Mathematical Modelling of Manufacturing Processes
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Lecture – 16
Mechanics of Sheet Metal Forming-2

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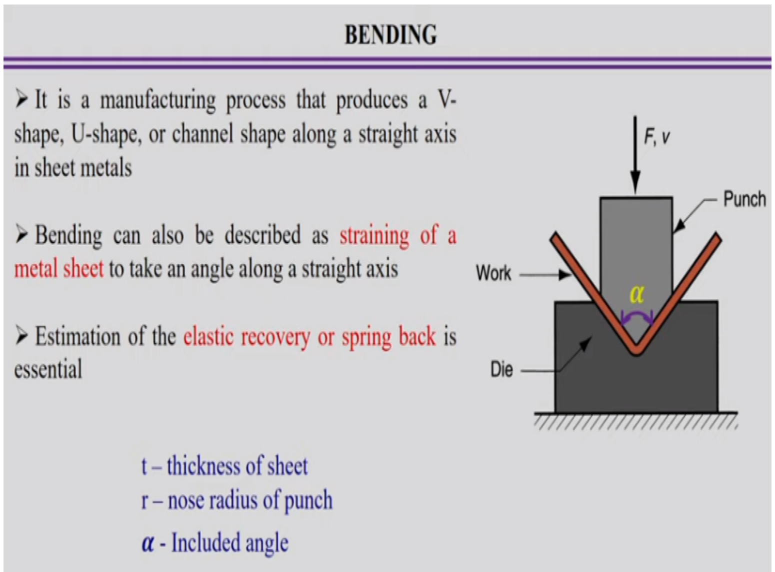

Apart from deep drawing process now I will try to discuss bending process in bending process what we can do in this cases we can get it from a flat sheet we can deform this in a particular shape and a particular angle for example we can produce the kind of v shape or u shape or maybe channel shape with respect to the straight with one straight axis in specific to the sheet metal.

So of course bending can also be described by the straining of a sheet metal or sometime we can use the straightening of the sheet metal to take a particular angle with respect to one straight axis. So here we can see from figure also see suppose this is the sheet metal and it we started it from the flat sheet plate and then having thickness t in this cases and we apply the force here f with a particular good velocity v and this sheet metal takes the shape according to the angle of the punch.

Or and of course this punch and this Die could be merged in such a way that it can create the certain bending angle. I think that bending angle can depends on the what the value of the punch angle we provided here. For example here alpha is the punch angle so within the Die and punch we can create with different material and then we can get the we can create the we can create the straining this thing with this we stick to the particular straight axis.

That is typically called the bending process but one of the most important thing is that since material behaves like elasto-plastic in nature so therefore elastic spring back or may be elastic recovery is more important to design or to decide the what should be the punch angle when you try to make the bending at a particular angle.

So we will try to discuss in that point of view but of course if you want to get the angle particular angle alpha to one to produce in the work piece material but when we just remove or just remove the punch then some amount of the angular recovery will be there and that happens because of the material behaves like elasto-plastic in nature. So therefore we need to takes care of that elastic recovery accordingly we can design what should be the bend angle in this particular case.

So mathematically what we can estimate this recovery process and what we can make decide the angle we will discuss these things but here in this particular configuration process this t is the thickness of the sheet and r=nose radius of the punch basically the radius here some cone so here some radial distance r is there. So that knows radius of the punch and alpha is the included angle here.

Alpha is included angle and then alpha is measured on the with respect to the punch. So that is the alpha is the included angle so this parameters we tried to describe the process further.

