Plastic Working of Metallic Materials
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Module 3
Lecture - 1
Forging

So today, we will be discussing about our new module which will be the forging, forging operation.

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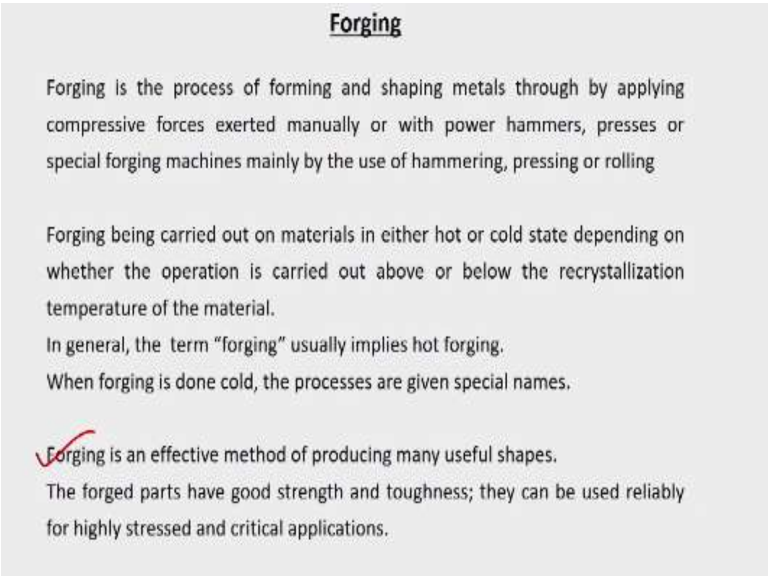

We have seen various operation in our introductory lecture, so out of that this forging, it is a process of forming and shaping metals by applying compressive forces which are exerted manually or with the power hammers, presses or special forging machines mainly by the use of either hammering, pressing or rolling. So like when you talk about forging, what comes to our mind generally is the power hammer or the presses, but there are other cases also, like presses means it can be hydraulic press, it can be pneumatic press, it can be mechanical presses, but in addition to this, there are other forging operations like ring rolling, so it is a rolling operation okay.

So by rolling also we can do the forging operation, so that is a part of the forging. This forging is generally done either in hot or in cold condition depending upon whether the operating temperature is above recrystallization temperature or below recrystallization temperature of the work piece material. If it is above the recrystallization temperature, you call it as hot forging, and if it is below the recrystallization temperature, then you call it as cold forging, but in general when people talk about forging operation, they refer to the hot forging.

This is because when it is under cold a condition, different processes are given special names. So the general term when you talk about forging is people talk about your the hot forging operation. This forging is an effective method for producing many useful shapes, say like maybe if you look at something around 50 years back, the complete automobile industries, they were making the components of their automobiles, whether it be automobile, say even shipbuilding also, crankshafts, the IC engine parts, piston, connecting rod, simple spanner these are all made by forging operation.

Because by forging operation, you can get some special properties also, say for example many of the cast alloys, the metallic alloys, the ductility is very poor, but when you want say for example, you take aluminum alloys or steel. The cast steel or cast aluminum alloys or any material the cast condition, ductility may be poor and hence like it cannot be used because when the ductility is very poor, that brittleness will result in failure without any warning, so **we** generally people don't prefer for that.

So most of the industrial purpose for structural application whether in automobiles or whether it in railway industry or whether it is in aircraft industry, it is the rod products which are being used okay, so that the cast material when you are forging it into or plastically deforming it by a special technique and obtaining the final shape, whether it be in the shape of sections like I section, square sections, cylindrical section, rectangular section, channel section or angle section, these are all under secondary processing is being done, so you call it as a rod products.

So in most of the materials which are subjected to dynamic applications, you need to have better higher ductility and other things, so people always prefer the rod product where the properties can be enhanced by secondary processing and followed by heat treatment. So in forged condition, you will find that the very good strength and toughness are obtained and they develop the directional properties, so anisotropic properties are coming the picture, but depending upon the deformation direction, you can get say better properties along the deformation directions, that is another advantage of plastic deformation.

So in forged component, most of the automobile components were made by forging, maybe around 15 years back, now also it is manufactured by forging, though some cases okay like the newer alloys like **(( )) (05:18)** and the other materials have come, but still it is the forging industry which is manufacturing this.

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So you will find that the typical forged parts a few cases if I say that rivets are there, the bolt, bolt head these are by forging, rivet head is also made by forging operation. Then the hook for crane, heavy duty crane or even light duty also, so the hooks are made by forging operation because when you are making by the cross die forging technique, the metal flow you can visualize the plastic flow of the metal and along the metal flow direction the strengths are better, so this plastic flow of the metal results in enhanced properties.

So even hooks of cranes are forged, they are never cast. Most of the connecting rods are made by forging operation. Gears, gears are made by forging operation, of course gear hobbing is there, but finally no they may give for the final shape and other things. Turbine shaft, they are also made by, all the, most of the shafts are made by forging operation so that the mechanical properties are better. Then several hand tools, railroads and other things are there. So you can say some common forging processes say open-die forging operation.

It can be basically classified into open die and impression-die forging, so these are the two basic forging operations which are there. So now depending upon the machine in which it is going you call it as press forging or hammer forging, drop forging, upset forging, swaging, rotary forging, roll forging, etc., many of these things are there, but in general, you can classify it as open-die forging and closed-die forging.

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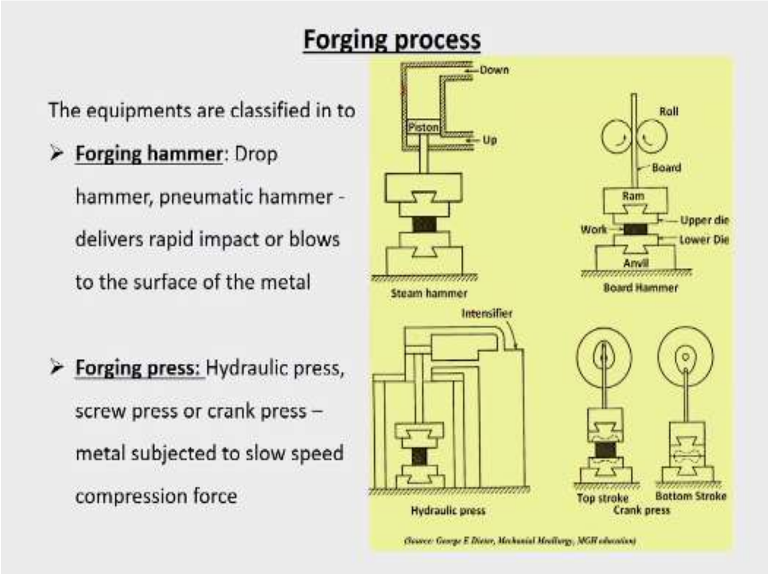

When you look at the forging equipment, there are large number of forging equipments, but the most common are say either it is by a hammer, forging by a hammer or by a press, these are the most in general thing and in some cases by roll forging also it is there, but a major part of the forging operation is carried out either by hammer forging or press forging. So in hammer forging itself, we can classify it as steam hammer or pneumatic hammer and they say board hammer, so these are the two hammer.

In hammering operation, the work piece materials, like say work piece material is kept in between in an angle and from a top die the upper die, it hammers, it gives an impact on the work piece. So the energy, the impact energy is transmitted into a work piece by repeated blows okay, it is not one blow or something, so repeated blow it is given, and after each blow, the material may be rotated depending upon what shape you want okay. So it is not that it is just a one blow and then it is so in the process of this hammering, so this repeated impact blows no if you give it you call it as hammering.

So with the repeated hammering operation, the cross sectional area gets reduced and with a concomitant increase in the length of the work piece, so that is the hammer operation generally or if it is kept inside a shaped die, then the metal will flow and fill up the die cavity, then it is in impression die forging, but most of the hammer operation. So say for example, this is a steam hammer. So there is cylinder and the piston arrangement is there.

So this is the old form, steam, but now steam hammer is replaced by a pneumatic hammer itself by proper control valve at one stage, the gas or air enters into this chamber and moves the piston down and by that, the impact energy, because this the speed of the hammer can be controlled in a pneumatic hammer, but mostly when you give the impact force, it is done at a very faster rate, so in that case the metal deforms and the next stroke what happens it moves backward.

The piston moves backward because now the second stage air will be passed through because you control the control valve and then what happen, the controller opens and then it pushes this piston backward and the die gets lifted, and at that time the operator may rotate it with his hand or maybe with means of tongs and other thing they can rotate it. So in all the directions no you can rotate it, so only thing along the length, there will be an increase in the length but cross sectional area keeps on decreasing.

