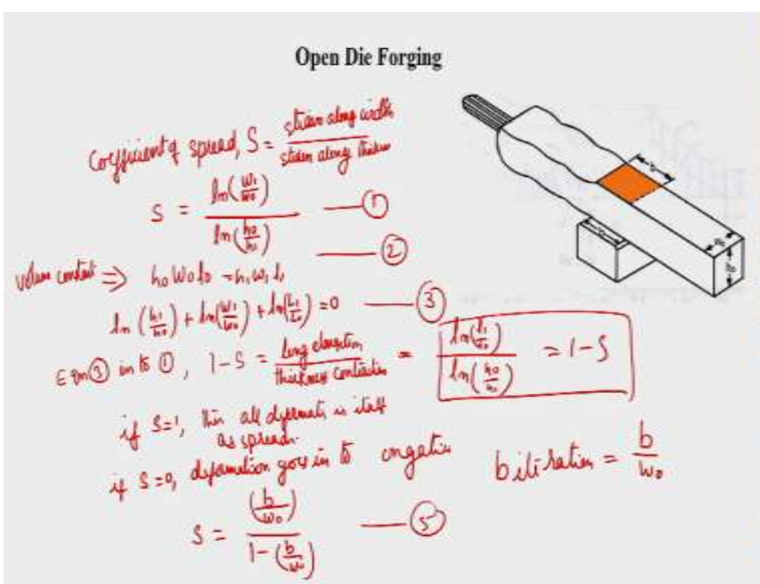
Plastic Working of Metallic Materials
Prof. Dr. P.S. Robi
Department Of Mechanical Engineering
Indian Institute of Technology – Guwahati

Lecture 15
Analysis of Forging (Contd..)

So we will come to now the open die forging okay analysis. So what are the things which people consider when you discuss with the when you deal with the open die forging the simple example of an open die forging is the cogging. So and as we have mentioned the earlier, the large billets they had to break down the structure, because large billets always contain, large amount of inter generate segregation, coring, maybe some internal differs, gas ferocity all those things may be there, and its size is also relatively very large.

So, normally by open die forging people just reduce the cross sectional area and in general the cross sectional area will be maintained the same similar, but it is not that always it will be like that, but in general if it is a square cross sectional area people will prefer to have a square cross sectional area. So they will keep on rotating after each forging operation after each impact or and these are generally done by power press or pneumatic press or even hydraulic press also they can do it.

(Refer Slide Time: 01:34)



And this figure also tells that okay it is kept on bottom bench bottom die and the billet is kept in between then from the top which is just impacting at this region this straightened region it is there so, with the B and the without the billet is w_0 and then it is just compressed, okay by applying a compressor force it is being compressed okay. Normally the hydraulic press or power hammers are generally used for this purpose, because we need a very high capacity press for this because the billets are very larger number.

So, when you are doing this, the billet size is much larger than your tools at any time when you look at it, the deformation is confined to a small area like this, it is only confined to this small area not around the full length of the your ingot. So, that is one thing. So, at every stage a deformation, it just deforms by a small amount, not small amount it just deforms, there is a change in the cross section area you may rotate it by 90 degree. So that now again, so, the moment it is pressing, normally the lateral flow of the material will be there.

And when you rotate it by another 90 degree again that height will reduce So, ultimately what happened the cross sectional area, it may maintain the same cross sectional shape, but the dimension will keep on changing and with the result that it is a length will keep on increasing. So here x_0 will get reduced w_0 will get reduced, but length of course length is not from here that will get increased. So, that is what will happen.

So, in this case, the material deforms under compression and simultaneously with the conceder there is a considerable spreading in the lateral direction. So, that is what it is a cross section area gets reduced and when you are considering the constant volume relationship, you can find out how much length increasing there. The simplest open die forging is a cogging a billet between flat tools to reduce the cross section area.

And, in this when you talk about the open die forging, the term which comes is coefficient of spread, defined by S is equal to the width elongation the strain in the width direction divided by strain that is positive along with the thickness direction, the strain along the width divided by strain along the thickness. So that is S = the ratio of log w 1 by w 0 and along the thickness it is the compressed so log h 0 by h 1 is it that an open die forging this straddling mean.

