Plastic Working of Metallic Materials
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Module No # 01
Lecture No # 05
Friction and Lubrication (contd.)

So, in this lecture we will be discussing with the friction and lubrication, a continuation of our last lecture that is, lecture number 4. So, in the last lecture we were discussing about coulombs coefficient of friction that is where it is assumed that there is a sliding between the work piece material and the die as the deformation takes place work piece material flows radially and there is sliding which is taking place.

So, that is why and it is satisfied by the coulombs law of friction. But in this particular lecture, we will be discussing about the sticking friction. Where the metal is sticking to a surface and at some distance from the surface, that is at subsurface. There is an internal shearing taking place. So, let us come to that point.

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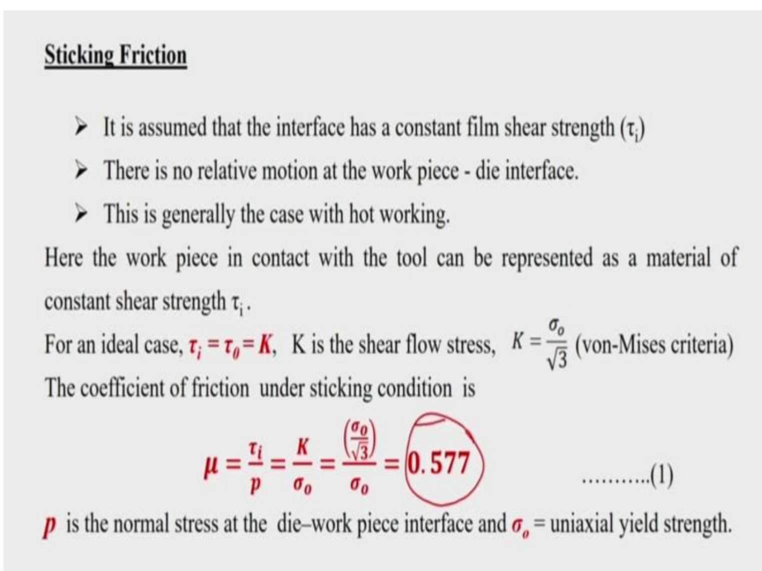

We were discussing about the coulomb friction, but today we will be discussing about the sticking friction which is generally people encounter during the metal working operation. And this sticking friction is, it is one phenomena which takes place when the material is being hot worked at a higher temperature. The metal is very plastic, ok and whereas in coulomb friction generally, which is for elastic material which takes place. But here, it is since it is highly plastic.

The metal can deform very easily and so that is why this will be basically will be encountering in the case of hot working operation. So here, it is assumed that the interface has a constant film shear strength. When you are deforming a highly plastic material the, it may not slide. Rather it may be having an affinity to stick to the surface. So, on that case basically the metal is going to shear.

So, that the interface between the work piece and your die material will have a constant film shear strength. So, that is one assumption we are taking and in this case, where there is a sticking friction. There is no relative motion between the work piece and the die interface ok. So, you are assuming that is not there is no relative motion between that ok. So, it is basically a sticking it is adhering to that surface and here the work piece which is in contact with the tool can be represented as a material of constant shear strength.

At τ, so the material is having a constant shear strength. Which is τ_i so which is equal to your film shear strength that we are going to assume. So, in an ideal case where there is a perfect sticking condition we will say that the interfacial shear strength is equal to the shear yield strength of the material. So which is equal to your K, as per the von-Mises criteria. This K = uniaxial sigma 0, which is the uniaxial yield strength of the material divided by under root 2.

$$\tau_i = \tau_0 = K, K = \frac{\sigma_0}{\sqrt{3}}$$

So, that is what the K is that so the coefficient of friction under sticking condition. We can say that, it will be under this case. It will be τ_i / p, where p your normal load on the surface and that you can say that it equal to your k or the shear yield strength divided by σ_0. So, that is what you are going to get it. So, and that way you can find out that okay this μ in this condition is equal to around 0.577 theoretically.

$$\mu = \frac{\tau_i}{p} = \frac{K}{\sigma_0} = \frac{\left(\frac{\sigma_0}{\sqrt{3}}\right)}{\sigma_0} = 0.577$$

So, where p is the normal stress at the die work piece interface and σ_0 is uniaxial yield strength of the material. When you are doing a tensile test with a uniaxial tensile testing, so that we illustrate what is that that is what you are going to get it. So, in that case it is almost coming as if it is almost constant thing.

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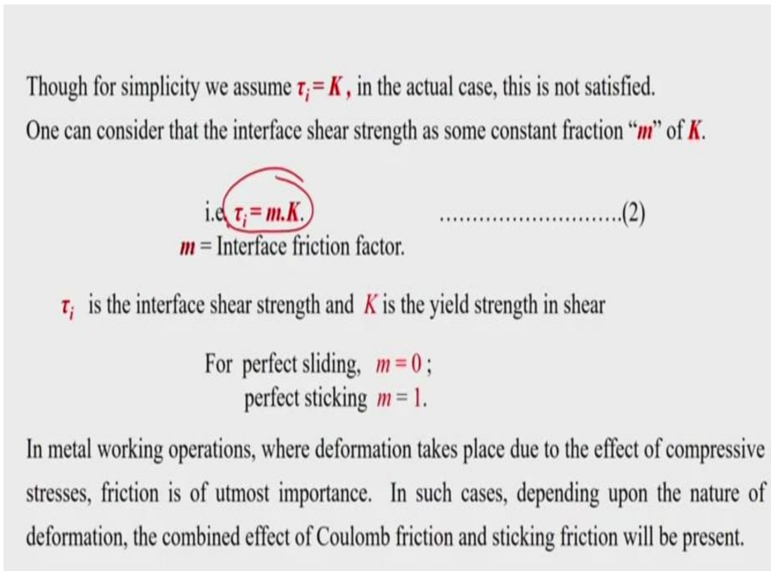

