Friction and Wear of Materials: Principles and Case Studies

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Lecture – 26
Tribochemistry in Wear of Cermets

So welcome all again. So today we will learn about the salient results of the studies done on the tribochemistry of a particular cermet materials. So outline of the present lecture will be, I will introduce these titanium carbonitride-based cermets. And brief introduction on their microstructure characterization.

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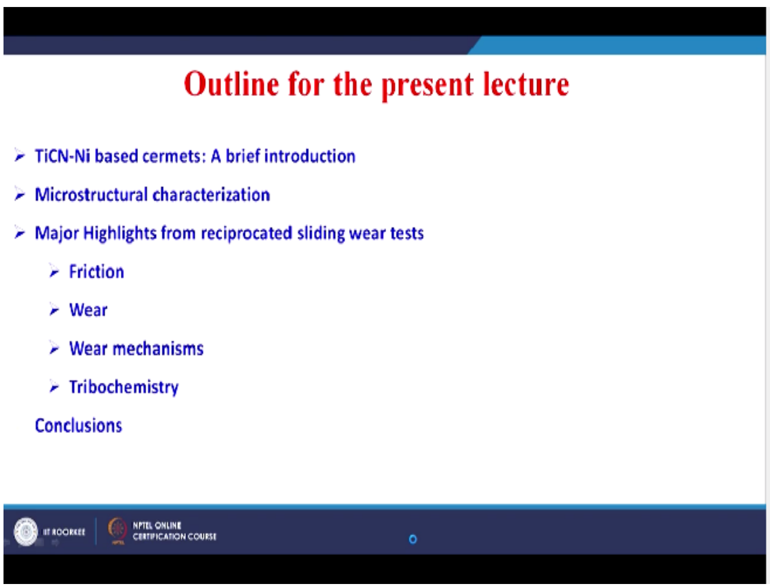

And then I will focus majority of this lecture on explaining the friction results, wear results and the dominant wear mechanisms and the tribochemistry involved in the wear. So let us start understanding what is this cermet. Cermet is a ceramic with metallic binder. So it is called a cermet.

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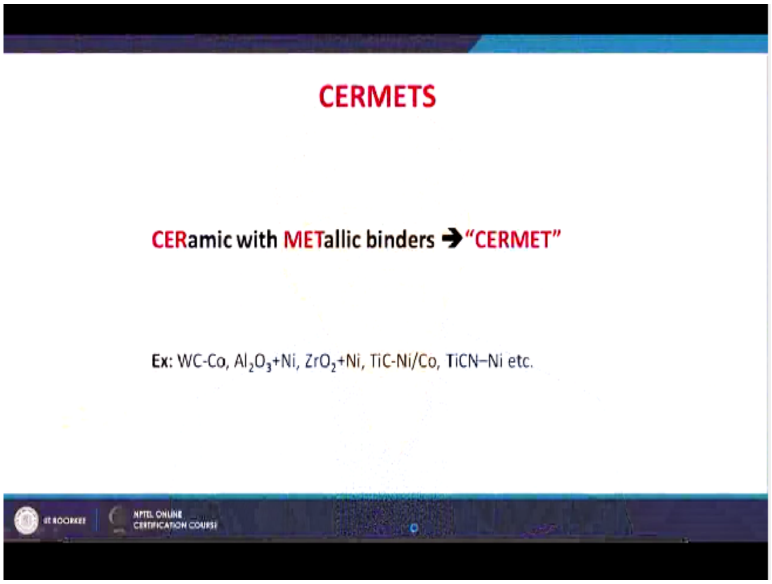

So several examples of cermets are used in engineering applications. So few examples like tungsten carbide cobalt cermet, aluminium oxide nickel cermet, zirconium oxide nickel, titanium carbide with nickel or cobalt or titanium carbonated nickel, these are several examples of the cermet materials used in engineering applications.

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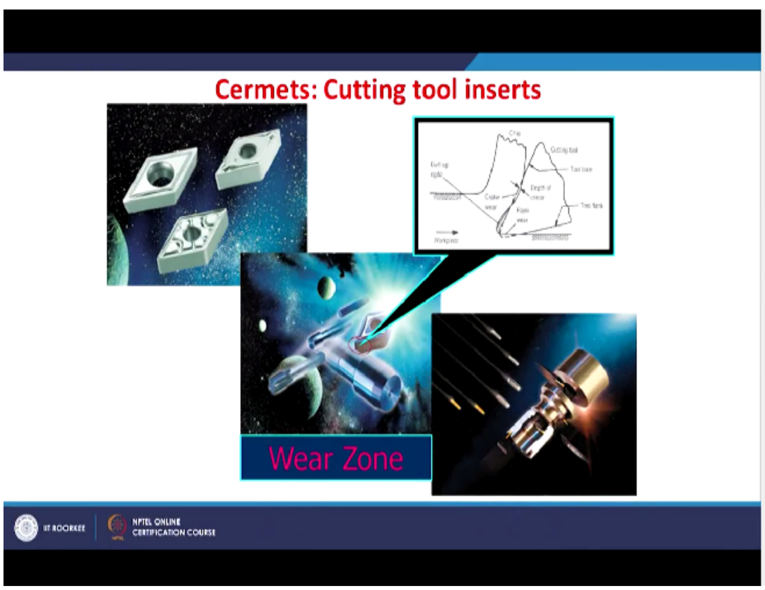

Regarding the engineering applications, these cermets are mainly used in cutting tool applications as an insert for the cutting tool. So in machining, if you look at the tip of this, nose of this tool and the work piece, there is a large amount of friction generated. So this friction induces the wear.

But this friction induces the temperature, high temperature as well. So the friction induced heat at the same time the dummies, both simultaneously occur and lead to the material degradation. So particularly in this cutting applications, the mechanisms shall be studied in the crater wear or the flank wear of this cutting tool inserts.

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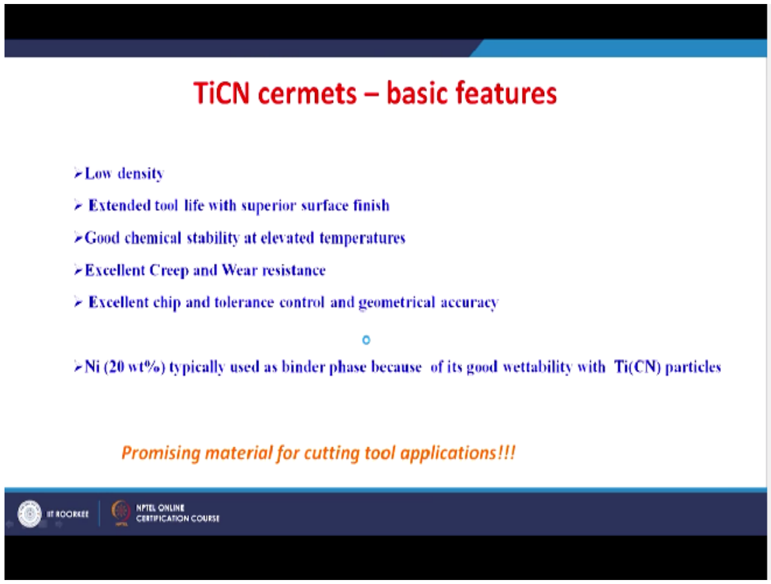

So titanium carbonitride based cermets, they are important because they have lesser density, extended tool life with superior surface finish, good chemical stability at elevated temperature, and excellent creep and wear resistance, excellent chip and tolerance control that leads to geometrical accuracy. So the market of the cutting tools used for machining harder materials is generally dominated by the tungsten carbide cobalt.

So compare to comes tungsten carbide cobalt cermet, these titanium carbonitride are attractive because of their properties as mentioned here. So in these cermet materials, the ceramic of titanium carbonitride is attached with a metal, generally nickel, cobalt, molybdenum. So nickel generally used as a binder phase because of its good wettability with the TaCN particles. So the ceramic of TaCN attached with the nickel binder as a cermet, the titanium carbonitride with nickel, is a promising material for cutting tool applications.

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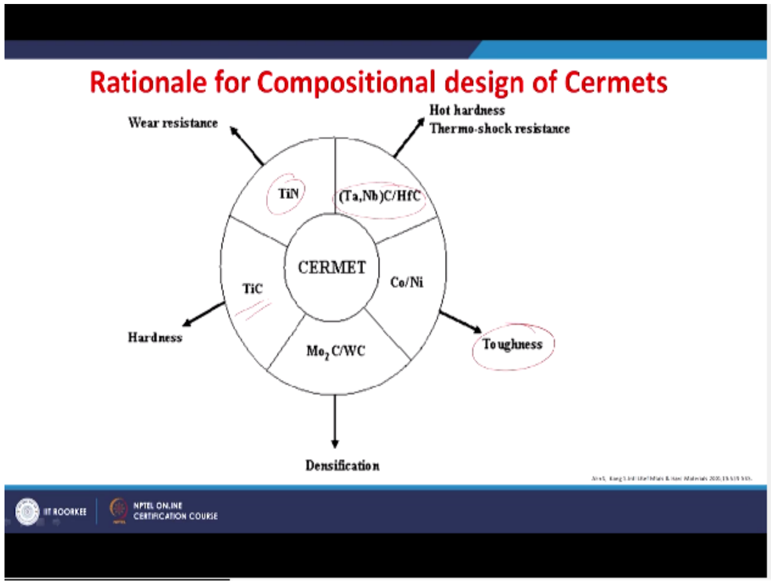

So apart from these binder phase which gives us the toughness, there are some time carbides or nitrides also added to improve the performance for the cutting tool applications. For example, the tantalum carbide or niobium carbide or hafnium carbide, these are generally used to improve the hot hardness or the thermo-shock resistance. So when these cermets added with these combination of these carbides, they improve the intermittent cutting performance.

