Mechanics of Sheet Metal Forming

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Week- 07
Lecture- 17
Deep Drawing, Redrawing, Ironing of Cup

So we will continue our discussion on cylindrical deep drawing. So in the last lecture we were discussing about you know the theoretical models to calculate radial stress, then cup wall stress and then maybe a circumferential stress also when you do a single stage deep drawing process and after that we have seen one small subsection on how this limit drawing ratio or limiting draw ratio how is it going to get affected by sheet anisotropy. If you consider sheet as isotropic material or anisotropic material okay and specifically when plastic strain ratio is greater than 1 or greater than 1 so how LDR is going to change we have seen in last class and at the end of that the change in thickness $\frac{\Delta t}{t}$ you know what is the change in thickness during bending and unbending while stretching okay that is what is situation seen in deep drawing that also we have seen in the last class and how this LDR is related to plastic strain ratio what do we need what are the conditions for R and for your $\frac{\rho}{t}$ bend ratio and friction coefficient coefficient of friction is not it how these three how do we need to control it to have particular LDR is what we stopped in last class and just before we go ahead in today's class there was one small confusion in the last class that this nomenclatures were not written properly with respect to your effect of die radius. So while calculating σ_r okay so we took effect of friction separately as compared to strain hardening right so in effect of friction there are two parts one is effect of die radius and the friction between blank holder die and the sheet so in the first part effect of die radius this was not properly written in the last slide so just this is for you to for us to just to refresh and just minimize the errors so from this we can integrate it in the die corner region and we can get this particular equation for $\sigma_\emptyset$ which is nothing but your stress in the cup wall $\sigma_\emptyset = \sigma_{ri} exp\ (\mu\pi/2)$ that can be obtained from this equation from this integration okay. So just one small change that we have we want to look into it okay so now let us go ahead in this particular chapter so today is a small section first section we are going to see three four important small-small sections to wind up this particular chapter. So first one is estimation of cup height so this is an approximate estimation of cup height okay so when you do you know deep drawing of circular cup what is the cup height at any stage how can we calculate it.

So let us consider the initial sheet of let us say radius R_0 and let us say thickness t_0 okay let us consider a sheet like this and then the sheet is drawn to a cup like this so on the left hand side I am drawing okay so the same sheet okay which is practically it would be something like this so you have a cup wall and there will be slight thickening and you will be slight thinning at the at the end maybe okay. So you will see that here you will have a larger thickness let us say t here thickness would be equal to t_0 and in the corner you may have less than t_0 okay greater than t_0 you can see. So in the cup edge region okay so because of thickening you may have thickness greater than t_0 here it is equal to t_0 and here it is less than t_0 actually speaking but we are going to neglect all such changes and we are going to assume that the thickness is going to remain same t_0 as that of t_0 here at any stage of deformation and we want to find this h height and let us say the inner radius is r_i okay your cup radius is r_i. So initial sheet radius is R_0 cup radius is r_i so R_0 should be converted to r_i okay and thickness remaining same t_0 remaining is t_0 and this h is a cup height at any stage so what I can do is I can equate volumes in both the you know stages initial and intermediate so $\pi R_0^2 t_0' = \pi r_i^2 t_0 + 2\pi r_i t_0 h$.

So I am going to neglect the change in you know like your corner, corner is not considered here okay so it is going to be a straight wall and it is connected to the cup bottom. So this is for the side the cup wall and sorry this is for you know your cup bottom and this is for the side cup wall okay and from this you can see that t_0 will go off because we are going to consider it the same π also goes off okay so and from this you can get $h, h = \frac{r_i}{2}\left[\left(\frac{R_0}{r_i}\right)^2 - 1\right]$. So where $\frac{R_0}{r_i}$ is our own drawing ratio so DR right R_0 is your initial cup radius you can also keep diameter okay and then this is your this is a sheet radius this is a cup radius r_i. So ignoring a change in thickness in the cup wall only approximate value of h can be estimated so this is what I was telling you so we are going to neglect this change in thickness in the cup wall. So instead we are going to get an approximate value of h it will not be fully accurate but still it is fair to have some quick idea what would be h at any stage.