Though for simplicity, we assume that interfacial shear strength at the die work piece interface is equal to K. In actual case, this is not satisfied so actual case it will be different. So one can consider that, the interface shear strength has some constant fraction m of K. So, it is not exactly K but a fraction of k where that m is the interfacial friction factor. So, you can write it that τ_i= m K, where m is the interfacial friction factor and atτ_i the interface shear strength and K is the shear yield strength.

$$\tau_i = m.K$$

So, for a perfect sliding condition when you assume, so sliding condition m = 0 in this relationship and for a perfect sticking condition m = 1. So, both these cases will not happen and your actual case will be somewhere intermediate between these two ok. So, in metal working operations, where deformation takes place due to the effect of compressive stresses, this friction becomes very important. So mainly, this is the problem which you are facing with it.

Where all this material working processor where compressive stresses are coming into picture and you will find many of the cases it is not say either perfect sliding or perfect sticking, but it is an intermediate case which is coming later we will come to that when you are doing the compression of a axisymmetric forging. Whereby, due to compressive loading you are trying to deform the material.

Then, you will find that up to certain region from the center you have one type of condition and outside you have from center to some region in between you have sticking friction and from that interface to your surface you have a sliding friction. So, these two things are there actually. So, it is not that any 1 of that will be working. But mostly, it will you will find that both the case may be there. But, when you come to say high, at high temperature deformation or hot working conditions basically the maximum will be with the sticking friction.

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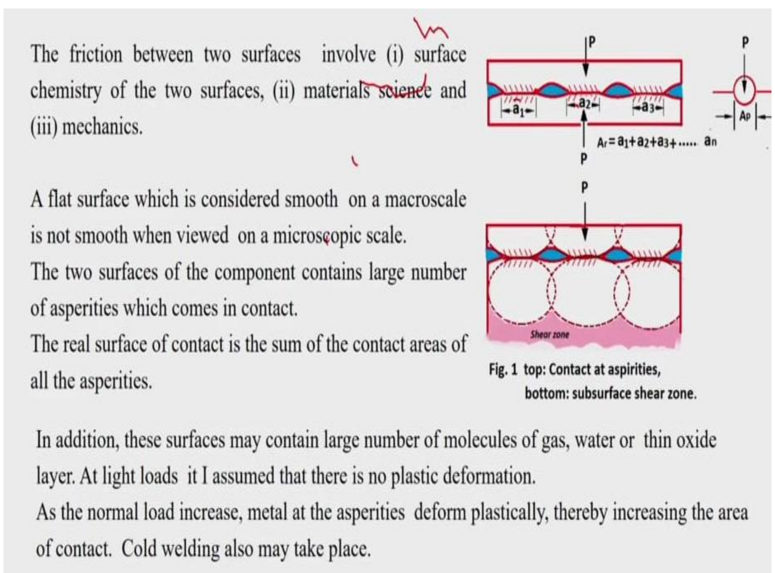

So, when you talk about the sticking friction between two surfaces, you will find that it involves one is the surface chemistry of the two surfaces. Second is the material science and so combination of these mechanics also all those are coming into picture. So, if you look at say two phases are matching, though it may be very highly polished surface like a mirror polish you are getting. And then, you may find that okay the surface is very smooth.

But in actual case, your surface is not very smooth. So, on a macroscopic level, when you are looking surface may be very smooth. But at on a microscopic level, when you look at it there are say hills and valleys and other things. So, you will find that many of the cases know some aspirations are there, on these asperities are there, not aspirations. Asperities are there on the surface so like hills and valleys like the typical things this type of things are there.

So, when these two surfaces are being joined together when they are in contact you will find that, the contact is coming between the asperity region only ok. So, though your apparent actual apparent area is something but in actual area of contact is only very small. So, that happens so you can say that total area is a sum of all these contact areas between the aspirations. So, it is not perfectly smooth ok.

That is, what we are telling, so a flat surface which is considered smooth on a macro scale is not smooth. When you are on a microscopic scale the real surface in contact is the sum of the contact areas of the all asperities. Now, in addition to this you will find that the surface of any metallic materials when you take it. It will contain some large number of gas molecules adhered on the surface. Because, due to adhesion know some gas molecules may be there any metallic material if you take it.

And sometimes know you may find the presence of moisture; sometimes you know some oil also may be there all those things may come into picture. And sometimes the surface will get oxidized like Aluminum, Magnesium or Iron and other things know. After you leave it for some time know you may find that the surface is getting oxidized. So, all these things can come into picture and so, while you are deforming the material or when you are it in use. You will find that you will be adding some lubricants ok.

So, you will be adding some lubricants and other things. So, there will be a film of lubricant also coming into picture, which these are so this is a part of tribology, which one has to be looked into that. So, but whenever is there if you consider these type of a case, where the two pieces are in contact and it is not coming in contact at all the areas but only at some part of that only so in that case when you are applying an when your normal load p is very low nothing is going to happen ok.

So, that time there is no plastic deformation, which is taking place ok. And then, it is a typical case for a sliding friction. So, it is not having any bond between these 2 surfaces. And then, there is a relative motion, when you are trying to do that ok. It will slide that is, that is a case of sliding friction, where the coulomb law of friction the loss of coulombs law of friction has to be satisfied. But, the normal load is very large.

When you increase the normal load, you will find that these areas which are in contact it is going to plastically deform. And how it causes it can be you can say that it is almost similar to the case where like a hardness. So, when you are trying to intend with this one when the it may try to deform ok. So, you can say that hardness is nothing but the area divided by a contact area, that is the thing or if you know that.

