Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-49
Surface Modification Techniques: Principle of Thermal Spraying

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know that we are talking about one approach where in a layer of the required material is deposited on the surface of the substrate. So, that the required improvement in tribological life of the component can be achieved and under this category we have talked about the world surfacing and laser cladding kind of process is where in the melting of the material to be deposited and the substrate as well is insured in order to have a good mythological compatibility between the two materials.

So that time a very coherent and adherent surface is formed and there is no issue of the bond strength. But there is another category of another category of the process is where in a layer of the material is deposited using the thermal spray processes. And in this case the melting of the substrate is not insured. In some of the cases the melting takes place but that melting is very limited that is why the dilution is not an issue in this group of the processes.

So, what is the basic principle of the process and how does it work and how do we get the layer of the required material on to the surface of the substrate for the property enhancement or better for enhancing with tribological life of the component. So, this group of the processes are called thermal spray processes.

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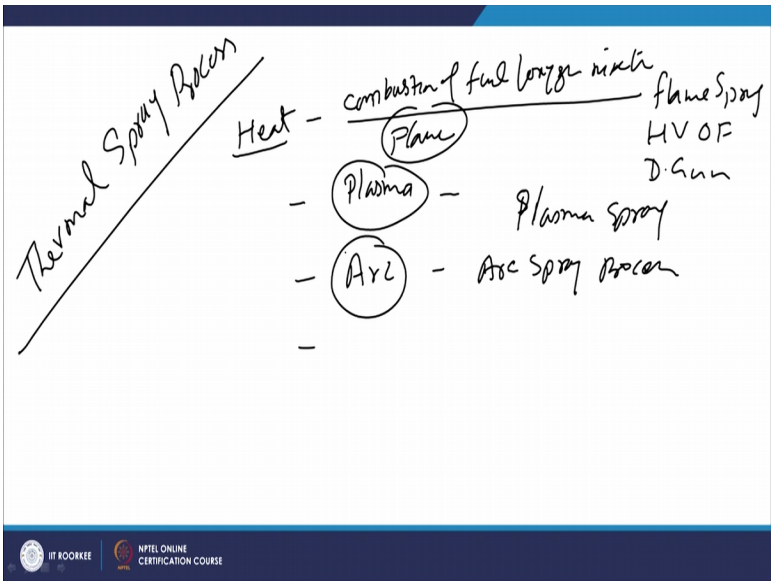

Thermal spray processors means we have to use the heat in one or other form which can come from the combustion of the fuel oxygen mixture and this happens especially in case of the flame spray processors, high velocity oxy fuel spray process and detonation gun spray process. The heat can also be used from the plasma which is generated, so, the heat of the plasma which is obtained through by establishing residual arc between the electrode and the nozzle.

So, this is plasma is used for having the required for thermal spray process and the process which uses the plasma for spray purpose is accordingly termed as plasma spray process. In some of the cases even the heat of the electric arc is used for spraying the material on to the substrate and they are called arc spray process. And then there is one more category where in the energy in the suitable form can be used for development of the coating on to the surface of the substrate.

But these are the three most common sources of heat which are used for thermal spraying of the material on to the substrate this is the like flame, plasma and the arc . So how does these process works.

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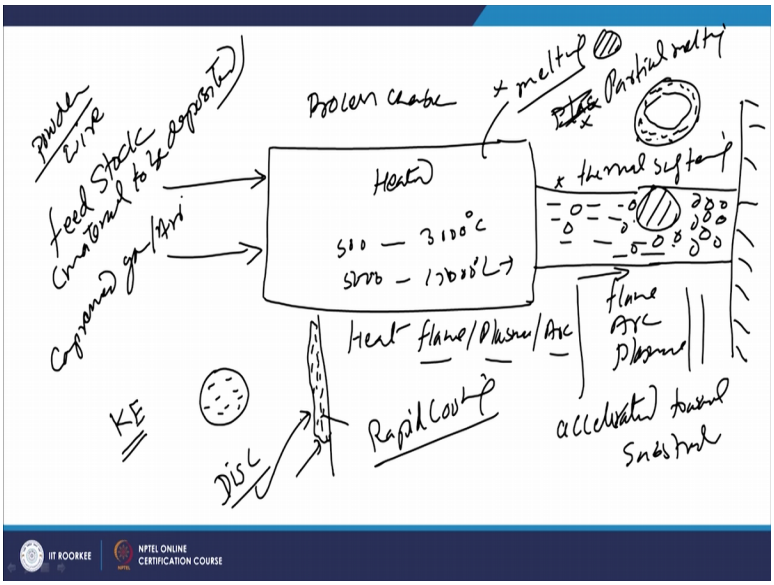

