Mechanics of Sheet Metal Forming
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Week- 04
Lecture- 08
Stamping Analyses

Music So, now we are going to start our next module, module number 4 that is called as simplified stamping process or simplified stamping analysis we can say. So, in this particular module which will going to complete now in this session itself. So, we will see how to do a simplified analysis of a stamping process, certain things which we have already studied and certain things will be new to us in this particular chapter and already whatever we have studied we will try to put it for the simple simplified stamping analysis ok. So, what are those assumptions ok, how we are going to apply you know whatever we discussed before for this kind of stamping process is what something we need to know. So, that that complexity involved in stamping analysis can be reduced ok. So, though it may not be fully accurate we will see that, but it will give you very good idea of what is going to happen in the sheet during stamping process.

So, stamping process what do you mean by stamping process. So, stamping process means for instance it could be any sheet deformation process, it could be any sheet deformation process ok. Generally it is of industry component level ok. So, suppose you want to make some component for example your front bumper, rocket panel, tunnel ok, B pillar inner ok, roof rail inner something is called as sub plate these are all actually stamped products.

Stamped product means actually from industry point of view ok you can make that component by sheet forming ok. Similarly there of shallow parts which is required depending on the situation ok. So, it is a stamping is a very conventional process used in industries to make many such components ok which cannot be made by simple bending or folding process ok, which cannot be made by simple folding or bending process. And this stamping process will involve mostly stretching type of you know deformation ok that is what is indicated they used to form shallow parts in approach by stretching the sheet over a shaped punch or die. There can be other tools also to create that shape ok.

So, unlike your sheet forming process can be divided into you know two important categories depending on the temperature, working temperature here also you can call it as hot stamping and cold stamping process. Hot stamping done at elevated temperature, cold stamping done at room temperature depends on the material ok. Some examples are given here, cold stamping is used typically for light weight materials like aluminum alloys, hot stamping is generally used for high strength steels, HSS or UHSS ultra high strength steels ok. So many examples are given here this kind of components can be made by using let us say different hot stamped automotive parts are shown here. Similarly cold stamping is also possible.

So this will give you a fair idea of where we stand you know when you discuss about stamping process. So this is the context ok. So just to tell very basic tools required for stamping process which is already known to us it is all conventional tools available to us but then it is more of a intricate shape that is required here. You can see that this diagram A, B and C which are taken from this particular book. So you will see that it has got a punch ok and it has got a you know blank or a sheet ok and you will see that there is a blank holder ok and there is a die kept here and there is a draw bead ok on these locations.

It is a sectional view, it is a sectional view you can say. They all are there ok. So now punch is not touching the sheet here ok there is a gap ok. So now punch is going to move down and is actually stretching the sheet ok on its surface. So now you keep pushing down some shape will be formed and if you want to have a counter punch, counter punch can also be you know pushed from a bottom side ok and it can deform the sheet in this region ok.

So that if you want to make any re-entrant shape that can be made ok. Re-entrant shape means you can see that the sheet is deforming like this and then there is an inward movement of the sheet and then it is coming down and it goes undeformed. So this kind of reentrant shapes can be made by with the help of counter punch ok. So punch you have blank holder, you have draw bead and then you have counter punch and of course you need a die ok all together is going to give you this particular shape ok. But it is not mandatory that you need to have a die because you can make a unshaped component, unshaped component means a component shape is derived by how much you deform ok.

So in this case you can see counter punch can be seen in the form of a die which is going to give you some shape at one particular location ok. These are all certain important tools, these tools are known to us ok and I hope you understand the meaning of blank holder. Blank holder is to hold the sheet which means that this can be done in a double stage stamping process. Double stage means two stages, one is first of all this blank holder will come and hold the sheet in this location ok, in this location it is going to hold the sheet and then your punch will come and then it will deform the sheet. And punch will keep on deforming until that the last phase of the you know deformation you have to hold the sheet ok, blank holder has to hold the sheet.

Otherwise if you do not provide appropriate blank holding force there will be lot of wrinkling that will happen in the flange of the sheet, flange of the sheet is this ok. So it is a double stage stamping process. So blank holder has to be used to hold the sheet that is number one it will come separately and then punch will come down to deform the sheet in this fashion ok. So now if you want to analyze this particular you know process and then calculate certain important quality ok, the quality of the sheet at different locations ok. Quality when I say how much you know strain it can withstand at one particular location, how much you know thickness it can withstand at one particular location ok and then how much is the tension you know T_1 , T_2 , σ_1 , σ_2 principle stresses.

So all those things what will be β, α at different location. So all those things can be calculated from whatever we have studied before how we are going to put that into this situation is what we are going to see now. So now we are going to consider something called as a two dimensional stamping model, two dimensional stamping model and a typical schematic is shown in this particular figure ok, schematic of a 2D stamping process is shown here ok. There are lot of you know nomenclature one has to you know indicate with respect to this figure and I have noted down that ok. So we will go one by one.

So you will see that so this black color one is the sheet ok, this black color one is the sheet it has got O, A, B, C, D and then this particular portion is actually zoomed in here ok, A, B, C, D, then E, then F and at the end you have G ok. So O, A, B, C, D, E, F, G actually covers ok one half of the sheet metal component or stamped component ok. So now here you can see that punch is actually deforming the sheet ok, punch is actually deforming the sheet ok and h, you are going to call this height as penetration height or draw depth something like that you can call. So you can call it as punch penetration, how much height it has deformed the sheet ok. So with respect to punch we are going to call this a as punch semi width ok, punch semi width.