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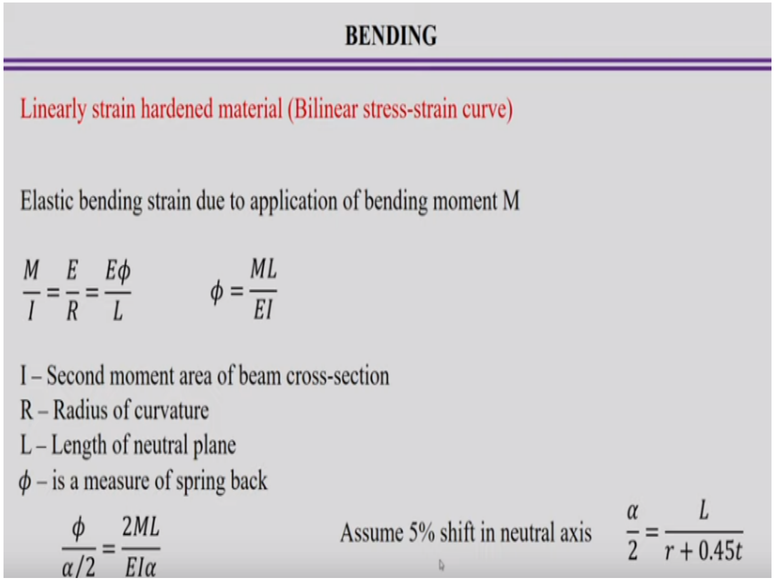

Now if we assume the linearly strain hardened material so the stress-strain behaviours we know the stress-strain behaviour can be represented at simply that instead of taking this is the elastic part one linear and this is the L cross and the elastic deformation and that is called the stress strain and this is the stress so this the stress-strain curve it is more simplified way to.

We can represent in the Bilinear stress strain curve that means this is small linear represents the elastic deformation components one is the L point and the second linear component depending on the slope depends on the strain hardening effect particular material but this is another linear slope that represents the elastic deformation.

So once this up to deformation up to this point so if we remove the load at this point then there some amount it will come back to this point. So this part is called the elastic deformation but this is the elastic recovery and that elastic recovery rapidly can estimate from the stress-strain diagram for a particular material. Of course there must be some amount of the elastic recovery will be there that depends on the two things two components.

One is what is the initial flow that means Young's modulus of a particular material and that means unit of the strain given up the stress level with respect to the straining to the particular component. So that this elastic permanent deformation and this amount is elastic deformation So that elastic recovery you can say so that elastic recovery you can estimate in the bending process also but in different way. So what we can do these things let us look into the typical bending process. So here we can we have seen that this is the typical bending process now with respect to this bending process we take this as reference both are symmetric component then we can represent in the one symmetric part is something like that.

So it is a kind of so kind of a cantilever beam so that it starts bending with respect to that and of course this is the neutral axis of this beam this is the suppose this is the thickness of the beam t and it bent with respect to the angle. Suppose this is the angle phi and we measure the radius up to the neutral axis that is radius r and the length L that length L actually measure over this neutral axis.

Now with this configuration because we can assume the situation kind of the cantilever beam it is fixed in the side and suppose it is subject to do peer bending moment m. Now when it is subjected to peer bending this beam and that creates that creates the length over the length is measured over the neutral axis and then we can say that this expression M/I=E/Rand that subject to the peer bending elastic bending.

Of course it corresponds to elastic bending due to the application of the bending moment M then we can hold from the from this beam configuration the relation within this M I. I is the second moment area of the beam cross section so it is a and then E is the Young's modulus and R is the radius of the curvature.

So once you know that thing then radius of the curvature can be represented and of course this phi is the included angle. So this phi is the included angle because initially it was a straight beam with application of the bending moment it deformed then creates the angle phi. So then we can put the S=R theta in this case is L=R* phi so that means R =L/phi so if you replace R=L/phi then can be represented that M/I E/R = so therefore E/R is like that E/R R=L/phi.

So therefore E phi/L so we get this relation. Now if you relate with respect to the bending M and I then we can find out that phi=in terms of the bending M L/E*I so that relation you can found out but phi is here important because phi comes because it is a measure of the spring back effects. So and this angular form this angle is the measure of the spring back particular to the bending process here? Now this alpha we have already estimated that alpha sorry we have already defined the alpha that alpha is included angle and that is on the punch.

Then alpha/2 is half of the angle so therefore because we are considering the half of the beam so we can say phi/alpha/2. So we can from here we can relate to that simply divided by alpha/2 and right side also we can divide alpha/2 so it becomes phi alpha/2=twice ML/EI alpha there things but alpha can also be distributing other way also if we assume the 5% shift in the neutral axis. So of course if beam is a straight beam.