So, how does this process work in here like we have to use the; we use one basically the processing chamber that we can say where the suitable source of heat is utilised in form of the flame, plasma or arc under; in this process chamber we have to feed the material to be deposited. So, we have to supply the feedstock which is basically material to be deposited on to the surface of the substrate. At the same time same times we apply also the compressed gas or air so that the required velocity to the heated particles can be given.

So, this feedstock mostly is used in form of powders but it can also be used in form of wires. So, the feedstock is fed into the process chamber where we have heat coming from the flame or the plasma or the arc and here other feedstock is heated. So, according to the source of the heat the temperature rise may vary from likes say 500 to 3000 or more for the flame or for the flame base processes.

But for plasma and arc it may be in range of like say 5000 to even 15000 degree centigrade. So, significant rise in temperature takes place in the heating chamber where the feedstock material will be heated. And under the effect of this heat the feedstock will be subjected to either complete melting. It can occur on only that like to the partial melting in such a complete melting or the partial melting of the feedstock incomplete melting and tap out of particle will be brought to the molten state.

While in case of the partial melting only skin of the power of particles will be reaching to the molten state. And there is one more possibility that heat can cause just the thermal softening of the powder particles. So, there is no melting but only the softening of the entire particle remains

the solid state. Only the softening of them of the powder particles takes place. And once this happens then these particles will be accelerated towards the surface of the substrate.

So, like this is the heating chamber through which the flame will be coming out or the arc will be coming out of the plasma gas itself. And this will be the career for the powder particles and through this the flames or the arc of the plasma these are powder particles either in molten state or semi molten state or in plasticizers thermal soft state and they will be coming out and these are accelerated.

These particles are accelerated towards the substrate. These particles will be accelerated towards substrate and they will impinge the substrate almost at 90 degree. So, so impingement of these are particles that in molten conditions or in working condition for in the thermally soften and condition. They will be impinging with the surface of the substrate so, depending upon the kinetic energy of these particles at the time of the impingement with the substrate.

The completely melted particles which were a spherical before impingement they will get flattend after the impeachment. And this will be leading to the; this flattening will be leading to the formation of one typical disc shaped geometry. And since the powder particles; these particles are very small in size and when they impinge with the surface of the substrate which is much large in size the heat of these particles is extracted very quickly.

So, that the molten particles are subjected to the rapid cooling. Because of this rapid cooling where ever the impingement of the particle takes place; there this molten particle will get solidified with the surface of the substrate. And this is; and this is how the each particle will be impinging with the surface of the substrate or already deposited material layer and this kind of the disc shaped structure which is formed after the impeachment of the molten particle be the surface of the substrate is called splat.

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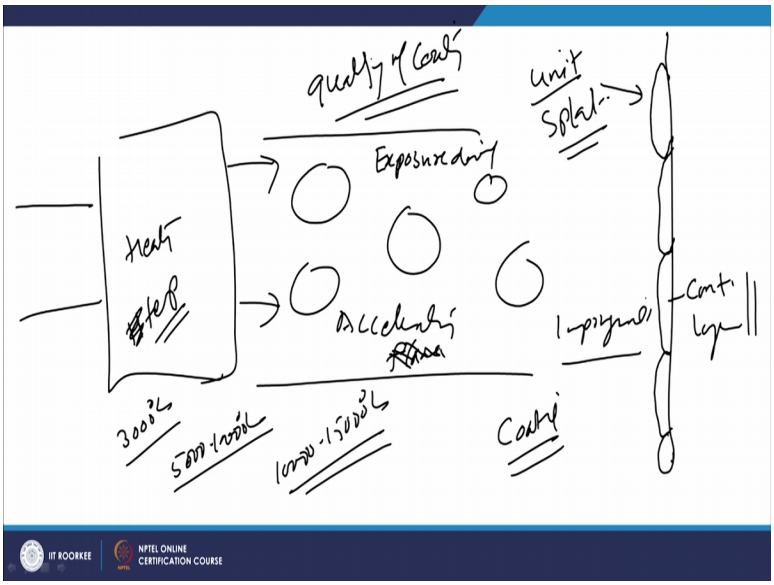

