Fundamentals of Materials Processing (Part- II)

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Lecture – 19
Types of Friction

Welcome back friends. We will continue our discussion on sticking friction. So, what we had discussed in the previous lecture was what is called as sliding friction.

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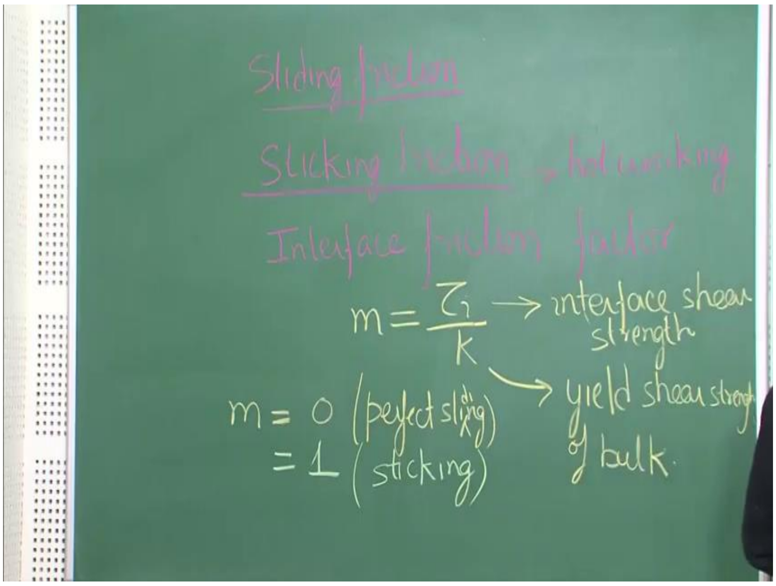

There is something called as sliding friction where we had defined the term coulombic friction and then we moved, now we move on to sticking friction and in the previous lecture also, I emphasized that sticking friction is used mostly for hot working. Now sticking friction is where the material is sticking, but the way we define it, it is not the factor that we will define, which is called interface friction factor. So, it deals with all the condition starting from no sticking that is fully sliding to completely sticking.

How is it defined? It is defined as m equal to tau i by K, what is tau i? It is the interface shear strength or you can say the stress that exists at the interface, K on the other hand is the yield shear strength of the bulk. So, this m describes the ratio of tau i by K and this m can vary from 0, when it is 0, it means tau i, there is no shear stress or there is negligible shear strength of the interface which is fully sliding; perfect sliding condition; when it is equal to 1, it means tau i is equal to K, when m is equal to 1, it means tau i by K is equal to 1, it means tau i is equal to K; that means, in this particular condition, interface shear strength or stress has reached the bulk yield bulk strength shear strength and; that means, it starts to stick it will no more slide. So, let me correct this spelling, this is sliding the ratio this m varies from 0 to 1 in the 0 condition, when m is equal to 0, it implies it is perfect sliding therefore, if for example, if you are talking about die and the work piece then the die and the work piece can completely slide.

And this is kind of condition we assume when we took that plane strain indentation example, the other is other extreme is 1 when it starts to stick. So, if the inter facial strength or the stress at the interface increases to the point that it reaches the yield shear strength then it cannot slide anymore, it will start to deform the material and in that condition, it will stick, there will no more sliding. So, that is the range for m.

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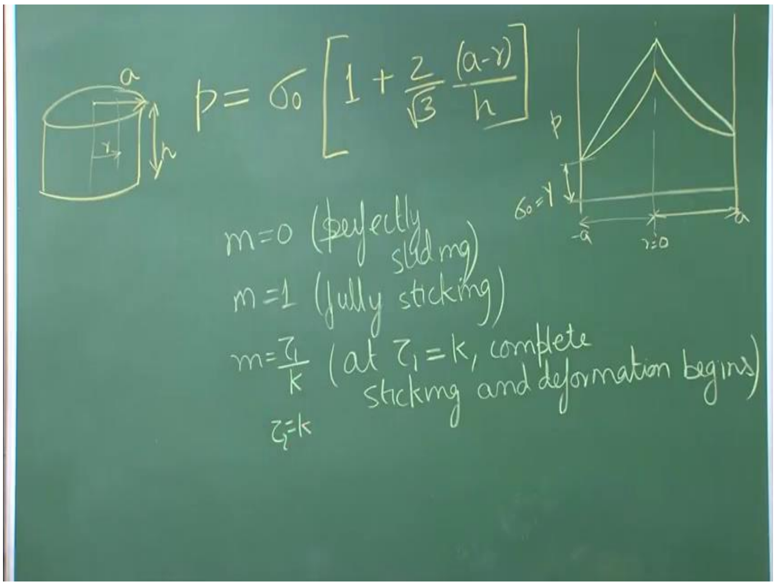