So this from center axis to this particular portion is actually your punch one half of punch so we call it as punch semi width, width of punch width but it is semi width a and then you are going to have this b, b is called as blank semi width, blank means sheet, sheet semi width one half of the width you can say this is b from this axis to this end, this is b. c is a side clearance, c is the side clearance between your punch and the your blank holder or punch and the die you can say. So here you have to be little bit careful in deciding what is c as we discussed before there should be appropriate clearance between the you know clearance defined by C otherwise what will happen here is lesser the clearance that means clearance is lesser than the sheet thickness for example then you are going to have ironing you will see that briefly later on that should not happen. Larger clearance will also create other you know defects in the material ok. So we need to have appropriate clearance that we discussed in the first section.

So then we have something called as e ok *a, b, c* then we are going to call this as e, this e is this particular region we call that as a land width ok this basically this e is a region where you do not have any you know compression force or blank holding force that is going to act here ok nothing is acting here ok when compared to f. So when you go to f that is where you are going to have clamping ok f is nothing but width of a frictional clamping ok that is where you can imagine that there is a draw bead ok and it is located here and that is going to give you some clamping force restraining force to the sheet ok or you can have you can imagine that there could be a force equivalent force whatever draw bead force is given an equivalent force can be given at this location which can restrict the movement of sheet ok that all are going to happen at this f ok in this width. h is already informed to you and t is a blank thickness ok at any you know location you can pick up ok t and there are three radius R_F, R_P

and R_D ok. So R_D is a die corner radius, R_P is a punch corner radius, R_F we are going to call that as a face radius there is a small radius ok given to the punch ok there is small radius given to the punch ok. So this is little shallow in nature you can imagine so that is R_F and there are different zones one can define ok one is OB material in contact with the punch from O to B you have contact with the punch and from B to C it is unsupported region that is nothing but your side wall like in deep drawing we say cup wall know so here BC is unsupported region ok that is your cup wall between your die and the end of punch ok.

And CD is actually sheet in contact with the die corner radius so wherever you have contact in this R_D that is your CD and your DE is basically sheet on the die land without contact pressure ok. So this land width we said know in that location whatever sheet is available you call that as DE and EF is a region on which a blank hold of force is acting that I already indicated you can call that as let us say B ok and FG is a free edge of the blank ok FG is a free edge on a blank. So now it is going to have since you are going to clamp it with some blank holding force you will see that the sheet is going to stretch ok on the punch surface and you are going to make some component and we are going to call that as a stamping operation and this angle θ is going to be important and this θ is actually referred with respect to this particular region between A and B this is basically the inner angle here ok. And this angle is same as that of this particular angle which is subtending with respect to your cup you know your or die or your side wall that is between basically your BC ok between that is along BC this angle both the angles are same θ and θ this fellow and this fellow. And B is a blank holding force that is going to act which is what is shown here and you will see that this F is the punch force F is the punch force you know that has to be calculated ok punch force will change with respect to h the F is going to change with respect to h there is a typical diagram you can draw F with respect to h ok F is going to change with respect to h.

So, these many details are there in this particular figure and then what we are going to do is we are going to do analysis on this ok. So, now a usual way we always start with strain of an element. So, what we are going to do is assuming there is a punch rigid punch ok this punch is given here this yellow colour one and below that you are just picking up a small element in the sheet that is this orange colour one and this is your sheet the grey one is actually sheet a part of sheet which is below the you know rigid punch which is actually getting stretched actually getting stamped and there is a small element you are going to pick up ok and that element strains and state of stresses are shown here ok and the directions are shown here. So, basically along the sheet we are going to call it as 1 perpendicular to that is 3 and perpendicular to the plane is actually 2 we are going to pick up that as 2. So, perpendicular to your sheet perpendicular to your die or the plane of the in a diagram is actually 2 ok.

So, we are seeing an element deforming and sliding below punch face. So, this could be anywhere here you can just simply say anywhere here ok in this location or in this location anywhere here ok. So, what we are saying is basically ε_1 ok that is nothing but strain ok direction on the sectioning plane ok sectioning plane ok. So, you are going to section this entire setup know. So, on that plane you are going to have 1.

So, that is what is given here and ε_2 is nothing but $\beta\varepsilon_1$ that is known ok that is perpendicular to the principal direction that means perpendicular to the plane of this particular diagram that we are going to call it as a plane strain and that is going to be 0 ok. So, ε_2 that means along this 2 direction we are going to keep that as strain as 0 because the material is actually not constrained in that direction material is actually not constrained in that direction. So, you can imagine that this particular section will remain the sectioning plane you can cut that entire setup at any location this situation will remain same ok. So, this section is done at any location this situation ok your punch die all this situation your sheet situation should remain same ok. So, which means that there is no constraint for the sheet to deform in the 2 direction.

So, you can call that as a perpendicular to principal direction we are going to call it as 0 this is an important one for us ok. And ε_3 this we already derived $-(1+\beta)\varepsilon_1$ and since β is actually you know 0 here. So, you can put $-\varepsilon_1$ that is because of $\beta = 0$. And we already have an assumption $\sigma_3 = 0$ ok. So, that is what is noted down here ok.