So this is the simple case of a steam hammer and this is quite fast. Another is the board drop hammer which is there. So what happens is that there is also an upper die and a lower die and the work piece will be in between them. So one is the on the anvil the lower die is kept and in the ram of the board hammer no the top upper die is kept. Now with the means of some friction rolls, it lifts this board upward, now it will be lifted by some certain height and the weight of the ram and the upper die is so high, so above certain height if you lift it and then suddenly drops it down, with a very high impact it come.

So depending upon the weight and the height at which it is lifted, that potential energy is converted to kinetic energy at the time of impact and that mechanical energy, due to that mechanical energy what happens, the metal deform. So the only thing is that if you want a higher energy, you lift it to a higher height and because your weight is remaining constant for a particular die and this keeps on repeating.

A typical example, many of you might have observed the type of impact given in construction sites also where they give the impact for piling operation, a similar type is there, but here the thing is that in many of this case if there is a die cavity inside, this a material flow inside that, that is the only difference. With a hammer forging, it is the impact energy which causes the deformation, so it is a very fast process, so one has to be careful. So your die should have sufficient toughness to withstand this impact.

If it is very hard and brittle, its many times no to prevent the wear, you may have to harden the surface. So in that process of hardening, it may become brittle. So in such a case due to the impact, the die may brake and cost of the die is very high, so the industry people cannot afford to breaking the die very often okay. So in that case, the thing is that what people look for is the die should be tougher, so heat treatment has to be accordingly, maybe like the hardness may not be very high but it should be tough because otherwise it will not be able to sustain that impact rod and the die breaking may take place.

To overcome this, people go for hydraulic press. So in a hydraulic press, there is a hydraulic pressure intensifier and other things and it pushes the piston down, but as in a hydraulic press what happens is the moment of the die is very slow compared to that of a hammer okay, forging hammer. So press trust movement is generally low, so you can have it a hydraulic press or a pneumatic process that also is there, you can control the speed, so instead of a pneumatic hammer, you can use it as a new pneumatic press provided it is moving at a slow rate.

So in this case what happens is that the die can be harder, impact the material toughness need not be that very high like in a hammer, but here the toughness of the die need not be very high, but at the same time the die should not wear off because the metal plastically deforming material it is getting work hard and it will be rubbing on the surface of the die and at that time after a few forging operation, you may find that okay the dimensional accuracy is lost because the die wear may take place.

So in case of press since the operation is at a very slow rate, the die surface has to be very hard, so that wear resistance will be high, so that is the thin. So this is the same process, similar to this you're the hammer, pneumatic hammer. So on the forward stroke, the piston moves down and on the backward stroke, piston moves up, because in this case the hydraulic fluid will be entering into the top of the piston in the cylinder and it exerts the force necessary force and allows that the ram to move down.

Once it has reached the necessary height, then the valves will be opened and now the fluid will enter through this area and exerts a force upwards so that the piston will move upward, but the drawback with the press especially hydraulic press is that it is a very slow process, it takes time, but you get a very good dimensional tolerance, the dimensional tolerance are higher and then that is one biggest advantage and like many other defects which otherwise may form during the impact operation that can be eliminated by using a press.

Now there is mechanical press also like simple crank press, slider crank mechanism. This is very quick but its press capacity is not very high. So like the earlier times no, the metallic toothpaste, aluminum toothpaste tubes were made out of this one by means of a crank press only and it is very fast, very fast in the sense that it is like an automated process you can just go do it, so maybe the number of components it will make per minute maybe something around 60 to 120 also, it can go as high as 120 pieces also per minute, so that is the biggest advantage with that.

This is the operation, so there is a shaped cavity here and the work piece is kept inside that and when on the bottom dead center when it reaches, you will find theoretically the force which is exerted, the stresses which are exerted on the component will be very high, maybe theoretically it is infinity, but natural case that will not come, so you get a very high force and then the metal will just deform and fill up the die cavity when you it cross no just shown by this dashed lines and other things okay. So it can fill up that cavity very fast and it is a very fast process, the heat generated also will be very high.

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Table: Typical values of velocity for different forging equipment

Forging machine	Velocity range (m/s)
Gravity drop hammer	3.00 - 6.00
Power drop hammer	3.00 – 9.00
HERF machines	6.00 - 24.00
Mechanical press	0.06 - 1.5
Hydraulic press	0.06 – 0.3

In open die forging, as the metal flows laterally between the advancing die surfaces, there is less deformation at the die interfaces because of friction forces than at the mid height. Thus the sides of the upset cylinder becomes barreled. The metal flow most easily towards the nearest free surface since this represents the lowest frictional path.

Now depending upon say if you look at the various velocities at which the material deforms because earlier also we have discussed that strain rate sensitivity depending upon especially at the hot forging temperature or a hot working temperature the material is strain rate sensitive. So at a higher velocity when you are deforming it, you will find that its flow stress may be very high also, but that is not the thing. You can say that in a gravity drop hammer, the velocity of the ram, ram moves at something around between 3 to 6 meter per second, which is quite high.

In a power drop hammer, it may be between 3 meter per second to 9 meter per second and high energy rate forming machines are there, it may move anywhere between say 6 meter per second to as high as 24 even 30 meter per seconds also, one has to be very very careful while dealing with this. So these are the high velocity forging operation, but when you come to press in a mechanical press, you will find that the velocity is something around as low as some 0.06 meter per second to 1.5 meter per second.

Whereas in a hydraulic press, it is still lower, say maybe from 0.06 meter per second to 0.3, it can be even smaller than that also, so to 0.3 meter per second. So in the process, the velocity of the die block or the ram is very less compared to that of a hammer forging. In open die forging, so classification is open-die forging. In open-die forging, the metal is kept between two flat plates or maybe some contour shape, but it is not filling up into any cavity okay whereas in closed-type forging, the terminology is not correct one, has to call it as impression-die forging.

In the die cavity, there is an impression, a cavity is there into which the metal will flow and fill it up that is called as the impression-die forging. So in open-die forging as a metal when the ram moves down, the metal will flow laterally between the advancing surfaces and there is less deformation at the die interface because of the friction force at the mid height okay, so there is less deformation. So at the mid height, you will find that large the deformations are taking place whereas at the contact between the die and the work piece, the deformation will be slightly less because of the frictional forces.

Thus the side of the upset cylinder becomes barreled. So if you are keeping a cylindrical piece and then pressing it at the top, because of the frictional force lateral flow will be less whereas at the middle section, mid high section, it will be more. So if it is a cylindrical piece, you will find that the shape attains that of a barrel, barrel the central portion will be having a bigger diameter than the top and the bottom that is why this is called as a barreling. So the metal flows most easily towards the nearest free surface since this represents the lowest frictional path.

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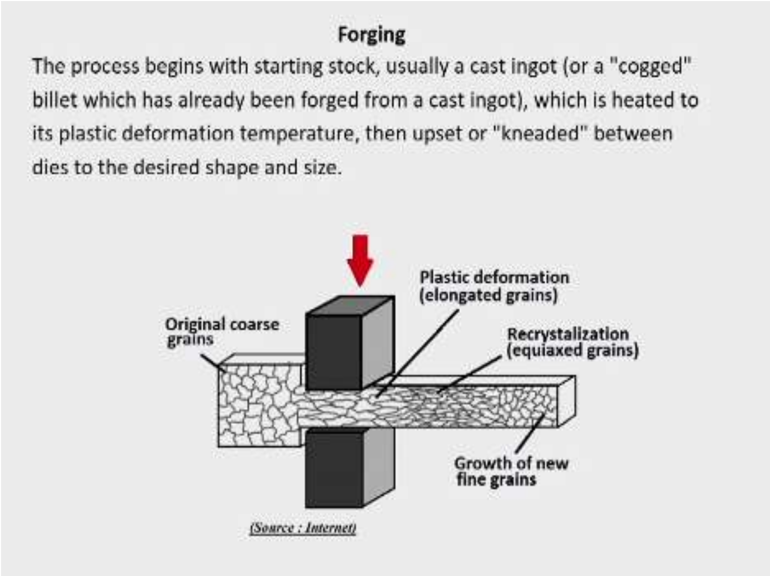

Now when you are doing this forging operation, there are some specific advantages also, whether you are doing cold forging or hot forging. When you look at a big forging industry, what they do is they get the billets, the billets may be as big as say 1 meter or 1.5 meter diameter depending upon the press capacity you are having and that billet okay after doing some machining operation and surface treatment and other things, so you will be heating it in a big furnace and then with the manipulators, you will be taking in to a very high capacity press and then pressing it and the process is called as cogging, which is represented here.

