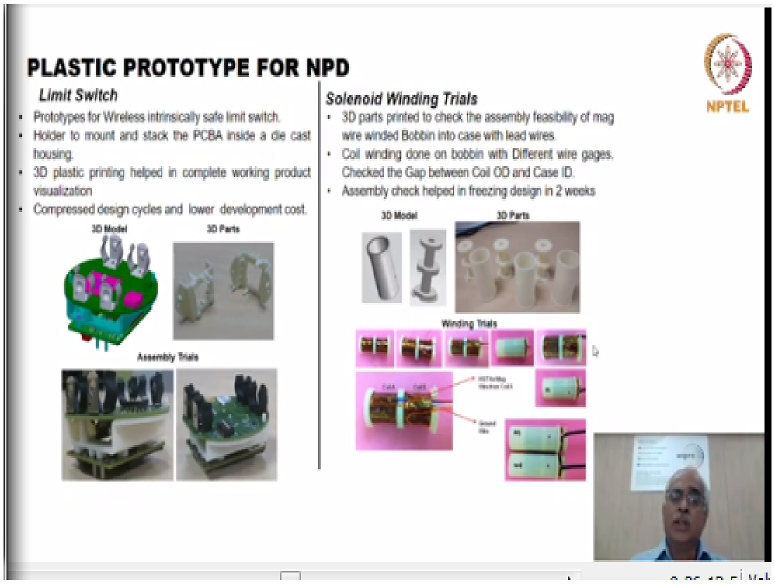

So, in many cases we do not make the prototypes for the actual material, we can make it out of polymers or plastics. So, there are some examples which I am showing it here. On the right-hand side, you can see that this is for the solenoid. The coil winding is the critical thing for the solenoid. We can do the winding trails on the bobbin of a polymer bobbin and then do all your winding trails and then finalize it and then reproduce that on the final part also.

Similarly, you can see on the limits which where the PCB assemblies stacked and need to check those quick assembly trials. Also, we could quickly make a plastic part and then assemble it and then check it and finalize the design. So, that way if it is although it is a non-functional part but it helps in finalizing the design from the assembly and then design validations.

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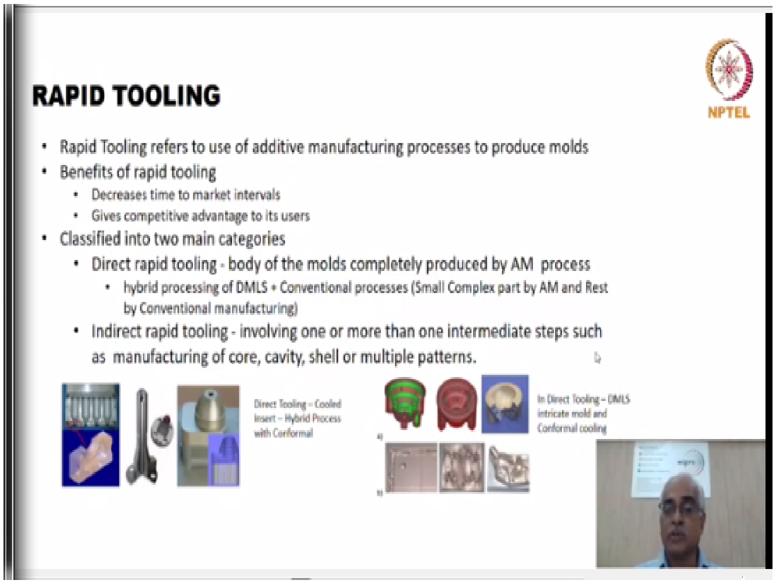

Coming to the tooling, so tooling is another big area where additive can play a big role. The reason why the tooling application is very wide for additive manufacturing is. The tooling is not getting into the final product, so we do not have to we can keep the tooling design in mind come considering the overall product application and then there is no need for any additional qualification or certification of the tooling itself.