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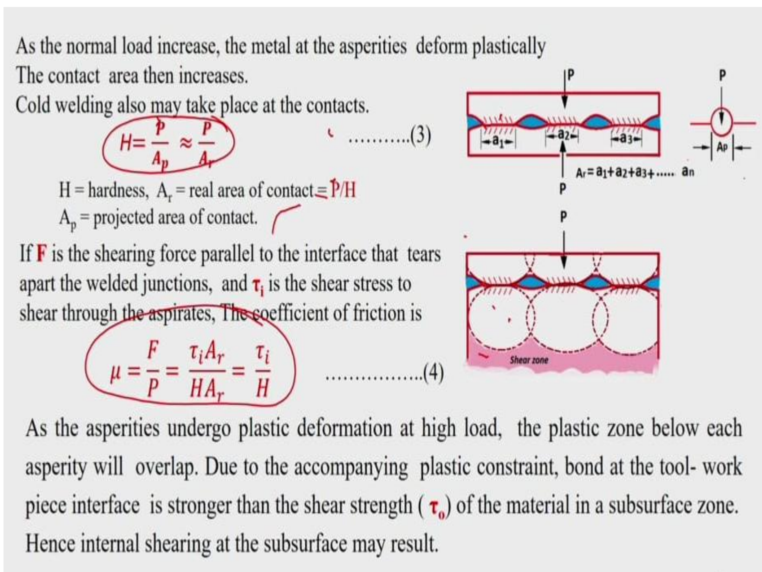

So, it is the total load divided your projected area or the real area we can we can say that and in that case you know when you are trying to apply shearing force parallel to the interface. Parallel to this interface, when you are applying this shearing force, see this has to shear through the interface. So, when you are applying this normal force at larger value of load, this may get cold welded. So that, chance is always there it will get cold welded and plus the metal below that will also start deforming ok.

Because there will be a shear zone, which is coming and the metal below that also will start shearing plastically deforming into that. So, you can say that there is a subsurface zone of the material where it is going to where it is plastically deforming. And when you are applying this load, say maybe here there is going to be a shearing. So if, this material is cold welded and is sticking together, and in such case the bond strength at the interface may be higher than that of the shear yield strength of the material.

So, that is what is going to happen. So, cold welding also may take place at the contact. So if H is the hardness of the material. So that is equal to we can say that P / A_p or this relation is there where H is the hardness A_r is the real area of conduct. So, that a real area of contact we can calculate it by PH and this is the projected area of contact. If, F is the shearing force parallel to the interface that shears apart the welded junctions the cold welded junction ok.

$$H = \frac{P}{A_p} \approx \frac{P}{A_r}$$

Then, and τ_i is the shear stress to shear this through the asperities. The coefficient of friction we can get it by this equation μ = τ_i / H ok. As the asperities undergo plastic deformation at high load, the plastic zone below each of the asperity will overlap ok. Due to the accompanying plastic constraint, the bond at the tool- work piece interface is stronger than the shear strength of the material in a subsurface zone.

$$\mu = \frac{F}{P} = \frac{\tau_i}{H}$$

Hence internal shearing so when you are applying this stress it is not the shearing is taking place. At this portion, because this portion is having a higher bond strength compared to your material. So, rather what will happen is that at a subsurface shearing only will take place. So, that is what is called so the part which is in contact with the die material the work piece material which is in contact with the die material under sticking friction it is not sliding.

Rather, it is having a good bond with the work piece but a slight distance away from that from the interface. The work piece material starts internal shearing ok. So, that is what the basic assumption or people interpret in that way. So we were discussing about the conditions for the subsurface shearing. How the internal shearing takes place at the subsurface.

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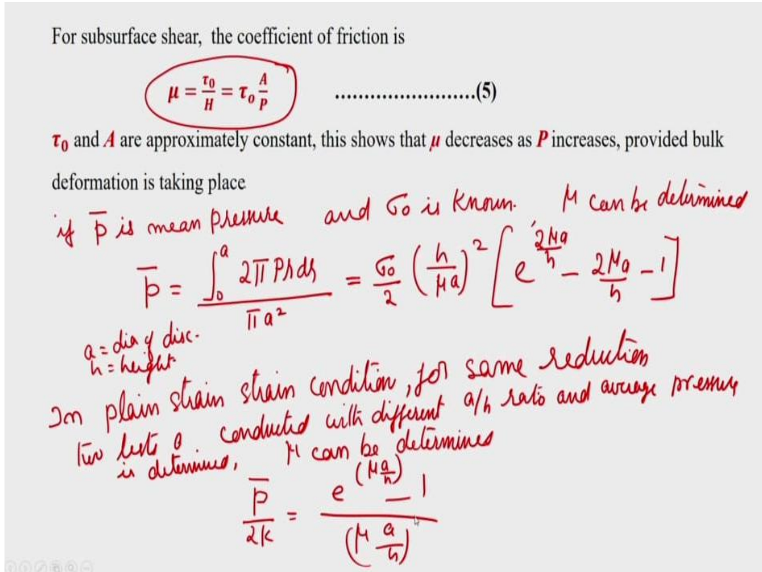

And for a the condition is that for a subsurface shear the coefficient of friction can be obtained by this relationship μ = τ_0 / H and that = where H see the hardness of the material and τ_0 is equal to that can be equated to hardness is nothing but the load by area or stress by cross sectional area a area of contact. So that is what, so that way we can write like this. So τ_0 and A are approximately constant and this shows this indicates that μ decreases as the load increases.

$$\mu = \frac{\tau_0}{H} = \tau_0 \frac{A}{P}$$

Provided bulk deformation is taking place. Now, there are basically two approaches for measuring the μ and m ok. So, under metal working condition, so test are been developed for evaluating the lubricant under light load conditions, which is not relevant for metal working operation. Because under metal working condition the loads are very high okay. So the most common approach is to measure the average deformation pressure and flow stress.