So here it is just shown as a rectangular piece, but normally it will be cylindrical piece. So when you deform it, so this is the initial height and this is the final height of the piece okay. So after each successive pressing no, you may rotate it also to get your specific cross-section dimension, may be normally either cylindrical or square cross section you may get it. So in this, it with the starting stock material which is generally a cast ingot and then you are pressing it.

So when you are pressing it, the cross-sectional area decreases, but at the same time, it moves along this direction, may be perpendicular to your movement of the die, so it moves in that direction. So the grains in a cast case you may have dendritic grains, there may be a lot of what you call it as interdendritic segregation okay, coring will be there, all these things will be there, and maybe if it is heat treated and softened you may get an equiaxed grains also, but after this open-die forging or the cogging when you do it, you will find that.

So initially it was almost an equiaxed grains, but when you are deforming it, material flow in this direction perpendicular to the movement of the ram, so in such case, you will find that the grains get elongated. Now upon us the velocity of the ram movement, if it is such a higher, see in all this plastic deformation process whatever energy is impacted to the material, 90% of that is converted as heat and specially if the process is very fast, this heat cannot be transferred at that fast rate, so there no it will become very soft, the temperature may go high also.

So if it is at a higher rate, then what will happen is that, so initially it is a plastically deformed grains are there, but if the temperature is very high and if it crosses the recrystallization temperature, stress free crystals may start nucleating like the small grains you can see on this, it may start nucleating, and with the time if you are keeping it for some more time at that temperature if the cross-sectional area is very large, then heat cannot be conducted very fast.

So there what happens, complete recrystallization may take place also, new finer grains may take place and that may result in another equiaxed state, but definitely the size will be much lesser than or finer than that of the initial material. So either you get elongated grains or you get a very fine equiaxed grains or you may get an intermediate grain size of elongated and with a partially recrystallized material depending upon your operation, process parameter.

If it has high velocity, then every chance it will cross the recrystallization temperature and you may get equiaxed grains, but in cold condition when you do it and if it is done in a press and other thing, you may not reach that condition.

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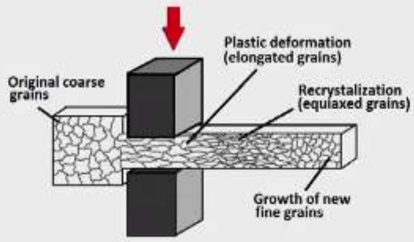

(Source : Internet)

During this hot forging process, the cast, coarse grain structure is broken up and replaced by finer grains. Shrinkage and gas porosity inherent in the cast metal are consolidated through the reduction of the ingot, achieving sound centers and structural integrity. Mechanical properties are therefore improved through reduction of cast structure, voids and segregation. Forging also provides means for aligning the grain flow to best obtain desired directional strengths. Secondary processing, such as heat treating, can also be used to further refine the part.

So during this, but generally what we do is that it is done in the hot condition, large ingots no you will be forging in the as an open-die forging in the hot condition. So that means, you will be taking it out from the furnace and then okay kept in between this die and then press it, compress it okay. So in such case, the material itself is hot and there is every chance that the temperature may cross the recrystallization temperature and the process is hot deformation which takes place, but in that case, the material get elongated.

There are lots of advantages, the microstructure completely changes. If it was an equiaxed grains or a dendritic structure with interdendritic segregation and if there is a coring also, when the metal flows in the transverse direction or in a direction perpendicular to the direction of application of the force, many times if it is dendritic structure, it gets broken down, if it is equiaxed structure, it gets elongated and even dendritic structure also.

It may get broken down, it may get elongated, all those things, but after this repeated the forging operation, open-die forging operations, what you will find is that the very fine grains are there, the dendritic structure is no longer existing, the inter-dendritic segregation is also eliminated, so you may get a more or less a uniform chemical homogeneity, so chemical composition may be more or less homogenous, I am not telling 100%, so chemical homogeneity will be there, so you may get very fine grains or you may get elongated grains.

So properties will be different compared to initial starting material. In addition to that in the cast condition, there may be a lot of casting defects, like gas porosity maybe there, say generation gauge cavity may be there, all these things may be there, say blow holes, pinholes these things may be there. In some cases, you may find that some inclusions are also, metallic inclusions are there or nonmetallic inclusions are there. So these all causes the properties of the cast material to be very poor and ductility also will be very poor.

So when you are forging this in open-die forging at a hot condition, what happens? A gas porosity, maybe it was in a spherical shape, but when you are applying the force, it collapses, the surfaces gets cold welded because of the temperature also and the pressure which is applied, the surfaces will get cold welded and then it may flow transverse to the direction of application of the force okay. If there are inclusions that may be broken down to very fine dispersoids and then it may get distributed throughout, so all these advantages are also there.

So you will find that the voids, segregation, the coring these things are more or less eliminated, but there are cases where you cannot eliminate it 100% also, like say for example hot work dies tool, so there will be a banded structure also that in some case, but the extent you can reduce it, but in normal metallic materials for structural application which you will be using, these can be eliminated, more or less eliminated, completely eliminated. So this process it enhances the mechanical properties, it imparts directional property.

So in any material under dynamic condition during your application, if it is under dynamic loading condition also, it is note that the stresses will be always be along all directions, it will be along, mostly it will be along certain particular direction because the forces are transmitted along some particular direction only. So along that, the strength will be very high if it is done by a forging operation, that is the biggest advantage of this. Now after this hot forging, you can give, impart a heat treatment to that for further enhancement of the properties. These are another advantage of that.

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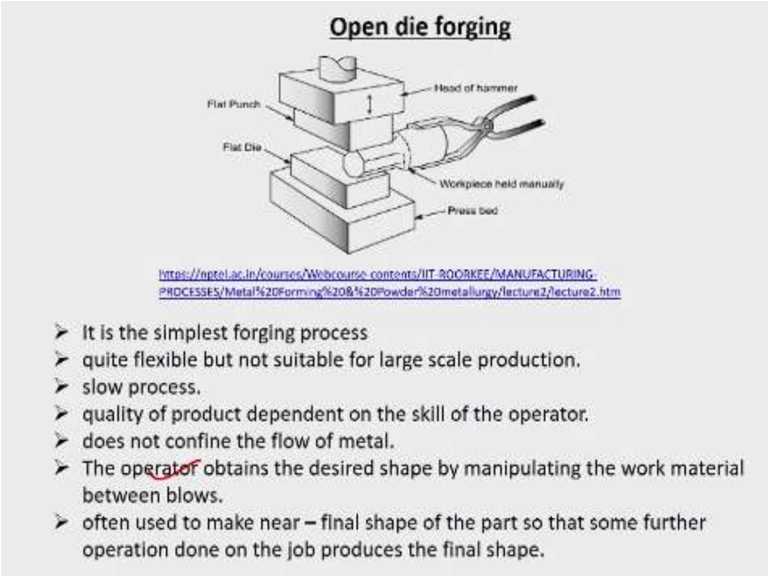

So let us come to open-die forging process. So this is the typical schematic which has been downloaded from this net shown at the bottom design web course which has been telecasted under NPTEL course okay, so I just took it from there, so this figure. So this open-die forging is the simplest forging process because you don't have to work on the die piece because there is no impression or there is no cavity on that and very good surface finish it is not required. So this is very flexible, but not suitable for the large scale production.

These are the things generally done for cogging operation or reducing the cross sectional area, so that is the main purpose of this open-die forging. It is a very slow process because most of the case your billet size is very large, diameter is very large, so it takes some time, and quality of the product is dependent upon the skill of the operator because you have to hold it and rotate.

Nowadays at a higher levels, manipulators are there, so that will not be a problem, that is a good thing but those people who are not of those industries, who are not having these manipulators, mechanical manipulators, they have to depend upon the skill of the operator, so that is one major drawback with it. Here because there is no shaped die cavity, the metal is not confined okay, the metal flow is not confined, it is free, it is open to move in the way where minimum resistance is there, that is another advantage.

So operator obtains the desired shape by manipulating the work material between the blows, between each blows no the operator, it is like in a what iron smith, iron smith shop no after each hitting, he will rotate it, so for him it is a skill, so he knows how to do it, but in industry when it comes no, nobody will be there, machine will be moving up, the ram will be moving up and down but after each successive operation, the operator manually will be rotating it okay, he will be manipulating and then finally getting the shape.

