Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
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Lecture-51
Surface Modification Techniques: Improving Performance of Flame Spray Coating

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know we are talking about the approaches which can be used for modifying the surface properties so that tribological life of the component can be improved. And under this heading we are talking about the processes where in a layer of the material having the required set of the properties is deposited over the surface of the substrate for improving the tribological life of the component.

And further in these categories we are talking about thermal spray processes. So, in a last presentation we have seen that tab in the flame spray is very simple process where oxygen and fuel gas mixture is used for ah developing the coating. Which offers quite good position rate and simple equipment easy handle, easy adopt and manufacturing system but this process commonly known has oxy-fuel powder spray process is very simple process but it suffers with some of limitations.

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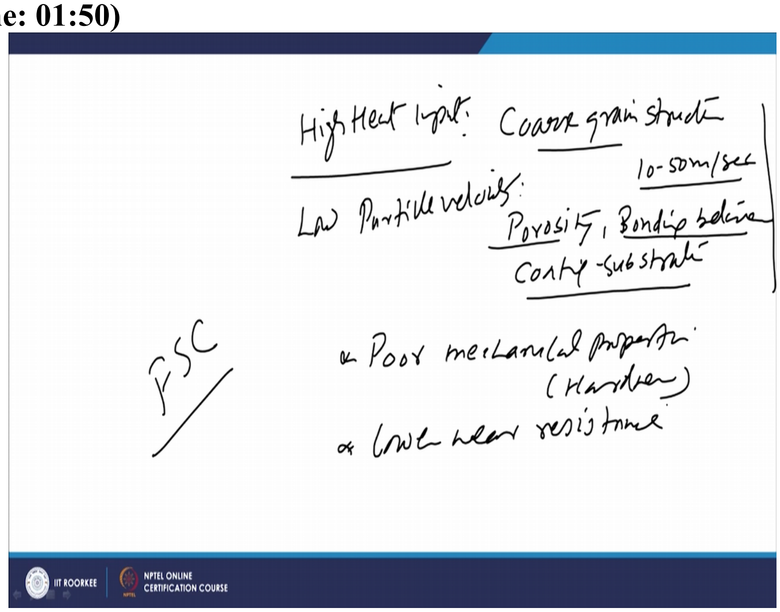

Which are primarily associated with the high heat input so because of the high heat input we get very coarse grid structure with these coatings? And the low of particle velocity which is attained by the powder which is being sprayed during the flame spray process and therefore the velocity of the particles at the time of the impact with the substrate surface is very limited which may be in range of say 10 to 50 meters.

So, such a low velocity leads to the presence of the porosity and poor bonding between the coating and substrate. So, the porosity poor bonding between the coating and substrate coarse grain structure so because of these undesirable features we find that these coatings like flame spread coatings are poor in terms of the mechanical properties primarily like the hardness and then these and because of the poor mechanical properties especially the hardness we find the lower wear resistance.

Although it may be better than the substrate but is still as compared to the other processes where is still offered by the flame spread coatings is lower if the same material is coated using other processes that that may offer much better wear resistance, so the lower wear resistance. So, in order to overcome these limitations some of the approaches have been developed and this includes like that densification.

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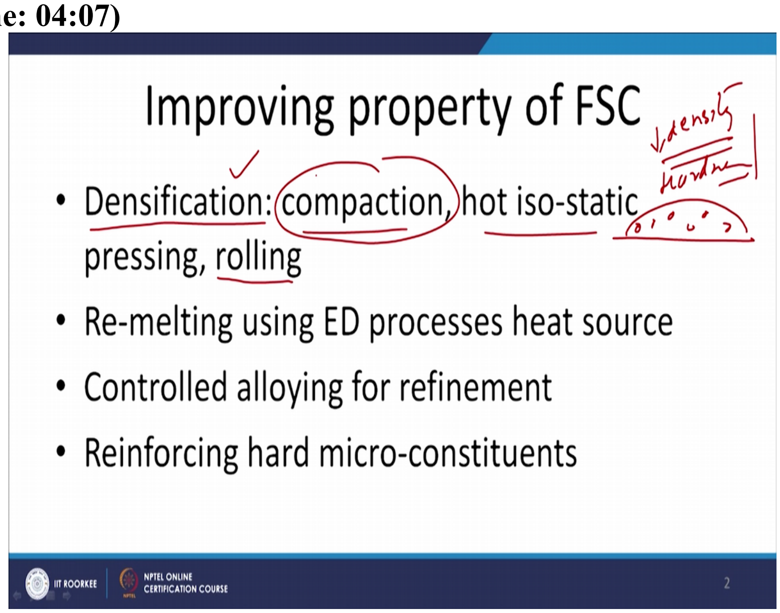