Similar to the prototypes but most of the cases the tooling what we talk about is the tools which are required either for the moulds or the dyes in a casting or a forging process or the tooling could be for the assembly fixtures or even when you are doing the conventional CNC milling or drilling you need to have those fixtures to hold the part, so may require those tooling. Some of those tooling needs will come requirement will come very late and it could take time if we both have the conventional approach.

In many cases the tooling will decide the quality of the end product and to address that quality related issues, the tool needs to be efficient. So, that quality of the final part is not affected. So, in a molding industry typically we have two types of tooling, one is the direct rapid tooling. In the direct rapid tooling, the entire mould assembly is produced through the process AM process.

The rapid tooling could be completely done through a conventional process or it could be done completely through an additive manufacturing process like DMLS or SLS or it could be hybrid.

Typically, the hybrid process takes advantage of both conventional as well as the additive manufacturing. So, that we get the optimized tool done, both in terms of cycle time as well as the cost. In the indirect rapid tooling, we are not making the complete assembly. We have more than one intermediate steps in manufacturing the core and then the cavity, so that is the indirect rapid tooling.

So, there are two examples are shown in the bottom, the first one is a cooled insert which is done through the hybrid process. It also incorporates the conformal cooling, so that we reduce the cooling time for the mould itself. So, the complex part which is on the top what you can see here which also has the conformal cooling. So, that is one which is done through the additive manufacturing.

The bottom one which is much easy to machine that is what is done through the conventional process. Similarly, you can see here an example of when intricate mold which could be done through the conformal cooling in a much better way which reduces the cooling time as well as uniform cooling, so that we get a better quality of the part.

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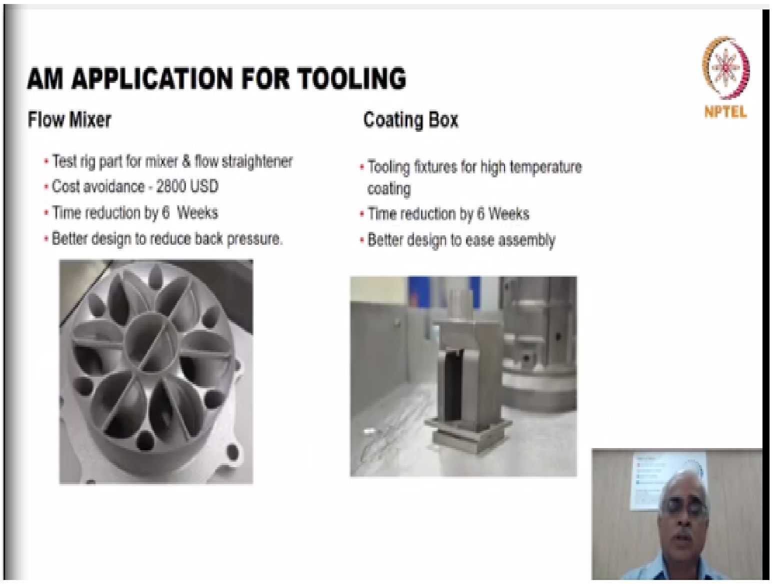

So, few more examples of the tooling here. This is a flow mixer; this is a test rig part for testing some of the flow meters or any other flow devices. So, this one we can come out with a real innovative design using the additive manufacturing by which we can reduce the cost. We can also reduce some of the back pressures which otherwise will be there with the conventional designs.

Then there is a coating box, so this is the coatings which you do on the parts, so that fixture which is required for these coating. So, the conventional design would have taken about 8 weeks whereas we could do an additive in 2 weeks, so reducing the cycle time is a key thing. It is better design from the assembly point of view.

