Manufacturing of turbines (gas, steam, hydro and wind)

Dr. Sunny Zafar

School of Mechanical and Materials Engineering

Indian Institute of Technology Mandi

Week -03

Lecture 11

Welcome to this course on manufacturing for turbines. So in lesson 11 of this course, we will see further details about the manufacturing of gas turbine blades. So this lesson will cover hot isostatic pressing, which is used to consolidate the microstructure of the gas turbine blades. So in the hot isostatic pressing, we will see what the healing mechanism and advantages are. Applications and effects of hot isostatic pressing on gas turbine blades. Next, we will look at the requirements of machining processes, the classification of machining processes, and the objectives of machining in gas turbine blades.

So we start with hot isostatic pressing. So, hot isostatic pressing is one of the material processing methods where we compress the components by applying high pressure and temperature from all sides at the same time. So, here is basically what happens: the gas turbine blade that is obtained after casting may have some defects, such as pores or possibly some internal defects. So, it is very much necessary to heal those defects or pores.

So, in this regard, hot isostatic pressing becomes a very important process. So, if you look at a typical diagram of a gas turbine blade, So here we will see that as the requirement for gas turbines is increasing, the size of the gas turbine is increasing. So whenever we try to cast large objects, there is a possibility that some defects may creep in while the casting is done. So here in hot isostatic pressing, what we want to do is we want to heal up those pores or maybe some defects by applying heat and pressure. This heat is applied at the order of several hundred degrees or maybe up to two thousand degrees of temperature.

And the temperature at which the hot isostatic pressing is conducted is also known as the soaking temperature. And there is also application of pressure on the order of several tens to up to 200 megapascals at the same time. So, here importantly what is happening, application of heat and pressure, this is simultaneous and this is also from all the directions. So, this means that in this facility, which is needed, or we can say a furnace that is needed for hot isostatic pressing. So this is not like any generic furnace; it is a sort of pressure vessel.

So we can see that the enclosure of this furnace is a cylindrical pressure vessel. So pressure vessel is basically used so that it can handle this high value of pressure and temperature. So in this pressure vessel, we have heat insulation, which is indicated by this blue color. So, this heat insulation basically ensures that there is minimal heat loss to the surroundings. Then at the bottom of the furnace, we have a support on which the component that has to be subjected to hot isostatic pressing is placed.

And then surrounding this component, we have several heaters or heating coils that will be heating and providing the required temperature needed for hot isostatic pressing. And to apply this isostatic pressure, which is the same pressure from all sides and remains constant during the process. So, this pressure is applied using an inert gas that is argon. So this pressure of 200 MPa it is maintained by pressure of argon here and this argon is introduced into the furnace using this gas inlet and subsequently the material is subjected to hot isostatic pressing. So we understand now that the need, as we have now understood, is basically to heal micro pores or micro defects in the cast gas turbine blades.

So this is the need. This is the process in which we are simultaneously applying heat and pressure from all directions. Now, the important aspect is when we are applying heat or pressure, particularly the pressure from all directions, as indicated by these arrows here. So what happens to the near net shape of the product does not change. So if pressure is not applied uniformly from all directions, we can say that from one direction the pressure is high or from some other direction the pressure is low.

So what will happen because of this non-uniformity is that some face or side of the component may be deformed more than the other side. So in that case, what happens is that the near-net shape of the component is disturbed. but in hot isostatic pressing as same pressure is applied from all the sides so the near net shape of the component is remained constant, Although it is also observed that in hot isostatic pressing the overall dimensions slightly reduce compared to the component that is not hot isostatically pressed. So now if we try to understand the mechanism how the hot isostatic pressing process works. So hot isostatic pressing process it works on eliminating internal voids and micro porosity by combination of three mechanisms which is the plastic deformation, creep and diffusion bonding.

So essentially, it is the diffusion that is taking place because of high temperature. This diffusion is basically, you know, is enabled. And basically, in creep, we also have two varieties of creep taking place. So one variety of creep is Nabarrow Herring. Creep and the other creep that is taking place here is the Coble creep.