And if you do similar analysis that we talked about, we did not describe it, but similar analysis to describe the pressure variation across a dish of height h and radius a. So, let us say, we are talking about some radius r inside this; then this pressure is given by sigma naught. Now what do you notice? First thing you notice is that the form of the equation is very same is very similar, not same, is very similar to the pressure variation that we found when we were talking with respect to coulombic equation and that should not be surprising because in both cases, we are dealing with friction it is just how you define it and which one is more accurate model at the particular for the particular example.

These 2 are not very far off form of the equation remains same, the only thing is that pressure here varies linearly with r over there, we saw it varied exponentially with r and that implies that if you are looking at pressure as a variation, as a function of radius. So, this point is a, this point is minus a, r equal to 0. So, earlier we saw the pressure had a variation like this where the extreme value is what extreme values will equal to y which is same as sigma naught we are using different notation, but it has the same thing.

Now, when we are talking about; talking with respect to this sliding friction, sorry! This sticking friction then in the sticking friction which is the where we use the interface sticking factor, in that case, we kept a equation which is of this form and if you plot this you will get as I said in the form of the equation is very similar and even if you plot it as a function of r, you get very similar value. So, here at r equal to 0 you get maximum so this is the highest value that you will get for the pressure and if you get r equal to a, this factor goes away and you what you get is P equal to sigma naught which is the max, which is the lowest value of P and which is equal to sigma naught so at that point they are both same.

Again let me emphasize the fact that when m is equal to 0, what you have is perfectly sliding condition and when you have m equal to 1, it is fully sticking condition, there is another implication for this, what we see here is that normal, this is P is what? Normal stress is acting on that surface the normal stresses can exceed the value y which is the yield strength; however, since m can go only from 0 to 1 which is tau i by K, since tau maximum value of m is 1, so tau i cannot exceed K and therefore, tau i will remain the maximum value of tau i will be K which is the yield shear strength and if it reaches that tau i equal to K then it means complete sticking and deformation starts to take place.

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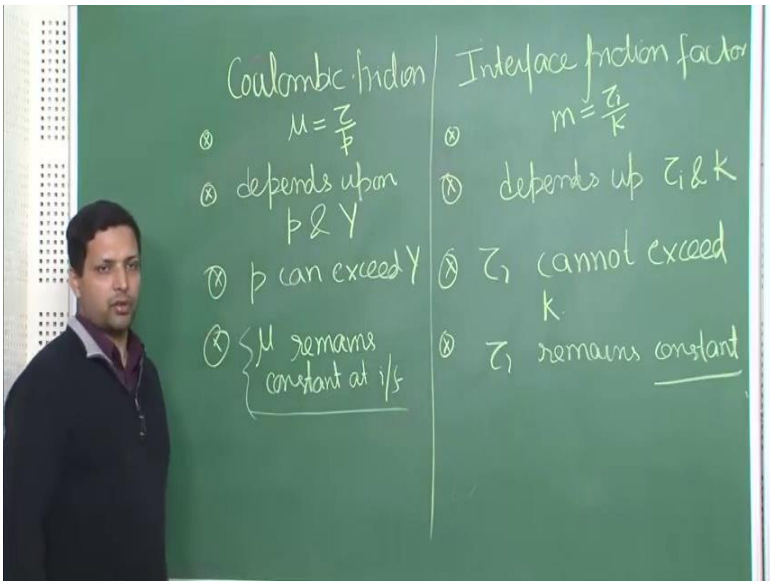

As if you keep what is happening is that tau i, value is gradually increasing at the lowest value which is 0, it is perfectly sliding, there is very smooth movement and at tau i equal to K you will keep increasing the interfacial strength and when it reaches the bulk shear yield shear strength, then it starts to deform the material and the material and it cannot just slide anymore. So, that is the affect of tau i equal to K. Now that we have described 2 different ways, one is the coulombic friction factor and the other one is this interface friction factor, let us compare the 2, it is important to understand some minor and major issues that differentiate the 2.