So in this particular structure the straight beam that neutral axis is exactly at the middle point. But in case of the curve beam there is a shifting of the neutral axis. If we assume that there is a 5% shift in the neutral axis then we can found out that alpha/2 that means half of the included angle that means similar with the L= alpha/2 but the neutral axis into the radial distance R+0.45*t so this 5% shift in the neutral axis depends on the thickness of the beam

So in this case if it is like that if we assume this is the included angle alpha/2 bending and if we assume that this is the radial distance R and this shifting of the neutral axis such that this is the only 45% of that means 5% of the change that means 45% of the thickness, thickness of the is this one so from here I can found out that L= alpha/L=R theta.

So this is the theta angle and this is the distance R the reference to the neutral axis. So from here we can estimate the alpha/2 =L/ this thing but if we assume that but if we assume there is no shifting of the neutral axis is exactly the middle, middle point so maybe this we can say exactly middle point without any shift so it should be 0.5t half of the thickness. So therefore it should be 0.5t so depends if we assume the 5% shift in the neutral axis then only this expression we can write in that way in that also we relate the alpha value.

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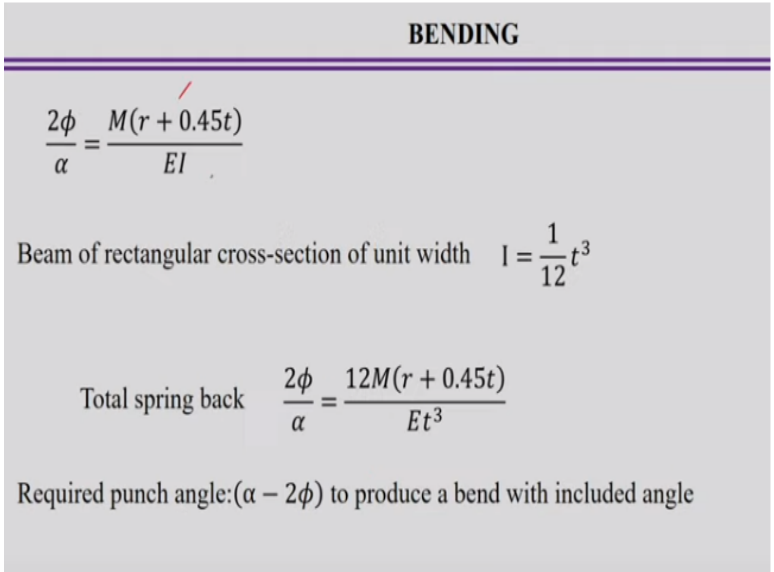

Now once we do this thing then we can found out from the situation that 2 phi/alpha= M r + this =EI. Now if I assume that beam is the rectangular cross section of the unit width. So width of this beam=unit value then I can be that I can be estimated that 1/12 and t cube t t to the power 3 and with respect to the neutral axis exactly or the middle point. So if you put this I value so we can found out that 2 phi/alpha=12M this is the radial distance and E t cube.

So you can simply putting this value and we can get the spring back in terms of alpha and phi here we can found out but actually so this is the relation of the spring back effect if you want to analyse in specific to the bending process we need to use this relation. But what you can modify the design of the punch so the required punch angle should be less than that what is the actual assuming this in which angle do want to bend?.

So then actual punch angle to be alpha – twice*phi so that if you know all this information we can relate between the phi and alpha and but if we individually estimate what is the phi and alpha then the actual required punch angle can be estimated that alpha-2/phi not exactly alpha. So if you want to create the angular deformation at the included angle alpha then punch should be less than that angle

So what is that value that is alpha - twice phi so this way you can make the design and it is a roughly estimate what is the punch angle if we consider the spring back effect in case of bending process. Now this another sheet metal forming process that is called punching and blanking process.