Maybe you may be starting with a cylindrical billet cross sectional area is a circle, but then you can get a square shape, you can get an octagonal shape, you can get a hexagonal shape, but all these depends upon the operator. Most of the case in open-die forging, they use this to get near final shape, not the final shape, the near final shape as per the requirement and then what happens is that you have to just cut it off and then okay do minimum deformation inside an impression die, so that is the biggest advantage. So this is generally used for that.

So most of that even if it is a closed-die forging also, people will have an open-die forging setup will be there, so that depending upon the shape of the billet and the size of the billet, you can just reduce the cross section to whatever desired value it is required.

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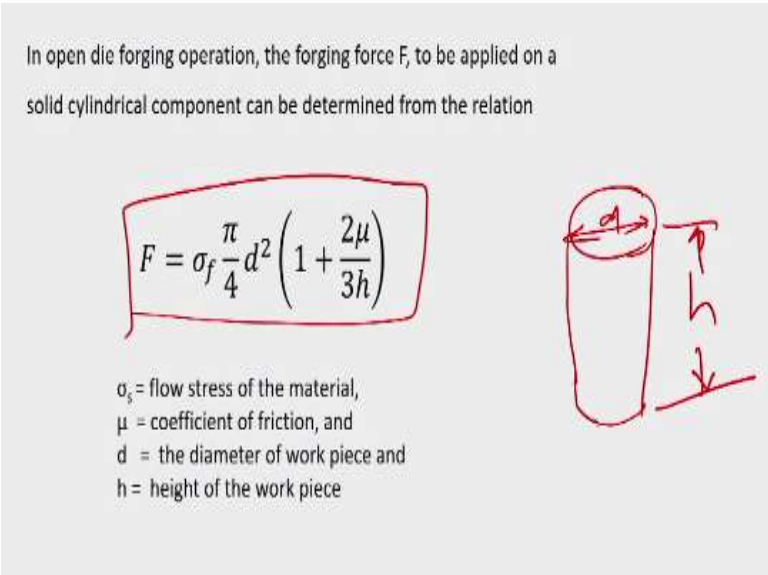

So in open-die forging operation, the forging force F to be applied on a solid cylindrical component can be determined by this relationship F = sigma f into pi by 4 d squared into 1 + 2 mu by 3h. So this is for a cylindrical piece for getting compressed along the axial direction where d is the diameter of the work piece material, σ_f is the flow stress of the material, you can take an average flow stress also depending upon how much reduction you are going to give, and μ is the coefficient of friction between the work piece material and the die surface and h is the height of the work piece material.

$$F = \sigma_f \frac{\pi}{4} d^2 \left(1 + \frac{2\mu}{3h}\right)$$

So if you are having a cylindrical piece like this, so this is your d and this is your height, so initial height, now it will change, this is an empirical relationship which people use it actually okay, so that is what. Now when you are pressing it between that, there will be a friction between the work piece material and the die. So for a free flow, the friction should be reduced, so you may apply the lubricant also between, not may, you will have to apply lubricant between the work piece and die, otherwise no your forces will be very high okay.

So you can see that from this relationship itself if $\mu = 0$ how much the force required will be very less actually, so that is the thing. So you reduce that and to have a free flow the metal with the minimum friction, you may apply lubricant, industrial lubricants are available which is generally people use it for that purpose. So this is a simple relationship by which you can determine the force necessary for the open-die forging.

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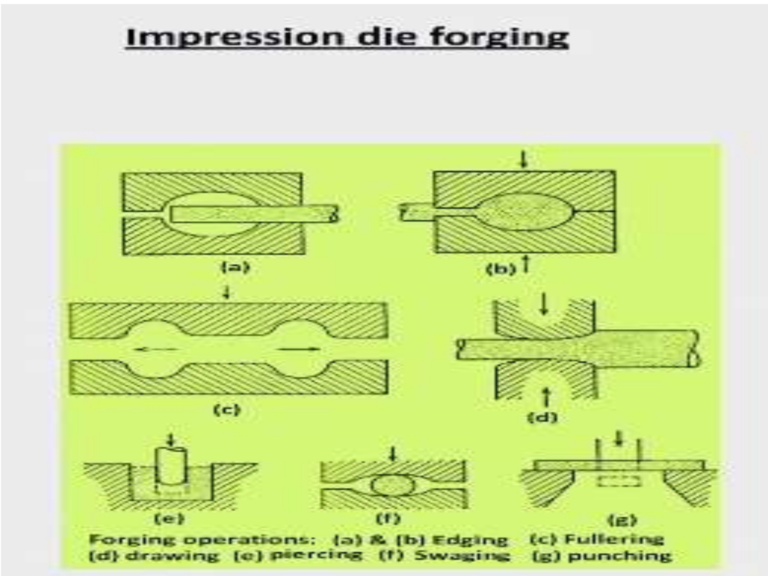

Now when you come to an impression die forging. So impression die forging is a process by which you have a die, inside that you keep the billet and then you close the die, say a pair of dies, inside that you keep the billet and then press it, so metal will start flowing, may be battling also will take place and then when it is closing down, you will find that the metal fills up, it is confined to the die itself and it fill up the die cavity completely so that there is no defects and other things okay, so that is called as the impression die forging.

The forging operation is carried out in a die impression, so that it completely fills up the die cavity, so that is called as a impression, the other case it is open-die forging, so here it is not closed die forging, people use the word, correct term is impression die forging. So impression die forging is you want shape the component, in open-die forging you don't need to have a very particular shaped component, depending upon the skill of the operator you can get different shapes, but in impression die forging, it is not like that.

The shape of the component is obtained by the shape of the die cavity and the surface finish you are going to obtain inside and impression die forging obtained for the component which has been subjected to impression die forging depends upon the surface finish of the die cavity, so that is there. So many times, it is not a cylinder just passing it down, you may have to get different shapes, so for example a connecting rod, it has a very complicated shape okay.

So if you have a gear wheel, so the shape is entirely different, you need to have that particular shape, and if it is a spanner you see that different shapes, the spanner had the two end of the head no it is having a specific shape with the fork set that and whereas at the main part no you will find that it is an I-section. The connecting rod if you look at, big end is there, small end is there, and in between that no you have this shape which is having an I-section, so all these things, very complicated shapes are there.

So in impression die forging when it comes, it is not a single operation, it consists of different operations like edging operation, fullering operation, drawing operation, piercing operation, swaging operations, punching operation. So let us look at one by one.

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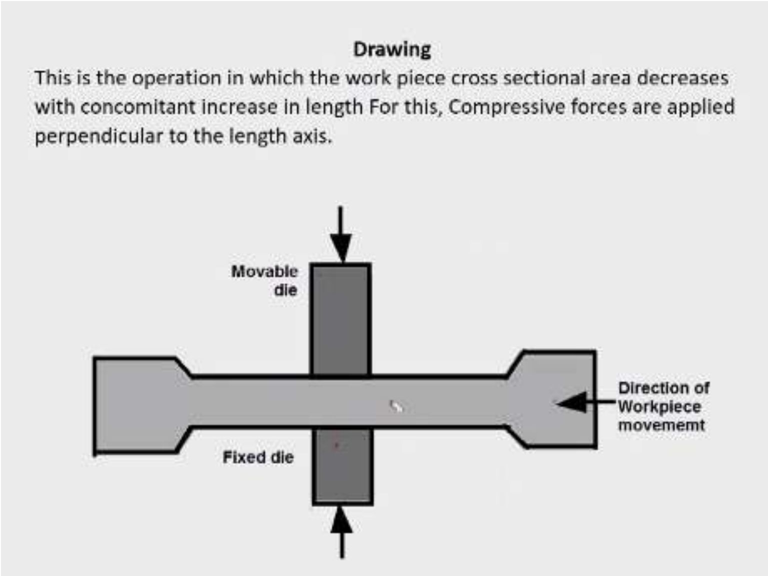

Say first is drawing operation. So this is your work piece material and then it is kept between on the top of a fixer die and then a mobile die is there which will be pressing. Now depending upon the shape of this, if the shape is concave like this what happens is that the material will flow perpendicular to the direction of the mobile die, movement of the die okay, so it move laterally and then it gets elongated.

So this is the operation with the work piece cross sectional area decreases and simultaneously increase in the length, so maybe this movable die its width may be very large also and having as if you have a concave shape like this or convex shape like this no it can just deform it and then get it elongated, this operation is called as a drawing operation.