So, in case of the densification we know that time the flame spread coating process is having the pores because of the low velocity. So, these because of this we find that the density of the coating is somewhat lowered due to the presence of this air pockets as well as these lower the hardness. So, to; in a; so for eliminating these pores and normally have some of the processes which are used light compaction high hot isostatic pressing and the rolling.

So, when the flame spread footing is subjected to these processes then of course the density of the coating increases by elimination of these portions and thereby it improves the mechanical properties and wear resistance one typical method will taking up like the compaction.

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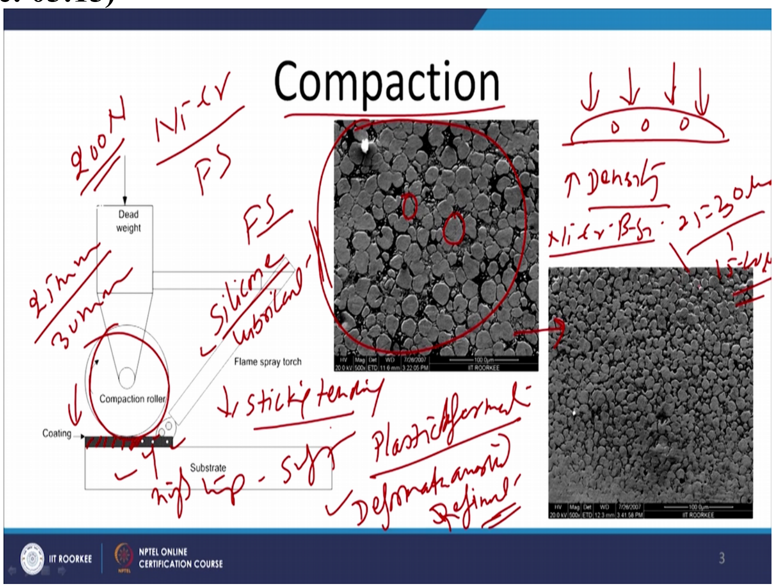

So, in case of the compaction what we do if in case of the compaction like the coating is like here and during the coating itself means as soon as coating is deposited we compress the coating using the suitable rollers so that it is compacted continuously during the flame spray process itself. So, such kind of compaction or pressurization leads to the collapse of the pores and inclusion if they are present.

And there by it will be increasing the density by eliminating the pores and the facture in the inclusions if they are there. So, this kind of the process is called compactions. So, here like say this is the substrate and this is the torch that is being used develops coating on surface of the substrate. Since the coating on the surface of the substrate is being developed using the flame spray process because of the low particle velocity it is having say some of these pores.

To eliminate this roller is passed through the; over the surface of the coatings which has been just developed will also be at high temperature. So, at high temperature it will be soft, so when the roller will be passing over the surface of the coating under pressure then it will be collapsing all those pores and inclusions which are there and making it more dense through the elimination of the pores. So, at the same time since the plastic deformation is taking place.

The deformation is occurring at high temperature, so the deformation assisted refinement also helps in the reducing the grain size. So, here we like in this particular case say for Nickel chromium coating being developed using the flame spray process. And as soon as the coating is spread roller is compaction roller is passed using a normal load of 200 Newton's using the steel ball of the 25 mm diameter and 30 mm length.

So, the diameter 25 mm length of the roller was them in this particular case of the 20 sorry 30 mm and since at high temperature there will be tendency for the coating to stick coating material to stick with the roller. So, to reduce the sticking tendency of the material in the roller coating material with the roller the silicon lubricant was used to reduce the, such kind of the sticking tendency. So, basically the idea is simple where in just spread just flame spread coating is subjected to the pressurization through the compaction roller.