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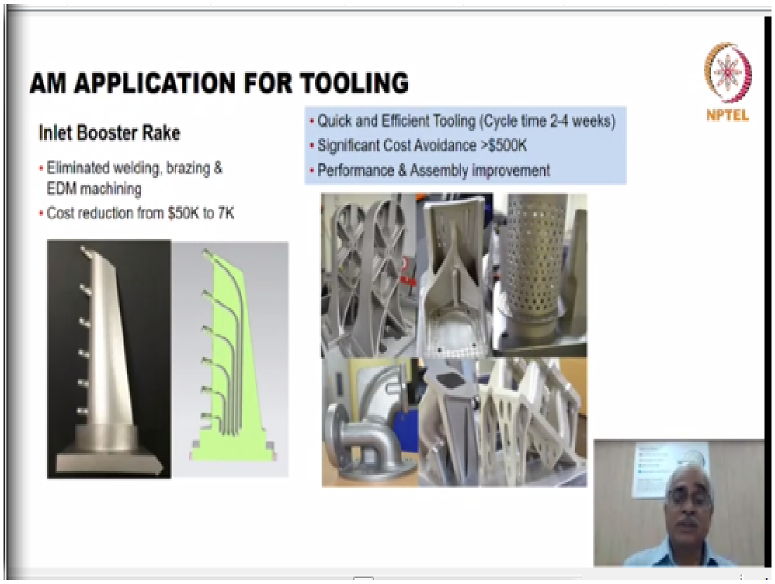

This is another good example of the rake, the measurement. It measures the pressure across the airfoil. Typically, this takes a lot of time to make it through the conventional process. It also involves a lot of welding, brazing and then the EDM machining if you follow the conventional process. Additive is the right way we can make this part and eliminate the welding, brazing which helps in reducing the cost as well as the cycle time.

So, and few more examples are shown here for the tooling applications. Typically, we can reduce the cycle time more than four weeks. We can also reduce the cost and then we get a better performance from the tooling.

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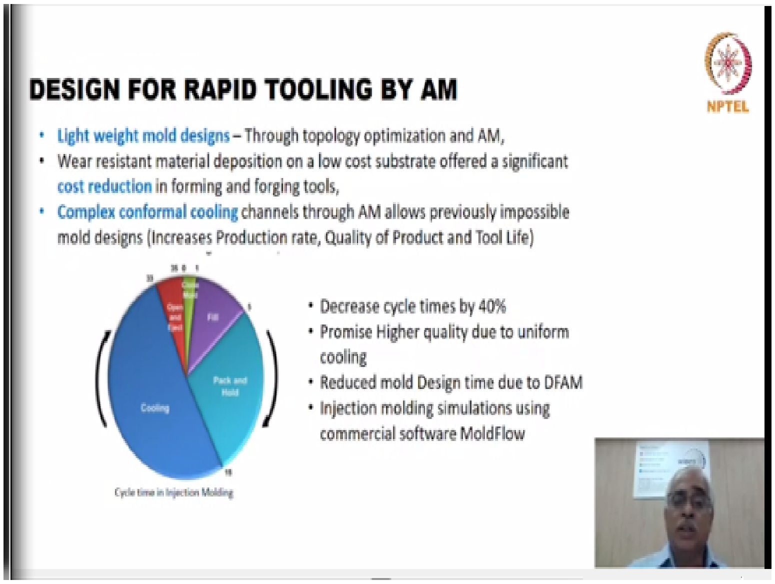

So, since we are using additive for these toolings we can take benefit of this additive. This is a typical application for the conformal cooling applications. So, when we do the mould designs, we always keep in mind how that mould can be produced. With the conventional of machining we can always have the straight, vertical or the horizontal or the holes we cannot have the curved holes.

Because of that typically the cooling time is cannot be optimized. So, the pie chart here you can see that out of all the cycle time in the injection molding, Cooling is the one which is takes almost 50% of the time, what is shown here is in seconds. So, cooling takes almost like 18 seconds out of the overall 35 seconds of time what it is takes. All other process which is involved injection molding takes the remaining 50%.

So, this can be optimized by coming out with the additive manufacturing design. We can come out in the complex informal cooling channels which otherwise is impossible to produce using the conventional approach, which helps in the quality of the product by having a uniform temperature. It reduces the cooling time, so it increases the production rate and then the tool life is also increasing.