So now some one or two important points we can understand from this suppose if you keep $\frac{R_0}{r_i} = 2.2$ so in the previous section okay we derived that LDR is almost equal to 2.72 and then we said that this is theoretically high okay. So instead of that practically if you take η as this is $\eta = 1$ so this case will come if you take $\eta = 1$. Suppose if you take $\eta = 0.6 - 0.7$ we said that LDR can have between 2 to let us say 2.2 so and we worked out that if it is 0.7 it is 2 okay if it is 0.7 it is close to 2 okay. So you can imagine about LDR can be about 0.2 for sorry 2 to 2.2 for practical case this would be the case this is highly theoretical in nature okay. So LDR is 2 to 2.2 is advisable for us right.

So if you keep $\frac{R_0}{r_i} = 2.2$ in this so you will get $\frac{h}{r_i} = 1.9$ okay so you can substitute so $\frac{r_i}{2}[(0.22)^2 - 1]$ okay and you will see that this $\frac{h}{r_i}$ you take it down denominator you will get that is 1.9 which is less than 2 or height to diameter ratio suppose $\frac{h}{r_i}$ can be cover to $\frac{h}{d} < 2$ this would be $\frac{h}{d} < 1$. So what does it indicate? Indicates that the height that can be cup can be drawn okay maximum value is going to be equal to the top diameter of the your cup okay so you cannot have more than that in one stage. So $\frac{h}{d} < 1$ indicates that deeper caps can be obtained only by redrawing operation okay. If you want to draw more than this okay so then you have to go for redrawing operations. So redrawing basically means suppose this cup is formed okay this is drawn again okay the so this is the flat sheet to this cup is 1 and this cup is further made in the form of another cup of different dimensions that is all.

So this is basically your you know redrawing okay. So redrawing means again and again you draw it until you make your actual cup okay. So now when we go for redrawing of cylindrical cups when you go for redrawing of cylindrical cups this can be actually divided into two varieties one is a forward redrawing the other one is a reverse redrawing okay forward redrawing and reverse redrawing okay these are the two you know types like for example we have forward extrusion and backward extrusion or direct extrusion and indirect extrusion. So similarly we have forward redrawing and reverse redrawing okay. Let us pick up this forward redrawing first and develop some simple expression for this okay so I have drawn here a schematic of forward redrawing you will see that so what are the things available for us so you have a punch okay you have a die so naturally so on the die you are going to keep your drawn cup the first level of drawing is done.

So you are going to have a cup that is located on the die like this it is located on the die like this so your cup is like this first your cup is actually located like this on the die okay so now on that you are going to push your punch to come down okay your punch has to be displaced in this way and this the cup drawn cup is actually positioned above die by using this retainer otherwise you can say it is a blank holder only okay. And once you are going to push it down so you will see that the bottom part of the cup is actually drawn okay so that is how it is so your sheet is actually going to be drawn to make this particular part of the cup. So the upper part this is belongs to the first stage and the one which is now done by this die belongs to the second stage here so this would be first stage this would be the second stage of drawing okay. Second cup that is formed this is the second cup that would be formed okay so basically you have to push it punch down such that this wall is going to bend is going to bend here and bend here bend here and un-bend here so that is how it is to be so this wall region has to come down it has to bend it has to un-bend it has to bend and it has to un-bend to form a full cup wall here finally you will have a cup of radius r_2 okay. So initial cup radius is r_1 new cup radius is r_2 if this is sufficient that is fair but if this is not sufficient then r_2 will be again drawn to next cup with radius r_3 the same way okay so in that case this would become r_2 this fellow will become r_3 like okay so that is the point here and so now the question here is so how are we going to model it using some simple mechanics which we already discussed okay so that is what is this slide is going to show and the main aim of this particular derivation is to get this F so the punch is actually getting displaced but F has to be found out that is a punch force have to be found out for forward redrawing okay.