And using the suitable using suitable load so that all the pores and inclusion, pores are closed and inclusions are broken and this will be reducing the extent of adverse effects because of this true undesirable features. At the same time whenever the material is deformed at high temperature through compare compaction and deformation assisted refinement helps to reduce the grain size. In this particular case Nickel, Chromium, Boron, Silicone coating which was coarser we can see here the grain size a size of Nickel solid solution cell is coarser.

And after the compaction we noticed that the grain size was reduced. So, this kind of the grain refinement and may take place like say from 20 to 25 to 30 micrometre to 15 to 20 micrometre the reduction in grain size is further expected to enhance the properties.

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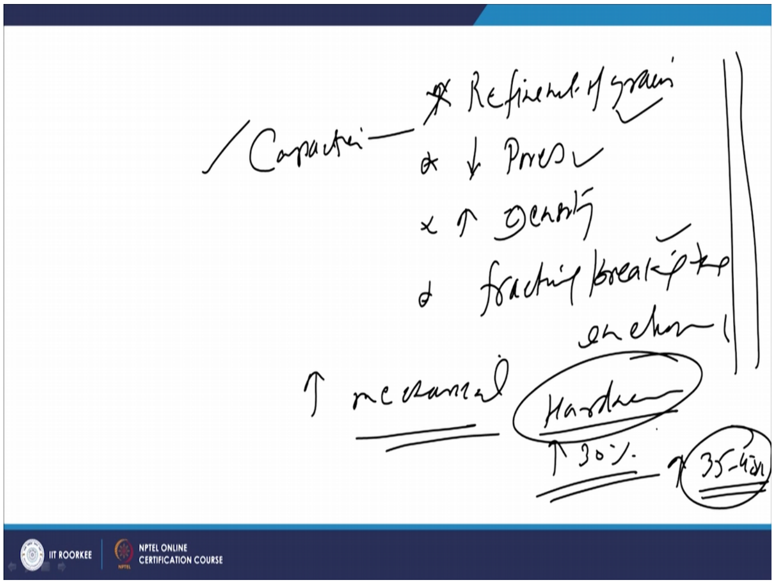

So, if we see here the compactions is leading to the leading to the refinement of the grains reducing the pores and increasing the density and maybe fracturing or breaking the inclusions. So, all these factors are expected to enhance the mechanical properties and in this particular case increase in the hardness after the refinement and elimination of the pores 30% increase in the hardness was observed.

And this in turn also led to the improvement in hard improvement in wear resistance 30 to 40% improvement due to the compaction. So, that is obvious part like if the things are getting refined pores are eliminated and their inclusions are been fractured then they this will be simply increasing the coherence and stability of the coatings which intern increasing the hardness and increasingly leading to the improved wear resistance.

So, this is one way of enhancing the performance of the flame spread coatings which suffer primarily from the coarse grain structure porosity velocity and other and the presence of the inclusions as well as poor bonding strength. However this process compaction may not able to do much with the enhancement of the coating substrate bond strength.

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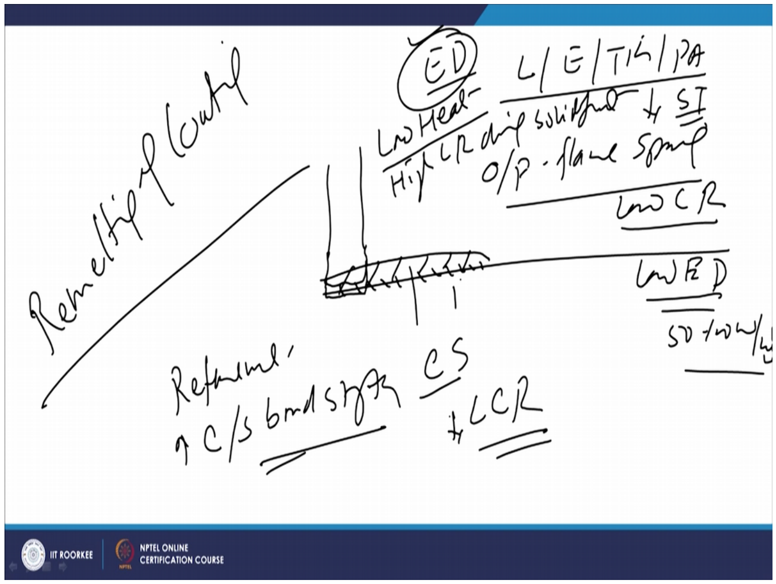