So that, μ can calculated by analytical relation between these factors. So, if you consider the, for a homogeneous compression of a circular disk, if you consider homogeneous compression of a circular disk, so when you are trying to deform a circular disk under normal compression load. And during that compression for a particular reduction if $\bar{P}$ is the measured. If, $\bar{P}$ is the mean pressure during this compression and if sigma naught the flow stress is known.

Then, we can determine μ. μ can be determined using the relationship $\bar{P}$ is equal to integral from 0 to a 2 π P r. This is the normal compression testing under the forging know. We will be deriving it actually into dr divided by π a square. Where a is the diameter of the disk into is equal to $\sigma_0$2. This is the flow stress of the material into h / μ_a square into e raised to 2 μ_a / h – 2 μ_a / h -1 where a is the diameter of the disk and h is the height.

$$\bar{P} = \frac{\int_0^a 2\pi P r dr}{\pi a^2} = \frac{\sigma_0}{2}\left(\frac{h}{\mu_a}\right)^2 \left[e^{\frac{2\mu_a}{h}} - \frac{2\mu_a}{h} - 1\right]$$

What is important is that determining the value of σ_0 is slightly difficult actually ok. So, that is another condition so in plain strain condition, if you do two test of identical test. Identical means same reduction but with two different values of say a / h. So, in a plain strain condition for same reduction two test are conducted with a different a / h ratio and average pressure is determined.

Then μ can be determined using the relationship $\bar{P}$ / 2k, k is the shear real strength. This is the pressure into e raised to μ_a / h -1 / μ_a / h. So, you substitute this equation into this equation for the two conditions and from that you can find out the value of you can calculate the value of a. So, that is a value of μ that is one method of finding it out. Now, another method is by these are all slightly cumbersome to find out the average of pressure and other things.

$$\frac{\bar{P}}{2k} = \frac{e^{\left(\mu\frac{a}{h}\right)} - 1}{\mu\frac{a}{h}}$$

But, without determining the without the knowledge of pressure also there is a technique by which we can find out the value of μ or m depending upon what condition it is. This is called as and this is widely accepted test to find out the coefficient of friction in metal working operation, specially for high temperature deformation test. This is much more useful compared to any other method. So, that is called as the ring compression test.

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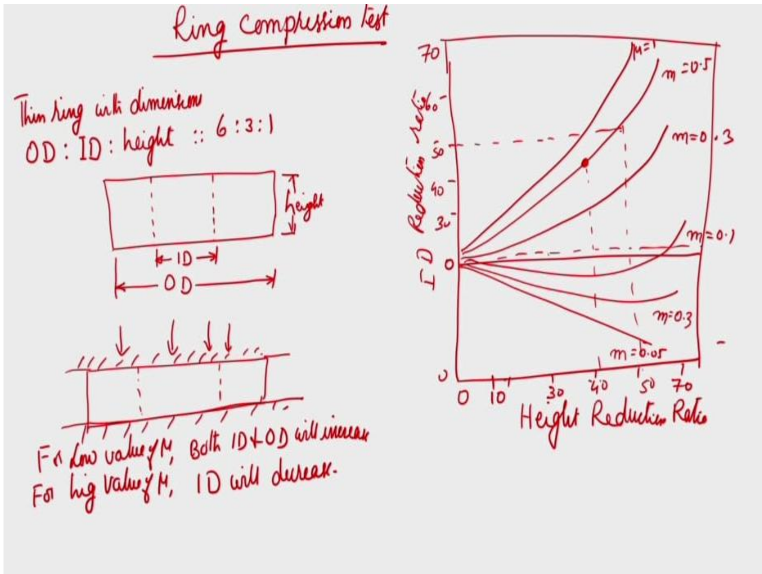

So, this ring compression test has been widely accepted. Here you take same size of a ring but with a ring with thin ring. You take large number of samples with the dimensions outside diameter is to inside diameter is to the thickness of the ring means, not thickness, the height of the ring. so if it is in the ratio 6 is to 3 is to 1. Because, this is a universally accepted practice, it is a standard which is being used.

But there are people who people just find out what will happen if the thickness or this height means that is thickness the ring. If it is like this you know so see so this is ID, this is OD and this is say let me just write height. So you take this type of a ring, number of rings under different friction conditions. Under different conditions, you carry out the test for different strains and even with one condition itself, interface friction condition itself, we can carry out for a large number of strains ok a large number of reduction.

Reduction ratios ok that means based on the height, if this is the height and then you find out what is the reduction in the inside diameter. See for low value, low friction values see because what they do is that they find out the friction factor know the determined by measuring the percentage change in the inside diameter of the ring for different percentage change in the height or reduction. So for height reduction, what is the height reduction ratio you find out for different height reduction ratio.

What is the inside diameter reduction ratio you find out see that is the case in case where the coefficient of friction is very less. What will happen is that there will be identical deformation which is taking place for the inside as well as outside diameter. That is, when the height comes to maintain constant volume relationship. If the coefficient of friction is very less, so you are just doing this compression testing of the ring.

Keeping it on a annual and then applying the pressure uniformly here and then change in height is measured for the change in height you find. What is the ratio of what is the reduction for the same reduction in height. What is the reduction in the inside diameter, so that is what we have measured so if coefficient of friction see like if I say that ok. This is also the two platten is there. If the coefficient of friction is less both inside diameter and outside diameter it will just deform in a similar way.

With where the material will flow outward, say when you are coming to, when you are compressing it, if the friction coefficient of friction is very less the inside diameter also will increase, the outside diameter also will increase. But, if the coefficient of friction is very large then what happens is that outside flow of the metal especially at the outside region it will be restrained. Because, there are more area so it cannot move that easily.