So, we can optimize the design and then we can verify validated through a mould flow software and then finalize the mould design.

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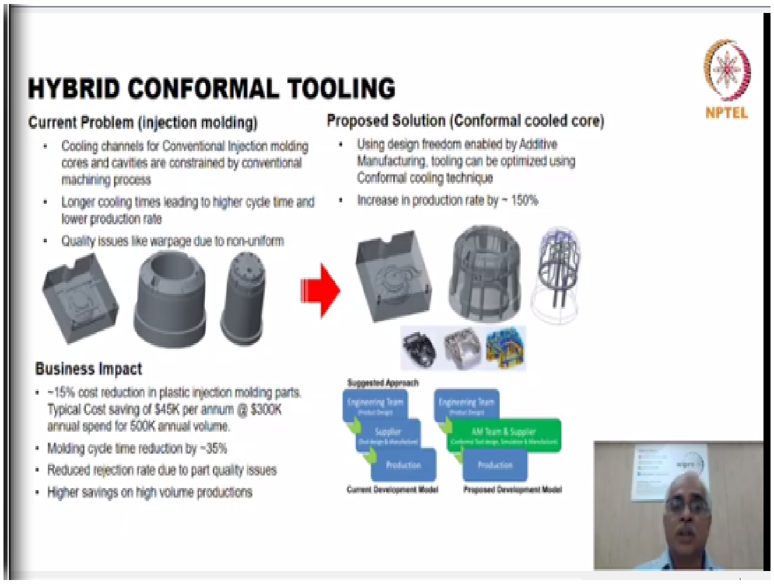

This is a practical example of deploying the hybrid conformal cooling. This is for one of the fire safety devices what we are talking about. The mould design was optimized by using the mould flow software and we could get a reduced cooling time of more than 50% as part of this. This design can see here that the conformal cooling which channels which are incorporated. So, that we can quickly cool the mould and then you also get the uniform temperature.

The process which is followed is we have the engineering team which is the product design team and then we have the AM team involved to design these tools and then the production agency which will implement this and then validated it. This whole thing was validated where in the production rate we could increase by almost 50%. The 5000 parts which were able to manufactured in a day.

We could increase that to 10,000 parts in a day. So, that is the validation of the things and then we could demonstrate a cost savings of about 300K per annum as part of this part. So, this is a good example of using conformal cooling for the mould design.

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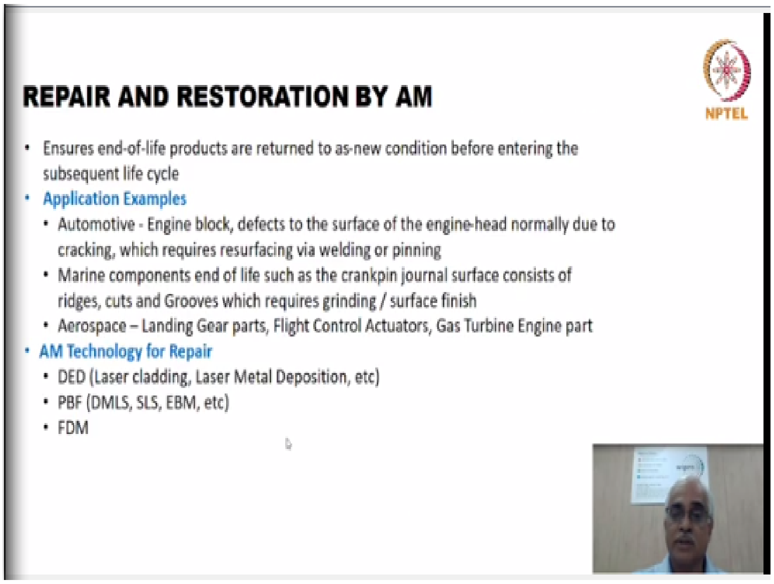

The third topic which I want to touch upon is the using additive manufacturing for the repair and restoration. This is not a new thing which is already in use in many of the applications could be automotive or for the marine components or for the aerospace components. We refurbish the part as a new condition and then it can have an additional life incorporated. Examples are for an automotive it could be an engine block or it could be some defects which would come into the engine blocks and then that needs to be addressed.