This is the remelting of coating another approach where in remelting of the flame spread coatings we know that on the surface of the substrate like this coating is been deposited using the flame spraying process which is having the coarse grain structure due to the low cooling rate. And so in order to enhance the performance of the such kind of coating the refinement of the grains as well as if the melting of the interface also can be facilitated can be facilitated using controlled heating of the coating.

Then that can also increase the coating substrate bond strength. So, in this particular approach of the remelting of the coating since the oxy fuel flame spray process uses the low cooling rate offers low cooling rate because of process itself is of the low energy density and energy density like say very low like 15 to 100 watt per mm square because of the lot of heat is supplied in where in there may not be melting of the substrate.

But it gets lot of heat and it is preheated so the cooling rate offered by the substrate to the coating is very low and that is why we will be getting the high cooling rate. Use of those heat sources which can offer the higher energy density like the laser or electron beam or the Tig arc or the plasma arc. Those heat sources can effectively be used to these hopes heat sources are applied on to the already coated surface developed by the flame spraying.

So, this will be causing the controlled melting of the coating either; and only the coating or coating can be melted with; it can be melted along with the substrate up to the interface. So, that unnecessary dilution is also avoided. Since melting; for this kind of melting using high energy density source it need low less heat supply for melting as compared to that of the gas oxy flame oxy fuel flame.

Because of the high energy density it uses the less heat input for melting and therefore it causes the high cooling rate during the solidification time and high cooling rate during the solidification time during the solidification reduces the solidification time and reduced solidification time leads to the refinement of the grain structure.

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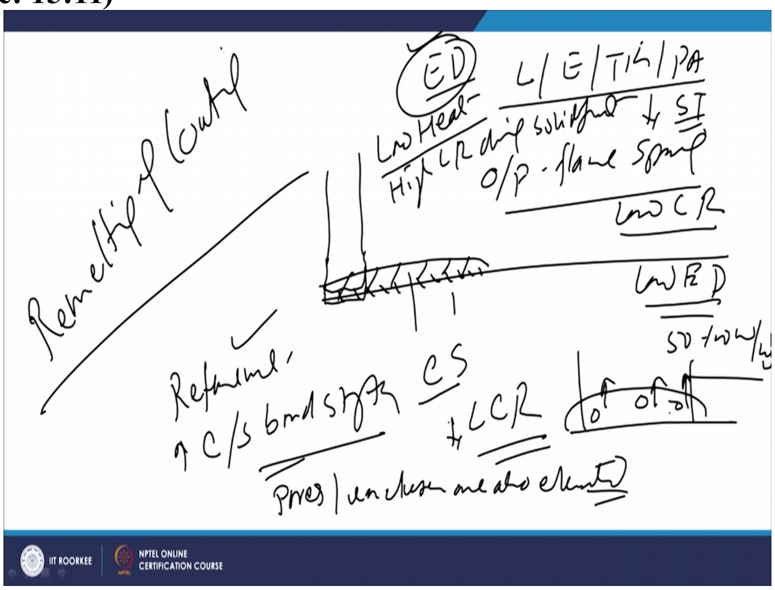

So, there is very simple logic when the cooling rate is high effective transformation temperature is reduced and if reduction in effective transformation temperature affects the other nucleation and the growth rate. Suppose these are the two curves corresponding to the growth rate and the nucleation rate. So, at a higher temperature what we see at high temperature growth rate is higher nucleation rate is low. While at the low temperature nuclear growth rate is low and nucleation rate is high.