So initial cup radius is r_1 new cup radius is r_2 let us take thickness as t and let us assume the thickness is not changing the usual way we are going to do that and so initially we know $\sigma_\emptyset$ you know cup wall stress in the cup wall we have already derived that so now you imagine that there is one tension because of that that is $T_\emptyset$ okay let $T_\emptyset$ be the tension in the cup wall between the bottom of the punch that is this portion bottom of the punch and the die okay between the bottom of the punch and the die there is a cup wall and the cup wall you have a tension of $T_\emptyset$ okay that is given by the $\sigma_\emptyset$ okay $\sigma_\emptyset$ is we are aware of that in the previous lecture. So now the force exerted by the punch is simply given by $F = 2\pi r_2 T_\emptyset$ okay. So now this wall tension actually you will see that it is going to depend on the severity of drawing, severity of drawing means it depends on what value of r_1 is converted into what value of r_2 which is given by $\frac{r_1}{r_2}$ which is otherwise called as like for example some sort of reduction this is the reduction you have this is the reduction in the cup you have at the end of second stage okay. So r_1 becomes r_2 so how severe is this is it like 100 to 50 or 100 to 30 that is a point so 100 mm radius is converted into 30 mm radius or 100 mm radius is converted into 50 mm radius so that this $T_\emptyset$ actually depends on this ratio so what we are going to do is we are going to we are not going to develop this equation rather this is actually taken as it is directly okay and I am going to say that by assuming yield tension as $\bar{T}$ the wall tension is given by $T_\phi = \bar{T}\, ln\frac{r_1}{r_2}$ okay. This portion is actually not derived let us accept it right now okay T_ϕ depends on $\frac{r_1}{r_2}$ by following this equation $T_\phi = \bar{T} l\, n\frac{r_1}{r_2} = \sigma_\mathrm{f} \cdot \mathrm{t} \cdot \ln\frac{\mathrm{r}_1}{\mathrm{r}_2} \cdot$ which is the usual definition we have right from the beginning okay.

So $T_\phi = \sigma_\mathrm{f} \cdot \mathrm{t} \cdot \ln\frac{\mathrm{r}_1}{\mathrm{r}_2} \cdot$ okay so this T_ϕ can be substituted in this equation so $F = 2\pi r_2 \sigma_f t ln\frac{r_1}{r_2}$ this fellow is nothing but my T_ϕ okay. So drawing force in forward redrawing can be obtained by the simple expression $2\pi r_2 \sigma_f\, t\, ln\frac{r_1}{r_2}$ where all are known things like r_2 would be your new cup radius σ_f is only material property you have here which is nothing but the flow strength of the material okay and t is your sheet thickness which you assume the constant and $\frac{r_1}{r_2}$ is nothing but the ratio your tells how much is the reduction that will be your $\frac{r_1}{r_2}$ anyway r_1 is basically initial cup radius which is what is given here. So you know all these values if you substitute it you will get a force okay this would be the punch force required for forward redrawing. So this is a simple equation of course you know that the σ_f can be kept as a constant value or it can be made as a function of you know strain to consider strain hardening it can be made as a function of strain rate okay σ_f can be a function of strain you can make it as a function of strain rate also or you want to keep it as an average one $(\sigma_f)_{\mathrm{avg}}$ like what we have done in the previous section that is also possible. So all are possible here but the form of the equation will remain same it is very simple to use $2\pi r_2 \sigma_f\, t\, ln\frac{r_1}{r_2}$ okay.

So now we are not going to keep it so simple so what we are going to do is so we are going to now introduce one more addition to this equation that is nothing but the change in tension due to bending and unbending during this redrawing operation. There will be some change in tension this T_ϕ this value $T_\phi$is going to have an addition of one particular value that is because of bending and unbending during this drawing operation. So what is it? Again we are not going to derive this is actually taken from a different chapter okay so which is not derived but then let us accept it let us go ahead in the derivation. So because of either a bending or unbending so one bending or unbending during forward redrawing the tension increase is given by this equation, this equation again is not derived I am telling this is for us to take care okay $\Delta T_\phi \approx \frac{\sigma_f\, t^2}{4\rho}$ where t is nothing but your cup thickness where ρ is your this one here it is written this is ρ okay. So this is this equation is valid for one bend either one bend or one unbend okay.

