Basics of Mechanical Engineering-2

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Week 05

Lecture 18

Basics of Forming (Part 3 of 5)

As part of the basics of mechanical engineering course 2. So, in the last lecture, we went into full detail about rolling. And you are now convinced that if you have to make a uniform cross-section, you can do it through the rolling process. For example, railway tracks can be made by the rolling process. If you want to make flat sheets, use the rolling process.

If you want to make threads on an object, rolling can be done. Ring rolling can be done. So these are all different advancements or variations of the rolling process. Generally, rolling is a continuous process. Generally, thread rolling is an exception.

So generally, rolling is a continuous process. Now, let us get into another process, which is called forming. In forming, what we do is we try to keep a constant volume of material inside a die and try to hammer it from one direction or all directions. The hammering can be done through mechanical means, hydraulic, or it can be done through pneumatic. It's possible; you can try to use depending upon your material properties.

An impact, a sudden impact is given, and the shape of the die is produced on the part. And then you try to get the output from it. Let us take a simple example of a spanner. A spanner can also be produced by the casting process. For example, in casting, you try to take a metal, steel—assuming steel—you try to take it to a higher temperature.

A phase change happens, it becomes liquid, you pour it into a mould or a die, then you try to get the part. There, the grains, whatever grows, start growing from the mould surface. Where there is a steep gradient of delta T. From there, the grain starts growing and moves towards the centre. So now, directional solidification plays an important role.

Whereas when you try to make the same component through metal forming, the grain growth and new grain distribution, everything happens along the direction of the applied force. So what is the big difference? The strength properties are much better in the rolling process and forging process compared to casting. In casting, if I know the weakest direction through which the grains are aligned, and if I apply force in that direction, it can quickly break.

And the strength properties are not uniform when you cast a material, or I can put it this way. A cast part cannot be put under mechanical loading to a large extent. It is a generalized statement. There can be exceptions. But whereas in rolling or forging, what happens is, whatever part you make, that part can try to take huge impact loads. With that introduction, let us get into forming.

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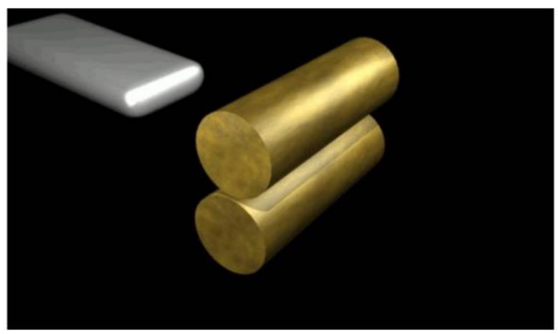

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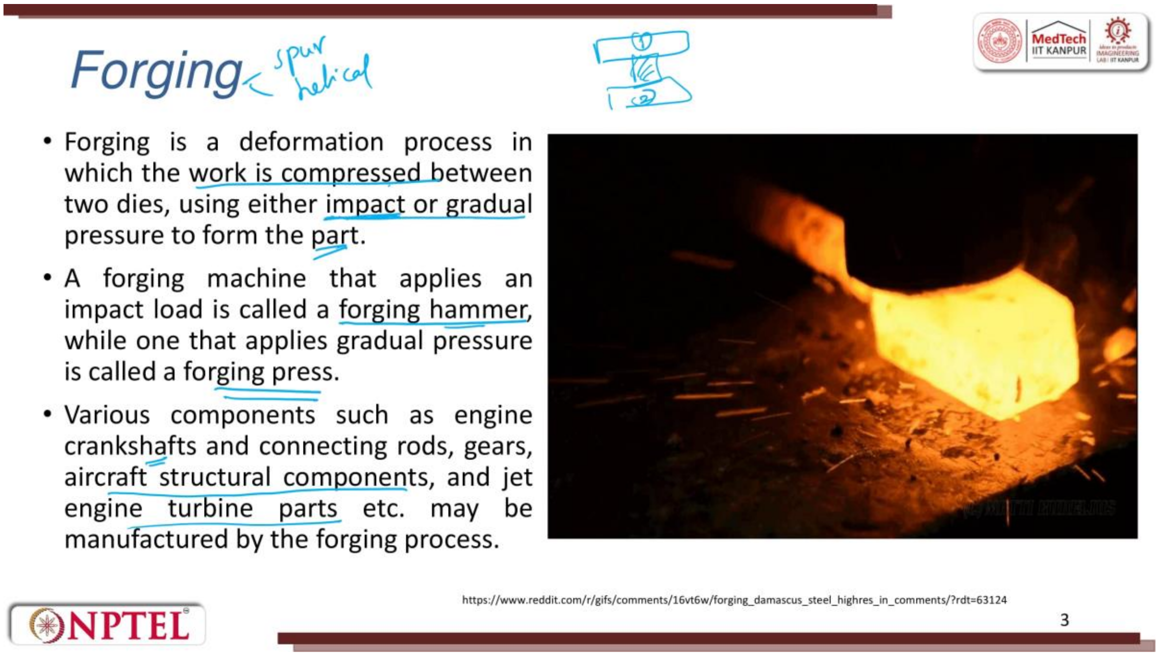
So here we will start understanding forming—an introduction to forming. Then we would try to do classifications, like we did with bulk and sheet. Then we went into many of those classifications in metal forming.