So, when the cooling rate is high the effective transformation temperature is reduced and when we have the lower effective transformation temperature this offers the high nucleation rate and low growth rate. So, because of the low, high nucleation rate and low growth rate we find that there a large number of nucleons and the growth occur up to the limited extent and combination of these factors leads to the reduction in grain size of the coating and which in turn reduces the grain size.

So, apart from apart from the refinement of the grain structure if there are impurities present in form of inclusions here and there remelting of the coating will be leading to the floating and elimination of the pores and inclusions up to the surface should not just the grain structure is refined but the pores and inclusions are also eliminated. So, elimination of the pores and inclusions and refinement of the grain structure in totality is expected to enhance the mechanical performance and tribological performance of such coatings.

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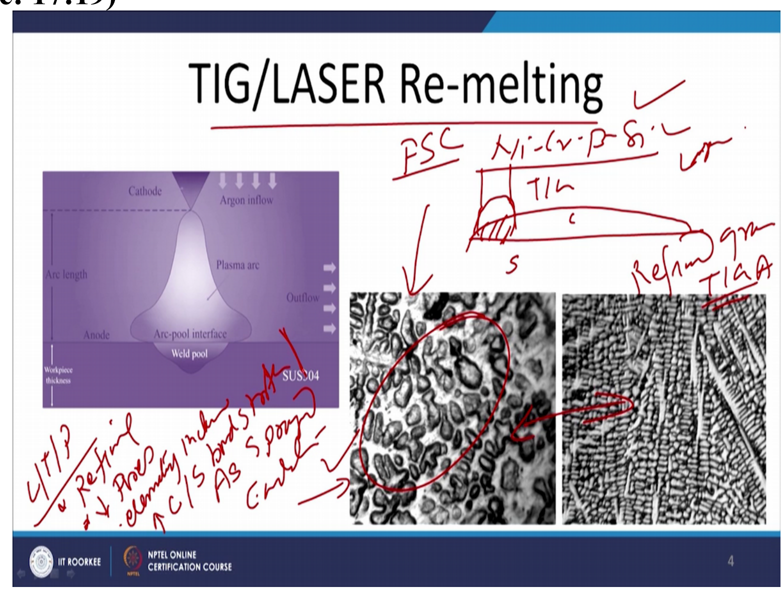

In this particular case one flame spread coating of the Nickel Chromium Boron Silicon deposited this resulted in the coarse grain structure like this. And so when this coating likes this one when it this is substrate this is coating and when it is subjected to the application of the remelting using the Tig arc this resulted in the melting followed by the fast cooling and fast cooling resulted in the very is refined grain structure.

So, if we compare these two grain structure this structure is comparatively coarser then the of the and then the one which is subjected to the tig remelting. So, this structure corresponds to the frame spread coating of the Nickel Chromium Boron Silicon material subjected tig arc remelting well this is simple and the flame spread coatings in as spread condition. So, just after the flame a spring of this material what is the structure and when it is subjected to the tig remelting using tig we get the very refined grain structure.

Apart from this if we see if a laser is used laser is of the higher energy density and for the higher energy density I will be leading to the higher cooling rights so that will be leading the further refined grain structures and improved mechanical properties. So, we can say here that the either it is the laser or the tig or the plasma arc all these remelting of the flame spread coating will be refining the grain structure reducing the pores.

And eliminating the inclusions if they are there and if the controlled melting up to the substrate coating interface is carried out it can also enhance the coating substrate bond strength. So, the controlled melting can be very useful controlled remelting of the flame spread coating can be useful with regard to the enhancement and performance of these coatings.

