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

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Lecture 16

Welcome to this course on manufacturing for turbines in this lesson 16 of this course we will see the manufacturing processes for thermal barrier coatings which are used to increase the thermal efficiency of gas turbines. So in this lesson we will see the manufacturing processes for thermal barrier coating such as the electron beam physical vapor deposition, atmospheric plasma spraying Subsequently, we will also look at how we can improve the thermal efficiency of the thermal barrier coatings. Although there are some other processes which are there in the research stage which are used to deposit the thermal barrier coatings, but out of all those processes the electron beam physical vapor deposition and atmospheric plasma spraying process are very popular to manufacture the thermal barrier coatings on gas turbine blade substrates. So, the unique characteristic of these processes include development of 10 to 30% porosity which is effectively helping to reduce the thermal conductivity by 100 to 150 percent. So, reduction of the thermal conductivity in these processes is result of assortment of features because of these features present in the coatings such as deposition induced defects like pores of various sizes, some cracks. myriad of interfaces which includes splat.

So, in summary we can say we deliberately engineer some defects into the coating so as these defects ultimately help in reducing the thermal conductivity of the coating. So we will see both of these processes in detail and understand how the process characteristics influence the microstructure of the deposited layer, and consequently this deposited layer how it functions by acting as a thermal barrier against hot gases thereby preventing creep related failure in the gas turbine blades. So we start with the first process that is electron beam physical vapor deposition. So the electron beam physical vapor deposition process, it relies on a highly energetic electron beam.

So this highly energetic electron beam is created in this electron beam gun here. with this electron beam is then focused on the ingots which are placed at the bottom in source 1 and source 2. So, the electron beam when focused on these source 1 or source 2 the ceramic ingots, so it melts and consequently vaporizes the ceramic by creating a high vapor pressure over this ingots. So, the electron beam here it is being used to melt the ingot and create the high vapor pressure. Subsequently, the substrate or the gas turbine blade here which is mentioned as aerofoil or this is the gas turbine blade is then introduced into this vapor cloud.

And upon introduction of this substrate or the gas turbine blade in the vapor cloud, the vapors of the ceramic material which are generated because of the interaction of the electron beam are physically deposited on the gas turbine blade. So, we can see that this preheating of these substrate is also very essential. so as to increase the deposition efficiency. So to do that before introducing the substrate directly into the vapor cloud, it is placed here in the heating zone. So as the surrounding heaters they heat the substrate and another important aspect of this process is continuous rotation of the substrate with the help of this rotation shaft.

So this continuous rotation of the substrate helps to develop columnar and inter columnar gaps, which also originate not only from the vapor pressure but also macroscopic shadowing effects which are caused by curved columnar tips triggered by rotation of parts during deposition. Now since shadowing occurs primarily along the plane of vapor, so the columns are significantly wider in the direction which are parallel to the rotation of the axis than perpendicular to it, leading to anisotropy of in-plane compliance with notable consequences of strain tolerance of the thermal barrier coating system. So because we have seen the thermal barrier coating material is a ceramic material which is coated on a nickel base super alloy which is a metallic material. So both the materials they have a significant difference in the coefficient of thermal expansion which creates a situation of strain mismatch. which can lead to the failure of the thermal barrier coating.

And by introducing this columnar type of microstructure that we will see shortly, we can anticipate the compliance of the strain which is generated on these layers. Here another important criteria is to achieve the desired stoichiometry of the zirconia. So, sometimes oxygen may also be bled into this chamber which is a vacuum chamber and this oxygen then results in conversion of zirconia which is also compensating the reduced zirconia content because of the disassociation upon interaction with the electron beam. and rotation of the parts is mandatory so that coating can take place from all the sides on the blade. So due to the formation of the vapor pressure and combined action of shadowing and crystallographic growth selection, columnar microstructure, the thermal barrier coating achieves high level of strain compliance.

This ensures continuous growth of the ceramic coating and cylindrical ingots of ceramics are continuously fed from the bottom. So with all these aspects, we can see the microstructure which is generated. It is closely related to the processing conditions. And often in the microstructure, the gollular or elongated sphere pores are observed. And each layer represents actually one layer of the coating which is deposited in one rotation.

So due to this rotation effect of the substrate, so there is a situation of sunset or end sunrise which is created and in the direction perpendicular to the deposition, the bent sub columns are also observed. So we can now see the microstructure. So this is the typical microstructure of the layers which are deposited with the electron beam physical deposition. And in the microstructure, there is another notable observation of the feather arms. So, we can see this type of feathers arms are also generated.