So, basically in the thermal spraying the molten or the semi molten particles which are being accelerated towards the substrate they will be impinging with the surface of the substrate and then they will be glad getting flattened. So, this is how; in this case the heating is a primary taking place of these particles and the metal is been deposited in form of the unit pieces in form of splats. So, is splat will be for is basically a lump or other piece of the material which is being applied over the surface of the substrate.

And when the continuous splat deposition over the surface of the substrate will be leading to the formation of a continuous layer, layer of the material which is being applied on the surface of the substrate and this takes the shape of the coating. So, this is how the process works in the material like the raw material is fed in the process chamber and then it is accelerated, so heating then acceleration and then finally impingement of these particles with the surface of substrates.

So, these are the things, so up to what temperature? What is the temperature up to which the heating is taking place and how long the high temperature is maintained? How long the particles are exposed stock material is exposed to the high temperature. So, the exposure duration of the feedstock material at high temperature; these are the crucial things which will be determining the quality of the coating material being applied.

About this will be talking in detail in the subsequent portions related with this presentation. So, now if you see; since the different heating sources offering the different temperatures like in case of the flame spread coatings is 3000 to 5000 to 10000 degree centigrade arc processes

which process and plasma based process like 10000 to 15000 degree centigrade and they are accelerated to attained the maximum velocity.

As per the process the acceleration magnitude will be varying significantly and the accordingly the particle velocity there are two aspects one is the velocity at which hot flue gases will be moving and another one the velocity at which the particles will be moving within the flame. Normally the velocity of the flame or velocity of the hot gases are the plasma is higher than the velocity of the particles which will be with which it will be moving and finally impinging will be taking place with the surface of the substrate.

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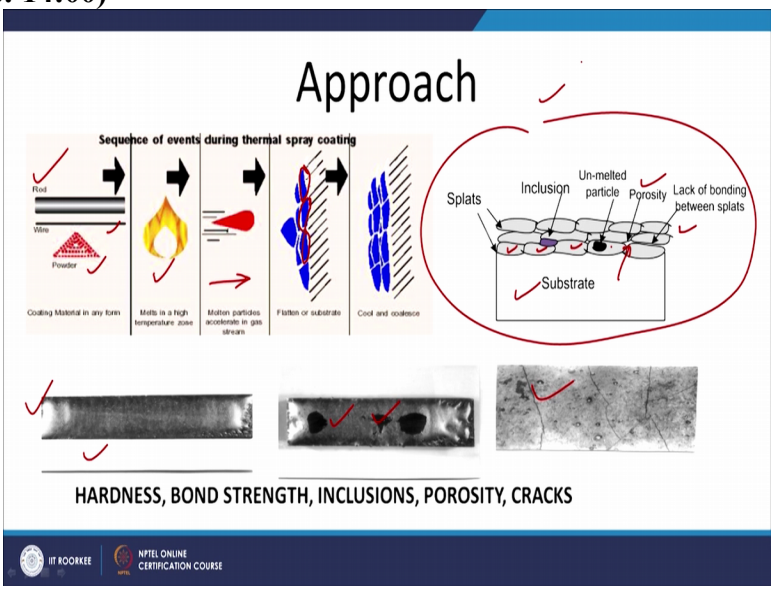

So, for this only; if you have to see this is what the scheme is like the material may be used in form of the rods in form of wires are in form of powders and this is subsequently heated using the suitable source of the heat. The source of heat maybe in form of arc or the flame or the plasma and then it is accelerated towards the surface of the substrate. And once the accelerated; these high velocity particles are impinging with the surface of the substrate.