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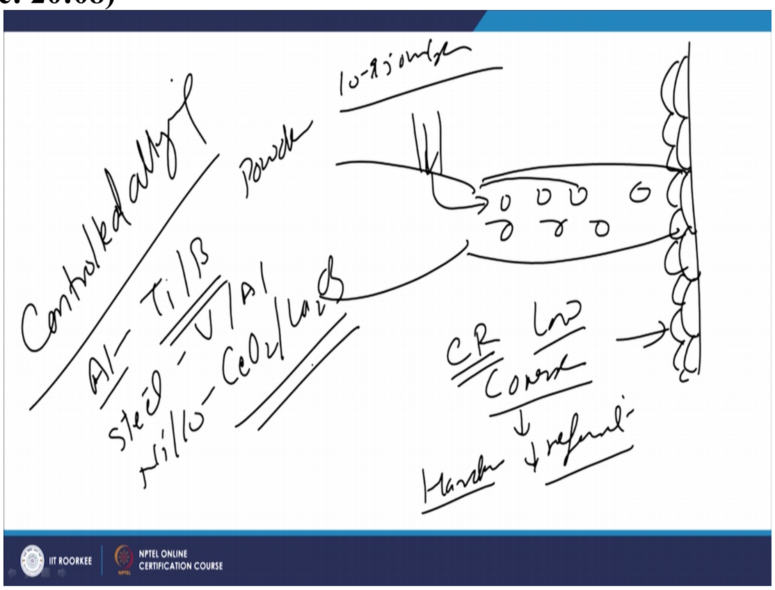

Third approach of enhancing the performance of the flame spread coating is the controlled alloying since it uses basically the material to be quoted is used in form of the powders and which is flame spread through the oxyacetylene flame on to the substrate after heating to the molten state and accelerating it towards substrate moderately high velocity it is not very high but it is like 10 to 50 M per second and then after impingement will get the coating.

So, like this is the torch this is the flame and here we are feeding the powder it will be going with the flame and in the flame it will be heated to the high temperature and then it will be deposited on to the surface of the substrate. So, these are the; like coating deposited in form this splats on to the surface. So, in order to; since the cooling rates which are experienced in the flame spread coating is low that is why it offers the coarse grain structure.

So, in order to improve the mechanical performance and the tribological performance with regard to the resistance to the wear it will be good if the hardness can be enhanced by refining

the grain structure and therefore as per the material which is to be applied will choose the suitable refiner which can be added in the coating material so that the structure can be refined.
There various alloying elements like for aluminium base materials that Titanium, Boron kind of the elements are used as a refiner for steels Vanadium and Aluminium is used and like say for the Nickel Cobalt based systems even cerium oxide, lanthanum oxide like a rare earth materials can be used for can be used as a refiners.

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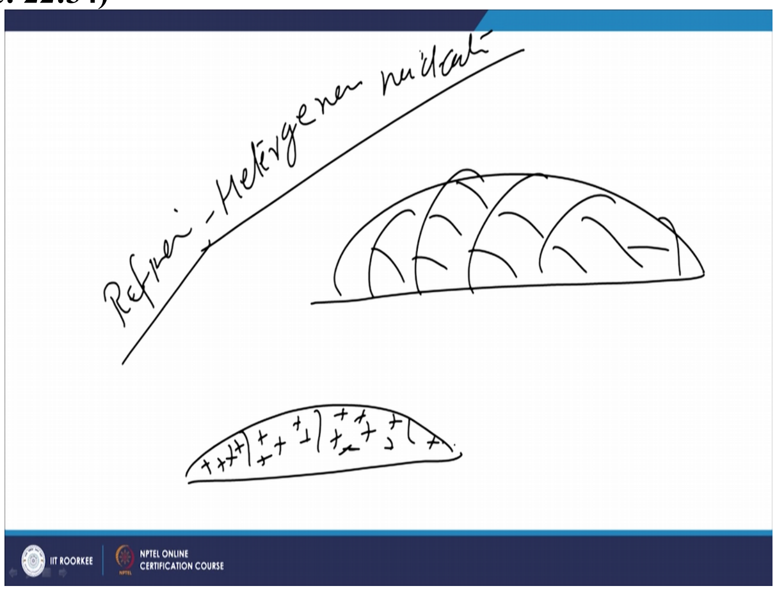

So, here, idea is that whatever the grain structure we get after the flame is spraying if it is coarse then the structure is to be refined. So, the coarse structure is being achieved because of the low cooling rate. So, if we add the refineries these will promote the heterogeneous nucleation. So, these refining elements will be providing likes say this is the mass which is solidifying so when there is a no refiner the number of nucleation's were very limited and that is why we will be getting the coarse grain structure.