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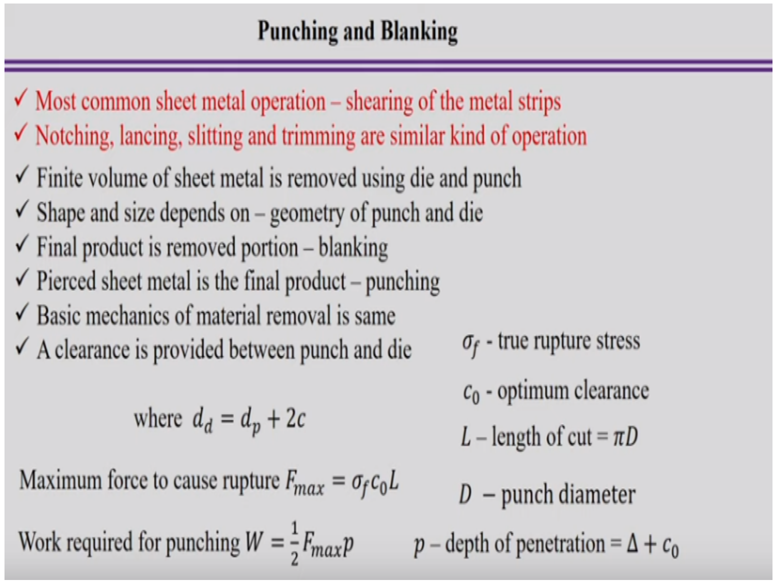

In most widely and most common process sheet metal and of course this punching and blanking normally happens due to the shearing of the metal shearing of the strips. So these are the other that are there are other types of the processes which is similar kind of the operation that is Notching, lancing, slitting, trimming out of the similar kind of the operation. But in principle they follow the similar kind of the mechanism.

Of course in general we can say this is the punching and the blanking operation in case corresponds to the sheet metal process. So finite volume of the sheet metal is removed using die and punch. So normally if we design this is the and the sheet metal on this. This is the die and if we design some punch this is punch and this is the die such that punch and die can be in such a that this sheet metal is just punch applied the load in the sheet metal at the edge there is a shearing happens the edge and then separate the material.

So this is the typical mechanism of the punching and blanking operation so finite volume of the sheet metal is removed using simply die and punch set particular set. So in these cases the shape and size of course the shape and the size depends on the particular shape and size if you are going to produce the difference in the geometry of the punch and die and combination of the punch and die.

So final product is removed first removed portion and the final product is the which part is removed if final product is that part then this is called a blanking operation but if sheet metal is the final product not the removed product so in that case is that process is called a punching operation actually blanking and punching operation in terms of the mechanics basic mechanics are of the metal removal is the same irrespective of the blanking and the punching process.

So in general we discuss in general on that so therefore once we try to separate the material by shearing action at the edge of the sheet metal and between the particular system of the punch and die. So there must be some kind of not exactly some kind of clearance would be there within the diameter of the punch and the diameter of the die. So that clearance would be important parameter in case of the punching and the blanking operations.

So normally this relation is like that the diameter of the di=diameter of the punch + clearance c. So basically this both side we can provide some kind of the clearance c c c such that and this is the diameter of the die and this is the diameter of the punch. So that such that it gets this kind of relation diameter of the die= diameter of the punch + twice c. So this kind of we listen we can get.

So we can rapidly estimate the other parameters here also so maximum force to cause the rupture. Actually in these cases we are using these terminology rupture because fracture is normally used where there is a application of the tensile loading and normal stress is acting there and then in that case we can use the fracture happens and in a particular point separated of the material with application of the tensile loading but in case of but in case this punching on the blanking operation the normally the fracture happens with the application of the shear stress.

So therefore when the shear is responsible to separate the material then that in that mechanism it is called the rupture. So therefore we can say the rupture stress instead of the fracture stress because rupture stress we are telling because all this all this actually rupture happens due to the application of the shear loading condition. So therefore maximum force to cause the rupture we can say F max this is the rupture stress to rupture stress and then c0 is the optimum clearance and L=Length of the cut.

Actually if we look into the punch and the operation so is a there is a particular this is the punched diameter for example this is punch and then this clearance is given c0 optimum clearance and so therefore if this is the punch diameter d so this perimeter will be phi d. So therefore this area the actually shearing happens over this area. So this area=phi d*c0 that area multiply by the rupture stress that indicates the total maximum force F max equal to this.