The titanium nitride is generally used to improve wear resistance. Whereas the titanium carbide is used for improving the hardness. The densification will be improved if you add the tungsten carbide or molybdenum carbide. Tungsten carbide is also known to improve the toughness of this material.

So from the compositional design aspect of these materials, it is very important to evaluate and understand the influence of various additions on the wear properties. So on this basis, this particular study was done to understand the behavior of these composites, the ceramic with the metal composite that is called cermets in a sliding wear conditions. For these cermet materials were prepared by a powder metallurgical processing route.

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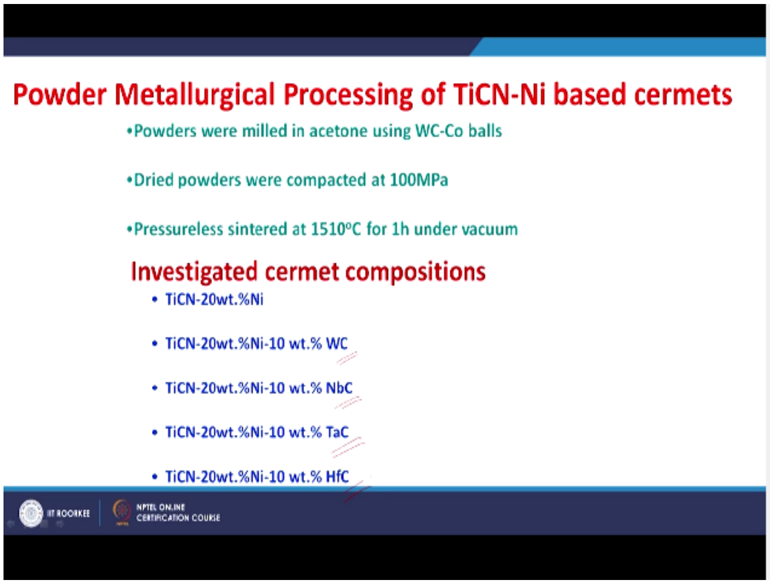

Initially the powders of the titanium carbonitride and nickel and then respective carbides of tungsten carbide, niobium carbide, tantalum carbide, or hafnium carbide were mixed in a ball mill using tungsten carbide cobalt balls in acetone. These were compacted at 100 MPa and then these cermet batch compositions after compaction, these compacts were sintered in a conventional way pressureless sintering at 1510 Celsius for 1 hour under vacuum.

So these are the investigated cermet compositions, TaCN with 20 weight percent nickel and TaCN 20 weight percent nickel with 10% tungsten carbide or 10% niobium carbide or 10% tantalum carbide or 10% hafnium carbide. So these cermets were studied. So after sintering, the microstructure looks like this.

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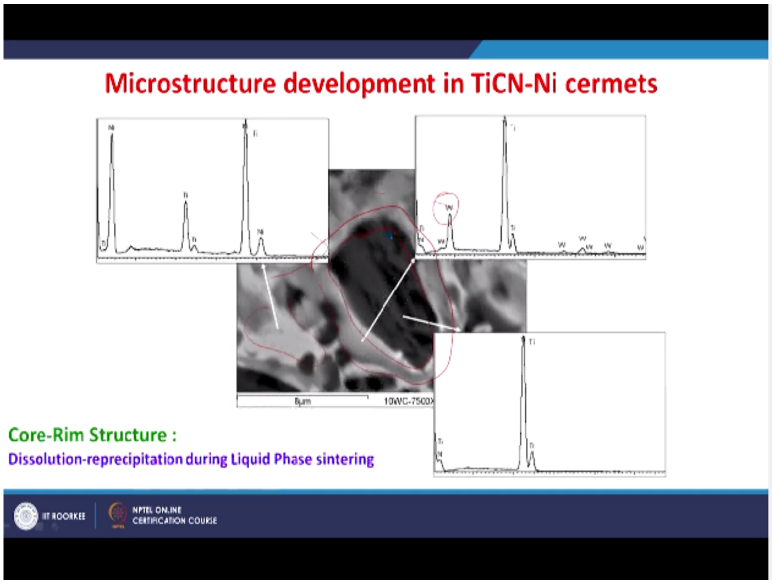

There is a black core region and then there is a shell generally called the rim region. And then attaching this binder phase. So the black region is the core, whereas this grey color region is a rim and then a brighter region is a binder phase. So EDS analysis of these respective 3 different phases indicate the core which is black is rich with the titanium, whereas the rim region also contains along with the titanium, the tungsten and whereas the nickel, this binder phase which is brighter a bit in the contrast having nickel titanium.

So these all, the core and rim structure is believed to developed by liquid phase sintering. So when the liquid forms, like nickel having a low melting point than this titanium carbonitride, while sintering these cermets, this nickel melt will penetrate among the particles of these ceramic cermix, titanium carbonitride and the respective carbides, so they wet these solid particles, the liquid wets the solid particles and there is a dissolution of the solid.

And in the process of sintering, there is a precipitation. So the undissolved portion is a core whereas the precipitated portion is a rim.

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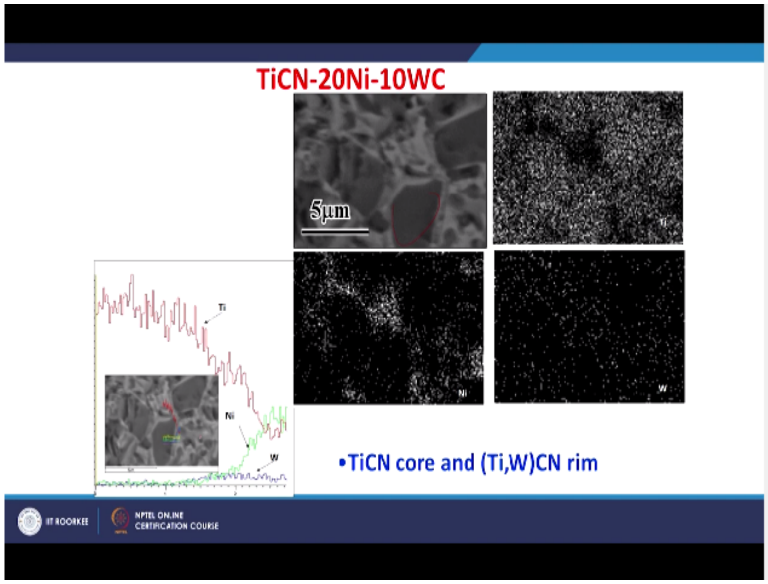

So if you look at the x-ray mapping of these cermet material, so you can also see there is a core region again rich with this titanium whereas the rim region having titanium and tungsten and carbon nitrogen and then binder region having the nickel or titanium. So we confirm that the core is of titanium carbonitride rich phase, whereas the rim is a solid solution of titanium-tungsten carbonitride.

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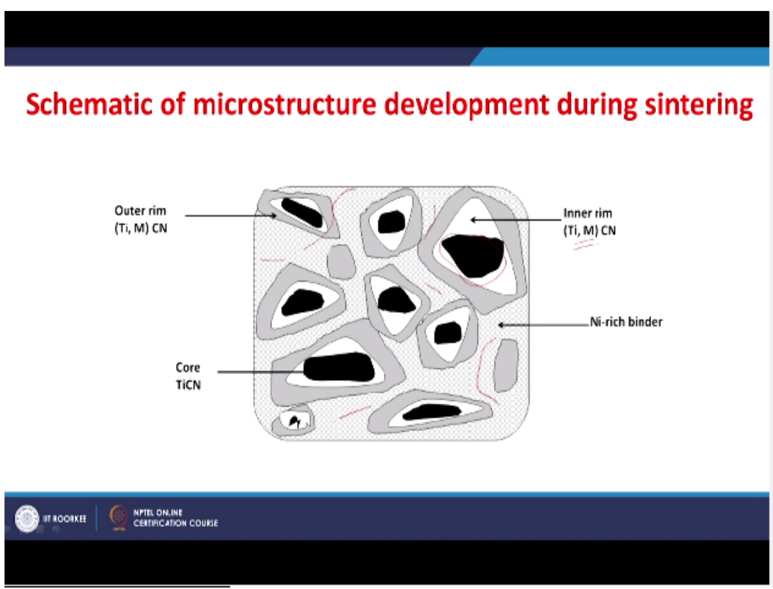

So it is a schematic representation of this microstructure obtained for the cermet material. So there is a core region and the rim region. And again the rim region is divided into outer rim and the inner rim. Generally inner rim is rich with the heavy metal from the carbides, from the added secondary carbides and this is the binder region which is nickel rich binder region.