Or it could be marine components like the crankpin journal where it could have a lot of cuts, ridges and then the grooves and then it needs to be grinded and finished. Or aerospace part like it could be a landing gear or a flight control actuator or a gas turbine engine parts like a turbine blades or a compressor plates which could worn out near the leading edge. So, those are the areas where we can deploy the repair.

The additive manufacturing technology for the repair, most of this thing has been around the direct energy deposition which is more like the laser cladding or the laser metal deposition which has been in use for the last 15 to 20 years. So, that is what has been largely used but in the recent past with lot of improvements were happening in the DMLS or the EBM or the SLS technologies.

The powder bed fusion is been extensively used for repairing the parts. Especially the complex parts, it is much easier and can be done in a much more precise and an accurate way. For the most of the plastic parts FDM is the one which is used polymers or plastics. So, that is where those are technologies which are being used.

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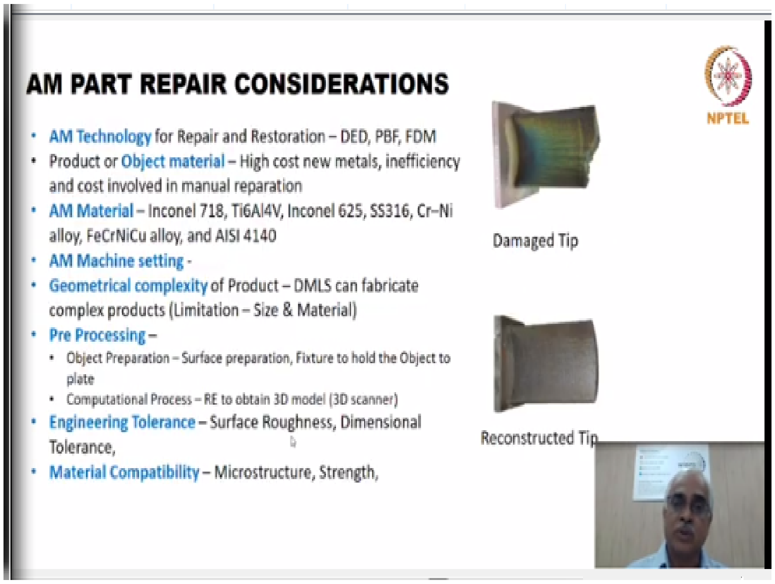

So, what we need to consider while we decide AM for the part repair ? One is we need to decide which technology you are going to use it for repairing whether it is a powder bed fusion or the FDM or the direct energy deposition. So, that depends on the type of repair what you want to do and then what capabilities each of these AM things offer today.

We also have to keep in mind what is the material of the original part. Typically, we high cost new metals and when you want to do it manually the inefficiency is involved. So, those are the parts which you consider it. We need to keep that in mind both with the product as well as the material which is feasible to do the repair through the additive way and then which material you are going to use for additively repairing the part.

Today these are the materials Inconel 718, Inconel 625, Titanium alloy and then the stainless steel aluminum. So, those are the things which is possible today with the additive manufacturing. So, we need to decide which materials are going to use to repair the part. We also need to decide on the AM machine itself and then the settings, what is possible? So, all those are the things which we have to finalize.

Also to consider the geometric complexity of the part in making the decision of which is a best process and what can be achieved. Most of the repair activities at the pre processing which is involved for the object preparation and then we have to do computational preparation to have the 3D model done. So, in the object preparation, we need to prepare the surface on top of which you are going to build the part.

Then we also have need a fixture to hold the object onto the base plate, if it is especially a DMLS approach. Then it has to be molted onto the base plate and joining properly and then we have to set completely aligned. We definitely need to have a 3D scanner the existing part which also decide it is superimposed onto the final product what you want and then that will decide the repair which needs to carried out, so this has to be very properly captured.