So now what we are going to do is this T_ϕ this ΔT_ϕ is going to be added to this T_ϕ okay to get *F*. So it is going to be $F = 2\pi r_2(T_\phi + \Delta T_\phi)$ that is going to be the case but there is one small thing in this that in this forward redrawing if you see the same schematic bend and unbend together are actually equal to 4. So you have one bend and then unbend another bend another unbend. So one bend so one bend is happening here and then that fellow is actually unbending another bending another unbending. So by considering all this what I am going to do is we find two bends and two unbends are required in this forward redrawing therefore my original equation $F = 2\pi r_2(T_\phi + 4\Delta T_\phi)$ okay.

So this is for either a bend or unbend so there are four such things four such activities. So I am going to multiply this by $\Delta T_\phi$by 4 and then I will add it with this T_ϕ to get my *F* okay. So what will I get? I will get $2\pi r_2$ okay so I will get $2\pi r_2$, $F = 2\pi r_2(T_\phi + \Delta T_\phi)$. So what is a T_ϕ? $\Delta T_\phi$is already we calculated it $F = 2\pi r_2[\sigma_f\, t\, l\, n\frac{r_1}{r_2} + \frac{\sigma_f\, t^2}{\rho}]$ 4 4 will be cancelled. So now this will give you $\sigma_f\, t$ is common so I am taking it out this fellow will have only $F = 2\pi r_2 \sigma_f\, t\; [l\, n\frac{r_1}{r_2} + \frac{t}{\rho}]$ that also where $\frac{\rho}{t}$ is nothing but our own bend ratio okay.

So what we are doing is because of bending and unbending during this particular process there will be some change in tension that is as a cumulative thing it can be quantified by $\frac{\sigma_f\, t^2}{4\rho}$ if you have either 1 bend or 1 unbend. Now there are 4 such activities so $4\Delta T_\phi$ would be right additional term to this F okay that is why it is going to become $2\pi r_2(T_\phi + \Delta T_\phi)$ okay so and then if you substitute T_ϕ value into this you will get this equation which will be simplified to this equation $F = 2\pi r_2 \sigma_f\, t\; [l\, n\frac{r_1}{r_2} + \frac{t}{\rho}]$ okay where you know that r_1 is nothing but the first cup radius this is a new cup radius t is a thickness rho is a corner your radius you know that the die corner radius and σ_f is only material property and think about the flow stress and t is a thickness all are known. So now this $\frac{r_1}{r_2}$ if it increases that is why I gave an example it is 100 by 50 or 100 by 50 or 100 by 30 okay let us say if it is 100 by 50 or 100 by 30 so $\frac{r_1}{r_2}$ if it increases that means reduction is going to be larger which means there are lot of chances that your force is going to increase that is what is given by this equation and at same time $\frac{\rho}{t}$ if you see if $\frac{\rho}{t}$ decreases it is a denominator $\frac{\rho}{t}$ decreases there are chances that f is going to increase if $\frac{\rho}{t}$ decreases there are chances that your f can increase. So anyway finally this is the drawing force in forward redrawing by considering the change in tension by considering the change in tension. So this equation and the previous equation $F = 2\pi r_2 T_\phi$ or this one $2\pi r_2 \sigma_f\, t\, ln\frac{r_1}{r_2}$ these two are two different equations for getting drawing force in forward redrawing.

So either this equation or the previous equation these two equations can be used for calculation but this fellow this equation is going to be little bit you know basically more accurate for us for the simple reason that you are going to have this equation is going to be more accurate because you are going to have change in tension coming into picture here as compared to the previous equation. So this is what is all about forward redrawing.