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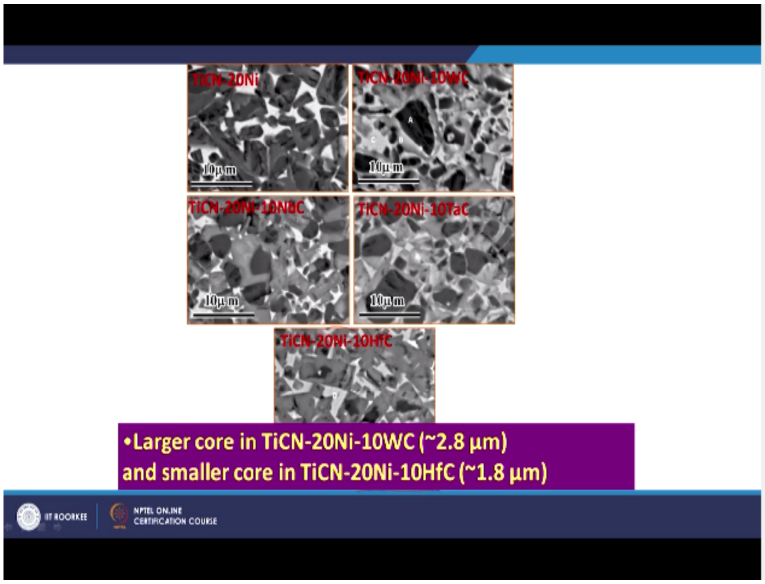

So this is a collection of the typical microstructures of the investigated cermets. So you can see more or less the similar features are present in the sintered materials. But there is a difference in the frequency of the core or the rim phases as well as the size of this core or rim phases. So very systematic investigation using line intercept method. It shows a larger core region. Average core region is around 2.8 micron meter in the titanium carbonitride nickel tungsten carbide cermet.

Whereas the smaller region of the core is in the titanium carbonitride nickel hafnium carbide cermet. So there is an average size difference in the cores obtained after the sintering.

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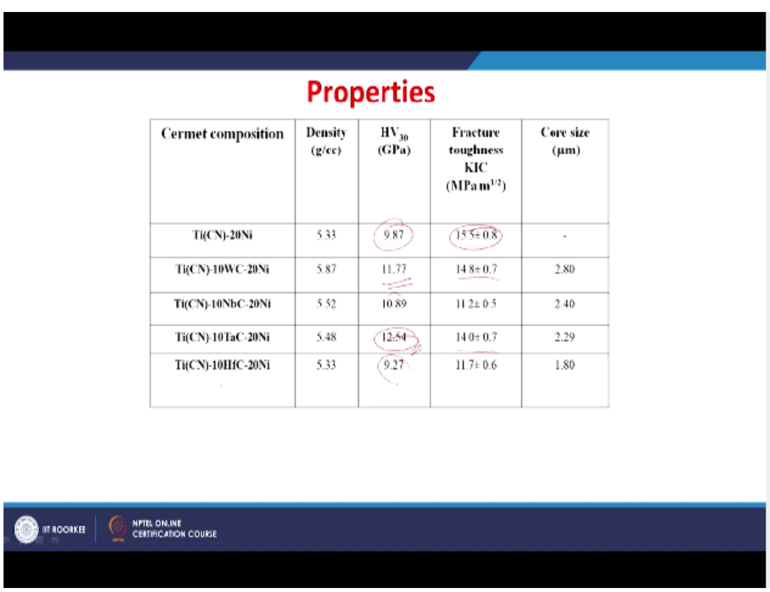

Cermet composition	Density (g/cc)	HV_{30} (GPa)	Fracture toughness KIC ($MPa\,m^{1/2}$)	Core size (µm)
Ti(CN)-20Ni	5.33	9.87	15.5± 0.8	-
Ti(CN)-10WC-20Ni	5.87	11.77	14.8± 0.7	2.80
Ti(CN)-10NbC-20Ni	5.52	10.89	11.2± 0.5	2.40
Ti(CN)-10TaC-20Ni	5.48	12.54	14.0± 0.7	2.29
Ti(CN)-10HfC-20Ni	5.33	9.27	11.7± 0.6	1.80

So this actually reflects on the mechanical properties as well. The hardness you can see, there it ranges from around this 9 to 12 gigapascal with change in the composition. Now more or less this baseline cermet without having any carbide and that having the hafnium carbide or this niobium carbide having a range of hardness between 9 and 10 gigapascal. Whereas higher hardness are obtained for the cermets containing tungsten carbide and the tantalum carbide.

Out of them, the cermet having this tantalum carbide shows the maximum hardness, followed by these cermet containing tungsten carbide. But you can see the fracture toughness, fracture toughness ranged from the 11 to 15 MPa root meter. Of course the maximum fracture toughness is obtained for the titanium carbonate with nickel without having any secondary carbides. So by adding the secondary carbides, the fracture toughness seems to reduce.

And out of these cermets added with secondary carbides, the cermet with tungsten carbide addition and the tantalum carbide addition shows the maximum fracture toughness. So with this information, we did some sliding wear for the cermets in a reciprocated sliding conditions. So as explained earlier, the reciprocated sliding gives the information, gives longer contact time. So the material will be subjected to more wear as well as the debris will be in longer contact.

So there is a difference in the subsequent wear. So for these experiments, we selected a sliding wear tester which reciprocates over a short distance.

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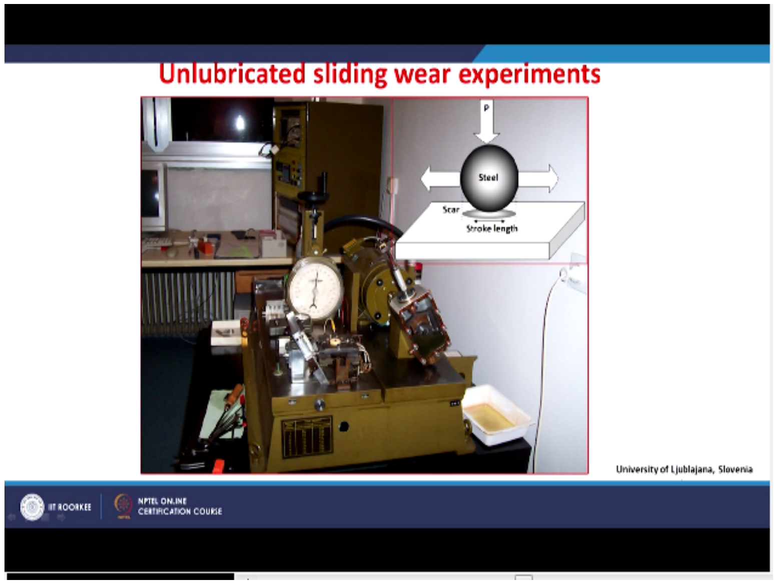

And these experiments were done in the university of Ljubljana, Slovenia.

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Sliding Parameters

Parameter	*Value*
Load (N)	5, 20 and 50
Stroke length (mm)	2.4
Frequency of oscillation (Hz)	5
Duration (Hrs)	1.67
Total sliding distance (m)	100.8
Linear velocity (mm/sec)	24
Cunterbody – Steel ball diameter (mm)	10
Initial Hertzian Stress (GPa)	0.9, 1.5 and 2.1
Temperature	RT

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So mainly the experiments were done for the investigated cermets with change in load 5, 20 and 50 Newton that gave initial Hertzian stress maximum of 0.9, 1.5 and 2.1 gigapascal respectively. And all other parameters kept constant.

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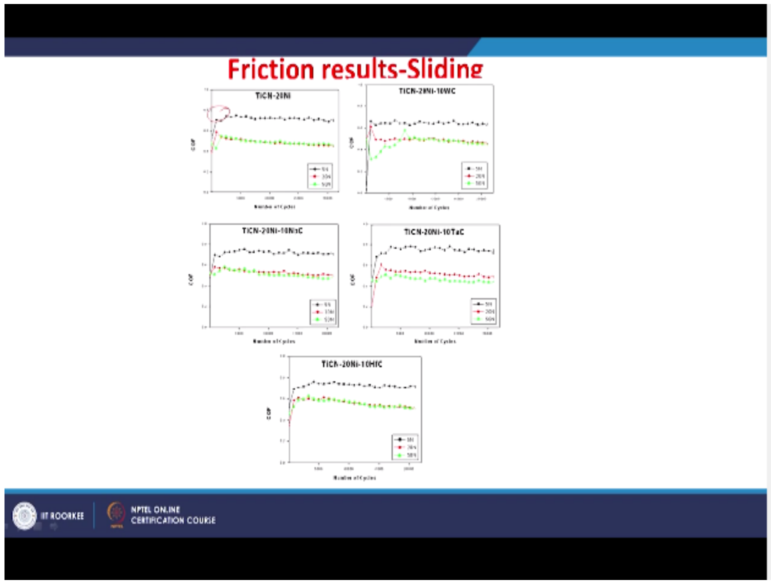

So let us understand the results obtained from these study. So if you can see the coefficient of friction as a function of number of cycles, so more or less the similar features can be observed. Now initially the coefficient of friction increases to a maximum value within few 100s of cycles and then it actually have the same steady state until the end of this experiment.

So generally speaking, the coefficient of friction is maximum in initial stages because of the running in period behavior where it is presumably because of the rubbing action of the asperities in the initial stages of this friction. Once these asperities are rubbed against each other, there forms a stable contact and that leads to a steady state. Now this running in period as well as the steady state is observed in all cermets.

But there is a difference with respect to the load or with respect to the cermet compositions. Let us understand with respect to load the coefficient of friction in the steady state is higher for any cermet at a lower load of 5 Newton. Whereas 20 Newton and for 50 Newton load conditions gave a reduced friction compared to that obtained at 5 Newton. But there is no much difference in the friction obtained at 50 or 20 Newton. So but there is a difference in the steady state coefficient of friction value.