They will be flattened like this and forming the splats and spreads will be depositing one over the other and when this process continuous after the solidification the coating is formed on the surface of the substrate. But these coatings or the thermal spray coating are not free from the defects. There are various issues related with these coatings but this we can say one typically flame spread coating of the Nickel chromium based alloy system on to the surface of the steel.

This shows that very sound and free from the defects but there can be defects other defects like the cracks in the coating as per the kind of the materials and the thermal expansion and contraction behaviour of the material as well as of the substrate material as well as the coating. And there can be the pores and other discontinuity is present on the surface on the surface or within the surface of the coating.

So, if you have to understand what are the kind of the discontinuities which can be there in the flame spread are the thermal spray coating.

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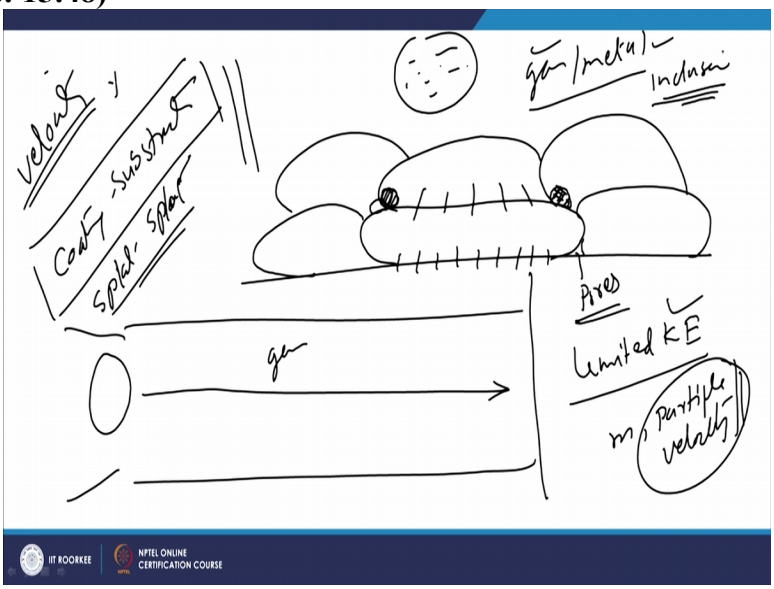

So, there are various things that we can I see here, like this is a surface of the substrate. So, when the molten particle impinges very surface of the substrate it will be getting flattened leading to the disc shaped formation. And similarly the number of such kind of the splats will be depositing over the surface of the substrates. One layer is deposited then another layer of the splat will be coming and will be getting deposited on the already deposited layer of the material.

But since the molten metal particle will be at higher temperature and it will be interacting with the other gases which are present all around the molten metal particles are the partially melted particles so there can be the interaction between the gases and the metal material of the feedstock and that will be leading to the formation of the undesirable chemical reactions resulting in the resulting in the inconclusion in the coatings.

These inclusions will be there if too much of the interactions between the gases and the feedstock material is taking place. And this is possible only when the high temperature is retained for

longer period like the particle is moving slowly through the heat source and getting lot of time for interaction of the feed stock material with the gases. And this will be leading to the formation of the inclusions and these inclusions may be present here and there. There is also a possibility if the impingement velocity the kinetic energy of the particles at the time of impingement is not very high.

Then it will be leading to the sum of the gaps and left unfilled. So, these gaps will be there in form of the pores. So, the pores are primarily formed due to the limited kinetic energy of the particles at the time of impeachment and this may be due to the smaller means very small mass of the particle or the limited particle velocity at the time of the impingement. So, the velocity of the powder particle is crucial especially with regard to the pores.

And further if the particle impinging may be the limited kinetic energy than they are; the bonding between the coating material that that is a splat and substrate or splat to splat bonding will be limited to their two aspects like the coating substrate bonding or the bonding between the splats, splat to splats bonding. So, if the kinetic energy of the powder particles or the semi melted or the melted particles is very limited.

Then there can be the bonding issues apart from the formation of the pores. These bonding issues can occur between the coating and the substrate or the splat to splat bonding. So, in that case there will be tendency for separation, removal or dilimination of the coating material from the substrate or the removal or the filling of are the delimination of one layer of the coating material from the another layer.