We have coulombic friction and we have interface friction factor, this was defined by mu, where mu is equal to tau over P, tau is the shear stress at the interface and P is the normal stress interface, friction factor is defined by m, m is equal to tau i over K, tau i is the interface shear strength or the shear stress at the interface and K is the yield shear strength. So, this is one is the basic definition. In general this depends upon P and y P is that is the normal pressure that you are applying and y is the yield strength of the material.

On the other hand, when we are talking about interface friction factor then this depends upon tau i and K not on the normal stress, it is not depending on normal stress which is a very very important point to note because it is because of this reason that we are able to use it in a wide variety of conditions wide variety of configurations, why? Because P can exceed y, the normal stress acting on the interface can exceed y which we have seen over here. In fact, it is ex higher than y for most of the point at except at the lowest point which happens to be on the outer edge.

On the other hand tau i cannot exceed K which is the yield shear strength, another fact; another important thing is that when we are talking about coulombic friction then mu remains we took or we assumed that mu remains constant at interface and when we talk about interface friction factor then what we assume is that tau i which is the shear strength of the interface or the shear stress acting on the interface that remains constant.

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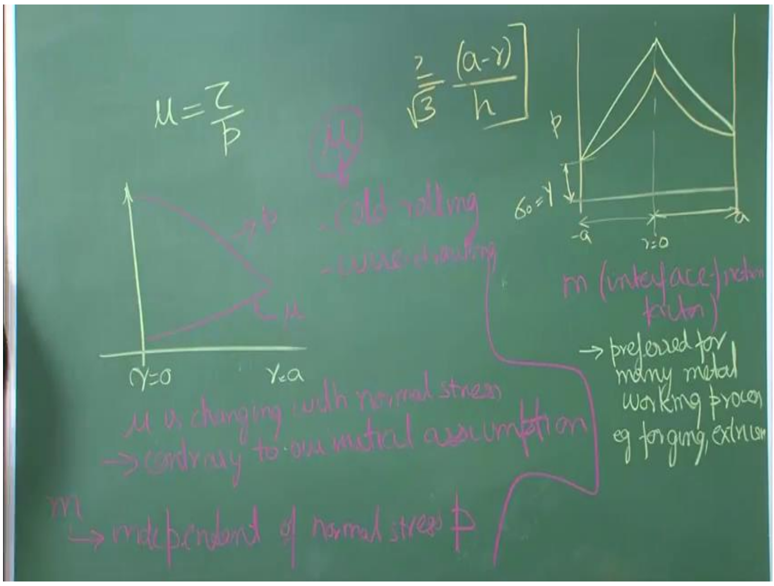

Now, the question is does this mu really remain constant at interface? Why I am asking is let us take a look at it over here, mu is defined as tau over P, now if tau is the shear stress acting on the interface and it remains constant, but our P, we have seen is varying like this. So, let us say I take, I say r equal to 0, if r equal to a, our mu sorry! Our P is varying something like this. So, this is our P. So, if P is changing like this and if the tau remains constant, it would imply that mu as to increase. So, this is mu, now this says that mu is changing with normal stress this is contrary to our initial assumption moreover this is not what is mostly observed on the other hand if you look at m this is independent of or this does not depend on pressure P, normal stress P.

Therefore it is because of this, these reasons m or the interface friction factor; this is preferred for many of many kinds of metal working processes. Particularly we are talking about processes which involve high temperature for example, forging extrusion which either involve high temperature or which involve a very large deformation. So, in those cases, m is a factor or is a parameter that is easier to obtain and easier to define and therefore, m is what is used to understand the friction in those conditions.