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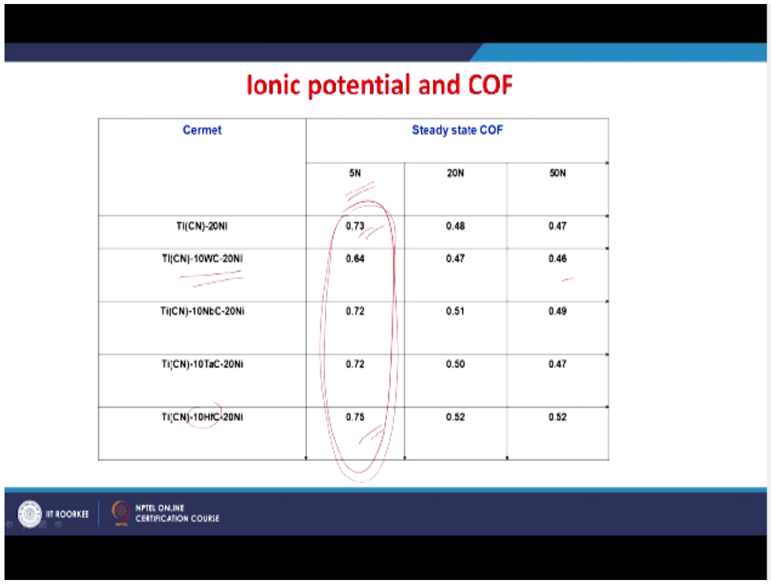

So these were actually tabulated. The average steady state coefficient of friction for the investigated cermets and as well as for the different loading conditions are like this. You can see higher coefficient of frictions are obtained at the lower loads. Whereas this actually decreased to at higher loads of 20 or 50. The average steady state coefficient of friction is in between 0.64 to 0.75 at 5 Newton for the investigated cermets.

Whereas at higher loads of 20 or 50 Newton, it is actually varying from around 0.46 to maximum 0.52. But there is no much difference from the friction obtained at higher loads of 20 or 50 Newton. Now among the investigated cermets, even at a lower load of 5 Newton, you can see the minimum coefficient of friction was obtained for the cermet having the tungsten carbide. Whereas maximum coefficient of friction is obtained for the cermet having the hafnium carbide or for the baseline cermet.

It is almost same or almost, there is no much difference here. But you can see the overall coefficient of friction at lower load, the coefficient of friction is high. Whereas at higher load, the coefficient of friction becomes less. So it actually indicates the 2 load same conditions. The higher load that is the 20 or 50 Newton or at a lower load, that is 5 Newton, the friction is changed. Now let us understand, the wear behavior.

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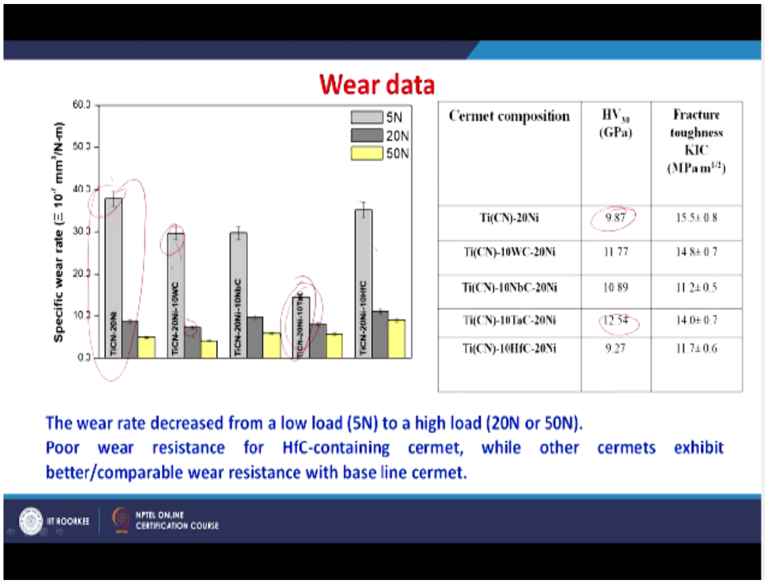

The wear behavior can be understood by the specific wear rate data. So again the surface profiles were recorded for each rank at a different locations. And then the depth and the width of this wear track were measured using stylus profilometry and then integrating over a distance, then we get a volume of the material removal. So it is normalized with distance and the time, so we get a specific wear rate.

Now see it is the specific wear rate actually varied in a very larger range. So the wear rate is maximum for the baseline cermet, particularly at lower loads. So at lower loads, maximum is obtained for the baseline cermets and minimum wear rate is obtained for the cermet having the tantalum carbide followed by the tungsten carbide. So the wear rate again decreased from low load to high load.

So if you take any cermet composition, the wear rate decreased from 5 Newton load to 20 or 50 Newton load. Again the difference between the 5 Newton and 20 Newton is much larger than from the 20 to 50 Newton in any cermet. So among the investigated cermets, higher wear is obtained for the baseline cermet and the cermet containing the hafnium carbide. While other cermets exhibit comparable wear resistance with the baseline cermet.

We can actually relate with the mechanical properties. So thus relation with the mechanical properties is like this. The cermet having higher hardness shows a lesser wear, right. And the one which is having the lowest hardness shows higher wear. But you can see there is no much relation between the fracture toughness and the cermet. So this may be related to the absence of any cracking at the interface of these core and rim or the rim or the binder. So which will be seen in the next slide.

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Let us understand these the behavior with respect to wear and friction by studying the worn surfaces. These are the SN images obtained for the baseline cermet of titanium carbonitride with nickel at 3 different load conditions. After wear test was done, these were subjected to a same analysis. And you can see these surfaces reveal almost like a deformed region and large pullouts in a lower load conditions.

Whereas at higher loads, the surface is more or less covered with the layer. Whereas such a layer is minimum at a lower conditions. So one observation is at higher loads, the wear is dominated by the pullout or the deformation conditions. And higher loads, it is basically by the layer formation and their removal.

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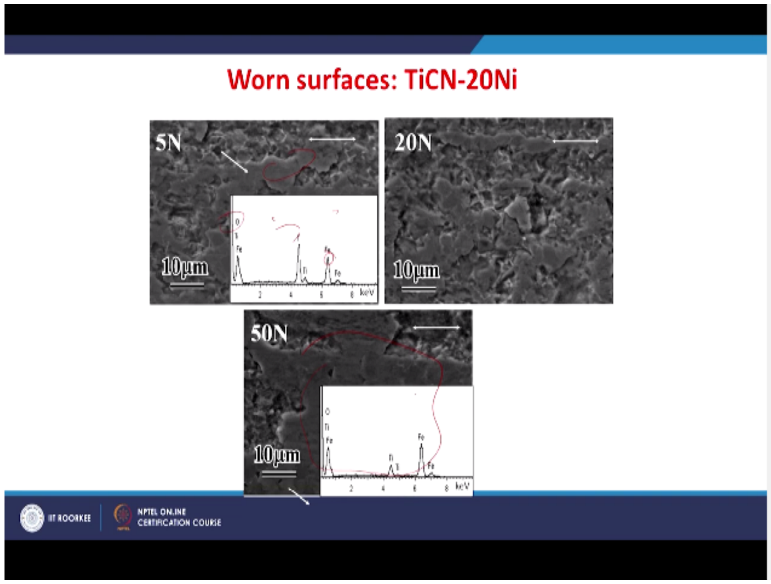

The EDS analysis of this particular wear fragments shows there is an oxides of titanium or iron. Whereas at higher loads, you can see again the oxides of titanium and iron but very interesting observation is the titanium peak actually is reduced, whereas the iron is increased. So with increase in load, the iron oxide content is more than the titanium oxide in the layer.

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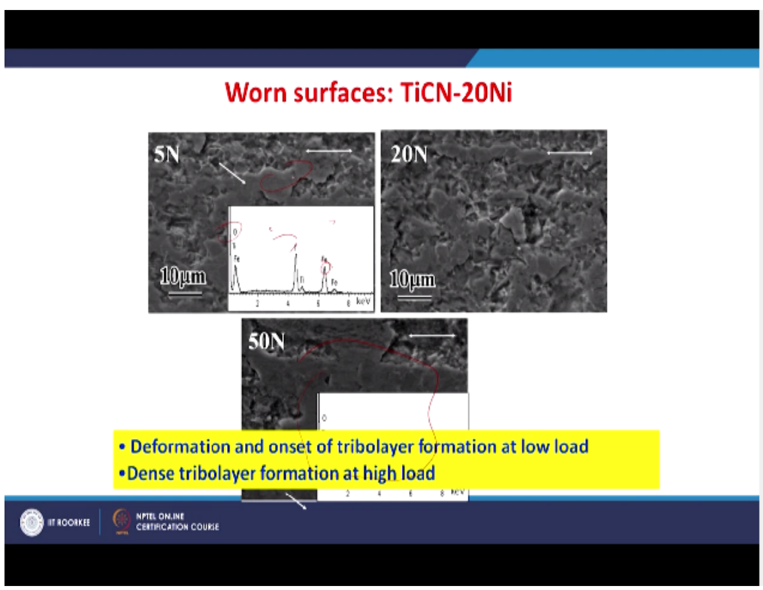

So there is deformation and in onset of the tribolayer formation at lower load whereas the dense tribolayer formation is observed at the higher loads.