So thus we can estimate the rupture here also. Now work required for punching equal to now this is the maximum force but this maximum force not normally reaching in that way. So if the if you look if you focus on the how shearing happens between the punch and die. We can see that the material is also there so that with the application of the punch deformation happens here and then after that with this material at the particular point.

Once over the top surface this it the application so deformation will happen but with the application of the load gradually increases and once particular point then fracture will happens over this sheet metal over this particular angle if metal it is a ductile material but this happens after certain deformation of the punch enters to the die up to a certain distance then after that it breaks.

So therefore load curve is something like that is linearly increasing from 0 to maximum load and this over the clearance delta. So over the length delta and then clearance that means once its reached gradually load is increasing and once it reach over the maximum point then suddenly rupture happens at the sheet due to the application of the shear load. So therefore that is why if you take the average value F=0 to F max and then there is the average value of the forces and p is the depth of penetration.

But depth of penetration it is not like that just punch a touch with the work piece material in the die clearance it will not break but once punch travels up to certain distance then only and reached the maximum value of the load then only the shearing happens. So that is why p is called the depth of penetration in these cases p depth of penetration can be estimated some delta and maybe clearance and plus clearance between the punch and die that value.

So depth of penetration depends on these two parameter and once you know this depth of penetration then we can estimate the work required during the punching operation.

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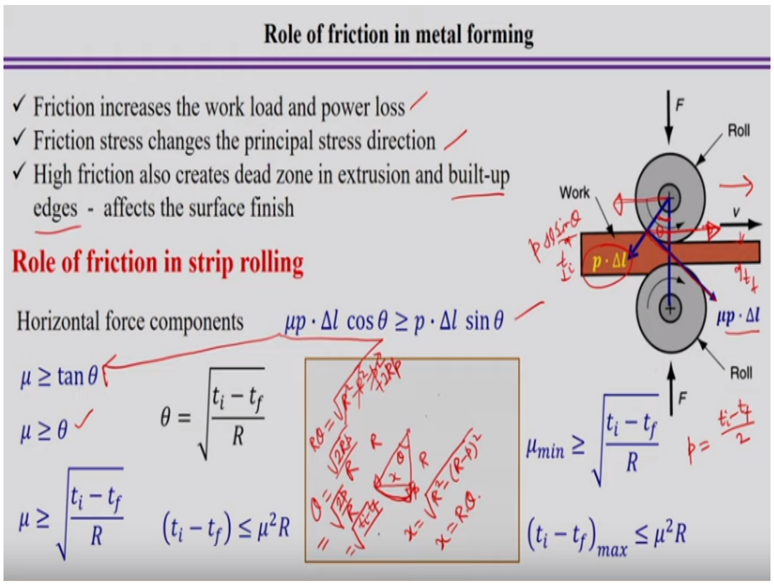

Now that look into the other elements in this process that is called role of friction in the metal forming process we can see that of course in the when you describe the bulk metal forming process and specifically the rolling process there is the friction happens between the strip and the wheel. So therefore role outside regular surface the friction normally acts here and with respect to we can estimate the frictional force or frictional stress also but definitely they are just some role in the in the metal forming process.

So therefore friction increases the work definitely the friction increases the workload and of course if it is accounted some amount of the power loss during the process. Because there is some power is required to overcome that friction but we can look into that how what is what way you can estimate the role of the friction in case of the metal forming process. So therefore frequent stress of course there is another role due to application of the friction so friction stress actually modify the principal stress direction.

So they are having some role to change the principal stress direction frictional stress and of course the adverse effect of the friction is too high that it create dead zone it can create some in extrusion and it can create the build-up edge also and that affects the surface finish process during the metal forming process but what we estimate the friction now if you take a small element and this work piece.

This is the roll contact and this is the centre point and we can take a small element delta L so delta L small element and this small movement is making this is the angle its making the angle at the angle theta and so therefore at this contact is acting and this is it this is the in inflow and this is the outflow of the material.