Rather, what will happen the deformation will be towards the inside, so there will be a reduction in the ID. So for low value of μ both ID and OD will increase for high value of μ ID will decrease. So you just by analytical means, we can develop this calibration charts so for different ratios of ID and OD ok. So here, if you just plot it at height reduction ratio and if you write here that the inside diameter reduction ratio and then plot.

So, analytically you can get different values so may be like you can just it is. This is for μ = 0.05. You can get the case for μ = 0.1. So, this is 0, maybe this is 50, this is 70, like so 60 so we can say 40, 30 like that you can just plot different conditions ok. And you can also find that may be for this is for 0.3. If this is for 0.3 μ = 0.3 may be μ may be for 0.1, μ = 0.1. So similarly, you can say μ = 0.3, may be μ = 0.5 and you may get this is equal to m = μ = 1.

So, instead of μ if I just say this is m and μ are interrelated, so you can write it like that. See whether it is m or μ, you can calculate that depending upon that condition you can get different curve ok. So here, this is typical case is m, because μ will not come to 1. So, where μ = 1 is the perfect sticking condition and here it is μ sorry m = 1 is the perfect sticking condition. And m = 0 is the perfect sliding condition ok. So, that is the condition.

So here, this may move from something around 70. So 0 to 70, we can say that ok. This is 50, 60, 40, 30 may you have to draw it to scale. So, this type of a curve you can get it always. And now, if you do that for different reduction ratios, under one condition you can use for example in one condition to have a very smooth almost 0 friction graphite can be used then for the condition may be molybdenum di sulfide can be used as another lubricant, which is a dry lubricant.

Where coefficient of friction is very less, so under different friction conditions you can carry out the experiment by using sometimes some coating ok. Sometimes you may use some lubricants. So, in that case what will be this thing and that this also depends upon the surface finish of the, surface finish at the interface of the work piece and the die material that also is very important. So, because of that your frictional conditions will be vary now after doing this experiment.

What you do that you measure the different reduction ratio, you do find out that particular reduction ratio. May be if the height reduction ratio is 40 and then you found that in the ideal reduction ratio was something like this 30. Then, you just plot like this here. Where it comes, so now, you can find out my m value is 0.5 or if it want to say maybe 50. So and then it came up to somewhere like this, so you can just say that ok this was my m value.

So, what is the interest where it is coming, so from this calibration chart you always determine the m value for that condition. So, this calibration charts are obtained my analytical means a simple compression test. You based on that also you can find out actually and lot of work has been carried out with the different ratio 6 is to 3 is to 1. 6 is to 3 is to 2 like that different ratios people have done it. But, the standard practice of a ring compression test is basically in the ratio 6 is to 3 is to 1.

Because, that is what people follow and then based on this you find out this. So, only thing you have to understand is that when the coefficient of friction is very less both inside diameter and outside diameter will increase. Because, the metal will flow outward but when the coefficient of friction is large then outside metal flow will not take place. Rather for the reduction to maintain the constant volume relationship, the material will start flowing whereby the decrease in the internal diameter will take.

This is the main thing, you measure this in the inside diameter. Now in case where there is barreling most of the case with the higher friction. There will be barreling with a low friction barreling may not take place. But with the high friction barreling is going to take place. And in that case, you may not get like, it is not a homogeneous deformation. So, what you will do that you will take an average value ok.

And then, average diameter you will measure it and then take it. You can slice it and find out the average diameter inside diameter and then you do the determine the value of m. If, it is this is for m for μ so you like you by the analytical method. You will be using that occurs for using μ. It is the same way only that is what it is. So, this which is important to note that in this particular case you do not have to measure the what you call it as the stress.

Whatever stress is there, it is immaterial. You do not have to measure the stress flow stress of the material at any condition it is not. You just compress it and then measure it that is the biggest advantage. So that, under that hot working condition of temperature and strain rate you just deform up to certain height. Measure the final height and then measure the in certain initial diameter. So, final diameter initial diameter is known, for all the sample you have to maintain the same dimensions.

And then you look at what are the things which are getting. So, may be for different reduction itself you can take. Say, what are the different reductions for that particular lubricating condition or interface friction conditions you get it. So, this is the biggest advantage of this. Now, let us come to say lubricants to reduce the friction. It is not that in metal working always you should have less friction.

Only problem with metal working is that the friction is high your forces will be very high. But in certain cases you need higher friction also at certain locations, not everywhere at certain location so, different types of lubricants are also available. Some lubricants are there which will reduce the friction. In some case, may be the sticking friction will prevail. Those type of lubricants are available, ok but anyway the what is the, what are the functions of a metal working lubricant for metal working operation let us just see.

In general, the lubricant should reduce the deformation load. Because, if friction is going to come, the lot of energy has to be given or dissipated for overcoming the friction. So your machine capacity has to be very high. So, sometimes it may go beyond the capacity of the machine also if the work is there. So, you always wanted less load so, for that if you are giving a lubricant then the frictional forces are reduced and you may almost get through the condition of a homogeneous deformation. So, that is 1 condition.