So now let us go to reverse redrawing and let us see what change we are going to make in this we are not going to derive anything. So reverse redrawing schematic is shown in this particular figure. So it is a same cup which is drawn. So we have shown this cup now. The same cup this cup now there is a cup wall and there is a cup bottom which is coming here right. So this cup is formed ok. So we are going to pick up the same cup ok. So you have a sheet, the sheet is drawn into a cup ok. Now this cup is actually further drawn into another cup either by forward redrawing or reverse redrawing. Now with respect to reverse redrawing the main point is when you go to the next stage you are going to keep it upside down. You are going to keep the same cup upside down and punch will come from this side and punch will come from this side. This is going to be your punch. This is going to be your punch ok. This is what you are going to do in reverse redrawing or let us say reverse redrawing your punch will be kept upside down. Reverse redrawing is shown in this figure. In this the cup is turned inside out ok. That means your cup wall is going to come down. The cup wall is actually is hanging down.

In the previous case the cup wall is going to be like this you know. So the cup wall is actually like this. In this case it is actually going to come down like this ok. And this will be kept on the retainer ok and punch is going to touch this surface and it is going to be displaced and you will see that of course the first portion that will form is basically the cup bottom. After that this cup wall is going to get formed. So now if you push the punch down it is all about the material coming from this side and is going to become a cup wall like this. It is going to get displaced in this way to form a final cup which contains only cup wall and the cup bottom that is all ok. So since the cup bottom is already formed so it is all about converting this wall to this wall via one bending one unbending. One bending the material is actually bent here and then unbend 2k per cup wall.

That is the only difference. So 1 plus 1. In the previous case it is 2 plus 2 here it is one bend and one unbend. So there is only one bend and one unbend operation therefore the drawing force F is reduced as compared to forward redrawing ok and what do you need to do is actually so all equations remaining same so instead of $F = 2\pi r_2(T_\phi + 4\Delta T_\phi)$ you have to write $F = 2\pi r_2(T_\phi + 2\Delta T_\phi)$ ok because it is only two activities one bend one unbend $2\Delta T_\phi$ that is all. That is the only difference you have here and then finally you will get this particular equation this is the drawing force and reverse redrawing by considering change in tension only difference is $F = 2\pi r_2 \sigma_f\, t\, [l\,n\frac{r_1}{r_2} + \frac{t}{2\rho}]$ everything remains same this 2 gets into this denominator. So instead of $\frac{t}{\rho}$ ok so $\frac{t}{\rho}$ becomes $\frac{t}{2\rho}$ or $\frac{1/2}{\frac{\rho}{T}}$ ok that is the only difference you have here. So if you put appropriate values inside this into this two equations you can find out that the drawing force and reverse redrawing is actually smaller than the forward redrawing ok so this is what the expressions that we can derive for punch force during forward and reverse redrawing in a very simple way the only thing is this equation is not derived you are going to assume this or maybe like we have this has been taken from a different chapter different source and then that gets added to T_ϕ to get F ok.

So another small section ok which is also important practically that is your wall ironing during deep drawing ok we are not going to derive anything what we are going to do is just some important you know new note some you know some bullet points type this is what we are going to understand from this. So wall ironing basically occurs ok wall ironing is actually a phenomenon that will happen during deep drawing process cup deep drawing it occurs when the clearance between the punch and the die is less than the initial thickness of the cup wall the clearance between the this is your punch let us say ok and this is your die the clearance between the punch and die is less than the initial thickness of the cup wall or initial thickness of the sheet ok. So if cup wall basically means you are going for further drawing if it is initial thickness of the sheet means it is a first time drawing so if the clearance is less then wall ironing will happen wall ironing will happen means like this you can see that you know a cup of t_1 thickness ok is coming into the die ok and you will see that because the clearance is less ok the clearance is less you will see that the cup wall is actually forged the cup wall is actually forged ok in this location or in this location either way you can locate the cup wall is actually forged inside this and thickness gets reduced and becomes t_2 in the bottom cup wall. So when the cup is getting drawn ok or when the sheet is getting drawn t_1 larger thickness is going to become a smaller thickness to accommodate the material in the cup wall itself because the material cannot go anywhere it has to get accommodated because of lesser clearance ok.