So then now over this element we can see if we consider a small element delta L above the roll and this angle included at that angle in contact and the work piece metal we can see this angle is basically a say this is angle theta. Now on this element what is the normal force or normal stress is acting? We assume that normal stress is acting the normal pressure is acting p so that p we have already calculated during the explaining some of the rolling process.

So once p is acting so then normal force and normal stress is normal pressure we can say that that means unit of stress here. So over this element delta L the p*delta L and in the other directions we can take the uni-dimension therefore this is the force is acting normal force then what were the frictional force? Frictional force will be that this is the frictional force acting for this small element here the mu*normal force.

So mu*p*delta is the normal force? So here is the frictional force acting and here other is the normal force acting during this process. Now we want to consider the continue the movement of the material during the rolling process with the particular velocity v in this case therefore we consider the horizontal force balance in these cases using these both the components. So horizontal force balance what do we can do?.

So we can take the horizontal components of this force first is the normal force p*delta L that is the normal force. So this horizontal component of this force is that we can see that along this direction this is cos p*delta L that is the I think sin component and this is the cos component. So horizontal force is acting here is the sin component. So p*delta L sin theta this is the horizontal force this thing.

Another frictional force if we look into the same frictional forces acting now if you consider the component of the frictional flowing in the horizontal direction which may be acting in this direction frictional force and of course this direction when frictional force is acting means new p L that is the cos theta component. Now since it is just flowing in the direction of the component horizontally component of the frictional force and its particular direction.

So that means to make the continuous flow of this different material then this frictional force must be greater than that equal to will be that normal force components and that is the horizontal force we can get from here this is greater than or equal to this. Now from this relation we can find out that mu>=10 theta.

So that means coefficients of the friction should be >=10 theta that can the relation and we can reach from here it means if theta is very small normally theta is very small in the actual process condition that means deformations this is up to certain limit is there. So then theta that is this angle is very small in these cases. So therefore we can approximate mu>=theta. Now theta can be estimated with respect to the other parameters.

So here you can see the other parameters in theta can be estimated also that this is the centre of the roller. So this is the radial distance rhis is also r. Now this is distance suppose this distance=x now x can be represented like that and this is a small list and so x can represented like that so x= root over of R square and suppose these distances p for example this is small distance p. So R square root of R square- R-p and then the x can also be represented that R*theta in this case we can approximate this x=R*theta and x=root over R square-R square-p square.

Therefore R theta=root over R square- R square-P square +twice R*P but p in this case we can say R square-R square balance and p is also very small in these cases so you can neglect this so basically theta=p square can be neglected because theta=root over twice R*p/R or you can say theta=root over of twice p/R. Now p can be estimated like that p is suppose this is the t I the initial thickens and the final thickness equal to say this is the tf. So this small element so p can be represented here p can be represented here like ti-tf/2 so difference but that difference both the velocity is there so difference/2 so p can be represented by ti-tf/2 or we can say root over of ti-tf/R.

So that is where theta can be approximated like that root over of ti-tf/R because in this ti and tf is the we can easily measure this parameter I this rolling process. So theta can be represented with respect to that parameter. So once we estimate the theta equal to this and then we can get the conditions mu>= in the terms of other parameter the coefficient of the friction must be greater than that equal to ti-tf/R or tit f and R all the parameters are all defined in a particular rolling process. Other way from here we can see that ti-tf<=mu square R.

So this is the realisation you can reach from the effect of the friction during the rolling process. Now you can make two conclusion one is that minimum value of the coefficient of the friction so mu so from this inequality we can get this minimum value of the coefficient should be ti-tf/R that is the minimum value of this I think we can better to say this is the minimum value and then maximum or other way in terms of or other what is the reduction ti to tf we can do in a particular rolling process if coefficient friction is known to us.

So then maximum reduction can be possible in terms of the coefficient of the friction. So and it depends on the coefficient of the friction as well as the diameter of the roll. So here we can put the criteria what is the maximum reduction it is possible during the rolling process and this kind of relation we can get from the analysis of the friction effect of the friction during the metal forming process. So this is all about the sheet metal forming processes so thank you very much for your attention.