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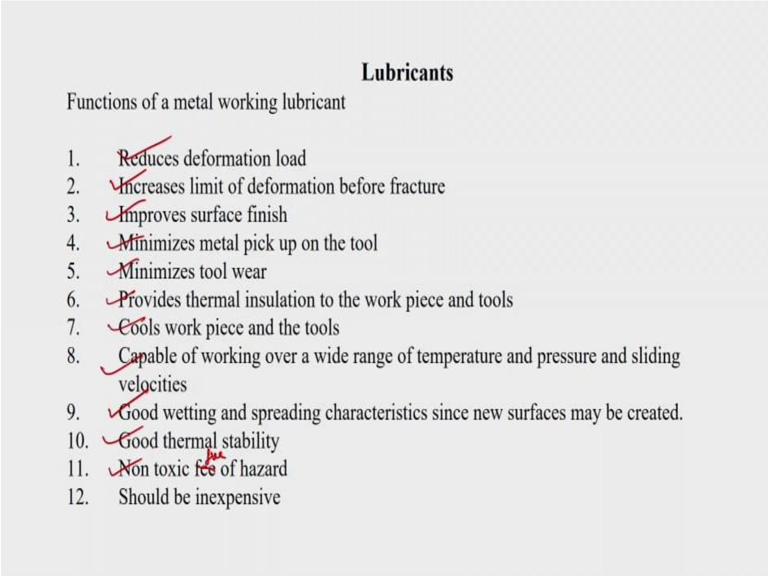

So, second is that if lubricants are there the extent of deformation, extent of strain which we can get can be increased frequently ok. So, it can be increased so that is another advantage because when friction is there the movement of the metal will be constrained. So that, then that will result in redundant deformation also many times. So and then what happened the extend of the maximum strain that you can get or the maximum deformation that is achievable gets reduced.

So, if you have a proper lubricant the, it increases the limit of the deformation before it fractures. And more or less a homogeneous deformation is taking place. That is the reason for this. So then, third it improves the surface finish because if there is no lubricant, say whatever smoothness you get you may see that it is like a mirror polish. But, if you look under the microscope you will see at the microscopic level there are say valleys and projections are there on the surface..

So, that may be at the micrometer layer. So it is not that perfect smooth, so but when you are having this lubricant in between that the direct contact between the metal and the work piece is not taking place. And there will be a film of lubricant so you will always find that the surface finish is very good when you are having a lubricant now. Now if there is no lubricant then as I said there are premises and the projections and the valleys and other things are there on the surface.

Because, it is not microscopically smooth and the die is having a higher hardness than your work piece material. So, what will happen is that the soft material work piece material which is soft when you are going to deform it. Some amount of this material will be filling up that valley region of the die surface. And then that will result in the metal pick up on the tool and when that happens fresh new and new surfaces are formed.

So, this will start building up and then at the end you will find that the surface finish is very poor. So if, the lubricants are added that it will act as a film and then this metal pick up on the tool will not be there. And then this also minimizes the tool wear because if there is a film which is their, which is not in the contact to the work piece and the job when there is a relative motion. So, the tool layer gets reduced then these things are remaining are not that important.

But it also gives some amount of thermal insulation to the work piece specially, at the hot working conditions it gives us some amount of insulation to the work piece and the tools. Then the lubricant also cools the work piece and tools many times you know. If you are not careful there will be cooling effect because of that so that should not takes place actually. Now, the lubricant should be capable of working over a wide range of temperature and pressure and sliding velocities.

So, it is not that with the sliding velocity low it is ok. But after some amount of sliding velocity this dissociate or decomposes that should not happen. Then its properties will change or may be similarly, when you are doing at the hot working condition at a higher temperature this should not decompose. And or higher temperature or pressure it should not decompose so that, that is another thing.

That is another requirement for the lubricant and many times when the metal is flowing a fresh surface may be formed. At the work piece interface work piece die interface. So, when that new metal is formed this lubricant should be able to spread to that surface. So, there should be a good wetting and spreading characteristics it has to be insured so lubricant should have good viscosity of that way and good very good wetting characteristics.

Vertability should be good there should they should have a good thermal stability. Otherwise, it will decompose and another important thing, nowadays people consider is that non toxicity. So, it should be free not fee. It should be free of any hazard ok. It should not do any type of harmful. It should not be a volatile and vaporize. And then, ok the operator and the shop know he inhales it and ends with his health all sorts of health problems may come in.

So, it should be non toxic also. And finally that it should be very inexpensive. Otherwise know, your cost of your product will be increased.

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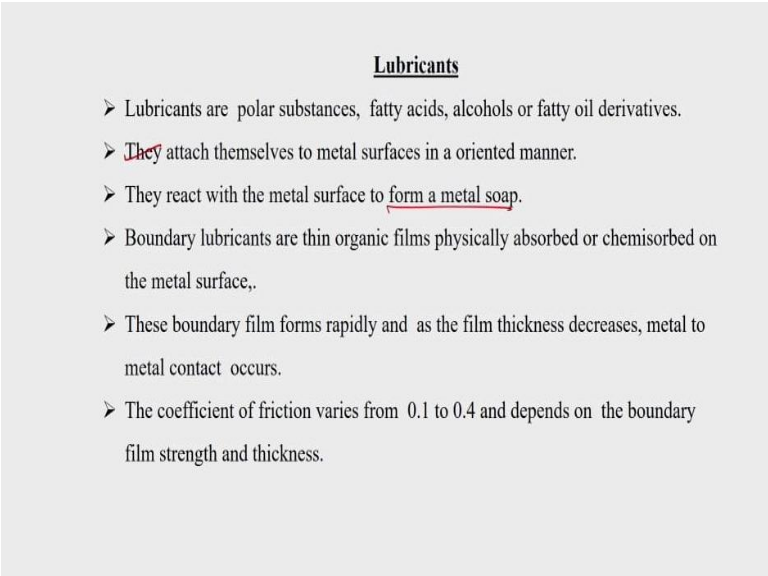

Now, what are these lubricants. These lubricants are generally polar substances or fatty acids or having a base of alcohol or fatty oil derivatives and they attach themselves to the metal surface in an oriented manner. When you are spreading it in a special orientation it will just attach to a metal surface. So it gives a coating type thing to a metal surface and sometimes they react with the metal surface to form a soapy type of feature.