So generally the clearance should be slightly larger than the cup wall thickness or you know sheet thickness but here it is less then the decrement in clearance will take care of thickness reduction t_1 to t_2 will be accommodated accordingly ok. So anyway the point is the cup with t_1 thickness is going to become t_2 thickness where t_2 is going to be smaller than t_1 that is nothing but your ironing operation ok. So now what will happen is suppose this material comes with v_1 velocity ok so it moves with v_1 velocity and at the exit ok you will see that the material actually the cup will go with punch velocity only v_p. So the velocity is not going to remain same as v_1 it is going to be v_p so the cup wall after the die if you monitor this velocity is nothing but your v_p only. So the velocity of the material as it exists the die v_p is same as that of your punch velocity whatever punch velocity you are giving that would be this ok.

So now what we can do is like during ironing since there is no change in volume and the rate at which the material enters the die equals the rate leaving the die so we are going to bring in velocity that is why v comes into picture ok and the rate at which material enters the die will be same at initial and at any intermediate level so you can write $2\pi r_i t_1 v_1 = 2\pi r_i t_2 v_p$. So you will see that v_1 is connected to t_1 and v_p is connected to t_2 and you can say that $2\pi r_i t_1 v_1 = 2\pi r_i t_2 v_p$ ok. So which will give you a simple relationship $v_1 = v_p \frac{t_2}{t_1}$ ok and your t_2 which is your second thickness this is going to be t_2 is going to be smaller than t_1 so hence $v_p > v_1$ here you would see that v_p is greater than the punch moves faster than the entry material ok the punch moves faster than the entry velocity so your output velocity would be larger than the input velocity and if you look into the interaction between the cup and the die ok let us assume that maybe like q is nothing but your normal force acting on the two interfaces one is on the inner surface that is here with respect to the punch and on the die side this side with respect to the die ok. So let us say the reaction force is the normal force is q then friction force can be obtained by $\mu_p q$ here $\mu_d q$ here ok I am not saying μ here μ here μ_p coefficient of friction on the punch side coefficient of friction on the die side they could be different ok and you will see that the direction also got changed ok. So here your friction force is acting downward direction and because of the thickness reduction this fellow will act against it this fellow is going to act against it ok so two things coefficient of friction is also changing and the direction is also changing so here it is $\mu_p q$ here $\mu_d q$ here it is downward here it is upward ok so this fellow is actually going to help this is going to aid the dry ok and the friction force between the punch and the sheet is actually downwards this assist the process this aids the process.

So what you need to do is advantage during ironing if you want to pick up ok so since you are on the punch side on the punch side your $\mu_p q$ that μ_p is going to help you ok so this μ_p has to be kept larger than mu d because this is actually going to help us so the helping factor aiding factor should be larger than the other one so μ_p has to be kept larger so μ_p has to be kept larger than μ_d that generally what people do is they roughen slightly punch is actually roughened slightly so that even if you put lubricant there are chances of $\mu_p > \mu_p$ and on the opposite side on the die side you put lots and lots of lubricant outside of the cup is heavily lubricated outside of the cup that is this side outside of the cup means this side is heavily lubricated and this side you will see that it is roughened the punch is roughened ok or maybe you do not put lubricant something like that ok so that your $\mu_p > \mu_p$ok. So this is these are some important node points ok so required for your wall ironing operation ok so you can note down this is one small section we are not deriving anything here any equation here this is just ironing operation is important deep drawing and though ironing operation is unwanted but sometimes you want to control the cup wall thickness you deliberately allow you know wall ironing so that you have particular thickness in the cup wall while doing so you have to keep these things in mind that is the whole point ok. So $\mu_p > \mu_p$ and you purposefully do it like you roughen the punch and then on the opposite side on the outside of the cup you put lots and lots of lubricant ok to maintain this particular situation. So with this we are completing this particular chapter on deep drawing but before that let us do quickly some two three important problems small small problems which will be useful for us.