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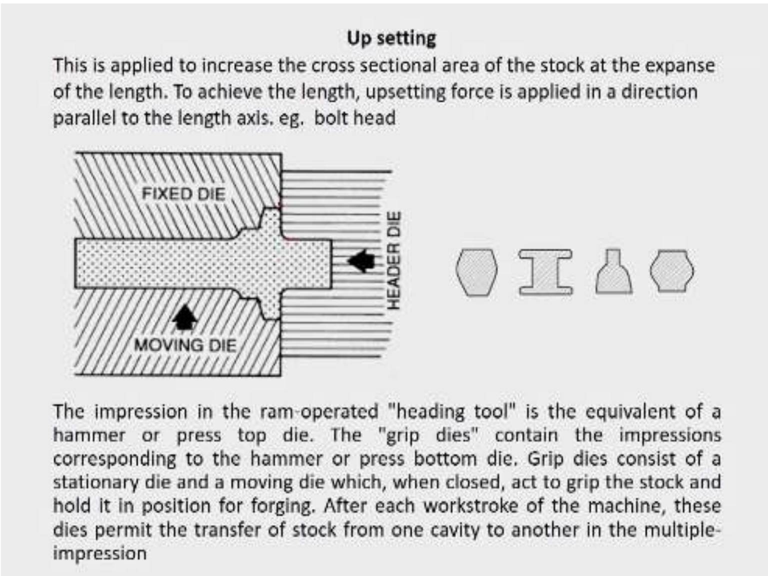

Another is the up setting operation. Sometimes at the end, you want the cross sectional area of the stock to be enlarged, so what you do is that you do an operation which is called as up setting. So, this is a process which is also used to for making bolt head. So you have a cylindrical tank and at the end you have a hexagonal head, so how you get it, that is by up setting operation. So in that case what happens is that we are applying a load along the axial direction and the metal flows say radial to this and then it fills up.

So your initial work piece may be enlarged like this, say elongated cylindrical piece like this, so this you are holding between a fixed die and a moving die, so between two parts it is held with a very high force, and then so here, at the end there is a cavity like this and then the head will be projecting, so the header die it will be moving along this direction and it causes the metal to flow like this and filled up this case, so you get the head operation, so that means at the end of the stock if you wanted to increase the diameter, then the process which you use is called as the up setting operation.

You can get different shapes depending upon what is the shape inside the header die or maybe inside this, when you are crossing it, this can be opened, the moving die can move backward also and then the material can come out. So in one die itself, sometimes you may find that different die cavities are there, so that also is possible in this case. So maybe in one case, this up setting operation itself may not be done in one single blow, so one blow you do it, its cross-sectional area increases by some amount, length decreases by some amount.

Then the moving die just opens it up and so this with the help of a tongs, the operator may move the next part and here another piece is kept, and then again the die closes and the header die gives an impact, so like that no with a continuous process, the shape keeps on changing, finally you get the final shape of that, so that is the thing. So it is not that it is one cavity, in the same die block itself, several die cavities may be there to get the final shape.

So you have this, this moving and fixed die they are called as gripping dies, so that will be maybe pneumatically activated or hydraulically activated, but normally it is a mechanical process, so it can hold with a very high force and then impacted. This is the continuous automatic production of a bolt, is made by this up setting operation okay.

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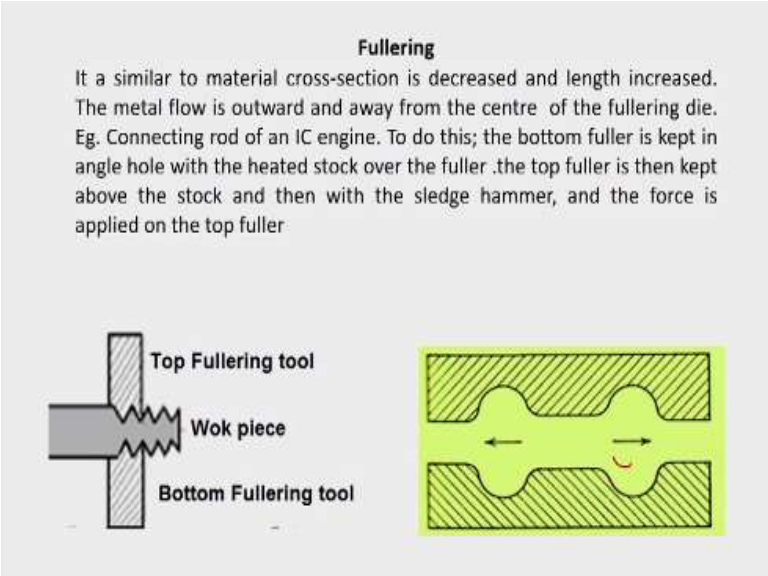

Then another is the fullering operation. In the fullering operation, what happens is that the cross-section is decreases and the length increases. So this is a cylindrical piece but showing the edge the portion only. So when you keep the billet here and then press it down, it will start flowing in this direction and at the same time it will flow in this direction and fill it up, so that also is there okay, this drawing is not perfect actually. So here you can see that between these two dies the work piece is compressed okay.

The bottom fuller is kept in an angle hole with the heated stock over the fuller. The top fuller is then kept above the stock and then this with the help of sledge hammer the force is applied, and so but in this process, what happens is that for metal to move faster, the fullering tool will not be parallel okay, it will be either concave or convex shape, sorry concave shape will be there. So when it is at one end, you are doing the fullering operation, it gets reduced, then you keep it moving like this in this direction so that entire length you can get it reduced actually, so that is the process, but in this process, there is a drawback also.

What happened is that even if the fullering tool, the two dies are flat also, it will leave some marks because normally they are not perfectly flat also, so there will be some what you call it as a corrugated shape will come in that case, so the corrugations will come and so surface will not be smooth, so this has to be straightened up also, but in the subsequent operation this will be taken care of.

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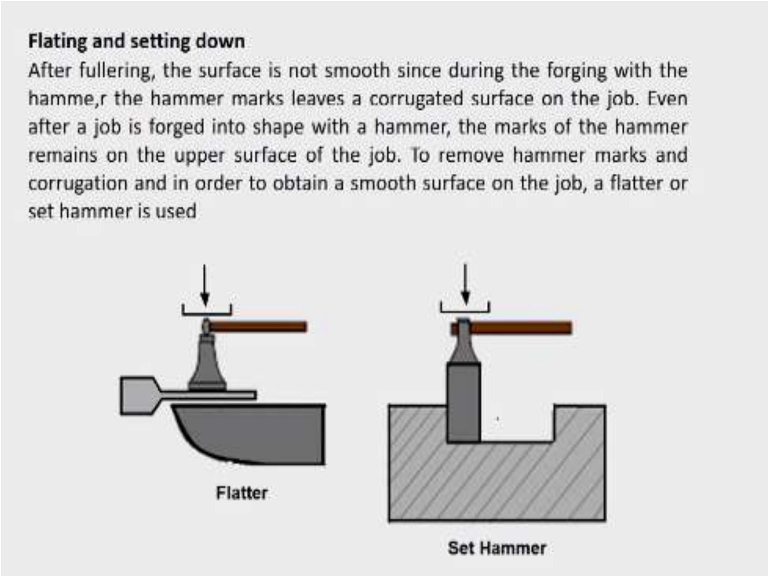

So for that, you call it as either flating or setting it down. Flating in the process, mainly this is done to smoothen the surface after the fullering operation. So when you are doing the fullering operation because it is just with the help of a hammer, it leaves some marks okay as if the surface is corrugated shape it is there, so surface is not flat. The marks of the hammer remains on the upper surface of the job, sometimes on the lower also, and to remove this, this flating and setting down is there with the help of a hammer no, you just press it keep it on a flat surface and then proceed slowly and then get the smooth shape.

So if it is a in this type shaped a cavity, then you call it as a set hammer and other things, so depending upon the shape, you just give one press, so that it will be smooth. So this is another operation which is done before the final because you may have to have certain shapes.