So fundamentally, both of the creep mechanisms are different. So the Nabarrow Herring creep is a process by which we can say that the atoms and vacancies flow through the lattice. While in the Coble creep, what happens? It causes diffusion along the grain boundaries, because of this so essentially both of these things are largely dependent on diffusion and diffusion As we know, it is a thermally activated process, and because of this, what happens is shown here in this healing mechanism of porosity in hot isostatic pressing treatment. So here we can see that the dotted line shows the vacancy diffusion along the grain boundaries. And the solid line shows the diffusion, bulk diffusion of the grains into the vacancies.

So we can see the interplay of Nabarro herring creep as well as Coble creep taking place while the hot isostatic pressing treatment is being done. and this basically results in the healing of this porosity that was there in the beginning, and in the end, we can see the porosity has healed. Although the grain size has slightly reduced because of the healing of the porosity and the filling of that pore region with the surrounding material. Now, as this hot isostatic pressing process is dependent on diffusion, all of this hot isostatic pressing is also conducted using a standard heat treatment cycle. so for example here for a typical nickel based super alloy denoted by K452 so here it is shown a standard heat heat treatment cycle for this alloy while it is Subjected to hot isostatic pressing, wherein the alloy is heated to a temperature of 1170 degrees centigrade in four hours.

And then it is furnace cooled, denoted by FC, at the rate of 15 to 30 degrees per minute, after which it is again heated to 900 degrees centigrade and then air cooled. Then again heated to 1050 degrees centigrade for 4 hours and air-cooled to 850 degrees centigrade, and then it is kept at 850 degrees centigrade for 16 hours, and subsequently, it is air-cooled again. So what we can understand is that every component, every product, and every material will have its own optimized standard heat treatment cycle on which the hot isostatic pressing treatment will be done. In addition to this temperature requirement, there will also be a requirement for the pressure of the argon gas. Because the pressure of the gas also plays an important role, it is ultimately the pressure of the gas that is being applied from all sides.

So after understanding this mechanism of hot isostatic pressing, we will look at the role of the argon gas. So, argon, as we know, is an inert gas. So the advantage of using an inert gas is that it is unreactive with the components that are subjected to hot isostatic pressing treatment. Because the temperatures are much higher during the hot isostatic pressing treatment, and the argon.

It basically facilitates the application of uniform pressure from all sides, and because of its inert behavior, it does not react with the component, so no degradation of the component takes place. So what happens the argon gas at 1000 degree centigrade and under say intense pressure of 98 megapascals it is likely to cause intense convection. So intense convection is much different from the convection that we know because, at higher pressures, the molecules of argon will be very near to each other. And of course, these molecules of argon, when they are very near to each other at elevated temperatures, they are likely to conduct or convect heat at a faster rate, thereby increasing the convective heat transfer coefficients. So heat transfer coefficients, therefore, become much higher than those of any ordinary electric furnace used for other heat treatment processes.

And this we can see from these figures, where we can see that the density of argon gas increases. Because it is compressible, it increases at a higher pressure of 98 MPa, which causes the rise in temperature in this case to be much faster compared to when it is at atmospheric pressure. This can be understood by looking at the slope of this curve. Secondly, we can also see the rise in temperature also as a function of with the viscosity, coefficient of viscosity of the argon wherein we can see that at higher pressures, there is a much higher rate of increase in temperature. Because of the intense convection, the nearby molecules of argon at higher temperature and higher pressure are likely to cause a faster rate of heat transfer than atmospheric pressure can cause.

So, we can now summarize the advantages of hot isostatic pressing treatment. So, we can say that hot isostatic pressing treatment results in densified castings that show improved strength and ductility. This improved strength in ductility is reflected in the fatigue performance because of the removed porosity and refined grain structure. We can say that hot isostatically pressed parts, or HIP parts, generally have consistent material properties. Because now what has happened across the dimensions of the product, the microstructure is uniform and refined.

Hot isostatic pressing can also sometimes be used to remove in-service porosity. So what we mean by in-service porosity is that some products may not have reached the end of their service life; rather, the service life may still remain. And we can also utilize the advantages of hot isostatic pressing to rejuvenate the microstructure of such materials. Products or castings that may further extend their service life by again removing micropores and voids. So we can say that hot isostatic pressing can be an effective way to repair porous castings or improve the yield of castings.