So, are the cohesive strengthen under such conditions will be limited and that is why it is important that the particle is having the enough kinetic energy. This enough the particle velocity at the time of the impeachment which of course is influenced by the kind of process for used for the thermal spraying significantly, so about that will be talking little later. So, it is important that the powders either in the thermal soft condition, or the molten condition, or the semi molten condition should have enough kinetic energy.

At the same time it should get the minimum time of exposure at high temperature during the deposition process. So, the flight or the movement of the powder particles to the heap shows should be for the shorter period. And in this regard the spacing that is called standoff distance at

the source of the nozzle and the substrate surface and subsurface distance has to be optimised not too very short not too very long.

Since the if the nozzle to the substrate distance is very less then these particles will not be able to attend much velocity and that will be leading to the number of defects inform of pores and limited bond strength. But if the if the distance is too much then the particle velocity me also get reduced and the stay of the powder particles are in the molten state or in semi molten state at high temperature will be longer.

And that will be leading to the formation of the inclusions as well as thermal degradation tendency of the constituents in the powder particles will also be increased. So, the velocity, how the part of the, of the powder particles is very crucial with regard to the high temperature exposure period as well as the chances for the interaction of the feed stock material with the other gases which are present all around.

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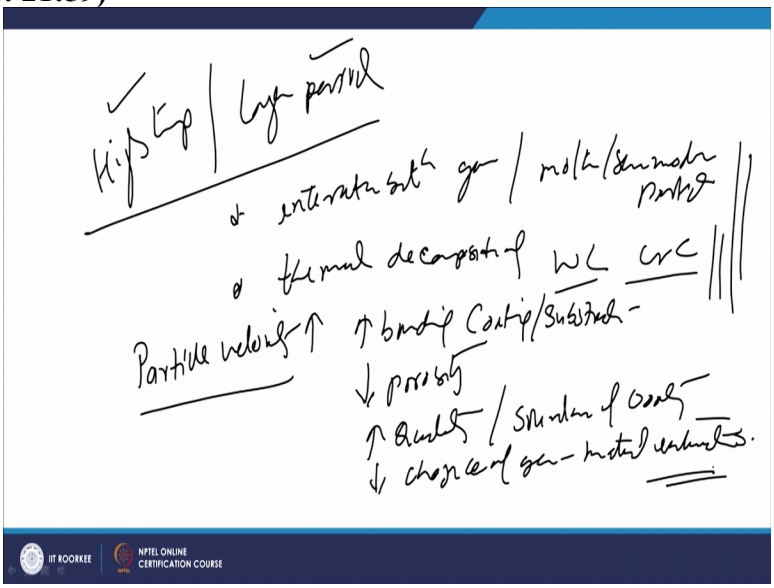

So, now I will see what the possibilities due to high temperature exposure are for longer period, what kind of the damages can take place? So, the damages which are observed primarily in form of the increased interaction between the gases around the molten or semi molten feedstock material particles. Another damage is the thermal decomposition of some of the constituents like tungsten carbide chromium carbide.

These particles are start getting decomposed and damaged with regard to the properties, so and composition so we do not get the properties which we are expecting on the surface of the

coating. So, high temperature exposure for longer period of the feedstock material during thermal spraying is to be avoided in order to reduce the chances for the thermal damage of the feed stock material during thermal spraying process.

So, now just to summarize now what will see that the particle velocity is increased then we will be finding the increased bonding between the coatings and the substrate it will be reducing the chances for porosity and he and this will be in general increasing the quality and soundness of the coating. Increase in powder particle velocity will also reducing the chances of the gas material interactions with otherwise leads to the formation of the inclusion.

So, now you will see the kind of the powder particles velocities which are realised. This one, this diagram basically shows the kind of the defects which can be formed during the thermal spraying, like this is the substrate on the surface impingement of the molten or semi molten particles takes place splats are formed and then they get deposited on the surface of the coating. There is a possibility that due to the largest size of the particles are due to the higher refractoriness characteristic of the feedstock material there may be un-melted particle also.