So, you will see that σ_1, ε_1 will exist $\sigma_2 = \sigma_1/2$. So, $\beta = 0$ what will be α we will see $\varepsilon_2 = 0$ ok. And you will see that $\sigma_3 = 0$ ok because we assume plane stress assumption here also and ε_3 is already here ok. So, this is the situation we have and you know how to get ε_1 and ε_3 ok. You assume that in this location a circle grid is plotted like the way we did the problem ok.

And circle grid will get deformed after sometime until there will be you know different you know dimensions from that you can get ε_1 because of the situations $\varepsilon_3 = -\varepsilon_1$. So, it becomes a simple case. Now, if you want to evaluate effective strain in that particular location by assuming one mises ill function we already derived this $\bar{\varepsilon} = \sqrt{\frac{4}{3}(1+\beta+\beta^2)}\varepsilon_1$. And then if $\beta = 0$ this fellow is become 0. So, then it will be $\frac{2}{\sqrt{3}}\varepsilon_1$.

So, $\bar{\varepsilon}$ also can be found out at that particular location. So, second important thing after strain evaluation and effective strain evaluation is the thickness. This is going to be important because we do not want thickness to reduce beyond a certain limit ok. Otherwise it will lead to instability right instability like necking fracture which you will see in the next chapter ok. So, thickness how do you get thickness the new thickness ok that also can be obtained by original expression $t = t_0\exp(\varepsilon_3)$ ok and $\beta = 0$ it will be directly $t_0\exp(-\varepsilon_1)$.

So, that also can be evaluated ok. So, where t_0 is your original thickness and ε_1 you know how to get it with respect to circular grid pressure. So, now let us come to the state of stress. So, as I already discussed with youσ_1 is going to be there and $\sigma_2 = \alpha\sigma_1$ as per our definition when $\beta = 0$ $\alpha = 1/2$ and hence $\sigma_2 = \sigma_1/2$ which is nothing, but $\sigma_1/2$ and the $\sigma_3 = 0$ ok. So, ε_1 , ε_2 , ε_3 , $\bar{\varepsilon}$ thickness all are found out. So, now, we have σ_1 , σ_2 and σ_3 also ok.

Now, all are known at that particular element below the punch which is undergoing definition ok. So, now, how do we get $\bar{\sigma}$? So, for $\bar{\sigma}$ if you want to if you want then you need to go for mean effective stress relationship with effective strain ok. And it is given by this particular equation ok $\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon})^n$ where ε_0 is nothing, but your pre strain value. This we discussed in the previous you know section ε_0 actually is called as pre strain and that is going to take care of the prior deformation of the sheet before it comes to the present stage ok. So, that is why when you say this strain as 0 there is going to be some $\bar{\sigma}$ available in the material which could be equal to your yield stress anyway fine.

So, now, if $\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon})^n$ ok then what we need to do is we need to put $\bar{\varepsilon}$ in this equation ok. So, because ε_0 is a constant K and n are material constants ok $\bar{\varepsilon}$ is going to change and it is going to change with respect to this particular equation which you already derived $\frac{2}{\sqrt{3}}\varepsilon_1$ I am going to put here power n ok and then $\bar{\sigma}$ can be obtained. So, if I know $\bar{\sigma}$ I can get σ_1 by relationship $\sigma_1 = \frac{\bar{\sigma}}{\sqrt{(1-\alpha+\alpha^2)}}$ from von Mises effective stress $\alpha = 1/2$ if I put. So, it will be $\frac{2}{\sqrt{3}}\bar{\sigma}$ and if σ_1 is known to me I can get a σ_2 and σ_3 is anyway not available for us here ok. So, this all are already available for us only thing is depending on the stamping process assuming it to be plane strain and of course plane stress you know $\sigma_3 = 0$ we are going to simplify all such analysis in this way.

Now, there is one important point that we are actually changed this equation $\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon})^n$ now what is going to happen. So, now if you want to get T_1 T_1 and T_2 ok T_1 and T_2 were introduced in the previous section ok where T_1 and T_2 are nothing but traction force or tension ok like this diagram I think we discussed in the previous class ok in Y axis you have T_1 T_2 X axis let us say ε_1 and T_1 T_2 are going to vary like this and these 2 are related by α these 2 are related by α right and we said in the previous class that whenever maximum tension T_1 is going to happen ok then that can be defined by $\varepsilon_1{}^*$ok. Whenever ε_1 becomes $\varepsilon_1{}^*$ ok then we say maximum tension is going to happen and I think in the previous section we derived $\varepsilon_1{}^* = n$ ok by assuming $\bar{\sigma} = \mathrm{K}\,\bar{\varepsilon}^n$,I think ok. So, you can refresh that so $\varepsilon_1{}^* = n$ we discussed I think ok anyway or I think we discussed $\varepsilon_1{}^* = \frac{n}{1+\beta}$ maybe ok.