Because the rejections may reduce if we encounter a small volume of pores or defects, they can be repaired. Using hot isostatic pressing rather than completely rejecting the casting will improve the yield of the casting process. Hot isostatic pressing treatment, it can be a cost saving method with negligible production of scrap and it can be also used to reduce the quality assurance costs because it helps to rejuvenate the microstructure, repair the microstructure, refine the microstructure and improve the properties of the products. On the right-hand side, we can see a typical canister or pressure vessel that is generally used for hot isostatic pressing. And by looking at this image, we can see that the thick walls of this pressurized canister can be very well used to house the components.

As well as the hot gases at elevated pressure, this causes the hot isostatic pressing treatment. Other than rejuvenating or repairing the casting of gas turbine blades, we can see other applications of hot isostatic pressing. So, these applications include pressure sintering of powders and diffusion bonding of different materials because sometimes dissimilar materials may also be joined with diffusion bonding, removal of residual pores, even in sintered items. Removal of inner defects in casting, rejuvenation of damaged parts, especially by fatigue or creep.

Sometimes, some microcracks may also have been generated under the influence of creep and fatigue, especially in rotating components. So we can rejuvenate the microstructure by subjecting it to hot isostatic pressing treatment. High-pressure impregnation of the carbonization method. So sometimes some carbon-based materials may need to be impregnated onto the surface of any other material. Again, in this case, the application of hot isostatic pressing can be done to impregnate the carbon.

But here it has to be noted that this impregnation will be only a few microns on the surface of the product, not across the bulk. So we can see that in hot isostatic pressing, as we were discussing earlier, since pressure is uniform, pressure is applied from all sides. So the net shape of the product remains constant. So, here we can see that there is almost, I can say, a 90 to 80 percent reduction in the dimensions.

So, this part is subjected to hot isostatic pressing, and this is a non-hot isostatically pressed part where we can see there is a slight reduction in the dimensions of the part, but the overall shape remains constant. Here we can see another evidence how hot isostatic pressing can help to minimize or closing the pores and cracks in additive manufactured parts which can further improve the mechanical strength. And here the image is captured using X-ray tomography, which shows a pore before hot isostatic pressing, and we can see this pore has almost healed up. And after the hot isostatic pressing, the presence of pores is not there. So, other than the applications we have seen, there are some other specific applications.

Where hot isostatic pressing can be used, especially with powder metallurgy parts, steel, and nickel-based superalloys, as well as titanium-based alloys. It can also be used in nuclear fuel assemblies. With boron fiber aluminum alloy composites, which are used in the space shuttle. Then it can also be used to remove residual pores in sintered items such as cemented carbides and cutting tools. Removing inner defects from castings, especially with nickel-based superalloys, jet engine turbine blades, and titanium alloys.

It can be used to rejuvenate parts that are damaged by creep or fatigue, especially with the superalloys we have been discussing. Impregnation is much needed in the case of, say, carbon composites. So, the hot isostatic pressing treatment is also helpful. So, here it is tabulated the summary of the main materials which are used in hot isostatic pressing treatment. The required temperatures and pressures are shown.

So, for the nickel based super alloy which is primarily used to make the gas turbine blades, we can see the temperature of the order of 1100 to 1280 degree centigrade Gas pressures of 100 to 150 megapascals are used to conduct the hot isostatic pressing treatment. Next we can see the how hot isostatic pressing treatment can improve the creep fatigue life which can improve the creep fatigue life by 1.3 to 3.5 times improving the elongation. And here are the different nickel-based superalloys that are used to make the gas turbine blades, such as INCONEL 738, RENE 77, INCONEL 792, and RENE 80.

Are used with casting, and the other state is casting plus hot isostatic pressing. And we can see there is an improvement of almost 1.3 to 3.5 times in the creep fracture lifetime. And of course, the elongation and contraction have also improved in most cases.