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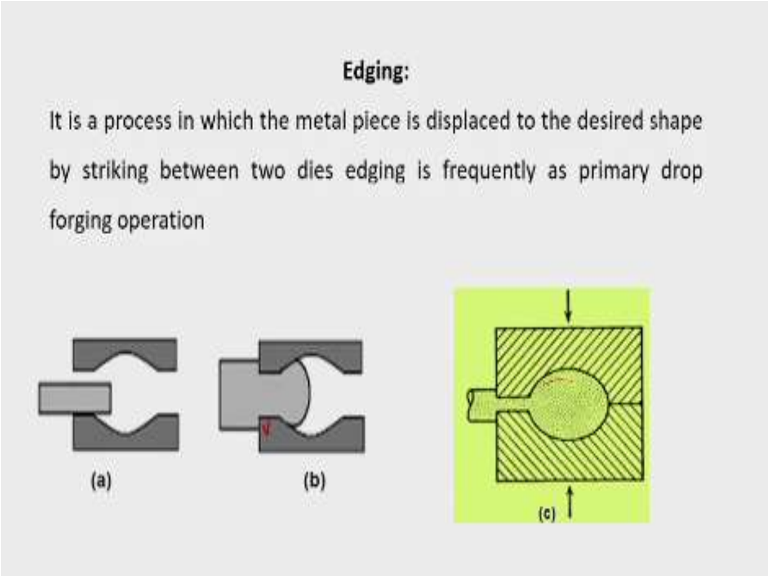

Then comes the edging. Edging is one part so where the metal is displaced to the desired shape by striking between two dies and the metal also flows into that and fills up this cavity. So you can see that initially it is this, when you press it, here the cross sectional area keeps on decreasing, so metal will flow in this direction and in enlarged view is just showing that it will just flow, but as it comes down, when it is moving down like this, the more and more metal will flow because the gap keeps on reducing and finally you will find that it is confined.

So you can get a confined shape for this, the metal flow is confined and then you get your shape, so basically at the edges side you may need, like suppose you wanted to make a spanner. You are having a cylindrical piece. So edge of the spanner is wider, so that part you have to make it wider, so for that purpose this edging operation is done. Similarly for connecting rod also, both the ends no you want wider part compared to other part, so for that purpose, you use this edging operation.

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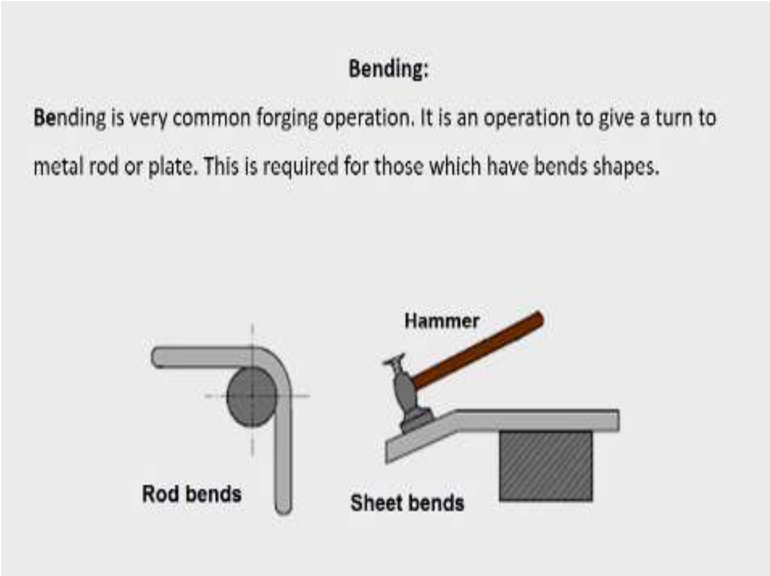

Then there are bending operation, normally which is done with the help of a hammer. If it is sheet bending, you bend it, or if it is a rod you can bend it on a roller and get the shape.

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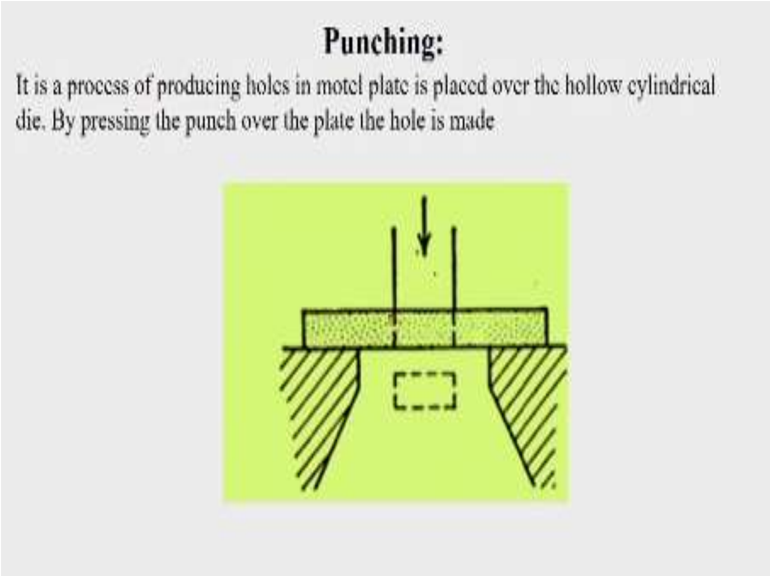

Then there are punching operation. The metal is kept on a die and this is the work piece material, it is kept on a die and punching tool no it moves downward and then causes shearing of the material resulting in a small die. Depending upon the shape of the punch, you will get a hole which is made there, so that is the punching operation which is done.

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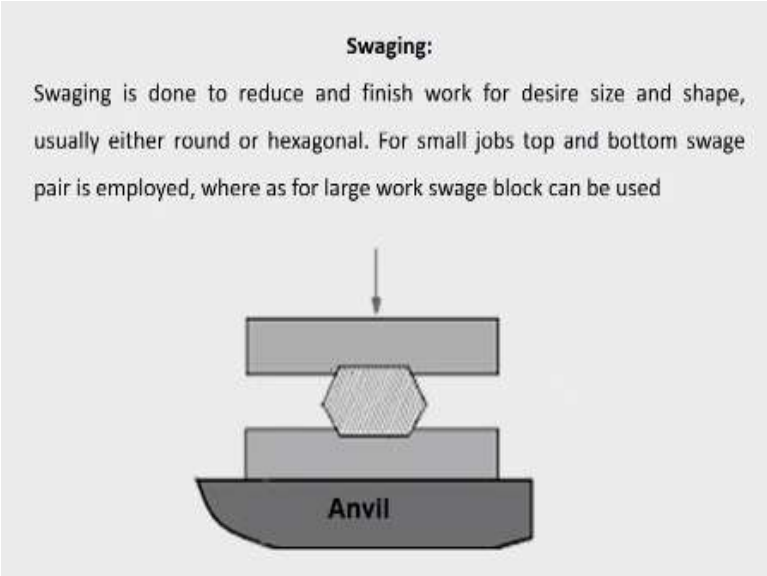

Then is the swaging. Swaging is done to reduce the finish work for desired size and shape, usually either round or hexagonal shape they obtain for that the swaging, may be to some extent there is the die cavity is there, so you get the very good shape for that. For small jobs, top and bottom swage pair is employed, whereas for large works swage block can be used.

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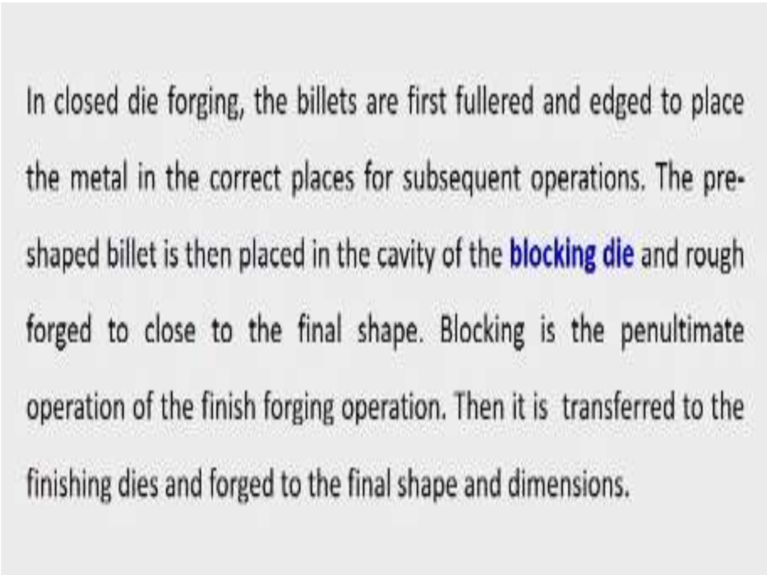

So when you look at it, in closed die forging, it is not a single operation, yes it consists of a different stages of operation or different process itself. So you may have bending, you may have edging, you may have fullering, or some part 1 or 2 may be in a separate person from that you are carrying it to here, sometimes it may be the large number of operations, may be in a single die also which will be there except the finishing die. So all these sequence of operations in forging will be carried out in a single die or may be in multiple dies and then it comes to what is the last but one shape is the blocking die.