And when the particle velocity is limited kinetic energy is limited at the time of impingement there can be un-filled gaps between the splates and substrates or between the splats themselves. So, this will be leading to the formation of the pores and when the particles do not impinge with the surface and kinetic energy there can be limited bonding between the splats themselves also and when the gases interact with the material of the feedstock then it will be given to the formation of the inclusion.

So these are various kinds of the issues and the defects. There are three common problems which are encountered during the problems in case of the thermal spray coatings. Now I will just see that the kind of the heating which takes place and the kind of particle velocity which is achieved during the three most commonly used thermal spray processes.

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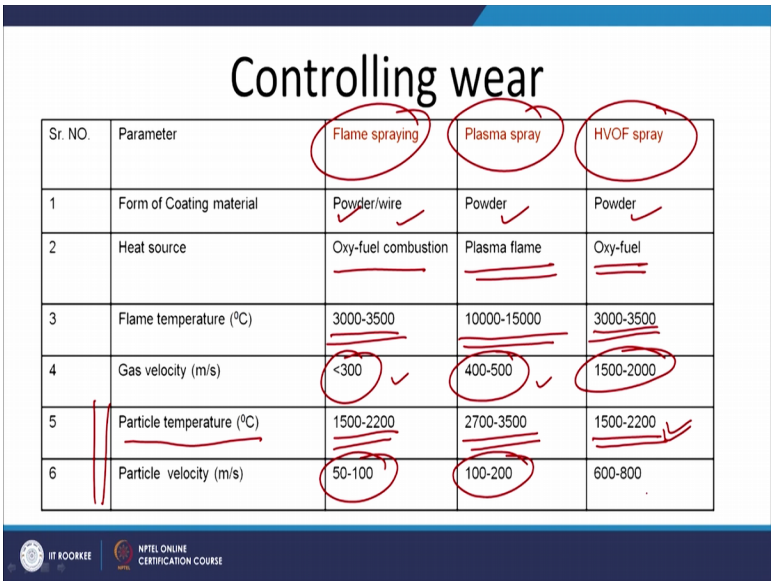

Namely flame spraying, plasma spraying and high velocity oxy fuel spray, so, the coating material which is used for flame spraying can be in form of powder or wire. For Plasma spray mostly it is a powder but it can also be in form of wires. And for high velocity of oxy fuels in form of powders and heat is generated basically from the, generated by the combustion of the oxygen and the fuel which can be like propane or acetylene.

And in case of the heat in case of the plasma spray is achieved through the plasma. And in case of the high velocity oxy fuel spray again it is oxygen and fuel gas mixture is burnt for generating the heat. The temperature which is produced is in the range of like 3000-3500. While in case of the plasma spray it is 10000 to 15000 degree centigrade. While in case of the HP spray process again it is in line with the flame spray 3000 to 3500.

The gas velocities in case of the flame spray is limited below 300 metre per second. For Plasma spray it is 400 to 500 m per second while in case of the HPA process it is 1500 to 2000. This is important because it will be dictating the particle velocity at the time of spray. Now coming to the two important crucial characteristics associated with these processes particle temperature governing the thermal damage of the feedstock material.

In case of the flame spray is the temperature is limited like 1500 to 2200 degree centigrade. While in the case of the plasma spray the particle temperature is around 2700 to 3500 degree centigrade. So, there are more tendencies for thermal damage while in case of the HPA spray again it is 1500 to 2200 degree centigrade. But since the particle velocity is too high so there

may not be any melting in case of the HPA process or the melting may be very limited at the surface only.

So, the semi molten state may be realised HVF process particle velocity is very limited or very less in case of the flame spray and that is why it offers larger porosity limited bond strength while particle velocity is in the range of 100 to 200 m per second and the plasma spray it is very high 600 to 800 m per second in case of the HVF spray processes. Since the particle temperature and particle velocity is deferred significantly with the process of the flash process of the thermal spray.

And that is why we get the different characteristics in the thermal spray coating with regard to the porosity, bond strength and the quality of the coating materials which is achieved. Now I summarise this presentation. In is presentation which I talked about the basic principle of thermal spray process and what are the crucial parameters associated with the thermal process switching on the quality of the thermal spread coating. Thank you for your attention.