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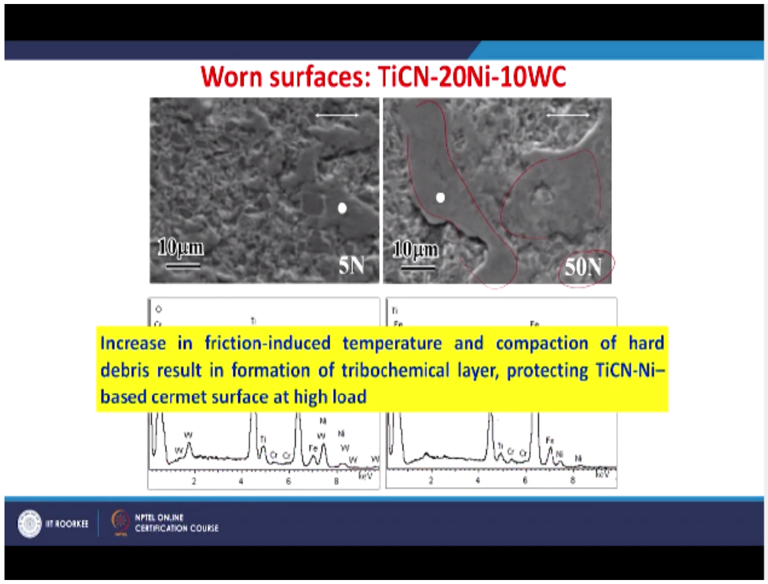

The worn surfaces of the titanium carbonitride nickel tungsten carbide cermet shows again at lower load, minimal presence of this layer whereas at higher load, you will see majority of the surface is occupied by this, covered by this layer. And again, the EDS analysis shows a similar observation that it becomes more rich with the iron oxide at the higher load conditions. So the increase in the friction induced temperature because of the higher loads and also the compaction of those debris result in the formation of such a layer.

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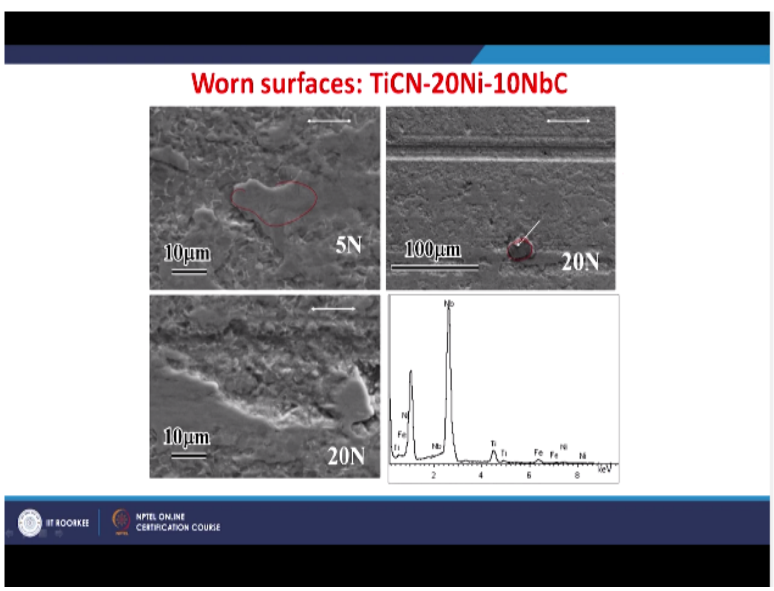

And this layer actually protects the underneath surface. So that reduces the wear or the friction. So these are the worn surfaces for the titanium carbonitride nickel niobium carbide cermet. You can again see, there is a pullout of this material and the signatures of this tribolayer and also the entrapment of the debris on the layer along with this abraded groups. So more or less the similar features are observed.

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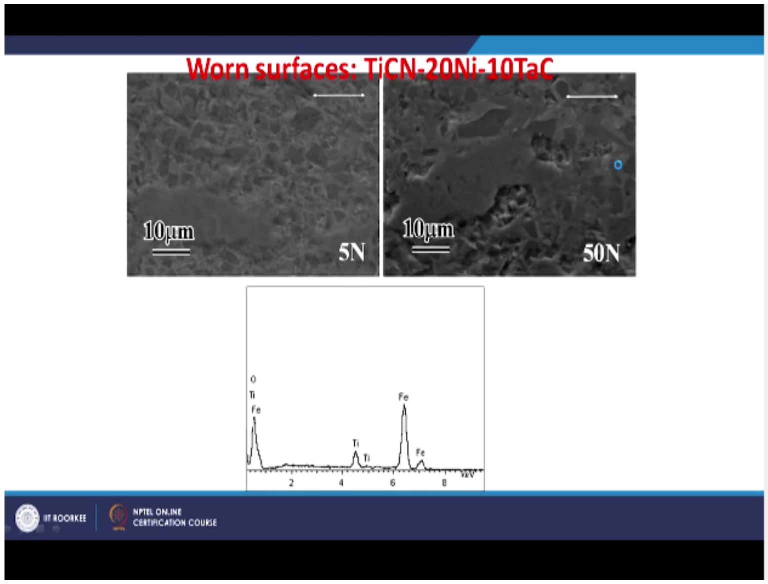

But in all these conditions, the nickel presence is very much minimum on the tribolayer. So these are the worn surfaces obtained for the cermet after sliding at 5 and 50 Newton. The cermet was titanium carbonitride nickel and tantalum carbide. Again it shows the coverage by the tribolayer at higher loads.

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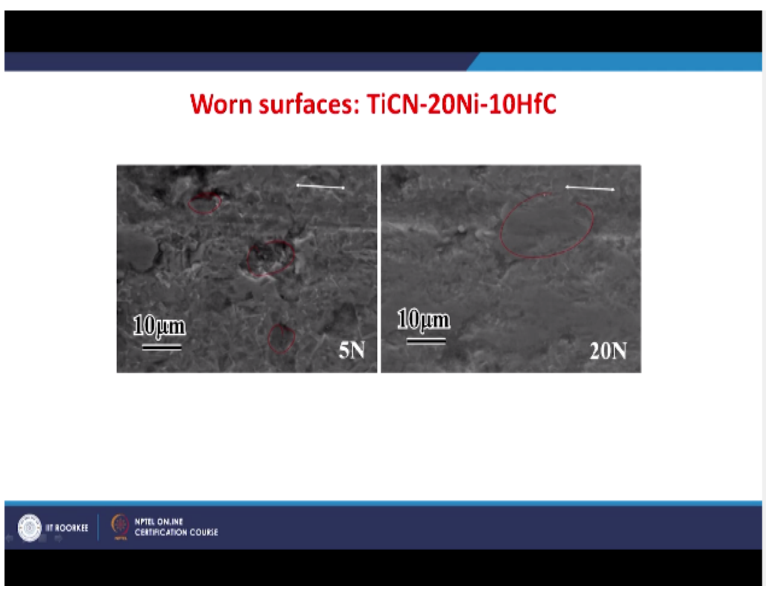

So hafnium carbide containing cermet shows very severe pullouts and the cracked material. Whereas at again higher loads, there is a layer formation.

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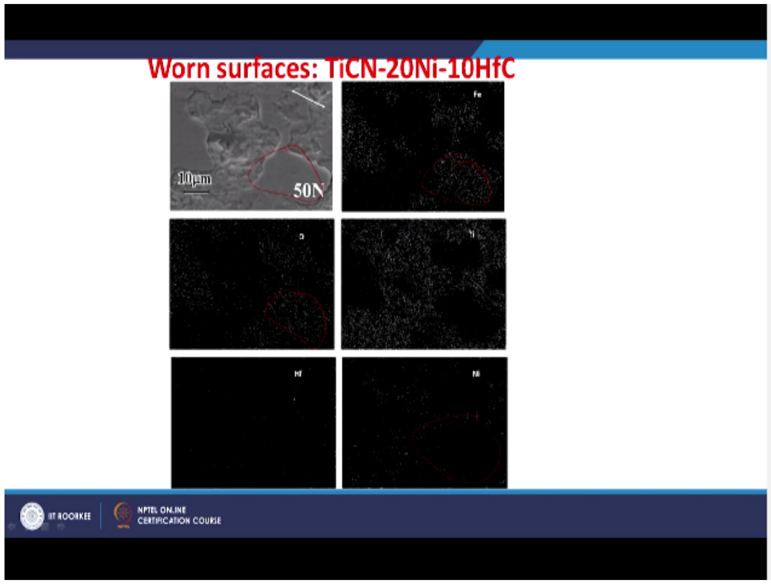

So the x-ray mapping of these cermet materials after sliding at higher load also indicate, see this is the layer and this is rich with the iron, oxygen. Whereas these layered areas are not having any nickel or hafnium or this titanium.