$$Coefficient\ of\ Spread, S = \frac{Strain\ along\ width}{Strain\ along\ thickness}$$

$$S = \frac{\ln\left(\frac{w_1}{w_0}\right)}{\ln\left(\frac{h_0}{h_1}\right)}`$$

Because of the barreling of the bar due to cogging it is difficult to measure the width natural strain. But you can easily measure the increasing the length because using the constants of your volume relationship that is nothing but h 0 w 0 l 0. So volume constant is equal to h 1 w 1 l 1. So, in this case now from that now we can find out that the relationship if you just take the natural logarithm log h 1 by h 0 + log w 1 by w 0 + log l 1 by l 0 is = 0.

$$h_0 w_0 l_0 = h_1 w_1 l_1$$

$$\ln\left(\frac{h_1}{h_0}\right) + \ln\left(\frac{w_1}{w_0}\right) + \ln\left(\frac{L_1}{L_0}\right) = 0$$

So maybe this was a first relationship. This is your equation number 2 this is your equation number 3, if you do that so if you substitute to this equation 3 into 1 we can get this relationship 1 - S is equal to length elongation by thickness contraction that is equal to log l 1 by l 0 divided by log h 0 by h 1 this. So this relationship is equal to 1 - S. So, in this expression if $S = 1$ then we can say then the deformation the all deformation is itself as a spread as spreading is there if $S = 0$.

$$1 - S = \frac{length\ elongation}{thickness\ contraction} = \frac{\ln\left(\frac{l_1}{l_0}\right)}{\ln\left(\frac{h_0}{h_1}\right)} = 1 - S$$

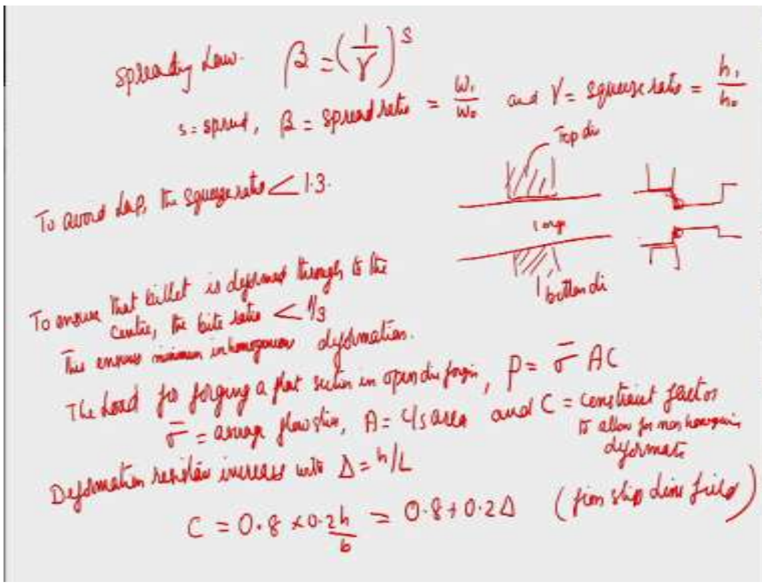
The elongation is taking place okay. So then the deformation goes into elongation. Now, you will find that this spreading depends on chiefly on the bite ratio. So, bite ratio that means the S is equal to the bite ratio is given by b by w 0 b is the top edge where it is in contact with that it is between compressed between width of that part okay that distance at with it is contacting. So, from that part will it will elongate, so, that is what, why it is called a b by w.

$$bite\ ration = \frac{b}{w_0}$$

So, S depends chiefly upon the on the byte ratio from experimental this one that people found that this b by w divided by 1 - b by w by this relationship byte ratio depends. Now, our this equation number 1 also known can be expressed in the terms of spread low.

$$S = \frac{\left(\frac{b}{w_0}\right)}{1 - \left(\frac{b}{w_0}\right)}$$

(Refer Slide Time: 9:24)



So, the spread law spreading law that is beta is equal to 1 by gamma the whole raise to S. Where S is the spread, where S is equal to spread and the β is the spread ratio which is defined by w 1 by w 0 the spreading is spreading in the radial direction okay, and the γ is the squeeze ratio which is nothing but how much it is compressed h 1 by h 0. So this ratio but this cogging when you tell it so open die forging has certain drawbacks one is that since only a part of the surface under the byte is being deformed identity is see we mentioned that I mentioned earlier also.

$$Spreading\ Law\ \beta = \left(\frac{1}{\gamma}\right)^{s}$$

$$S = spread, \beta = Spread\ ratio = \frac{w_1}{w_0}\ and\ \gamma = Squeeze\ ratio = \frac{h_1}{h_0}$$

Only a small area of the total length of the piece is being compressed, okay, the remaining length is not press simultaneously okay. Then there is a danger of crossing surfaces because if I just press between this and between these are the top bench top die and this is a bottom die and this is a ingot after the formation you will find that it is like this at any point in this I am telling okay it is like this or maybe like we can say that this part was along with that rod so, okay.