And then when we went into rolling, we also saw different classifications. In the same way, we will try to look at classifications in the forging process. Then we will try to understand the forging mechanism, then various hammers, then forging dies. Then we have a classification called open die forging, then closed die forging. Then forging defects—we will try to recap, and then we will try to get the references.



Forging is a deformation process in which the workpiece is compressed between two dies. Here, we assume that there is a top die and a bottom die. These are die 1 and die 2. You have the workpiece here. There is a compressive load applied.

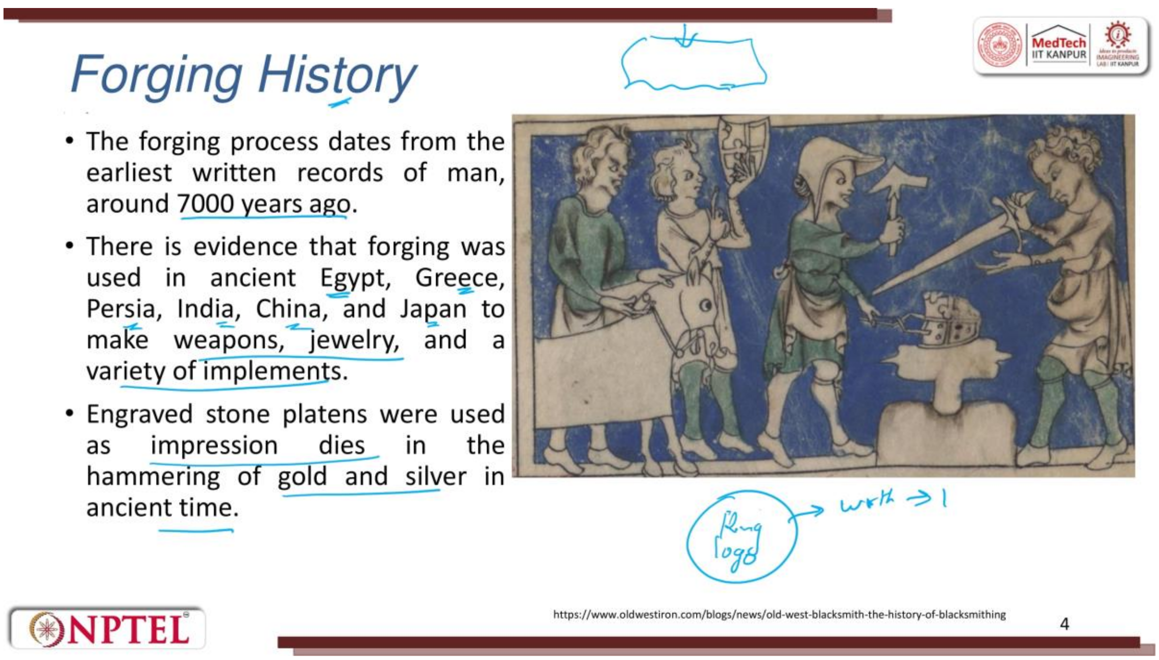
The compressive load can also be gradual. But when it is gradual, the deformation will not be as fast. Here, most of the time, we try to impact. The workpiece is compressed between two dies using either impact or gradual pressure to form a part. Most of the time in forging, we try to have impact—a sudden load.