So, maybe we will check it. So, that you can refresh it so $\varepsilon_1{}^*$ will be equal to one particular value then maximum tension will happen now but T_1 can be found out as $T_1 = \sigma_1 \mathrm{t} = \frac{K\left[\varepsilon_0+\sqrt{(4/3)(1+\beta+\beta^2)}\varepsilon_1\right]^{\mathrm{n}}}{\sqrt{1-\alpha+\alpha^2}} t_0 \exp(-\varepsilon_1)$ nothing but $\sigma_1 t$ where $\sigma_1 = \frac{\bar{\sigma}}{\sqrt{(1-\alpha+\alpha^2)}}$ and $\bar{\sigma} = \mathrm{K}\,\bar{\varepsilon}^n$ and $\bar{\varepsilon}$ is nothing but your effective strain this fellow power n you know like $t_0\exp(-\varepsilon_1)$ this we already derived ok. So, now when we say $\beta = 0$ and $\alpha = 1/2$ this equation can be reduced further which can be written as you know if you say $\alpha = 1/2$ then it will be $T_1 = \frac{2Kt_0}{\sqrt{3}}\left[\varepsilon_0 + \left(\frac{2}{\sqrt{3}}\right)\varepsilon_1\right]^n \exp(-\varepsilon_1)$ and in this way you can get T_1 and $T_2 = \frac{T_1}{2}$, because $\alpha = 1/2$ right. So, what are the variables here you can see t_0 is original thickness K is strength coefficient you know how to get it n is a strain not in exponent which will be given to you pre strain is a very small value let us say 0.005 or 0.008. So, all are known to as only difference is there is going to be ε_1 which is a variable ok. So, now what we are going to do? So, we are going to obtain $\varepsilon_1{}^*$ we are going to obtain $\varepsilon_1{}^*$ for this equation ok the main difference is there is ε_0 here in the previous section we derived an equation for this similar equation for this equation and here we are going to introduce pre strain then if you say by differentiating T_1 we obtain maximum tension at a strain $\varepsilon_1^* = n - \frac{\sqrt{3}}{2}\varepsilon_0$ if there is no pre strain then this factor will go off that is what I was telling you $\varepsilon_1{}^* = n$. So, when you put $\beta = 0$ here then so you will see that $\varepsilon_1{}^* = n$ both will remain same ok. So, the only addition we have is $-\frac{\sqrt{3}}{2}\varepsilon_0$ that comes because we are going to include pre strain into this particular strain hardening law ok. So, and we are going to say that this star generally refers to a limit strain value ok and $\varepsilon_1{}^*$ is known to you $\varepsilon_2{}^*$ can be obtained by $\beta\varepsilon_1{}^*$ providing your β is going to remain same ok when you reach this particular stage of deformation which may not be true also ok.

So, but assuming that your β is going to remain same then you can get $\varepsilon_2{}^*$here ok. So, just considering one element how to get all the principle strains then effective strain principle stresses α β of course and then you have $\bar{\sigma}$ then you can get T_1 and T_2 and further if you put this particular condition ok for maximum tension you can get $\varepsilon_1{}^*$ that is the major strain principle strain at which maximum tension is reached ok. After which you will see decay in T_1 ok and correspondingly T_2. So, which is actually different that is $n - \frac{\sqrt{3}}{2}\varepsilon_0$ because you are bringing in ε_0 into this equation ok.

So, now we are going to the next one. So, we need to get a few more important you know quantities required during this deformation what are they. So, we need to get p, p is nothing but contact pressure, p is nothing but contact pressure ok we need to get that. So, for this particular diagram (a) to (d) would be useful ok and this is similar to your previous one so let us say this is your punch rigid punch let us say and this is your sheet which is actually sliding on punch surface and it is getting deformed let us say ok. And this is an element of arc length let us say ds this given here ok so and length of the element ok $ds = Rd\theta$ where R is your you know your radius of curvature of this particular punch. So, $Rd\theta$ will give you ds ok and force acting on the element radially is nothing but you have $pRd\theta$ ok this is $pRd\theta$ right $Rd\theta$ ok and then $pRd\theta$ will be nothing but your force acting on radially and here this p is actually called as contact pressure ok this is nothing but your contact pressure and because of p ok there is going to be one μp which is going to act towards left because the sheet is actually stretching against it ok.

The sheet is actually stretching sliding against it so naturally $\mu pRd\theta$ will be in the opposite way and that will give you tangential force due to friction which is nothing but μp ok. This both the forces are actually plotted in this particular figure you will see that this is the same element ok and $pRd\theta$ is acting in this normal to this and $\mu pRd\theta$ is you know in the tangential direction and you will see that there will be some slight change in thickness from one location to another location which we are going to term as t on one side and $t + dt$ on the other side there is some small change ok. And because of that there will be some change in tension T_1

and $T_1 + dT_1$. So, T_1 is major tension there will be some change in tension $T_1 + dT_1$ along one direction this is along one direction no this is along one direction this is three direction ok. So, all are plotted here so now what I am going to do is I am going to plot this particular graph which is also easy to understand.

So, I am going to arrange all this tension in this way. So, my $T_1 + dT_1$ ok is kept in this way and then this will my $d\theta$. So, that my this one will be $T_1 d\theta$ ok. So, then what I am going to do is now I am going to find out the equilibrium of forces in the radial direction that is along this direction ok radial direction. So, what I am going to do $T_1 d\theta = pRd\theta$ which is what I am given here and this will lead to $p = \frac{T_1}{R}$ or this T_1 can also be written as what is T_1 for us here we already discussed this $T_1 = \sigma_1 t$. So $p = \frac{\sigma_1}{R/t}$ ok this R/t is actually called as bend ratio this is going to be important for us which we will discuss in bending ok.