So, now the next bench will be somewhere here next compression will be this area, so, there is a here if the deformation is very large this will come and material flow and then what will end up be that there is a lap so, metal will come over that so, then overlapping in the that is why is called us a surface lap so, there is a chance of formation surface lap in this case if the deformation is very large, especially okay so, the unforged portion of the workpiece you will find that.

So, just like if it is true large rage will be like cheering and there will be a step which is forms the next one when it comes metal rages for here and then you will have a lap at this region okay. So, that is not that is undesirable. So, you should know that is one thing. So, and how we can do that this laps will form is the deformities they above certain critical deformation critical strain. So, below that it may not happen, but above all that it is going to happen because the sideways barreling also is going to take place in this case and that will always cause for this one.

So, if your deformation your straight is very large, the chance of lap formation will be there and for avoiding the lap, okay to avoiding the lap the squeeze ratio maybe kept to below 1.3, so, that is one. Now, second thing is this open die forging has done for is being carried out for reducing the cross sectional area of large pieces. So, in that case your deformation has to the deformation has to reach the center of the piece that is also necessary otherwise what will happen already deformation take place of the surface but at the center nothing will happen.

So, to ensure that each billet is deformed through the center the byte ratio should be less than 1 by 3 so, open die forging you are going to deform the large the billets. So, when you are wondering grow that the main purpose of this is a mainly to break the structure especially generative structure, coring, segregation and all those things you have to pay further, so the deformation, strain to penetrate up to the center if the strain is less than certain amount of whole purpose will not be met.

So, for that case no byte ratio for further deformation to ensure that billet is deformed through the center the byte ratio is it should be less than 1 by 3. So, this ensures homogeneous deformation minimum in homogeneous deformation now if you look at that in open die forging the load required for the flat section in open dies. So the load for forging a flat section in open die forging P is equal to sigma bar AC, sigma bar is the average flow stress.

$$P = \bar{\sigma} A C$$

A is a cross sectional area of the billet and the C is a constant is a constraint factor we can say which is constant and with the constraint factor to allow for to accommodate allow for non homogeneous deformation you know that the earlier about the deformation soon we have decided that is the deformation resistance increases with the delta the deformation resistance increases with the delta which is nothing but h by L we have discussed earlier. So, there are cases where from the slip line field. We can find out that one relationship is equal to 0.8 into 0.2 h by b. So that we can say 0.8 + 0.2 delta.

$$Deformation\ resistance\ increases\ with\ the\ \Delta = \frac{h}{L}$$

$$C = 0.8 \times 0.2\frac{h}{b} = 0.8 + 0.2\,\Delta$$

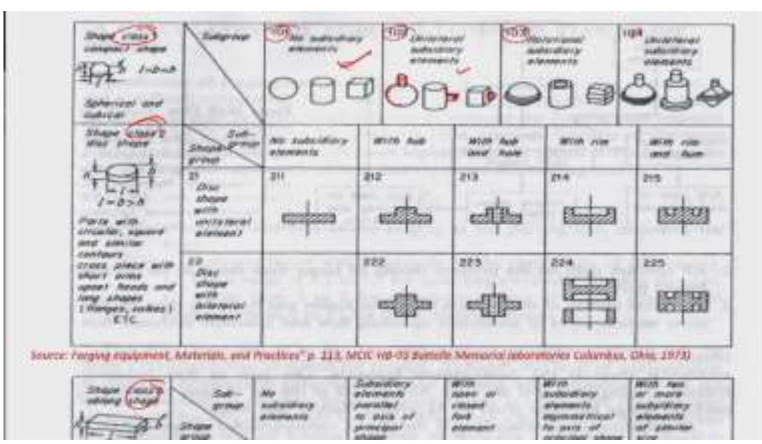
So, this is from slip line field theory people have arrived at this relationship, okay. So, now, we will come to close die forging, so in close die forging which is not that as simple as we have discussed, the deformation in a close die forgings is very complex, because the metal has to flow during the deformation, compression it has to flow in the lateral direction and it has to fill up the intricate parts of the material and during the metal flow the friction there may be a lap which can forms that should not be there, the die should be completely filled

And any excess metal has to squeeze out through the flash land and gutter. Okay these things are there the component shape is a very deciding factor for this purpose in a close die forging and close die forging you cannot get because this is a component itself you are going to get it which are to be put into use. And normally you will find that automobile industry is the crankshaft connecting rod many of these things are made by forging the hook of a crane. This is all made by forging.