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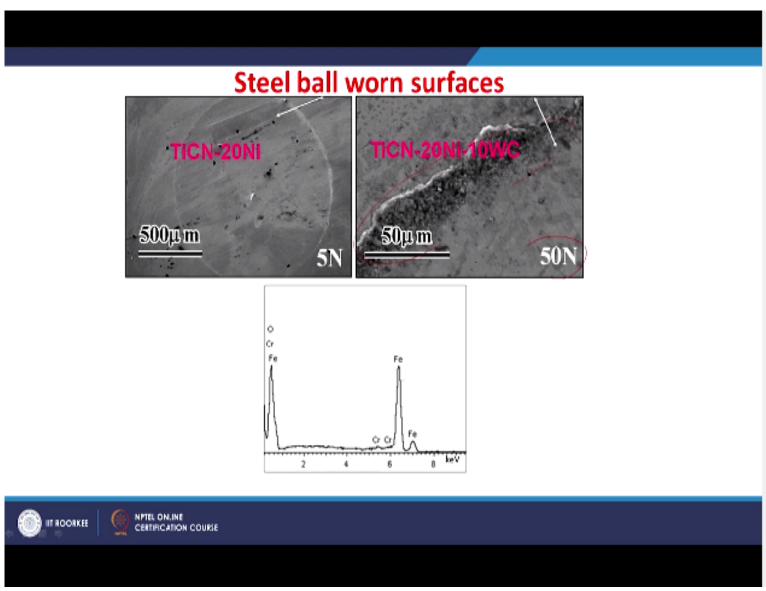

The counterbody surfaces also show this tribolayer formation at higher loads. So again these, the signatures of this layer formation on the counterbody is also rich with the iron oxides.

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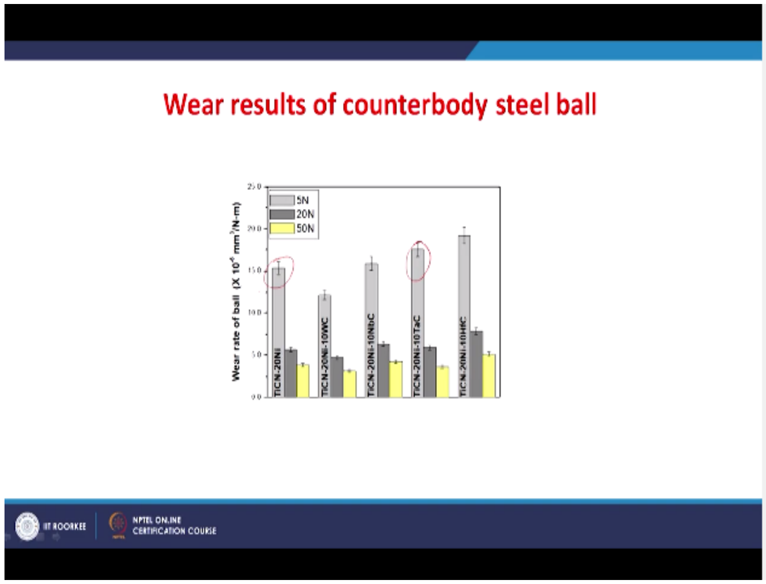

Whereas the wear results for the counterbody steel ball shows almost similar features with increase in load, there is a decrease in the wear. But very important observation is for that cermet having highest hardness, were showed the lowest wear at lower load. This showed highest wear for the counterbody, right. So the baselines cermets actually showed a lesser wear than this one.

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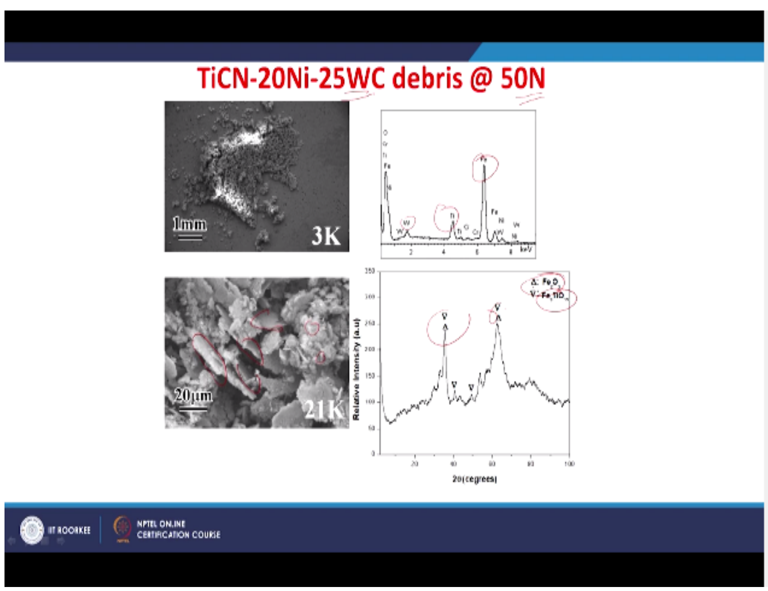

So let us understand this more detail by analyzing the debris. So these debris were collected for a different cermet which is having larger amount of tungsten carbide and subjected to the same conditions of the sliding at 50 Newton. These debris were collected carefully after sliding. And then these debris were subjected to EDS and x-ray diffraction analysis. So we can see the debris, the shape of the debris is like a platelet and some of them are very small and irregular in sizes and shape.

Whereas some of them are shape like, these shapes are plate like debris. So EDS analysis again shows the rich iron oxide or the titanium oxide with the minimum amount of the respective elements from the carbides. But you can see the x-ray analysis of these debris show the dominant presence of oxides of iron or the iron titanate. Iron oxide or iron titanate are observed.

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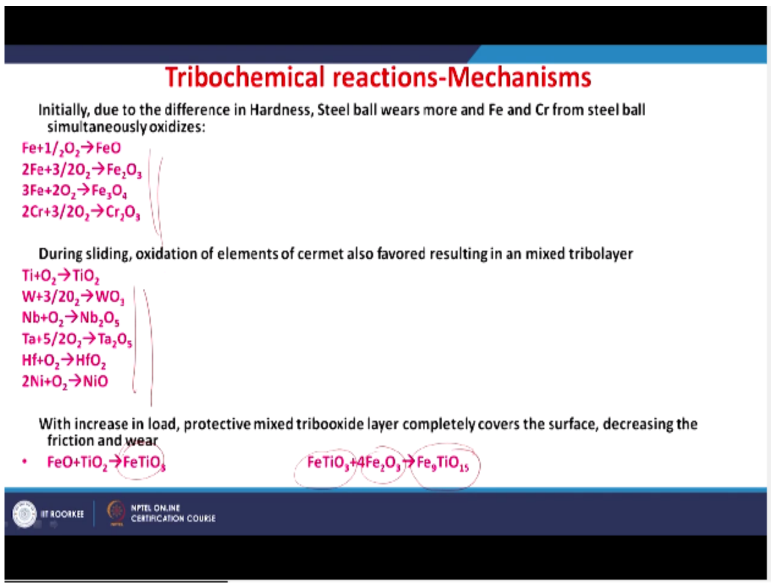

So all these results can be understood by the tribochemical reactions. The very important observation so far we obtained is lower loads. So lower loads, the friction is high and the higher loads, it is less. And same with the lower loads, the wear is high and for the higher loads, the wear is less. So at higher load, there is a domination of the tribolayer, whereas at lower loads, it is more or less the removal of the material by the mechanical fracture.

So it is now understood at lower loads, it is only the mechanical aspect which is contributing to the wear. Whereas at higher loads, it is the tribochemical layer. So generally what happens, initial stages of sliding due to the difference in the hardness between the steel ball and the cermet, cermet having higher hardness than the steel ball. Because of the difference in hardness, steel ball wears out easily and then the elements from the ball, iron and chromium from the steel ball gets oxidized because all these testings were done in an ambient conditions.

So there is a chance that iron oxides will form or the chromium oxide will form. So as the sliding is continued, these hard debris of iron oxide or chromium oxide, they will abrade the cermet material as well. So we will saw some signatures of the abrasion and entrapment of this debris. So these abrasion leads to removal of the material from the cermet surface. From the cermet surface, the material removal results into the oxidation of these elements from that material.

So we will have an oxidation of the elements. For example, the titanium gets oxidized or tungsten is oxidized or niobium is oxidized, tantalum is oxidized, hafnium oxidized, nickel oxidizes. So the oxidation of these elements of cermets is possible in the continuous process of this sliding. Initially the iron oxide is formed and then hot the iron oxide will actually abrade the cermet surface and the elements from the cermet surface also gets oxidized.

And we will have oxides forming on the surface. But higher loads, so these oxides debris will be mixed and then compacted and then form as a tribolayer. This layer is in between the actual bodies of the steel ball as well as the cermet. Particularly the higher loads we saw these layer protects the cermet surface from the further wear. So with increase in load, this layer which is rich in oxides completely covers the surface and decreases the friction and wear.

And based on the lubricity of this layer, friction also reduced and then because of the covering of the surface by this layer, the further wear is also reduced. So we have seen the reduced friction and the wear. And our XRD analysis also indicate the formation of an iron titanate or iron titanate is generally formed by mixing of reaction of the iron oxide with the titanium oxide with iron titanate or iron titanate further oxide with iron and then forms another form of iron titanate. So we have seen the iron titanates formed from the debris analysis.