So, we are saying that this contact pressure is inversely proportional to the bend ratio contact pressure is going to be inversely proportional to the your bend ratio that is the first one. So, contact pressure how do you get if you know σ_1 if you know R and if you know the current thickness then you can get p. How do you get σ_1? σ_1 at that location can be obtained by one of the methods described here σ_1 we already discussed $\sigma_1 = \frac{\bar{\sigma}}{\sqrt{(1-\alpha+\alpha^2)}} = \frac{2}{\sqrt{3}}\bar{\sigma}$ ok. So, in that way you can get σ_1 , R is basically it depends on the you know your punch dimension ok and then t is the new thickness you know how to get it. So, now if you want to take equilibrium along the sheet then we can write $(T_1 + dT_1) - T_1 = \mu(pR)d\theta$.

So, direction you can check accordingly and you will see that this pR what is pR? pR is nothing but this pR yes $pR = T_1$ you know. So, $pR = T_1$ ok. So, I can directly $\frac{dT_1}{T_1} = \mu d\theta$ ok $\frac{dT_1}{T_1} = \mu d\theta$ ok. So, what does that mean? That means the change in tension between these two points ok these two element these two points know how much is a change in tension between these two point which are actually deforming and sliding below the you know the punch ok that change in tension ok is independent of the curvature and just a function of coefficient of friction and we are going to call this $d\theta$ as angle of a wrap ok.

So, here pressure actually depends on the bend ratio ok which also depends on the curvature but the change in tension does not depend on the curvature rather it depends only on coefficient of friction and angle of wrap. So, now this equation not only is useful to relate you know change in tension with respect to some known parameters like mu and mu is coulombs coefficient of friction that you know ok. So, you can substitute some values and $theta$ is known you can get this. So, basically not only is going to give relationship between relationship for evaluating change in tension ok it is also going to give you how to calculate tension T_1 if you know tension at another point ok. So, that is what a small you know derivation is given here if the tension at one point j in the section is known then the tension some other point let us say can be found by integrating this equation if you integrate it.

So, you will get a $T_{1k} = T_{1j} exp\ \mu\theta_{jk}$. So, where T_{1j} if you know T_{1j} has to be obtained from original equation this one if you know that then you can get T_1 another location if you know coefficient of friction and angle between these two points otherwise in another location also you can get this way also provided you know all these values if you do not know the best way is to use this particular relationship, but there here you should know what is mu what is the angle between these two points ok. So, now this is what is going to happen between sheet and the punch ok. So, now if you go ahead and then go to this particular location ok this particular location where blank holding is going to be applied to play a vital role in sheet deformation. So, now question is how is a situation there, situation there is actually can be written in this particular way.

So, force equilibrium at the blank holder and punch ok force equilibrium at the blank holder and punch. So, now region EF ok we are going to call this region as EF ok you are going to call this region as EF which region is it, it is just below the punch this region EF on this region ok your B is going to act right. So, that region we are going to pick up and we are going to draw you know this ok. So, sheet is clamped into flat surfaces and the force is expressed as directly I am going to write. So, where B is my blank holding force acting from both the directions ok and my material if at all it is going to deform it is going to deform or slide in this way.

So, your μB is going to act opposite to that to restrict that moment and T_{1E}, T_{1E} is a T_1 at E point, T_1 at E point, E point is this particular point ok, E point is just at this particular point ok. So, E is here. So, this is your EF now EF just outside that whatever tension is acting that is your T_{1E} ok, T_{1E} ok. The T_{1E} if you know then you can calculate blank holding force ok from this expression. So, I am simply writing $T_{1E} = 2\mu B$ ok.

So, and if you see generally between this E and EF wherever you are going to have this you know where you know your blank holding force is going to act B is going to act generally it is a sensible to keep that as a linear variation. That means at E you will have T_{1E} value you will have T_{1E} value and it is going to decay linearly ok at EF and at EF it is going to become 0 ok. So, what I am saying is suppose you want to plot T_1 ok with respect to EF distance between E and EF I am going to plot T_1 then it is sufficiently accurate to assume that this T_{1E} is going to be or T_1 is going to be maximum at this E point and it is going to linearly decay and become 0 at EF ok. And this variation is a simple variation you can assume but depending on your draw bead force all those things this variation can change ok.

So, the tension is actually reduced linearly in this fashion ok. So, now I can get B from this I can get blank holding force from this it is a $T_{1E}/2\mu$. So, now I want to get punch force ok. Punch force is this F ok contact pressure has been obtained. So, now I want to get this punch force F ok and this punch force there are lot of ways to get it and then you will see that very simple analysis we can do to get this F for that I am going to use this particular figure this can be understood easily. So, it is the over location of the sheet then you have ABC DEFG will come in from here to here and my interest is between B and C which is nothing but my cup wall region ok.

So, θ_B can be obtained from the geometry of the you know deformation ok. Then what I am going to do is so I am going to say that since this is a unsupported region ok then since in this unsupported region. So, I am going to have T_{1B} acting along this T_{1B} acting along this ok which is going to have an angle of θ_B with respect to X axis. So, that my vertical component of there is nothing but $T_{1B} sin\theta_B$ ok. So, T_{1B} is a tension acting at a point B along the cup wall or the side wall ok in this direction.