So in all these things when you look at it is not a one step process and which we have discussed in our first lecture. So, it consists of several steps okay. And the intermediate steps is necessary for finding out the especially when the component is very complex okay. And your design for that intermediate steps, you know, it requires a considerable experience and skill. So, this is very important. Now, overall success of the forging operation, it requires an understanding of the flow stress of the material.

And understanding of the frictional conditions between the die and the billet at the droplet in condition. And an understanding about the flow of material in order to obtain an optimum geometry for the dies. So, it is not that anywhere it will flow that you have to know which way is forming so that now defects are not formed like laps, closure, these things should not form. So, you should have an idea about the flow of the material inside the die when you are operating. So, if you look at the rationalizing the design of closed die forging is basically by the classification of shapes, which are commonly produced by this thing.

(Refer Slide Time: 20:24)



So, a large amount of work has been carried out in terms of forging, close die forging and depending upon the complexity of the shape you will get it can be classified whether it is very simple or this complex or this very difficult and other thing. So, like you can see that it is divided into class 1 class 2 class 3 like that it is the where the class 1 is the compact shape generally which is spherical or cubical.

So, that means if it is cubical which is $l = b = h$ the normal or approximately equal to that shape can be classified as very simple case that is a class 1 or if it can be a spherical case, it can be a cylindrical case also cylindrical samples also where h is equal to your d height of the cylinder is equal to diameter or maybe approximately equal to not very long okay. So, in that itself class 1 itself you have different groups 101, 102, 103, 104.

So, in this class 101 there is no subsidiary element it is a simple sphere is a single cylinder or it is a single cube. So, in that case you call it as subgroup 101. So, class 1 subgroup is one that is 101 you classify it. And now when you are move towards the right, the complexity again increases in this second case, maybe a unilateral subsidiary element is there on this spherical part. You have a cylindrical part here as an attachment okay, a subsidiary element is here, so then it is complexity slightly increases.

So, or maybe in the cylindrical piece you have a rectangular piece as a subsidiary element which is there. So, this complicates the forging die. Now, if there is a cube, you have a small cylindrical piece has a subsidiary appendix type thing which is there. So, they are also it complicates the shape but it is not very complicated. So, that is a in the subgroup or so, this is the most simplest case, then comes this one slightly complex, but in this case, you know when you look at its rotational symmetry element.

For example, the sphere on if you have around the sim, sim type thing, you have like certain sim type thing. If you have something like that projecting across the periphery or diameter and other things, then it becomes much more complex or single cylindrical piece is easy to make, but in that if by forging, but in that if you wanted all, all of cylindrical piece it becomes difficult because that you have to provide facilities for that all of part.

So, in the die all the dies if it is required so, then it becomes a very complex thing similarly, for a cube also at the on the center of a piece or one part of the piece know you have some part throughout the projection if it is there then it becomes much more complicated because material for condition will be compromised. So, that is one and finally, the last subgroup will come under unilateral subsidiary elements more or there okay. So, you have say both this rotational subsidiary element as well as this subsidiary elements are there.

So, maybe a multiple numbers are there here there is one here there is an extra. So here these 2 cases are there and in this also you have all sorts of make this type of a piece of origin and get it into this case is it is a very complex. So, when you move from the left to the right the complexity increases. Now, from class one, when you move up to class to class 3 or around this figure, if you come down, you will see again the complexity is increases. So, here it was spherical case or cubicle case or but when you come to this you have a discussion.

So, the diameter is much larger than the thickness or if it is a rectangular piece also then you have the discussion, it can be circular or square the parts are circular square and the similar contours cross section piece with short arms, upset heads and long shapes, flanges, valves, all those things are coming. So, for example, your single shape in the simplest case 211 this class classification 211 which is a very simple disc with a unilateral with the no unilateral element.