The first one is a cup is to be drawn in a deep drawing operation fine the height of the cup is 75 mm the output height is 100 mm is given and its inner diameter is 100 mm ok. So cup height is 75 mm it is given and the inner diameter or maybe you can take radius also let us take inner diameter as 100 mm is to are given the sheet metal has got thickness of 2 mm so t_0 you can keep it as 2 mm blank diameter is 225 mm blank diameter means you can maybe like you can say d_0 as a 225 so 225 becomes 100 that is the point. So 225 becomes 100 the 225 the sheet diameter that becomes 100 mm diameter cup ok. So if that is the case you need to calculate few things one is drawing ratio reduction thickness to diameter ratio and converting this 225 into 100 ok this is the sheet diameter this is the cup diameter is it possible or not whether the operation is possible or not ok. So draw ratio we know it is very simple 225/100 2.25 reduction is generally given by $(225 - 100)/225 = 0.56 = 56\%$ ratio. So 225-100 ok so that will tell you the difference divided by the reference that is 225 ok which is nothing but 0.56 approximately 0.56 which is about 56 percent ratio ok. So this reduction is somehow similar to $\frac{r_1}{r_2}$ but not exactly same somehow similar to $\frac{r_1}{r_2}$ ok. So anyway so now this second one is calculated and the thickness to diameter ratio it is straight forward t/d so t is given ok 2, d is actually 225 it is about $t/d = 0.009$ you can check it ok and this all are calculated that is fine but is operation feasible or not it is said that it is not feasible because of the following reasons.

One what are they though we know all this are available ok there are certain design criterion for us generally it is said that draw ratio we have also pointed out that it should be 2 to 2.2, 2.72 is again I am coming back 2.72 is a theoretical one practically speaking 2 to 2.2 should be good ok limit drawing ratio ok. So now you will see that this is 2.25 which is greater than 2.2 ok even if you little bit conservative let us keep it as draw ratio requirement is 2 ok then it is greater than that so it is not possible. So again generally it is said that it should be closer to 50 or less than that generally these are conditions you have not seen it is just for us to record now ok it is for record now.

So reduction should be less than or equal to 50 but in this case you will see that it is greater than 50 and t/d should not be very small it should generally you know closer to 1 percentage or more than that if you convert this into percentage you will see that is less than 1 percentage because of that this you know operation of converting a sheet into a cup would be unsuccessful so we say it is not feasible, we say it is not feasible. So we are picking up three conditions one is draw ratio maybe you can keep it closer to 2 since it is greater than 2 is not possible reduction should be closer to 50 more than this it is not possible t/d

is actually very small which is also not comfortable which is not good so this is not possible ok. So though these values you know can be calculated but finally the process is not feasible. Suppose if you want to change this suppose 225 is not the case initial sheet is actually let us keep it as 175 that is your second problem.

Question 2 is same as previous problem but sheet diameter is 175 what is the draw ratio 175/100=1.75 fine it is less than 2 or less than 2.2 accepted reduction $(175 - 100)/175 = 0.43 = 43\%$ less than 50 it is fine t/d ok is greater than 1 percentage it is not too small ok $t/d = 2/175 = 0.011$ percentage it is slightly greater than 1 it is also accepted. So all these three are fine ok but still this drawing is not feasible because with 175 mm sheet diameter you cannot make a 75 mm cup. 75 mm this is the height you have to form now then we let us calculate height and find out so height is this equation we derived just now $\mathrm{h} = \frac{r_i}{2}\left[\left(\frac{R_0}{r_i}\right)^2 - 1\right]$ so it is r_i is a diameter is 100 so it is $\frac{50}{2}$ ok into 100. This is 175 diameter is not it so $\mathrm{h} = \frac{50}{2}\left[\left(\frac{87.5}{50}\right)^2 - 1\right] = 51.5\ mm$ so if you use 175 mm initial diameter of the cup though this descent conditions are acceptable this is fine but still the cup you cannot make it because the material itself is not sufficient for you to make a cup of height 75 mm why because as per this equation height is that we get is only $51.5\ mm < 75\ mm$ cup that is required ok. So this process again not feasible not because of the descent condition but because of you know the scarcity of material the material is not so diameter is not sufficient for us to make. So this type of simple problems can be solved from this.