So, like a it can very easily slip over that thing soapy means circle. You will find that ok. It is very smooth ok so may be it may react with the surface to form this metal soap. So, in this lubricants know there are boundary lubricants and mixed lubricating condition is also there. So, when you look at this the boundary lubricants are thin organic films physically absorbed or chemisorbed from the metal surface.

Most of these are organic solvents, ok and especially for hot working conditions and when you spray it will just get absorbed on the surface of the metal surface. And so, it will be sticking there it and this boundary film and so it forms a boundary film. There it forms rapidly and as a film thickness decreases, the metal to metal contact occurs. If it is a very thick layer then there is no direct contact between the metal and the work piece.

But if, the thickness is very less then naturally under the application of the load this film thickness may get reduced. And then, it may come in contact with the job and the die. So, in this when there is a boundary film which is formed the coefficient of friction, may vary anywhere from 0.1 to 0.4. And that depends upon the boundary film strength as well as the boundary film thickness.

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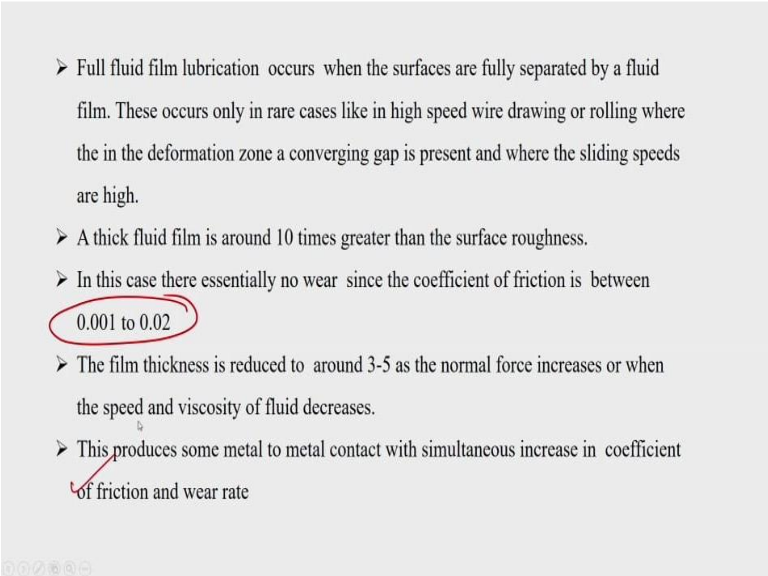

Now, second condition the full fluid lubrication this occurs when the surfaces are fully separated by a fluid film. The thickness is less then we found that boundary film. But if, it is like a large amount of lubricant is there. If it is very thick, then you will find that there is a, this work piece and the die. They have been fully separated by a fluid film and these are not occurring in all the metal working operation.

Normal case with a very high speed wire drawing operation this can happen. And maybe for rolling operation it can happen. Because, in both these cases there is converging die and the metal try to move in the deformation zone. It tries to move and because of the converging die this specially at high slide sliding spirits know you can get this full fluid film lubrication. The thick fluid film, generally, is around 10 times greater than the surface roughness of the surfaces.

So if, you are having a die you better make that die very smooth ok. So that, otherwise if it is very large this fluid film thickness will be there but when the metal is undergoes deformation. This will just get removed from there and there will be under the high pressure. There will be a direct metal to metal contact. So in this case, there are essentially no wear under the full fluid condition.

Since, the coefficient of friction is very low of the order of 0.005 to 0.02. When the normal force during the deformation, it increases or when the speed and the viscosity of the fluid is decreases then this film thickness will reduce. So, this full fluid film lubrication may not take place, may not occur in the case where the viscosity is very less ok. And if the speed is also very less, it may not occur.

But with very high speed and with a high viscosity, you may achieve this full fluid film lubrication ok. So in that case, when these happens with the film thickness gets reduced to around 3.5 times the normal times. In the other case, it was 10 times greater than the surface roughness. But here, it will be with 3 to 5 times the surface roughness with a high speed with a lower speed and low viscosity fluid. So, this produces a metal to metal contact with the simultaneous increase in coefficient of friction and subsequently the bare range.

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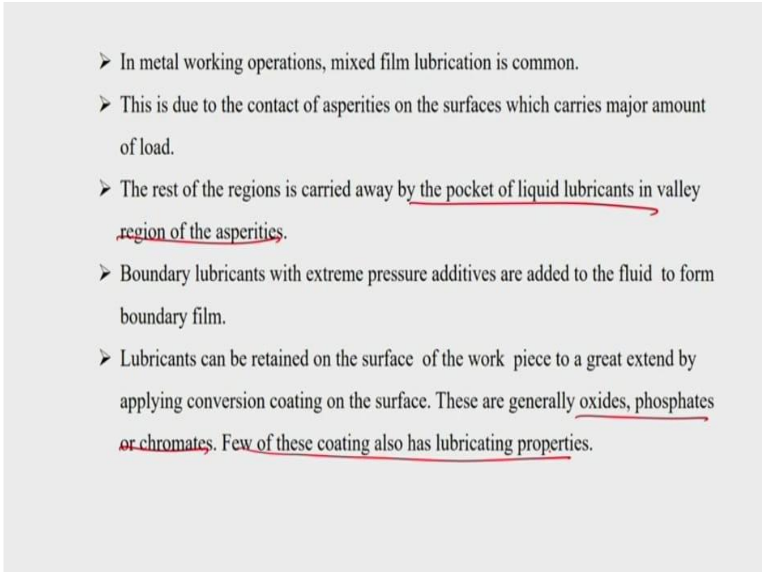

So, in metal working operation the mixed film lubrication is common. It is that is the in between these two. This happens because there is a direct contact of the asperities and as we have discussed earlier between the asperities on the work piece material and the die, there are asperities. So, when it is coming in contact, when it is trying to sliding it these will come in contact with that.