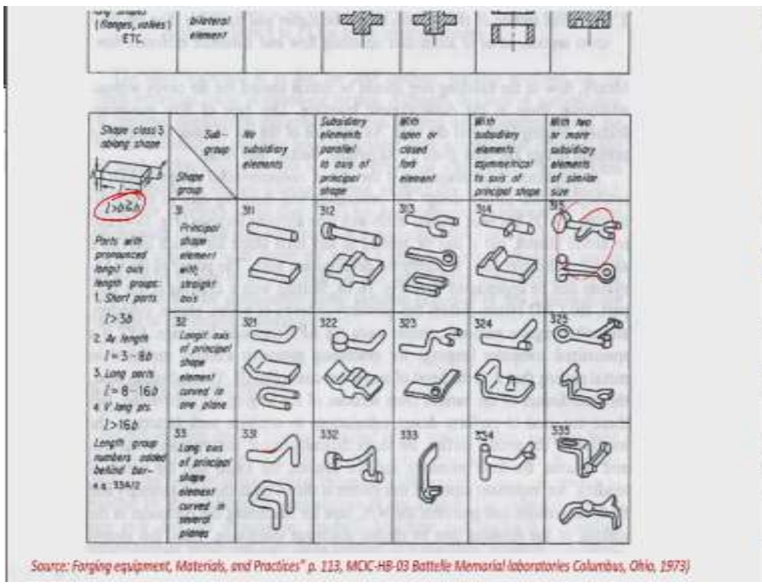
So, when you come this one, there is no subsidiary elements 211 there is no subsidiary elements simple disc, but when you come to see, if there is a disc with a hub, maybe this may be used for some flywheel or something if you wanted, then there is a disc and there is a hub, there is a complexity coming in this picture compared to this part. So here compared to this here, it is really complex, because one of the part you have to provide provision for this, this projection.

Similarly, when it comes to say a whole apart inside that so you have a hub and a hub which is all are the complex is going to be much higher. So similarly here, there is a disc but with the rim at surface only at the end there is a rim part is there then that also is difficult is to forge it is possible, but it is difficult compared to the other cases. And similarly, now with the rim and hub both coming, you will be a much more complex to get.

Because you have to have different more and more operations in each it changing in this case operation and finally, you have to provide for this facility in the finishing operations also maybe blocker die also you have to provide it. So, one is intermediate process is coming into picture, then your die has to be should be able to occur and not only in the finishing die but also in the blocker die this has to be there. So, blogging, blocker die also has to be designed accordingly.

Similarly, when you come to this 22, the disc shape with the bilateral elements here it is unilateral element but with the bilateral arm so maybe your hub is are on both sides that is again complex and hub and hole and rim, which is there on the both sides. So, here, so, there is a complexity still increase. So, this classification when you come, so, here examples are flanges and miles.

(Refer Slide Time: 27:16)



Now, the class 3, you will see that roughly 70% of the forging fall under this class 3, which is much more complex compared to shape class 2 and shape class 3, class 1. These are oblong shapes, you will see that one length is much higher than the other So, you can see that length higher than with much higher than the thickness and then there is going to be straightening complex compared to other one, example is the principal shape elementary with the straight axis like this.

You have this rod where the length is much higher than the diameter without any subsidiary element or a rectangular block right or whatever may be, that is also the simplest among this case, but in that is there is a subsidiary element here then it becomes difficult complexity is there. Similarly, you have this case also normal to the range to axis, the die also has to be listened, the blocker die has to be listen and you have to have extra process by which metal should be gathered before it reaches the blocker die.

So, the intermediate to operations are going to come whereas in this first category no subsidiary elements are there it is quite simple okay. Now with the open or closed fork element is coming. So, that is it increases the complexity is still higher so, when you move this side, it becomes more and more complex. Now, there are fork elements are there or this type shape is there where a hole is there and other things so, then it becomes much more complex.

Now with the subsidiary elements which are asymmetrical not symmetrical, then you may encounter other difficulties like die shift and other things may come into picture. So, you may have to provide some extra facilities for the die shift is not taking place and it becomes the die itself without difficult the intermediate changes increases and you see that with the 2 or more subsidiary elements of similar shape, that is much more complex.

So, when you move second longitudinal axis of principle shape element curved in one point so, here it is their curve is there, here it is curve. Here this curve you need intermediate process for a closed die forging of this. Similarly, the case is here also. So, here also you can see, where I am not going to discuss much about this fork shapes and other things are coming. So here, too much a complication is there.

And finally, the last part the longitudinal axis of principle shape element 11 several planes here like this, this type is extremely difficult a larger number of operations before the blocker operation blocker die you lie today and you have to bend it one way or bend it the other way all those things are coming here if it is there say here the cross section areas different all those things.

So, your operations keep on increasing with the complexity of the shapes or shape classification of forgings has been carried out and it is based on that you will find out what are the difficulties and other things So, you can see this is taken from published a paper. So, that is it and about the when you are doing the forging, how the flash is formed, gutter is formed that part we have discussed. Okay. So, with this class is, this lecture is over.