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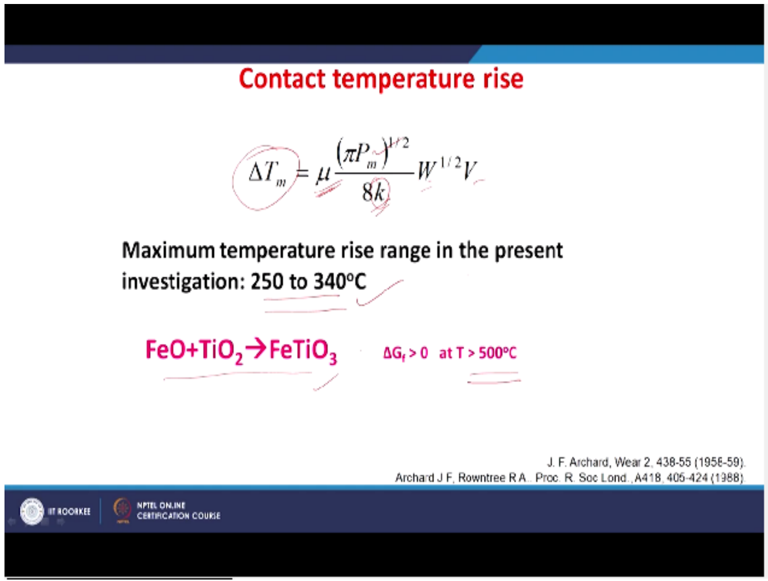

So let us understand these tribochemistry involved at higher temperatures with respect to the friction induced contact temperature. As I told, friction is generally high at the initial contacts and then later on, it gets a steady state. So because of this friction, there is a large amount of heat generated at the contact. But measuring the temperature at the contact is very much difficult.

So analytically these were studied by a formula and very importantly the formula used by Archard shows this, the change in the flash temperature is a function of this load and the stress and the load and the speed and the thermal conductivity and also the friction. So more is the friction, more will be the temperature increase at the contact for a given material and for a given sliding wear conditions.

So using data for the cermets used in the present investigation, the thermal conductivity was determined by rule of mixture and then all other the stress, maximum stress, the load and the velocity. So by incorporating all these values along with the respective friction coefficients, the temperature rise in the present investigation was found to be from 250 to 340 Celsius based on the cermet compositions at the highest load of 50 Newton.

So again the thermodynamic data also show such a reaction of iron oxide with titanium oxide giving iron titanate is not feasible at a temperature more than 500 Celsius. So it is indirect indication that the temperature is less than 500 Celsius for the present investigated materials in the selected sliding wear contacts. So this temperature also indicate the feasibility of this iron titanate.

So it is now very clear that the formation of this oxides on the surface lead to the mixture of this iron oxide and titanium oxide and then lead to iron titanate. So this iron titanate is thick and also viscous in nature and it actually facilitates the sliding, so the friction is reduced. Because of the coverage of this layer, so the material removal is also reduced. So and all these conditions indicate the formation of the layer and the removal of the layer at the higher load.

That means the tribochemical layer formation and the removal of such a tribochemical layer dictates the wear behavior. So our results show that the iron titanium oxide rich layer formation is beneficial in reducing the wear and the friction for this material. The friction behaviour can also be understood by a crystal chemical model proposed by this Erdemir.

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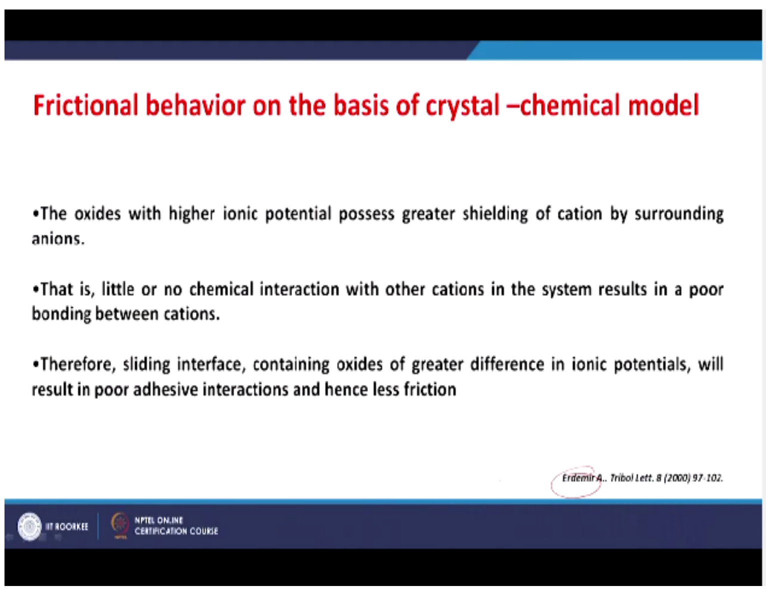

So as we have seen, there is a chance that several oxides are formed on the surface at the contact. So the oxides with higher ionic potentials possesses greater shielding of that cation by surrounding the anions. So the cation has a little or no chemical interaction with other cations in the system. So the sliding interface which is rich with the oxides of a very larger difference in ionic potentials will result in a very poor adhesive interactions. So it actually contributes to the lesser friction.

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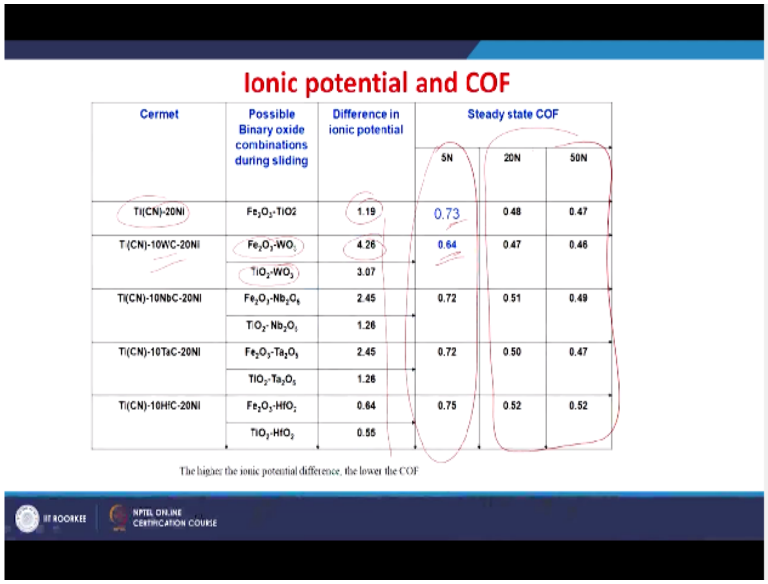

Cermet	Possible Binary oxide combinations during sliding	Difference in ionic potential	Steady state COF		
			5N	20N	50N
Ti(CN)-20Ni	Fe_2O_3-TiO2	1.19	0.73	0.48	0.47
Ti(CN)-10WC-20Ni	Fe_2O_3-WO_3	4.26	0.64	0.47	0.46
	TiO_2-WO_3	3.07			
Ti(CN)-10NbC-20Ni	Fe_2O_3-Nb_2O_5	2.45	0.72	0.51	0.49
	TiO_2-Nb_2O_5	1.26			
Ti(CN)-10TaC-20Ni	Fe_2O_3-Ta_2O_5	2.45	0.72	0.50	0.47
	TiO_2-Ta_2O_5	1.26			
Ti(CN)-10HfC-20Ni	Fe_2O_3-HfO_2	0.64	0.75	0.52	0.52
	TiO_2-HfO_2	0.55			

The higher the ionic potential difference, the lower the COF

So based on this, we again understood the steady state coefficient of friction with respect to the possible binary oxide combinations during the sliding and the difference in their ionic potential. So you can see the formation of this possible oxides are like this, iron oxide or titanium oxide are possible with the baseline cermets. Whereas in addition to that, you have iron oxide tungsten oxide or titanium oxide tungsten oxide combination is also possible in this particular cermet.

So we have actually listed down this possible binary oxides combination during this sliding of this respective cermet materials. And the difference in their ionic potentials are also listed. Now you will see here that particular in lower load conditions, higher the ionic potential, lower is the friction coefficient. You can say the higher ionic potential, lower is the friction coefficient. Lower is the difference in ionic potential you have, higher is the coefficient of friction.

But actually this behavior is not observed at a higher load region. That indicates whenever you have the wear dominated by the mechanical aspects, the abrasion and pullout and the fracture, then you have the effect of this oxides and then respective difference in the ionic potentials on the friction behavior.

Whereas at higher load, we have seen the surface is completely covered with the tribolayer rich in oxides and particular the iron titanium oxide, so it is actually happening like this. The surface is filled with the oxide. So the friction or the sliding is actually going on between the layers of these oxides. So the actual contact between the steel ball and the cermet surface is lost. It is only between the layers of this oxides.

So you do not have any such influence of this, difference in ionic potential at a higher loads where there is a domination of the tribochemical layer formation. So the crystal chemical model is applied only at the lower loads where there is a mechanical fracture, induced wear. Whereas at higher loads, this does not happen.

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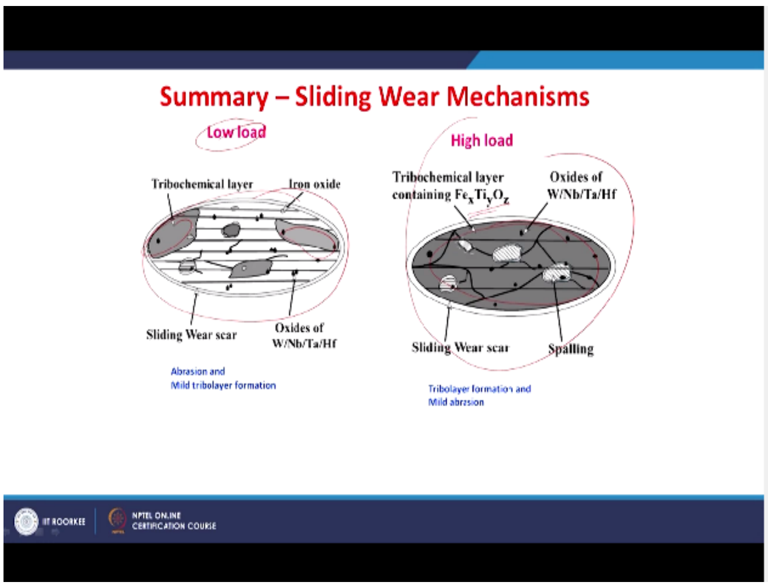

So overall putting this as a summary of this sliding wear mechanisms, at lower load, there is lot of abrasion and then debris and then that leads to oxidation of this debris. And there is an onset of such a tribolayers but this layer becomes dense on covering entirely the worn surface and this layer is rich with the iron titanium oxides. So the layer is cracked and then removed. So mainly the wear occurs at higher loads by removal of such a layer rich with the iron titanium oxide.