So, which is going to have θ_B with horizontal axis and which will give my vertical you know component as $T_{1B} sin\theta_B$ and what I am going to do is I am going to equate this F and this and put 2 before twice that of the tension $T_{1B} sin\theta_B$ because it is a taking as a symmetric with respect to the axis. Ok. So, we can get the force per unit width considering both side of the sheet we can get it as $F = 2T_{1B} sin\theta_B$ where θ_B has to be known to you ok and T_{1B} has to be calculated with the you know previous expression that we have derived in general for T_1 ok. So, now this all are calculated I have written 1, 2, 3, 4, 5 you can imagine strain of an element then you have thickness then stress on that element then you can say tension or traction force T_1, T_2 that will lead to this important expression for us and then we have equilibrium of forces in two ways one is radial direction and on the and along the sheet both will give you two important outputs one is contact pressure other one is change in tension if that is known then you can get a blank holding force ok by this particular expression and then you can get a punch force by this particular method ok and here you will see that this T_1 ok here this T_1 depends on several things right.

So, T_1 is actually depending on the material its hardening ability everything. So, you can have material properties K and n coming into picture T_1 know so K n comes into picture and original thickness of the sheet comes into picture ok and pre strain if you want that will come into picture and your how much amount of deformation you have given that actually changes ε_1 ok and hence T_1 ok. So, your punch force can be plotted ok F can be plotted with respect to change in strain ok F can be plotted with respect to change in strain ok. So, I am not going to show that but if you want to calculate it you can calculate it. So, now just to give you some idea of how this tension distribution over the section is going to be then this diagram would be useful ok this is the same diagram I have just taken only the sheet ok the sheet the stamped component is from O A B C D E F G, O A is below the punch phase and AB is that your punch corner radius BC is a side wall CD is die corner radius D is the unsupported land with region EF is a location where blank column was going to eat and F G is a free end ok. So, now in this you will see that this is a point O ok this is your point O here and in this entire section I am drawing a distance T_1 and distance you can say ok let us call it as yes T_1 and distance yes.

So, you will see that at particular point O you have some tension T_1 which can be calculated from the previous equation and at A there is some slight increase and in the corner there will be significant increase and BC there is a constant value and CD is going to follow similar to what is given in between A and B and is going to somehow reach almost same as it of this particular point then DE is going to remain almost same and EF situation we already discussed ok where E is your T_{1E} and suddenly decrease linearly to 0 at F and F G is a free end it will remain 0 ok. So, now there will be some slight increase in tension ok because we are going to choose a gently curved punch ok punch is not you know is not curved significantly is gently curved punch and tension is going to increase gradually between this point and this point that is why I have shown the gradual increase ok between O and A ok between O and A ok. So, now AB is a corner so naturally we expect the tension is going to increase significantly ok tension will increase from O to B as a sheet is sliding outward against the opposing friction B to O ok because your sheet is drawn stamped in this way ok you can expect ok your tension to increase between in this corner region moreover it is a corner region we expect tension to be larger when compared to the other location. Now what is the situation in B and C you know B point and C point will have same tension because it is a side wall it is unsupported region ok it is to some extent sensible to keep it as a constant value and if you move from C to D to E ok C to D to E is again CD is nothing but the corner region and you will see to you will see that it is going to decrease significantly and this point your D point and this O point ok your D and O point will remain almost same why because it is same angle yeah it is a same angle at which you are actually crossing ok the same angle ok θ_B and θ is going to be crossed here also. So, assuming that then we can say that you can see from C to D it is going to decrease and from D to E it is going to remain constant because it is again you know unsupported region and from E to F there will be linear decrease in your tension as per this particular you know our discussion E to F, E to F it is going to decrease linearly and FG it is going to become 0 ok.

So, we have to be little bit careful that is why you know like in this punch corner region where there is a sudden change in your tension where there is basically sudden change in your tension ok there is a slight increase because it is a gently curved one this is corner so naturally tension will increase this is a side wall region. So, tension can made a same between B and C ok and then since is again a corner it will slightly decrease ok and your D and E will have you know lesser tension as compared to the other locations and naturally it is also sensible to see a tension decreasing up to this point and E of is actually linear decay and after that it is going to remain 0. This is how tension is going to change and if you want to see how strain and thickness distribution is going to change in this cross section ok these are all some values given from this particular book you can look into it ok. So, again it is referred with respect to O, A, B, C, D, E ok up to that and you will see that thickness has got one particular value from O to A ok they say it is almost same thickness and then at the corner region is expected that it is going to decrease ok and because the tension is going to remain same between B and C thickness is going to remain same ok and at D and E between D and E since it is a unsupported region it will not thin down like what it was in this region so naturally it will increase ok and then you can connect this to this with an increase in thickness and then it will reach E. Suppose if you want to take strain, strain is generally opposite in nature you can see there will be some strain value between O and A ok and wherever thickness is coming down you see that strain is going to be significantly larger and here it is going to be constant strain is going to come down ok why because between D and E there will be decay in strain ok and this fellow will come and join here so to get the E profile ok.

So, again you need to be little bit careful in this transition zone between A, B, C, D ok A, B, C, D where you are both the corners as well as your sidewall region is going to come ok this is where your thickness and strain are going to change probably some values are given here for you to note down and you will see that so this accuracy of this simple model ok depends on certain assumptions ok. So, now here we have not considered what will happen if sheet because of sheet bending and unbending right sheet actually bends and unbends at a few different locations we are not going to consider that and because of that bending there will be strain hardening in the material that also we have not considered ok. So, bending and unbending under tension with tension know because it is stretching ok reduce the sheet thickness which will cause an early fail in the sidewall that is why I am saying the sidewall is important see the sidewall this location is going to be very important because you see that thickness is going to decrease drastically in this location you will see strains are going to be larger. So, we have to be little bit careful and it will cause early failure in the sidewall ok because of this bending and unbending ok under tension ok it is just not your moment it is moment with tension that is actually you know happening here so that is why you say bending and bending under tension ok. So, that is going to reduce the sheet thickness because of which you can expect the thinning you know more thinning and hence there will be fracture in the sidewall.