Reverse engineering 3D scanner plays a big role in creating those models. We also need to validate from the material compatibility point of view from the microstructure and then the strength, durability point of view. So, those are the questions which we need to clearly have the answer, so that repair process can be quickly approved and then certified.

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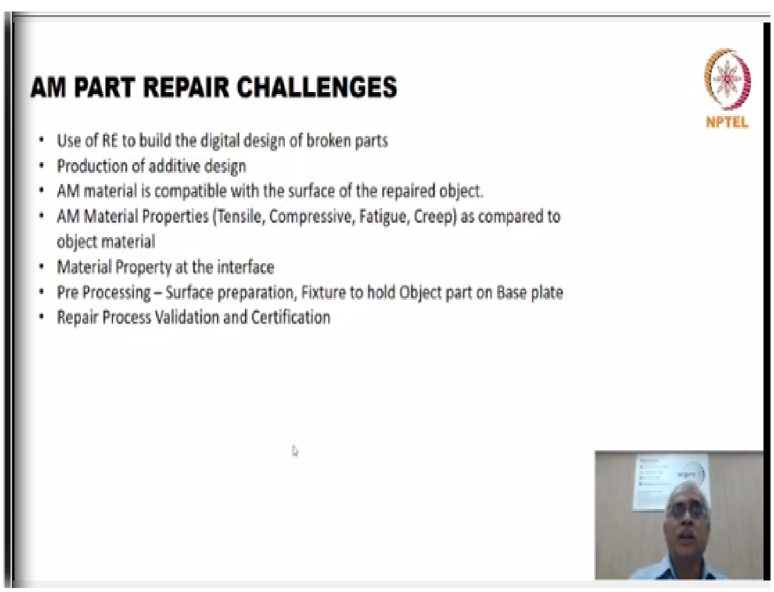

What are the challenges for the part repair using additive manufacturing? There are still process gets involved and then validated and then it is deployed. Few challenges which typically you come across while using additive as the process for part repair are, we need to build the model through reverse engineering, so that is the key thing to capture all the details and that is sometimes it may create an issue in while building the part.

Then when you want to produce these parts, we need to have those some of those fixtures and then the machine and the CAD model zero alignments and all the access. So, those are the things which we need to have trials done before we can use it for the production. Material definitely is an issue the how good is the pairing of the object material and then the AM material. So, if it is a same material then the problem is little less, if it is a different material then we need to understand the bonding between those materials and then validate it.

The material property itself when compare to the base material and the AM material properties as well as in the property of the interface. So, those are the things which we need to do lot of testing and validation before we say that yes additive is the thing what we can use it for repair. We also faced quite a few challenges in designing the fixtures to the hold the part with the accuracy is what is needed. So, the fixture needs to be flexible and adjustable, so that we can address the challenges, so that could at a risk.

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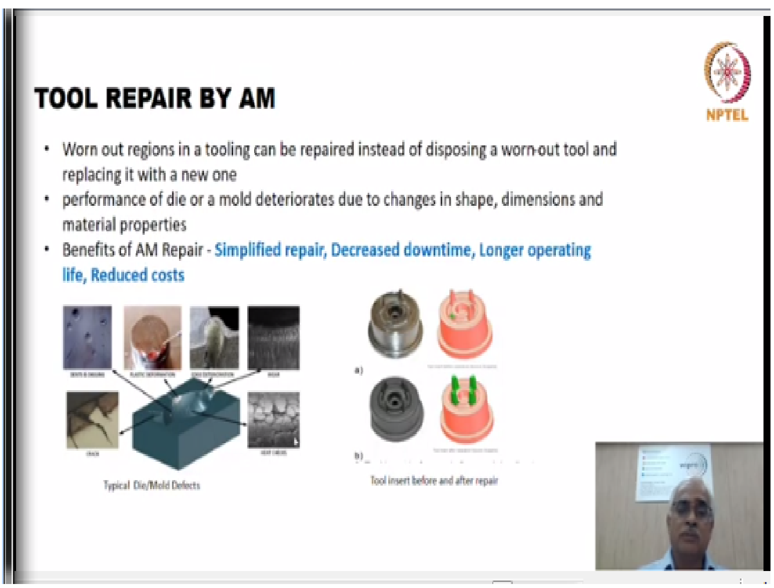