So next, we would also like to talk about the requirements of machining processes for the gas turbine. So what we have covered up to now is basically the casting process. So in casting, we have seen that the mold development for the gas turbine blade is done using investment casting. And then in the investment casting, these are further subjected to other specific furnaces, like the Bridgman furnace. We have seen the use of the liquid metal cooling process, the gas cooling casting process, and the dipping and heaving process.

The objective of utilizing all these furnaces is to develop a single crystal cast gas turbine blade. So that no grain boundaries are present, to minimize the possibility of creep failure. Then we have seen after casting the utilization of hot isostatic pressing which is primarily used to remove micro-level defects of pores or voids inside the casting to improve the microstructure and refine it. So, these two processes come under the category of primary manufacturing processes for the gas turbine blade. So, the next process that is the machining process for gas turbine blade so they come in the category of secondary manufacturing process for the gas turbine blade and we will see the requirement for machining in gas turbine blades.

So in general, machining is very essential for parts that are manufactured using casting or forming. Because many times machining is needed to control the dimensional accuracy and surface finish of such parts. Machining also facilitates the interchangeability of parts with proper function and reliability. And machining in generally is a subtractive process which involves removal of material from the workpiece in order to produce a specific geometry at a defined degree of accuracy and surface finish. So, machining is a very wide term in manufacturing and most of the material removal processes they come in this category of machining.

Machining is further classified based on traditional machining or non-traditional machining in traditional machining we know that there is a physical contact between a cutting tool and the workpiece and because of the inherent hardness high hardness of the tool material removal takes place from the workpiece so all the conventional machining processes are further classified based on cutting or mechanical abrasion so in cutting we can have different processes for circular shape which include turning boring drilling and for all other shapes we can have milling, planning, shaping, broaching, sawing, filing, gear forming, gear generation. Mechanical abrasion based processes are primarily focused to improve the surface finish which utilize either the bonded abrasives or loose abrasives where grinding, honing are coming in the category of bonded abrasives. While loose abrasives, they involve use of polishing and buffing.

In non-traditional machining, so Energy in some other form like the use of abrasives, use of temperature, use of plasma, use of laser, electron beam etc. is utilized to again remove material. So, in this case we have various processes listed here which include chemical machining, then we have electrochemical machining, electrochemical grinding. electric discharge machining, laser beam machining, abrasive jet machining, water jet machining, plasma beam machining and ultrasonic machining. So we can see that there are wide variety of machining processes but the question arises which machining processes will be used for gas turbine blades and why. So we will see this now. So in the gas turbine blades, as we know, we are already utilizing the nickel waste superalloys because of their properties of retaining their strength and hardness at elevated temperature.

So the conventional machining processes may not economically machine such materials. So these new materials, they are generally processed or machined using non-traditional machining processes. Because in non-traditional machining processes, they are able to meet the stringent requirement of machining complex geometrical shapes with high precision and accuracy. So, in the non-traditional machining processes, again we have different classification based on the action of the processes which include mechanical action, thermal action and electrochemical action. And here also for the gas turbine blade, the electric discharge machining and laser beam machining are primarily used to carry out the machining on such gas turbine blades.

Now, question is where such machining is needed. So, here we can see some images of the gas turbine blades where we see the presence of these holes which are known as the film cooling holes. So the need of machining process is to create this film cooling holes and use of electric discharge machining and laser beam machining has been very popular to make these holes and these holes basically they increase the surface area of the gas turbine blades thereby improving their cooling and this also enables the gas turbine blades to operate at higher temperatures thereby improving the overall thermal efficiency of the gas turbine. So, now we understand the objective of machining in gas turbine blade is to create these holes and the processes which are specifically used to do that are electric discharge machining and laser beam machining. So, we will see the details of this process in the next lesson. So, we will now summarize what we have covered in today's lesson.

So, in today's lesson we have summarized the hot isostatic pressing treatment which is used to rejuvenate and repair the microstructure of the cast gas turbine blades. Then we have understood the need of machining in gas turbine blades. We have looked which processes are there. So, primarily we will be dealing with electric discharge machining and laser beam machining and in the need we have discussed that development of film cooling holes machining process is essential for the gas turbine blade. So, next lecture we will cover the details about the electric discharge machining.

Thank you.