On the other hand mu has been very well established for some other metal working processes for example, cold rolling, wire drawing. So, what is common between these? With these processes one that they are low temperature second that the deformation overall deformation is much smaller therefore, we can say in general mu is preferred when you have low deformation low temperature is concerned and m is a preferred parameter to define friction when you have high temperature and very large deformation into that have to be taken into account.

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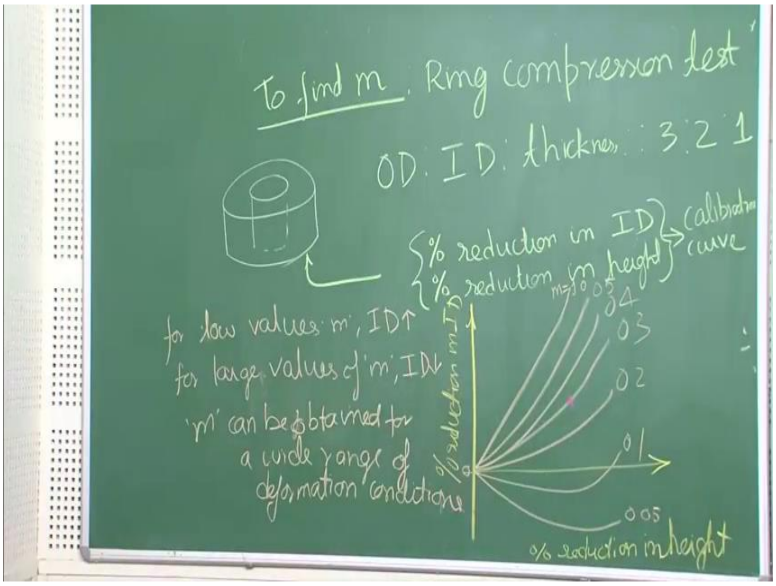

Now, let us take an example that we have talked about m and we said that m is easy to obtain let us quickly go through one example that is very widely used for forging to find what will be the m that is the to find m. So, the aim of our purpose; our objective here is to find m, so that we can find out the condition that exist in that particular configuration, it is called ring compression test and particularly useful for forging this is not very complicated all you need to do it is take a ring something like this where outer diameter is to inner diameter is to thickness is supposed to be in the ratio 3 is to 2 is to 1. So, in order to find the m value what you need to do is take a ring and there is a specific ratio of the outer diameter to inner diameter to thickness where there is no absolute dimension given; only the ratio of these dimensions are given. So, you have to take a ring with these outer diameter inner diameter thickness ratios in the ratio 3 is to 2 is to 1.

Now, once you have it, you deform it in the same condition that you would have deformed your own sample and then what you need to measure is percentage reduction in inner diameter and percentage reduction in height, once you get these information experimentally for this particular ring then there is a calibration curve and you compare it with that calibration curve to obtain. So, that calibration curve has basically been obtained by doing several experiments and after doing those experiments people have been able to relate the ratio this percentage reduction to a particular m value and that is what this calibration curve will provide you. So, this calibration curve will look something like this.

From the y axis, you will have percentage reduction in ID. So, that is the inner diameter and on the x axis you will have percentage reduction in height. So, this is the x and y axis now it has plot something like this and so, on you can keep on going like this and you may even you may get up to m equal to 1.0.

For example, let us say you get percentage reduction in height somewhere over here and percentage reduction in inner diameter somewhere over here. So, this would imply that the friction condition or the m value for this particular case was 0.3. So, it is it becomes a very straight forward way to calculate m and it is because of this reason it is widely used particularly like I said in extrusion and forging because this one when you are compressing it you are actually doing forging so you this when this curve can be directly related to forging and you can obtain the friction condition for forging.

There are couple of things that you can note here that when m is low for low values of m what do you see percentage reduction in ID is actually negative. So, this was 0. So, this is negative it means that the inner diameter actually increases in size ID increases, only when you go for large values of m that you see inner diameter to be decreasing and one another very important fact or utility of this is that m can be obtained for a wide range of deformation condition meaning no matter what stress, strain or strain rate that you take all you need to do is find the value of percentage reduction in inner diameter and percentage reduction in height and then compare it with this calibration curve and you will be able to get m the friction factor, interface friction factor.