So that is the penultimate operation, that is the operation just before the finishing die, so this is the blocker. So design of the blocker die is very important. In forging operation, what is important is the die design, die design is extremely important for forging operation. So the operation just before the finishing is the blocking die or we call it as blocker also. So it is close to the final shape, and once you get and the shape also is almost similar to your final shape, the variation in the dimension in the final component, the final shape is only very small, so at minimum metal flows into that.

Why minimum metal flows inside the die cavity in the finishing operation, because if large amount of a metal is flowing due to the work hardening, the work piece material will get hardened, and when it moves, the hard material it will drop and then it will result in dimensional inaccuracy and the material may get rejected. So to avoid that, always the final finishing operation there is as minimum metal flow as possible, but at the same time, it should fill up the entire die cavity, so blocker takes care of that.

Blocker die has the size and shape only deviating slightly from the final shape. So, it is the penultimate operation of the finishing forging operation. This is then transferred from the blocking, all other operations have done but then finally it comes to the blocking operation, sometime blocker die and finishing die may be in one piece, sometimes it may be in different press also, but mostly people take the finishing operation in a separate machine itself because if there is a die breakage and other thing, then you cannot afford to have that die breakage in closed die forging.

But whereas other operations no to some extent, there is a dimensional changes and other things that will be taken care of in the final operation. So blocking die design or blocker die design is very important doing that.

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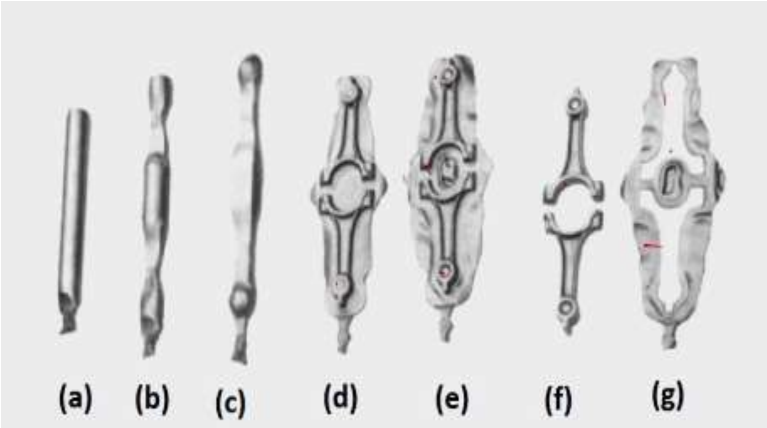

(a) Bar stock; (b) fullerin; (c) rolling; (d) Blocking ;
(e) finishing; (f) trimming; (g) flash.

So this is a typical case for showing the various stages of impression die forging operation. Say for example you want and see after finishing operation, there will be something called as flash and gutter that has to be removed by trepanning operation. So if you look at it, your starting material is start with a bar stock which is generally cylindrical in shape and then you do the fullering operation where the cross sectional area changes, the length increase is there, so this is the fullering operation.

After the fullering operation, you may do a rolling operation whereby different the metal flows the different cross section area is there, so this can be done at a faster rate. Then comes your blocking operation, see this is the, say maybe before that, there will be slitting operation, slitting die also is there because the fork part you wanted, so slitting also may be there. So whatever it be in these cases, it depends upon your die, it also depends upon the designer, die block designer that also matters. So this is after the blocking operation or deformation, say the blocker die you are getting like this.

So this part which you see is called as, like a finch no that is called as flash okay, that is very much necessary we will come immediately why it is important and other things and the same piece you are holding it here and then transferring to your finishing die and then subjecting it to deformation, you get the final, you see that here the shape and the size, there is only a different variation, you can see if between here small variation is there, here also small variation only.

The only small difference the metal deformation inside the finishing die is minimum, and after that what happens is that you are doing the trimming or you call it as trepanning also. So trimming, you get you trim it off from the flash and this part you are getting these two things okay, this flash is there, it will be removed, so you are getting the final shape. This is one typical example.

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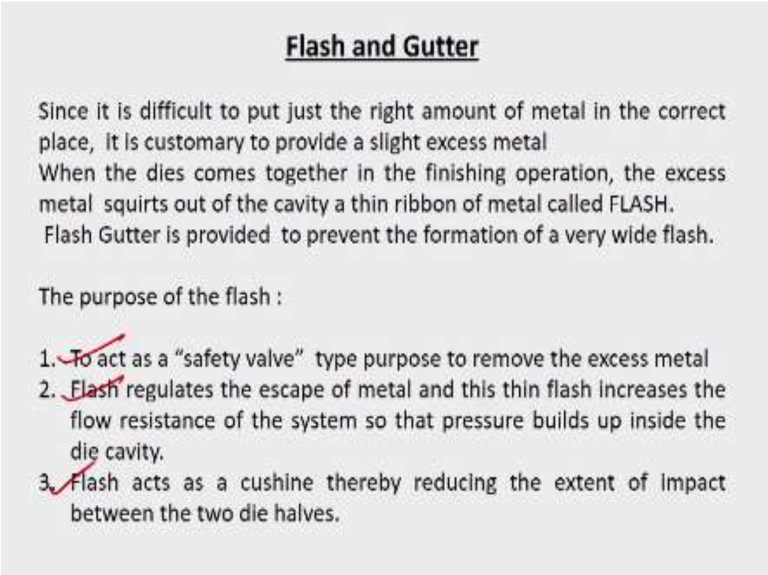

So in this case as I was telling is flash, so in the blocker die design as well as in the finishing die design, this flash and gutter is there, in impression die forging, this you cannot avoid okay, if you wanted to avoid it, you have to go for some special purpose deformation processing and other thing, but normally in industries when you do it, this flash and gutter is very important, you have to provide provision for that, otherwise it may cause impact on the work piece material, the die breakage and other things can take place at a very high rate also, that also is there.

See why this flash is required? Flash is the metal, an extra metal is provided in the stock material so that during deformation, complete die filling take place, the metal frozen fills the entire dry cavity so complete die filling take place and that extra metal will skews out through between the two dies, that is very important, and it has some special purpose. One you cannot have, even if I say a cylindrical piece if I buy from the market, you just measure the cross-sectional area at different places, you will find there is a small difference okay, it is not uniform.

With a larger diameter if this diameter variation is small, but volume will be very large, so you cannot afford to have cut it exactly what is required that is one, so you always take some extra material inside. So it is customary to provide as slight excess metal. Now when the material is kept inside the die cavity, when it comes down, this excess material or this metal just deforms and the excess material will just squirt out of the cavity as a thin fin or a ribbon of the metal and this is called as the flash.

So flash gutter is provided to prevent the formation of a very wide flash because sometimes no, the quantity which comes out through a flash will be very large, so then there are other difficulty, your total load required for deformation will have to be extremely very high also, to avoid those things, flash gutter that means after a small distance no, the width of that flash which is increased, so that is called the gutter. So what are the purposes of flash? One flash act as a safety valve to remove the excess metal, that is one.

So whatever extra metal is there, like in your safety valve in a pressure cooker also no safety valve is there, when the pressure is high, it will just lift out and release this thing, the steam. Similarly in a water pipeline also, you will find safety valves there, that is why sometimes you will find water is leaking through that valve region. When there is excess pressure, it will just leak out, otherwise no it will damage the pipeline, similarly here also. If the pressure is very large, then the metal has to come out.

If it is not coming out and you increase the pressure, die breakage will take place, so the extra metal has to come out. So this flash acts as the safety valve purpose. So the flash regulates the escape of metal and this thin flash increases the flow resistance of the system, so later we will come to that when you do the forging analysis you will find that, when the thickness gets reduced, the pressure build up will be very high, so that when the pressure inside the die cavity is very high, it will help in the metal to flow inside the die and fill up the entire die cavity.

So that is another advantage that so pressure build up inside the die cavity will be very high, so that the metal can flow and fill up the die cavity and whatever excess is there, like a safety valve it comes. Now third part is that if the flash is there, this direct contact between the two die surface it will not take place, if that happens, the die will break. So here, this is a plastic material which is coming out and it prevents the direct contact between the two dies so that the it acts as a cushion, cushioning effect will be there by reducing the extent of impact between the two die halves, so that is another advantage. So these 3 advantages are there with the flash.