So, this type of feather arms are a consequence of shadowing by the growing steps of columnar tips. At the center of the columnar tips, for energetic reasons, the 111 plane is more favored for the growth of this type of microstructure. and the presence of this type of inter-columnar gaps like this as well as the boundaries between the different columns as I am highlighting here. So, this all results in a lower thermal conductivity of the thermal barrier coating layer. So, means the process is deliberately introducing these defects which are desirable not only from this aspect of lowering the thermal conductivity, but also to create a situation of strain compliance compliance there and because of the strain compliance what is happening the thermal barrier coating it remains intact in the processing conditions.

So, now we can look at the advantages of the electron beam physical vapor deposition process. So this process results in the columnar structure as we have just seen which provides strain compliance as well as the pseudo plasticity. The resulting microstructure has higher erosion resistance, has a smoother surface finish which offers aerodynamic advantages. The cooling holes which are developed as seen in the previous sections of this course using electric discharge machining or laser beam machining they remain open because to deposit the coating we need a substrate and wherever the hole is present so it is a through hole so no substrate is there. Consequently the cooling holes they remain open but the process of this electron beam physical vapor deposition also has certain limitations which involve high cost because the deposition rate is the order of micrometers per minute.

So because of this very slow deposition rate, the cost is high. Also because of this electron beam setup, which involves a very complex vacuum arrangement system, the cost increases further. And because we are depositing vapor here, it is not that 100% all of the vapor gets deposited on the substrate. So consequently, there is a low utilization percentage of the raw material. as some of the vapour may also be getting deposited on the internal surfaces of the vacuum chamber rather the gas turbine blade substrate.

So, the other process which is also used to develop the thermal barrier coating on the gas turbine blade is the atmospheric plasma spraying or abbreviated as APS. So atmospheric plasma spraying, it is basically a thermal spray process in which basically what we do, is we have arc plasma jet in which we entrain several micrometer based metallic or nonmetallic powder particles. And these powder particles, when they are entrained in the plasma jet, they basically get melted. and they also get accelerated and these semi molten powder particles which are accelerating in semi-molten stage they get subsequently deposited on the substrate. This means in the plasma jet while the particles are entrained they get or they gain velocity they gain momentum as well as their temperature also rapidly increases because of heat transfer from the plasma jet to the powder particles.

And in this case the plasma jet is created by a strong electric arc generated between a positive charged pole and a negative charged pole anode and cathode. So, this positive strong electric arc because of the high potential difference this ionizes the flowing gases into the plasma state and upon injection of the feedstock material or the powder particles, the melting of the powder particles is happening also with melting these powder particles are propelled to the workpiece substrate. So we can see here the photograph of plasma spraying coating process being done on a gas turbine blade here to deposit the thermal barrier coating. So if we closely look in the microstructure which are obtained after the atmospheric plasma spraying. So here what is happening that the in the plasma spraying so we have this plasma gun, where we have the cooling water going in and out and then there are power cables connecting the cathode and anode with negative and positive respectively.

So in the plasma gun because of the high potential difference being applied, a plasma jet is created. And after the plasma jet is created at the exit of the gun, the powder particles are introduced and the powder particles we can see they interact with the plasma. They get heated up they get propelled or accelerated because of the momentum transfer and then they are subsequently deposited on to the substrate. So here what is happening in the plasma spraying the individual powder particle it is getting deposited in form of a splat and the relative solidification of each powder particle is independent. So this results in a chaotic assemblage of all these powder particles to form a brick wall type of a structure.

So here we can see the individual powder particles once it is getting solidified. So this sort of a microstructure is generated which contains lot of inter-splat boundaries but also some of the unfilled regions and this type of microstructure is known as the brick wall microstructure. So, presence of this inter-splat boundaries and there are several unfilled regions it also results in the reduced thermal conductivity and because of this the performance of the thermal barrier coating layer it drastically increases. So, powder particles size of the order 10 to 100 microns may be used, which result in a splat size of 100 to 150 microns.

And atmospheric plasma spraying conditions also decide or the process parameters of atmospheric plasma spraying, they also decide the resulting microstructure of the thermal barrier coating layer. And some of the notable process parameters of atmospheric plasma spraying, these include Particle trajectory, thermal and kinetic state of the plasma, degree of melting, substrate conditions such as substrate position, surface roughness, the speed of the substrate as well as the powder particles. which are impacting on the surface. So once this splat, it comes in contact with the underlying nickel base superalloy substrate, it immediately solidifies or it gets a quenched sort of a situation, because of which we can see this type of cracks which are generated from the top view of the splat. And if you look in the cross-sectional view, so these inter-splat boundaries as well as these unfilled regions which are visualized as micro porosity.