Whereas at lower loads, the wear is more dominantly by the abrasion or the cracking or pullout of this material. So because this is a cermet material, we have a nickel binder phase which is easily deformable then the ceramic phase in a structure of this cermet. Now sliding, during sliding, the deformable material which is the binder phase is smeared out. And then once this smeared out is comes out and then gets oxidized.

But once these are, the binder phase is detached from the ceramic grains, the ceramic grains are subjected to sliding. Because of the brittleness of this ceramic materials, so those get fractured and then small debris will form, again those debris will be subjected to oxidation. The process is like this. Initial conditions of the sliding, the deformable material or the nickel binder phase comes out and smears out and deforms, followed by the cracking of these ceramic core and rims phases.

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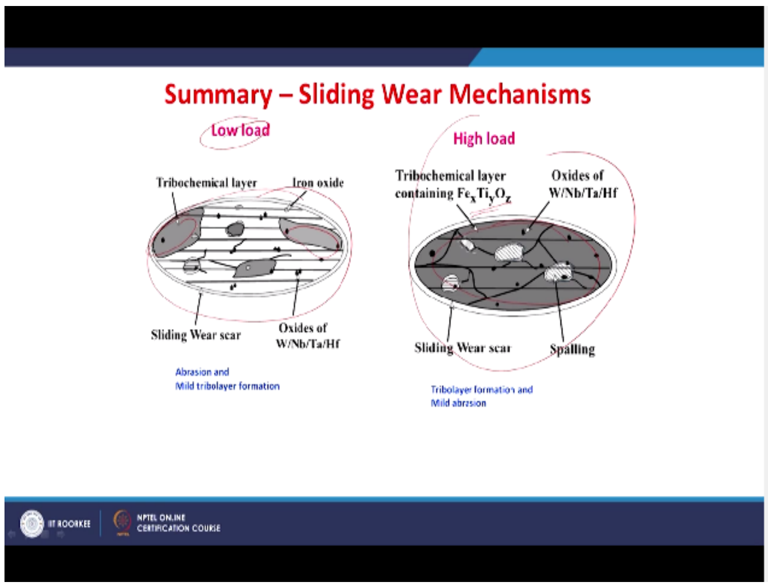

So at a lower loads, the oxidation or this abrasion is dominant. At higher loads, the oxidation of these debris, so that will lead to a compacted layer which is rich with the iron titanium oxide because it fills entirely on the surface and then it reduces further wear from the underneath surface.

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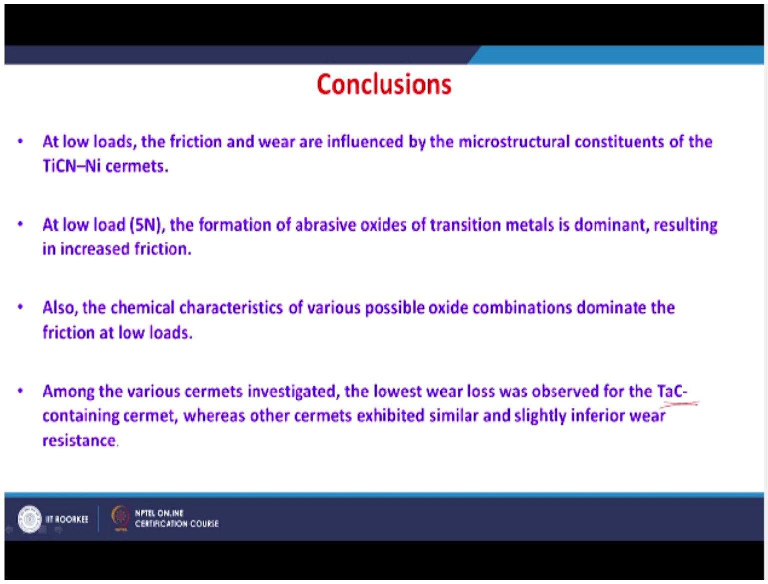

So the overall conclusions from the present study, at lower loads the friction and wear are influenced by the microstructure constituents of these titanium carbonitride nickel based cermets. At lower load, that is at 5 Newton, the formation of abrasive oxides of these metals, of these transition metals is dominant resulting in higher friction.

Also the chemical characteristics of various possible oxide combinations dominate the friction at lower loads. So among the cermets investigated here, the lowest wear loss was observed for the cermet containing tantalum carbide. Whereas other cermets exhibited similar and slightly inferior wear resistance.

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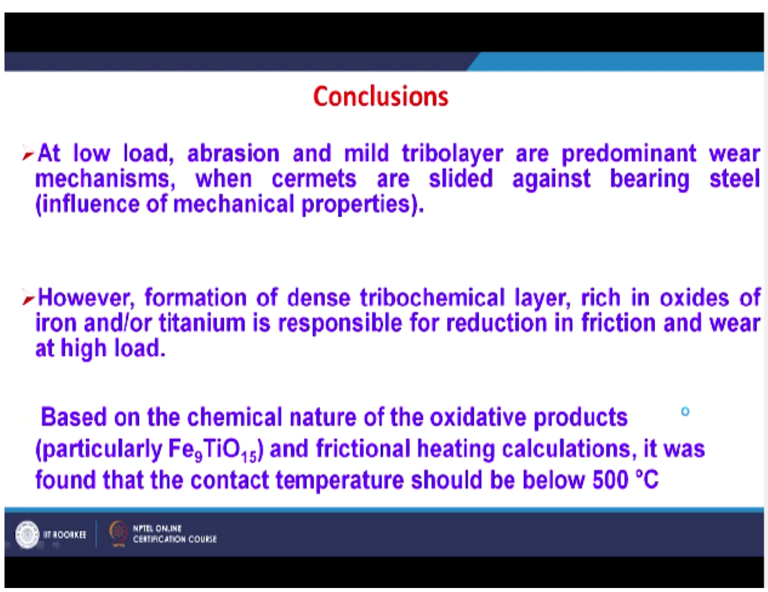

Regarding to the mechanism, at lower load, abrasion and mild tribolayer are predominant. However, the formation of dense tribochemical layer which is rich in oxides of iron and titanium or iron or titanium is responsible for the reduction in the friction and wear at higher loads. So based on the chemical nature of this oxidative products and the frictional heating calculations, it was found that the contact temperature should be below 500 degree Celsius.

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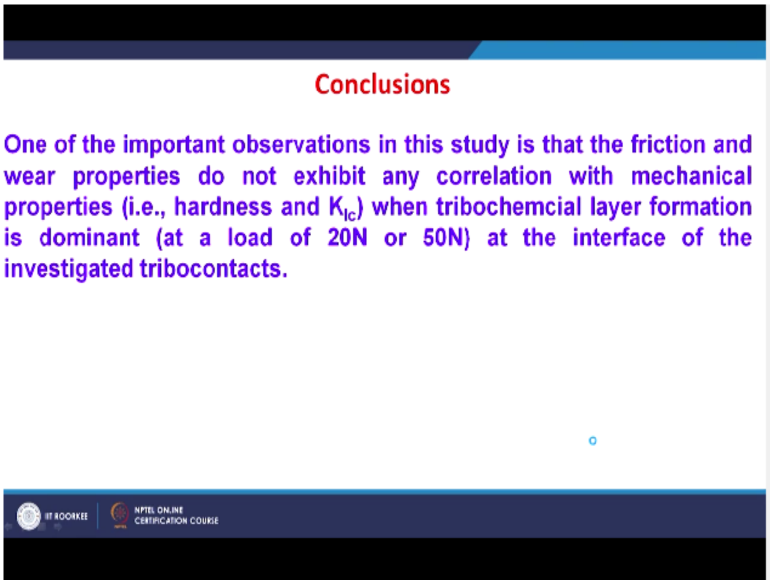

So one of the important observations from the study is that the friction and wear properties do not exhibit any direct correlation with the mechanical properties. Remember it has a hardness influence only at the lower load conditions. At higher loads, there is no such relation. So when tribochemical layer is formed, you do not have such a relation because of the properties. Because the contact surface is actually covered by this tribochemical layer.

So that means when tribochemical layer formation is dominant, you do not have any relation at the interface of the investigated tribocontacts. So this particular study highlights the evolution of the tribochemical layer that has a relation because the contact temperatures. So for the given cermet composition and the sliding wear conditions, the tribochemical layer evolves.

So it is very important study for the application point of view. So you have to identify the cermet composition and the suitable sliding wear conditions so that these cermets can be preferred for this tribological applications. For example, this cutting tools. Thank you. We will see in the next class.