And when the refiners are added this will be providing large number of the nucleons and which in turn will be promoting the heterogeneous nucleation and thus refining the grain structure. So, idea is to add those elements which can act as a refiner. So, that the grain structure of the flame spread coatings can be refined so, despite of the lower cooling rates we may get the finer grain structure.

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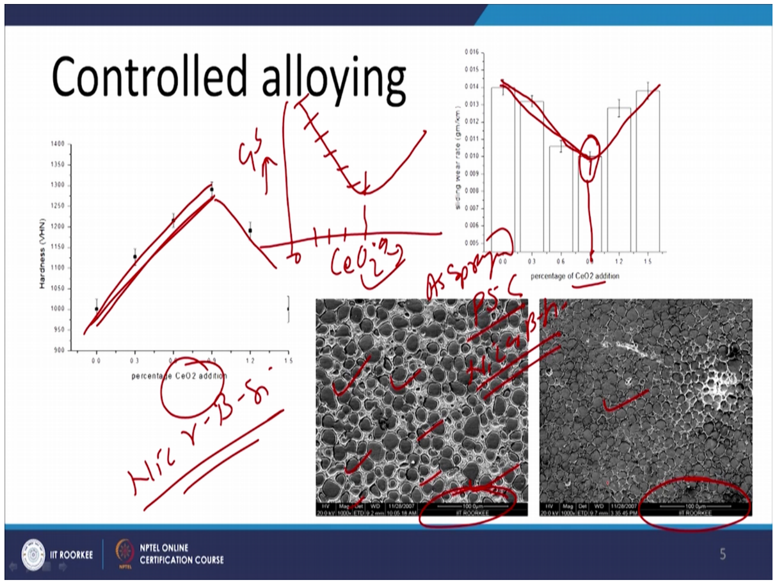

So, in this particular case say for Nickel Chromium Boron Silicon coatings in as a spread condition the structure is coarse. So, when the like cerium is added in the varying percentage like say point from 0 to like say point this is about the hardness variation and this about the wear resistance variations. So, if we see the grain structure variation also comes out like this the grains are coarse and then it gets refined.

Grain size if you mention in the y axis and in the x axis if we have the ceria edition then for about .9 % of the ceria edition starting from 0. When there is no addition the grain are coarser and increasing ceria content of to some extent life. 9% in this particular case refines the grain size thereafter against it starts increasing. So, if we see as there where there is reduction in the grain size there will be corresponding increase in the hardness of the material.

So, the same material when subjected to as ceria edition these will be refining the grain structure up to the .9 % and thereafter it will be increasing. Similarly just reverse trend is offered by the hardest variation as a function of ceria edition where in increase in ceria content up to the .9 %. 9% increases the hardness and thereafter it starts decreasing and these values are inconsistency with the grain size.

And if you see this abrasive wear resistance of these coatings then as the hardness increases the wear decreases which is a reflecting from the reduction in the wear rate. And this reduction in wear rate is a; can be observed of to the .9% edition of the ceria and thereafter further addition of the ceria starts means it does not help much to reduce the wear rate. So, the trend of the wear rate is reversed with further addition.

So, there is optimum value of the ceria edition for refining the grain structure for enhancing the hardness as well as reducing wear. So, this kind of the very soon can also be noticed this is as spread flame spread coating of the Nickel chromium boron silicon material where in the coarse average diameter of the Nickel solid solution cells is coarser as compared to the other case where nickel solid solution cells are finer under the identical conditions of the scale.

So, this kind of the refinement is activated is attributed to the heterogeneous nucleation been promoted by the favourable alloying elements. So, now I will summarise this presentation, in this presentation have talked about the three approaches which can be used for measuring the performance of flame spread coatings and these were like compaction which are primarily eliminates the pores breaks the inclusions if they are there.

In case of the remelting; remelting also helps to define the grain structure if you are remelting is carried out using suitable high energy density is heat source then it will refine the grain structure eliminate the pores as well as it also reduce the inclusion content. Similarly the control alloying element elements which are facilitating the heterogeneous nucleation and then they will be refining the grain structure increasing the hardness and improving the wear resistance. Thank you for your attention.