This is applicable for wide range of deformation conditions. So, that is the usefulness of this m1, that it is easy to calculate or obtain not calculate, let us say; let me say that we are able to obtain. So, we can obtain it much easily and that it can be used for a wide range of deformation conditions.

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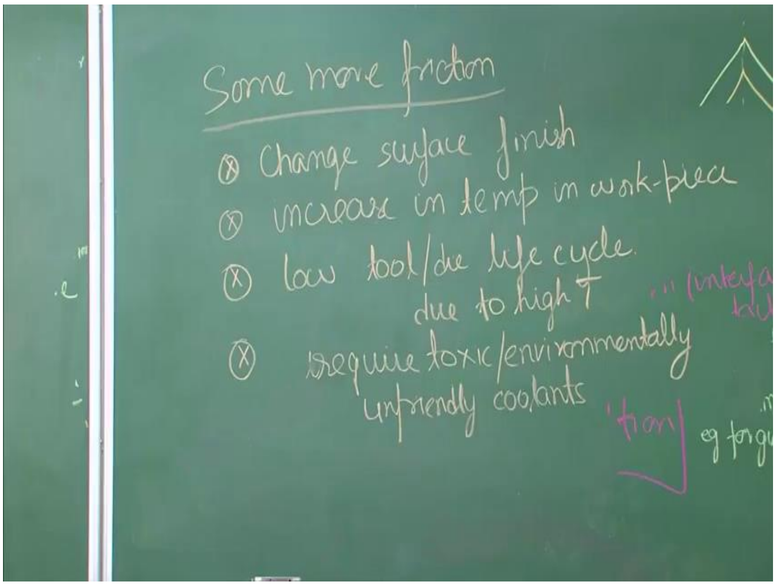

We have seen lot of things about friction, but that is not all there are there is still more to know about friction. So, some more friction what else does friction does? We know that it changes the mechanics; we know that it the overall stress requirement or the energy requirements will change because of the presence of friction, what else can it do? When we are doing talking about deformation, it will change surface finish or effect surface finish, depending on what kind of friction exists you will have different kind of surface finish. Mostly friction would lead to a poor surface finish, if you have less friction you will have a better surface finish.

When there is friction there is some work being done addition work being done and therefore, there will be increase in temperature in work piece. For most cases the temperature rise will be very small, but in some cases like in machining that we talked about earlier you will you may see very much very very large temperature rise and in fact, it can lead to low tool or die life due to high temperature and this temperature rise not only affects this, but it will also affect the microstructure there will be microstructure in the material of there is always microstructure in the material and because there is temperature rise which was most of the time unaccounted in the general stress strain behavior, but there is this additional temperature rise because of friction this will cause further increase in the temperature and hence further modify your microstructure. So, that can influence the final performance final properties of the material.

And what is the best way to get rid of friction people use lubricants, but those lubricants are mostly toxic. So, require toxic or environmentally unfriendly coolants to get rid of friction, we want to reduce the friction because of. So, many deleterious effect and for that you will need something like coolants and these coolants can be very very toxic, it can lead to poor or it can lead to poor health of the environment. So, they are not always desirable we are talking about friction so much so at this point let us also ask, what is the origin of this friction? There is actually a whole branch of science that deals with this and we will not get into the nit details or extensive analysis of friction we will just try to understand what is the basic premise of friction and why normal pressure increase in the normal pressure leads to larger friction that branch of science which leads to understanding friction between 2 surfaces is called tribology.