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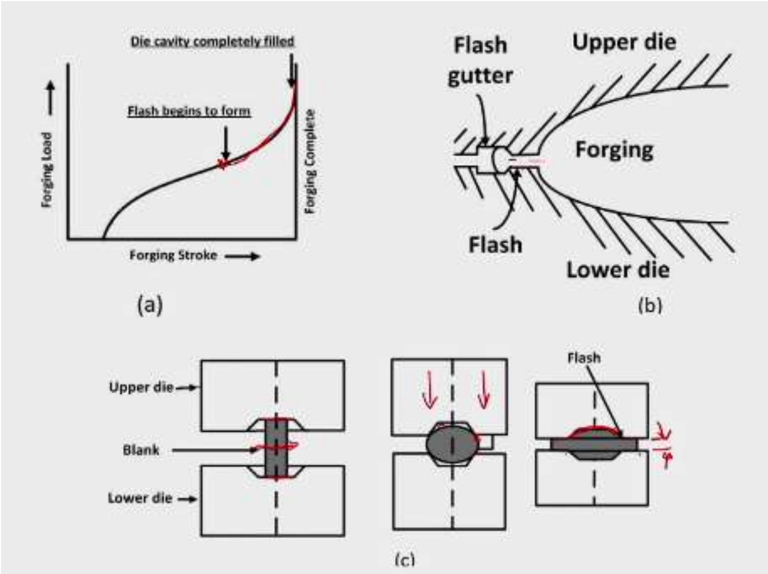

So this is the portion, how the flash forms. See you take a simple case here, in the bottom that figure C, the left hand side, this is your work piece material okay, this shown by this shade. It is kept, so this is the one part of the die cavity, this is the other part of the die cavity, lower die generally is the fixed died and the upper die is the movable die. So you will keep billet, what you call it as it is a simple cylindrical piece if we keep it and then okay, this is the shape final shape which you wanted to do it.

So when it comes down, there is friction here at the die work piece material, interface between the die and the work piece material, so here you will find frictional forces are there. So lateral flow of the metal is confined there because of the frictional forces, whereas at the midsection portion, it is free to deform, so it can deform very freely okay. So in the process what happens, the shape comes, so you will find that the center portion, the diameter is very large and the process what is called as barreling takes place.

As the die move downward, further downward, it will come and touch, the edges of the die no it will come and touch the barreled section here and then still it keeps on moving down and finally when the die crosses, say it completely fill up the die cavity here, everywhere the complete die filling take place, and maybe you are providing provision for flash, so it just comes out like this, you know all the entire circumferential area it moves radially out. So this is a cylindrical piece when you look from the top, it should be a cylindrical piece, so that is why it is shown like this.

So radial flow of the metal take place in a direction perpendicular to the movement of the die, and so now, when you look at it, see it is preventing the direct contact between the lower die and the upper die, so there is a cushioning effect and as the top dyke advances further, this height of the flash keeps on reducing. When the height keeps on reducing, the force required which will have to be very high, so that is another advantage, so that will facilitate the complete die filling it says, otherwise no some area the die filling may not take place and the material will get rejected, so that is another advantage

So all the 3 cases, so this is the typical case of forging where the flash is there and this is the flash gutter okay. So this enlarged area, we call it as a flash gutter and this is the flash. So metal will flow into that and then okay it will fill up this here and it is free to flow and other thing, normally this will not be filled completely, but whereas this flash region, it will be like a very thin fin type thing it is along that that will later be removed okay.

Now as the die moves down, so from here is the point where the plastic deformation takes place, from here the plastic deformation take place, so with the forging stroke increasing along this direction, you will find that forging load it increases, it starts increasing when the deformation takes place, and initially there is an increase, then finally it will be almost remains constant, at a constant rate it will be increasing as it advances further. Now when it touches here, you will find that okay here some plastic deformation has to take place, so your load will keep on increasing.

So extra path because here it is coming and touching here no, so frictional force are also coming into picture. So what happens is that the load keeps on increasing and finally when the complete, so this is the point at which flash starts forming, so when it comes down, the flow stress keeps on increasing, the total load required keeps on increasing, and finally after the complete die filling, you will find that the load increases drastically, so that stage you have to finish it, but normally there will be limit stops and other things so one need not worry about that.

The machine is automatically stopped moving forward because of the limit switch and other things, and so you can have the specific thickness of the flash that is done. So this is the shape of the forging load versus forging stroke curve, so each case, so from here the flash formation takes place, so the load keeps on increasing, with the further load coming down, later in our analysis, we will find that when the thickness when it further advance, the thickness keeps on reducing and then in that case your load will keep on increasing, a very high value. So this is how that flash formation takes place.

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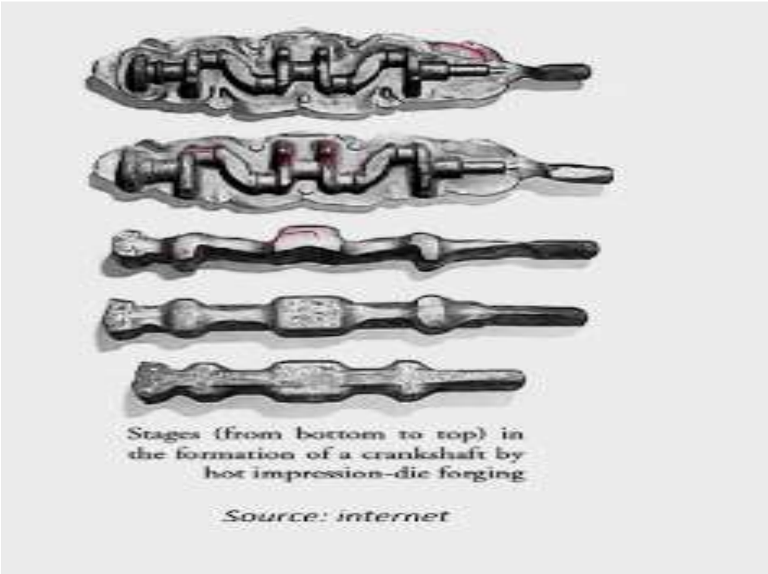

This is the typical case for the formation of a crankshaft, source is internet only. The initial operations are done okay, various operations like fullering, drawing, swaging and other things are done, drawing operations are done. So this part takes care of for this crankshaft portion and like this. So this is your blocking operation, this is your finishing die impression which you're getting, and then after that it will be trimmed off okay. So this is the final forging operation which comes.

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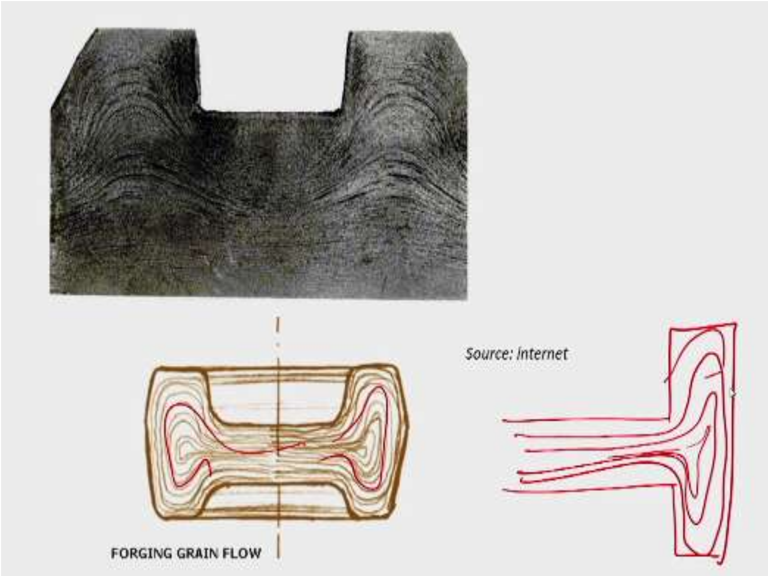

You see that this is a typical cross-sectional area, a macro structure at a very low magnification, you can see the clear-cut flow lines are there, the metal when it was advancing, the metal flowing like this and filling up here, so here it is. These are the flow lines which are there okay. So this will give you some specific properties, maybe some drawbacks or defects were there, which otherwise are spherical in shape that also has obtained which is lying parallel to what are the flow directions and other things, so that will increase the mechanical properties and other thing.

This is a disc which is with the rim and a flywheel, flywheel your cross-sectional area if you look at it, you will find that the flow lines are like this the metal flows. Say in case of a bolt head no if you look at it, say metal will flow like this, you can see that, this will be the shape of the flow lines, so for a bolt. So whenever there is and if you look at the hook of a crane, you will see very beautiful flow lines in this, you can visualize that also, that will increase the strength of that hook.

Otherwise if it is a cast, the hook was made by casting operation, the ductility will be very poor, it becomes brittle, and it will not be able to withstand heavy load and it will just fail because it is brittle without any warning also, that is very dangerous. So always the fork, the hook of a crane is a forged component okay. Thank you very much.