So let us go to the third problem So a fully work hard on the aluminum sheet of 100 mm diameter and 1.2 mm thickness it has got a constant flow stress of 350 MPa ok so your R_0 diameter is given but R_0 anyway you can get thickness is also given ok which is 1.2 flow stress is given let us say take it as $\sigma_f = 350\ MPa$ constant thickness so no problem a cup diameter is made of let us say r_i that is 50 mm diameter cup is made blank holder force is given as 30 kN which is nothing but 30000 N friction coefficient of friction is given as 0.1 so what is the question you have to find h and maximum punch force which is what we calculated just before which is nothing but F. So $\mathrm{h} = \frac{r_i}{2}\left[\left(\frac{R_0}{r_i}\right)^2 - 1\right]$ which is nothing but r_i is given what is it cup height is $\mathrm{h} = \frac{25}{2}\left[\left(\frac{50}{25}\right)^2 - 1\right] = 37.5\ mm$ so you can calculate it and find out it would be 37.5 mm height so with this particular aluminum sheet of 100 mm diameter 1.2 mm thickness can be converted into a 50 mm cup it has to be deep drawn ok so now they are saying that what is the final height this could be the final height that can be drawn for this particular type of material ok. Sorry this is 50 mm cup diameter sorry this is not height no this is not height this is cup diameter a cylindrical cup of 50 mm mid wall diameter so cup diameter is 50 correct so that is what we have given as 25 ok so final height is formed is only 37.5 mm so now let us come to the punch force this formula is already we derived $F = 2\pi r_i t_0 \sigma_\phi$ right so this equation we have derived in the previous class in the previous lecture $\sigma_\emptyset$ was derived by us what is σ_ϕ ? $\sigma_\phi = \left[\sigma_f \ln\frac{r_0}{r_i} + \frac{\mu B}{\pi r_0 t_0}\right] \exp\frac{\mu\pi}{2}$ this is we made it in general now we removed $\frac{1}{\eta}$ before this so $\frac{1}{\eta}$

was there before this so $\frac{1}{\eta}$ was there for the derivation that we have removed and then we kept a $(\sigma_f)_{\text{avg}}$ which is also removed now so ok all are removed and then it has gone back to r_0 and t_0 ok. So we have not really derived the punch force for conventional deep drawing rather we derived only σ_ϕ cup wall stress from σ_r ok that is what we derived as a σ_ϕ so now what you can do is you can multiply by $F = 2\pi r_i t_0 \left[\sigma_f \ln\frac{r_0}{r_i} + \frac{\mu B}{\pi r_0 t_0}\right] \exp\frac{\mu\pi}{2}$ ok.

So now here what is r_i? so r_i is 25 mm t_0 is your 1.2 mm σ_f is 350 and r_i is known what is r_0? r_0 is your same 50, r_i is again 25 I think you can write so B is 30000N , r_0 is again given t_0 is again given 1.2 exponential μ is 0.1 into π by 2 so if you substitute all these values you will get this value you can check it, it is 57kN this much of maximum punch force is required to draw a cup of this particular material ok so this much force is punch force is required. So remember we have derived punch force equation only for redrawing not for regular drawing so this problem will give you an idea of how to calculate the punch force provided you have σ_ϕ which is already derived by us before so that is not in this this is σ_ϕ no? so after this all these things we derived it so anyway so that you can look into it so this is one way to solve this particular problem you can check it. Thank you.