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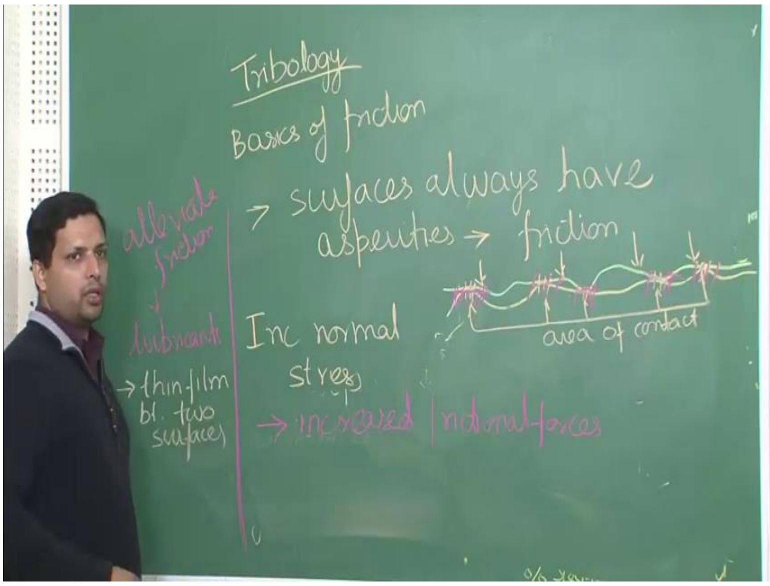

But we are not going into details of tribology, we are just trying to understand basics of friction. Now when you see 2 surfaces for example, let us say I take this wood duster and

I take this, now if I rub it against this both of them look flat and therefore, it may seen that should be no friction, but is it really flat if you go down to the micro nano level is it really flat and the answer is no. So, surfaces always have asperities and it is these asperities that lead to friction.

Let me draw a rough sketch of what I mean. So, let us say we take looking at one of the board dusters in the cross section. So, this is the plane of the board duster and we are looking at the cross section. So, if you look at the cross section there may be some something like this all throughout the surface although on the through the naked eyes it looks flat, but to the if you go to the microscope micro level in these cases it even in the optical microscope you would be able to see some unevenness and there are some asperities and let us put some another board duster over here and it will have a and put it close to it what we are doing is that some asperities getting touched getting contact.

Now when you are trying to move, you are moving against these asperities or you are trying to deform these asperities. So, the area of contact at this point is only these, these are only the point of contact area of real contact. So, for example, when I put these 2 together it may seem like I am both of them are touching throughout the plane, but that is not the case if you understand that at some level maybe micro level in some cases nano and in some cases even macro for example, in this case it will be macro level you would there will be asperities and it is only the asperities that are in contact and it is at these contacts that at these points that they are actually touching and these are the only area of contact. Now, if you try to move, you are actually moving these asperities against these hills and so on and it is these that create friction.

This also leads us to another fact that when you increase normal stress on the surface. So, let say I increase the normal stress on the surface on this surface what we observe is that friction increases. How do we explain it from this? What happens here is now that you have increased the stress, there will be deformation near this and there will the point of contact the area of contact will get deformed and it will become large. So, now, there is much larger area which is in contact because of deformation. So, this may have become deformed like this. So, this is you can say the new surface for the 2 components that we have in contact with each other and when we have deformed one that the area of contact as increased and second that there may be in for example, in particularly in cases of metal there may even be some small cold welding kind of things. So, the materials may get cold welded at places or even if it is not getting cold welded now you can see that the work has to be done against a larger area when we are trying to move this it has to do work against a larger area and that implies increased frictional forces.

These are some of the basic aspects about friction that we should remember what? How it is getting originated and one thing that we have already discussed if you want to alleviate friction, what is the way to alleviate friction? To alleviate friction, you need to add lubricants. Now what again from this model, what is the role of lubricants? How are we able to reduce friction? What the lubricants do is they create a thin film between the 2 surfaces. So, the 2 surfaces are not really touching each other, but they are both of them are just in touch with or in contact with only the lubricant or the liquid. So, this area this surface and this surface there will be somewhat distance between these 2 and there will be a thin liquid film in between these 2.

Now, that the shearing of liquid, we know is very easy, it has it requires much less lesser stresses and therefore, the surfaces can shear very easily against the liquid film and they are not really shearing against each other and hence we are able to reduce friction. So, that brings us to the important aspects of friction, a particularly I should say the deleterious effects of friction. In the next class, we will focus on the still another aspect of friction which is the good aspects of friction where friction can be good and for that we will take the example of rolling. So, we will meet in the next class for the other aspect of friction.

Thank you.