And first thing what happens is that when the load, normal load is high the asperities may deform there ok. So, these asperities, the contact of the asperities from the surface knows that carries major amount of load. Now, between these asperities you will find that valley region, there the lubricant gets entrapped to that. So, you will find a pocket of liquid lubricant in the valley region of the asperities are there.

So, that is getting trapped to them. So, that is why here you are conserving that is mixed film lubrication. So, boundary lubricants with extreme pressure additives are added to the fluid to form a boundary film and lubricants can be retained on the surface of the work piece to a great extent by applying some conversion coatings from the surface that also is done. This conversion coatings know you apply on the surface in that case the lubricants can be retained on the surface.

And these conversion coatings are generally coatings of oxides or phosphates or chromates. And some of this coatings know this conversion coatings have lubricating properties also to some extent not to a very high extent.

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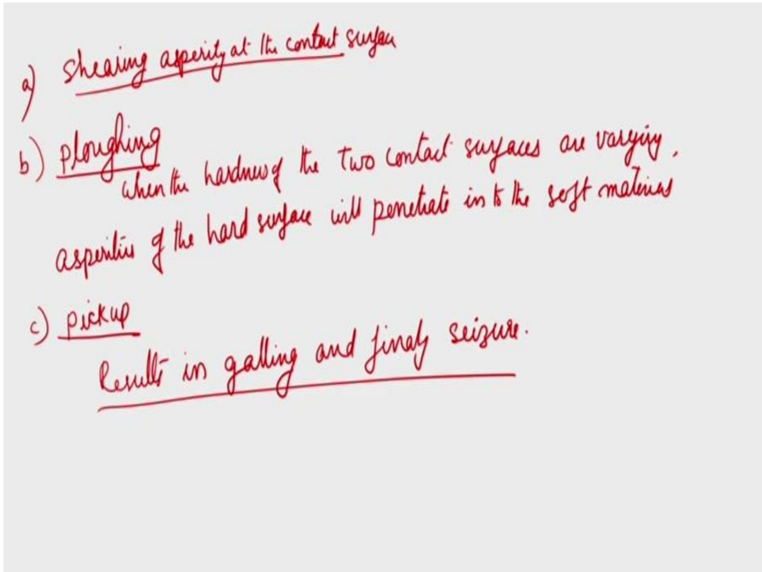

So, coming to that when you look at, how these lubricants help or how this friction is going to play an important role. Let us look at that so there are contact between the work piece and the surface. So, when the film the lubricant is added ok. See, if you just assume that there is going to be a relative motion between the work piece and the surface. So, when it comes in contact with each other the asperities you know they will come in contact first.

And because of the loading pressure, so one is that the shearing of asperity at the contact surface. So when these two surfaces meet the asperities will come in contact. And if, the normal load is high it may just deform also ok. And now, at the same time there is going to be a relative motion that is a tangential movement is taking place. Between this, so when that is happening this will shear off the asperities.

So, that is so if the lubricant is there which is not going to have a direct contact but unless the asperities are very large and the load is very large ok. So, this when the shear stresses are developed with the contact of interphase, then the shear stress and the shear stress reaches a the shear strength of the material or the asperities this asperities shear off. And what happen is that that is what is one mechanism of shearing of the asperity.

So, that is why, initially you will find you need a higher coefficient of friction. But, once it starts moving okay that gets reduced in the now, second mechanism is the ploughing. Say ploughing takes place when the hardness of the two sliding surfaces between the work piece hardness and the die surface hardness are varying to a large extent. So, when there is when the hardness of the two contact surfaces are varying.

Then what happen is that during this relative motion the asperities, the harder surface the asperities of the harder surfaces it will penetrate. In the soft material asperities of the hard surface will penetrate into the soft material. So, when it is moving over a large distance from the when this is penetrating into that and then it is moving. The volume of the material is just being displaced from the surface of the soft material ok.

So then, you will find that the volume of the metal displaced is proportional to a cross sectional area of the asperities as well as the distance by which it was smooth or the sliding length, how much it has taken place. So, you will find that when the ploughing is taking place large amount of material is getting removed. And there will be very clear cut markings features on the surface. It will be seen that is that happens when the material is very soft.

Work piece material is very soft and it is hard and at the same time surface roughness of the harder material is much higher than this, ploughing will be more pronounced ok. So, ploughing force is proportional to flow properties of the work piece the size and shape of the asperities. So, for this purpose if you have a very smooth die surface, then you will find that the friction can be reduced.

Because, this is always result in the friction. So, you can end this is a continuous process and after something it may build up also there. So, this ploughing is in addition to the shearing of the asperity conducts. So, that is also one has to be looking load it is not that these two are parallel and the third is the pickup, metal pick up. So, with inadequate lubricant if lubricant is very less, then what will happen is the metal from the work piece you know it will get transferred into the tools.

And this tendency for metal pickup, it gets directly it gets transferred into tools and this is this tendency is very high. When the interface of a rough tool is there, the interface of the tool is very rough. And it is depleted of a lubricant say, sometimes under higher pressure the lubricant may be depleted. So in that case, the pickup will take place and subsequent tangential motion of the between the two work piece surface know it shear.

So, the projecting soft work piece and then these results in poor surface finish and this also results may be in a progressive manner. The new fresh material will get start building up and then you will find that it increases. It results in galling and finally, so results in galling and finally seizure will take place. So, that is one thing. See, these are the main thing then in addition to that there are where also can take place at the seizure is there.

And ploughing, where also it can take place in there. So, that is where taking place is generally with the cold working condition not with the hot working condition. Normal case but these are the cases with the hot working condition which can take place ok.