So, but nevertheless additive has been now very extensively used for many of the part repair activities especially the worn-out parts may not be the safety critical parts that in all other ideas been very widely used. You can see the type of defects which you can see in a dye and a mould in the picture. So, those are the defects which we can repair it using the additive manufacturing and then fix it.

So, you can also see the tool insert here one of the things what you can see is broken off here and because of this you have to completely discard the tool and then remanufacture this tool whereas in an additive way we can rebuild that and then reuse it. So, that is way it will decrease the downtime. It will reduce the cost, so that is what additive is helping as far as the tooling is concerned.

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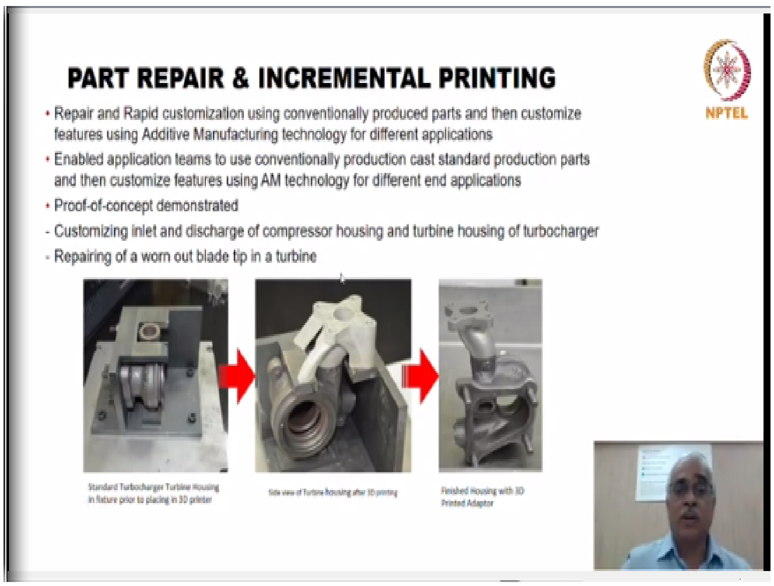

The other way which extension of this part repair process is the incremental printing which can be used. You already have a product but that product in terms of the critical performance is concerned, it meets the customer requirements. But for assembling into the next level of assembly it needs some changes. An example what you are talking about, here is the turbo charger. The turbo charger housing especially the end of flange which gets assembled onto the automotive engine, that needs to changed.

But basic other features of the turbo charger are not changing. So, this is typically made out of a casting and to make a casting of this housing and then get that complete assembly done. It could easily take 3 to 4 months even if tooling everything is available. So, we can take the existing housing chop off the existing flange and refill on top of that what the customer wants. So, that we can provide the customer demo very, very quickly and then he can do the assembly and then the initial field trials with these.

So, we could quickly provide this prototype to the customers in about 3 weeks of time. Then they could do the trials in maybe next 2 to 3 weeks and then give that feedback. So, that way you can it also helps to have a early customer engagement. So, this type of incremental printing as an extension of the part repair technology could be efficiently deployed and then used to create the differentiation with respect to our competitors.

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So, with that I will come to the end of this session, so additive is already playing a big role as far as it is application for prototype tooling and part repair is concerned and with lot of technology improvements happening in the area of metal printing to address the some of the challenges which maybe there. It is going to be a big game changer in the next 3 to 4 years. So, we can quickly come out with a product to using the AM prototypes.

Any of the tooling needs we can quickly address it and then for the products which are already in field, we can increase that life through the part repair. So, with that I conclude my talk. Thanks for giving me this opportunity to talk about this next future technology. Thank you. Thanks a lot.