These type of microstructure are very helpful for enhancing the performance of thermal barrier coating. So next is basically how we can improve the thermal efficiency of the atmospheric plasma spraying or maybe the electron beam physically vapor deposited thermal barrier coating. So we have seen two manufacturing processes which are used to deposit the thermal barrier coating. But we can further play with the material constituents because we know that in the thermal barrier coating, the 7 weight percent yttria stabilized zirconia, this is the main ceramic oxide, refractory oxide material which is used. But if we also mix certain other oxides into this composition, so we can further reduce the thermal conductivity of the thermal barrier coating.

So, as we know in solids, the heat transfer takes place by propagation of lattice waves, which is a result of moving phonons. And these phonons, it can be scattered by introducing certain defects or inclusion in the crystal lattice which impedes the heat flow and increases the thermal resistivity.

Now, if we dope the 7YSZ or 7% yttria stabilized zirconia with certain materials as mentioned here which are known as pyroclores. So, these pyroclores are also oxides of rare earth materials and this help to create regions of defects. And the thermal conductivity of the pyroclores is very low which transforms into impeding the heat flow from a crystalline structure to an amorphous structure which further reduces the heat flow. in the thermal barrier coating. So here we can see this schematic where the incoming heat Q is being dissipated inside the thermal barrier coating and the resulting heat Q1 is going out. And when we have these dopants of the pyrochlore.

So they help to dissipate heat because of which the heat which is going out is much smaller. So Q2 is much smaller than Q1. So we can see this impact of impurity concentration of the pyroclose which helps to reduce the thermal conductivity as well as enhance the performance of the thermal barrier coating. So here we can see the performance of several pyroclores which can be added in the 7% yttria stabilized zirconia and some of the special pyroclores they are also we can see that with the increase in temperature their thermal conductivity reduces which further enhances the performance of the thermal barrier coating. So here we can see comparison of the distress which is observed on the gas turbine blades with the pyroclores.

So, these blades 1, 2 and 3 are only 7% yttria stabilized zirconia. While these blades 4, 5 and 6, they had the gadolinia included as a pyroclore with the 7% yttria stabilized zirconia because of which we can see the significant improvement in the thermal efficiency or performance of the thermal barrier coating. and the testing of the TBCs although it is a very deep topic but it is also very important to understand what is the quality of the thermal barrier coating which is deposited. So some tests like this type of a Julich burner the test is also used where on the thermal barrier coating of on where from one side of the coating the Heat is applied using this gas burner and the sample is cooled from the back side using compressed air and then by looking at the thermal conductivity and heat flow, we can understand what is the quality of the thermal barrier coating which is deposited onto the substrate. So with this we come to the end of this lesson.

So we will summarize what all we have seen in this lesson. So we have essentially seen the manufacturing processes for the thermal barrier coating on gas turbine blade. So, in this process we have in detailed looked at two processes which included the electron beam physical vapour deposition or EVPVD. and then we have also looked at the other process that is the atmospheric plasma spraying for the APS process we have looked at how to improve the efficiency or thermal efficiency of efficiency and performance of PVC by adding pyroclores. And lastly, we have seen some aspects on testing of the thermal barrier coating using the Julich burner setup.

So, by covering these topics, we have come to end of aspects on manufacturing of the gas turbine blade. So, we will summarize the whole module on manufacturing of the gas turbine blade now. So, in this module of manufacturing, the gas turbine blade will form the most crucial component of the gas turbines. So, we have looked at processes starting with the primary shaping processes which involved utilization of the investment casting. which are used to create single crystal gas turbine blades made out of nickel base superalloys.

And we have also looked at the microstructure of the nickel base superalloys, how the coherent precipitates present there are basically used to provide strengthening into the gas turbine blades. So we have then looked at the hot isostatic pressing process which is used to consolidate the microstructure of the cast blades. Then we have looked at certain machining processes to develop the film cooling hole in the gas turbine blades. So, these processes included the electric discharge machining. And we looked at laser beam machining process.

Then we have seen the creep feed grinding process CFG. So the creep feed grinding process was used to create a smooth surface finish on the dovetail part of the gas turbine plate. And lastly, we have looked at the development of thermal barrier coating on the gas turbine blade. We have seen what materials are used in thermal barrier coating, why they are needed and how the thermal barrier coatings can be deposited on the gas turbine blade. So, these were some of the aspects how manufacturing of the gas turbine blade can be done.

And next in the subsequent lecture, we will start with the next part of this course that is manufacturing of the steam turbines.

Thank you.