So, you have to be careful in these locations between this corner you know your you know die corner punch corner and in between that in the cup wall you have to be little bit careful ok. So, now this you know brief calculations can be done if there is any stamped component ok some typical schematic is given here you can see that of course this is your you can say your die and this is your black color line is your sheet or blank ok and you will see that some dimensions are given here ok. So, these two points called as D ok so distance between that is actually $2d_0$ ok. So, two points we are taking on the two extreme locations here and then between the sheet edges you can call it as $2b_0$ and the new position of this after some deformation is actually you will see that it is D' , $2D'$ which is nothing but $2d$ so $2d_0$ it has become $2d$ and $2b_0$ has become $2b$. So, now that is a case you can evaluate stretch ratio or stretching ratio and drawing ratio like this.

So, stretching ratio $SR = \frac{d-d_0}{d_0} \times 100\%$ and drawing ratio is given $DR = \frac{b-b_0}{b_0} \times 100\%$ by. So, this will give you stretching ratio and drawing ratio which will be useful for some calculation. So, how much of stretching ratio has been obtained when you stamp a component how much drawing ratio is obtained you can get it from this is drawing ratio would be useful or draw ratio would be useful in deep drawing also we will see that later on in deep drawing also we will see this terms ok. So, before we complete this particular module ok which is a small one let us do one or two problems in this will give an idea of what is going on. So, the first question is ok so a material is deformed in plane strain is already given here with a major tension of T_1 is given here 340 kilo Newton per meter.

The initial thickness of the sheet is let us say 0.8 mm and the material is going to follow the strain hardening law $\bar{\sigma} = 700\ (\bar{\varepsilon})^{0.22}$ and K is given in MPa ok. So, you need to get major strain ε_1 at that particular point or other particular element you can say. So, straight away what we can say is for plane strain which you have discussed already we derived a relationship between T_1 and ε_1 we already have that relationship that relationship is given here and since this is $\bar{\sigma} = \mathrm{K}\,\bar{\varepsilon}^n$.

So, $\varepsilon_1 = 0$. So, you will get this particular simple equation $T_1 = \frac{2Kt_0}{\sqrt{3}}\left[\left(\frac{2}{\sqrt{3}}\right)\varepsilon_1\right]^n \exp(-\varepsilon_1)$ the same equation which we discussed before this equation this one same $\frac{2Kt_0}{\sqrt{3}}$ this fellow will become 0 plus $\left(\frac{2}{\sqrt{3}}\right)\varepsilon_1$ because this comes because of plane strain$\exp(-\varepsilon_1)$. So, same equation is actually used here. So, now what is the question T_1 is given K is given t_0 is given n is given so that is all. So, substituting all these values you have to iteratively solve this for which value of ε_1 you will get this T_1 ok. Or other words what you can do is like you can change you know all these components on terms on one side and keep only ε on other side you can get this expression.

So, $\left[\left(\frac{2}{\sqrt{3}}\right)\varepsilon_1\right]^n \exp(-\varepsilon_1)$ is kept here ok. So, $\frac{T_1\sqrt{3}}{2Kt_0}$ is kept here you can substitute all these values. So, $T_1 = 340 \times 10^3$ square root remains $K = 700 \times 10^6$ because 700 is a mega Pascal and $t_0 = 0.8 \times 10^{-3}$.

So, all are consistent you need you can keep ok. And then you can solve this to get 0.526. So, now you need to check for which value of ε_1 you get 0.526. You can take a small value and start you know evaluating it.

So, if you put ε_1 as 0.08 you get 0.547 then 0.06 you get 0.523 approximately which is same as it of this. So, $\varepsilon_1 = 0.06$ is a way you can get ε_1 ok. So, at that particular point you will get a major strain of 0.06 when you get a when you give a tension of $T_1 = 340kN/m$ and it has got initial thickness of 0.8 with this particular strain hardening law. So, that is what you will get.

So, now let us go to the next question ok which is a little bit complex ok. Let us discuss this one by one. So, this is a two dimensional stamping process which is provided to you. It is a same diagram like what we discussed before. We had only one section of this one part of this one half of this ok. Now it is full part is given ok blank holding forces acted ok. So, everything is given to you. So, this is your punch black color line is the sheet. So, it is said that situation is given given as side walls are vertical and face flat everything is given. If the blank holding force B is increased ok if you slightly increase a blank holding force that is the situation they are asking determine the maximum strain that can be achieved at the central line that means this particular they are calling it as ε_{1max} ok.

They are going to call it as $\varepsilon_{1,max}$ at the center region ok when B is increased. When you increase B slightly the strain ε_1 reaches its maximum that is the situation. When you increase blank holding force little bit ok here what you will see that ε_1 value is going to be maximum and then coefficient of friction is 0.15 is given and the stress strain law is given as $\bar{\sigma} = 600\ (\bar{\varepsilon})^{0.2}$, K and n are given in MPa. Now they are also asking maximum strain as well as what is the blank holding force required to reach this initial sheet thickness is 0.8 ok. Same sheet which you have used before ok. So, if you use the same thickness 0.8 mm ok so what is the blank holder force that is required to reach this particular strain which you are going to calculate. So, that you give appropriate blank holding force such that strain here will be lesser than this strain you know because maximum strain means there is something is going to happen there after that. So, that is the situation. So, what we are going to do is we are going to put this condition which you already derived before ok. So, we are going to say that when you apply when you slightly increase the blank holding force here ok the wall tension is going to reach maximum and because of that this ε_1 here will reach its maximum and wall tension will reach its maximum means you can put a condition maximum wall tension is when $\varepsilon_1 = n$.

Why $\varepsilon_1 = n$? $\varepsilon_1 = n$ is a condition which we got before here ok. We say $\varepsilon_1^* = n - \frac{\sqrt{3}}{2}\varepsilon_0$. So, ε_0 is anyway not there $\varepsilon_1 = n$. So, what is the condition? Condition we are going to keep here is when wall tension is going to be maximum ε_1 will also become maximum and that can happen because of any slight change in blank holding force and when it becomes maximum $\varepsilon_1 = n$ ok. So, T_1 is going to become $T_{1,max}$. The conventional T_1 which we have used in the previous equation say for this equation the previous problem this is going to become $T_{1,max}$.

Why? Because this $\varepsilon_1 = n$ that is what we have written here as $T_{1,max} = \frac{2Kt_0}{\sqrt{3}}\left[\left(\frac{2}{\sqrt{3}}\right)\mathrm{n}\right]^n \exp(-\mathrm{n})$ in place of ε_1 we are keeping n ok. So, now what we are going to do is so this T_1 at the center point is given by $T_{1,max}$ is at any location we have not specified anything $\frac{T_{1,max}}{\exp\left(\mu\frac{\pi}{2}\right)}$ this also we derived ok. If you want to know tension at one particular location you can multiply that with $exp\left(\mu\,\frac{\pi}{2}\right)$ which will give you $\frac{T_{1,max}}{\exp\left(\mu\frac{\pi}{2}\right)}$ is this ok $\frac{T_{1,max}}{\exp\left(0.15\frac{\pi}{2}\right)}$ and this $T_{1,0} = T_{1,B}$ somehow we have to bring in blank holding force into picture why because we need to calculate this and for that we are going to use this particular situation that situation is this situation like this your T_1 at this location will be same as that of what you got here what you got here ok at this particular so you so basically this particular point is what we need because this is where your blank holding force is going to act now between E and F. So, this particular point you need this is same as that of this particular one so we are going to pick up this particular relationship saying that $T_{1,0} = \frac{T_{1,max}}{\exp\left(\mu\frac{\pi}{2}\right)} = T_{1,B}$ but $T_{1,B}$ is a general case but $T_{1,B}$ is actually a general case $\varepsilon_1 \neq 1$ there $T_{1,B}$ is a general case so you will keep this original form of the equation as it is that is what we are going to do ok you see that. So, now $T_{1,max} = \frac{2Kt_0}{\sqrt{3}}\left[\left(\frac{2}{\sqrt{3}}\right)\mathrm{n}\right]^n \exp(-\mathrm{n})$ ok so I am going to substitute this here ok so $= \frac{2Kt_0}{1.266\times\sqrt{3}}\left(\frac{2}{\sqrt{3}}\times 0.2\right)^{0.2}\exp(-0.2) = \frac{2Kt_0}{\sqrt{3}}\left(\frac{2}{\sqrt{3}}\varepsilon_1\right)^{0.2}\exp(-\varepsilon_1)$. So, all the values are known to us ok except your ε_1 and you can modify this equation in this way so all known values you can take it on right hand side all unknown values you can keep which is nothing but ε_1 you can keep it on left hand side you can arrange this you can do some small calculation in between and like in a previous problem you iteratively solve this by giving different ε_1 values ok.

And finally you will see that for this particular case 0.002, ε_1 if you keep ok your this right hand side value is going to be same as it of 0.469. So, $\varepsilon_1 = 0.026$ ok to get this particular situation ok.

So, that is a question you know determine the maximum strain that can be achieved at the center line ok. So, you have to have this much amount of strain at the center line now for this how much is a blank holding force that is the next question. So, what I am going to do now I am going to now ε_1 I am going to put it here ok. So, $T_{1,0} = T_{1,B} = \frac{2\times600\times0.8\times10^3}{\sqrt{3}}\left(\frac{2}{\sqrt{3}}\times 0.026\right)^{0.2}\exp(-0.026)$here and I am going to get my $T_{1,0} = T_{1,B} = 267\ kN$ ok this one. If this is known to me then I can get a blank holding force how $\frac{267}{2\mu}$ ok. That B is nothing but my blank holding force ok which is what I am getting as 890 N here.

You can check it the calculation is correct ok. So, this way one can solve this particular problem ok. So, this little bit of you need little bit understand this so we are going to put this condition to get maximum strain at the center location ok. So, same situation does not exist below blank holder so you are keeping a general form of the equation. So, by equating these two ok you can get strain ok and then you put this strain value ok to get your $T_{1,0}\ or\ T_{1,B}$ ok both are going to same and then that can be used to get your blank holding force ok. So, we stop here with this particular section and then the next session we can sort a new module. Thank you.