Again, here you can see it is a hot working process. In a hot working process, the material softens, so the applied load is less, and you can quickly deform a large volume. A forging machine that applies an impact load is called a forging hammer. While one that applies gradual pressure is called a forging press. Look at the difference between a hammer and a press, right?

So, this makes a huge difference. Various components such as engine crankshaft, connecting rod, camshaft, then many of those components, gears are today forged. So, the forged gears has a huge difference mechanical properties or it put in service condition. It gives you a huge output that means to say without replacement the repeatability reliability is very high. It is today we are also making not only spur gears we are also making helical gears.

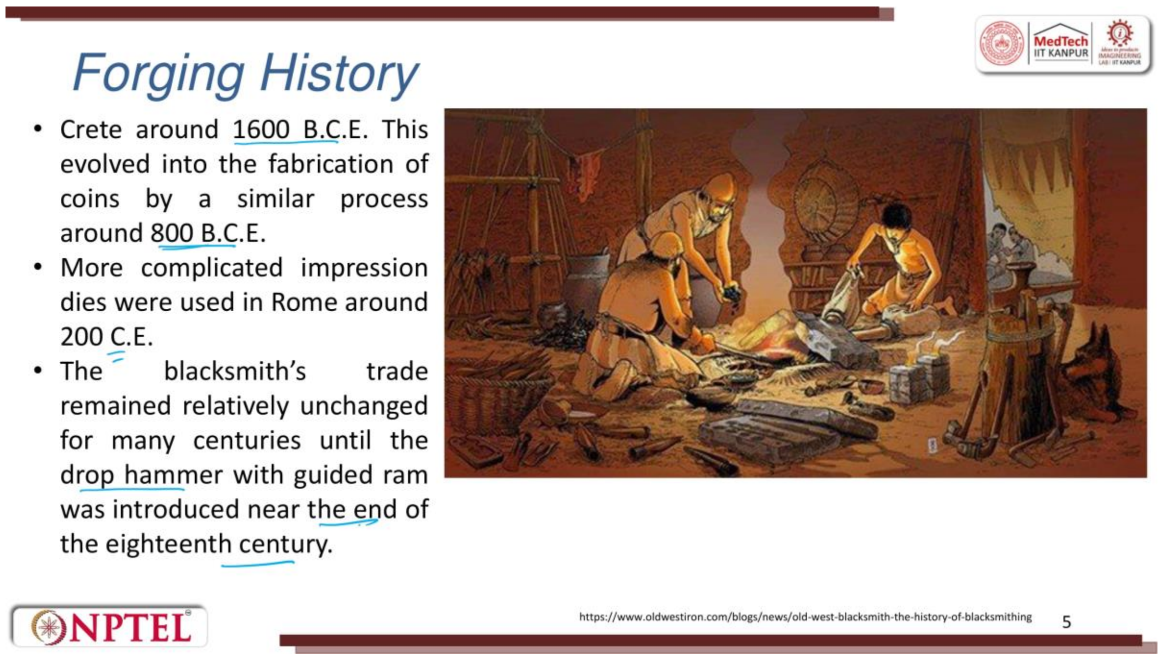
So what it does is it has a die you keep the block there. Then there is a top die which hits and then while hitting itself it tries to slightly orient so you get a helix. The helix will not be a full helix, but a small helix is given there. So today, helical gears are forged. Beautiful output you get.

The consistency, reliability is extremely phenomenal. Otherwise, we used to do it by machining earlier, but now we do it by forging. The production rate is very high. So various components such as engine, crankshaft, connecting rod, gears, aircraft structural component, jet engine, turbine parts. All are made through forging.

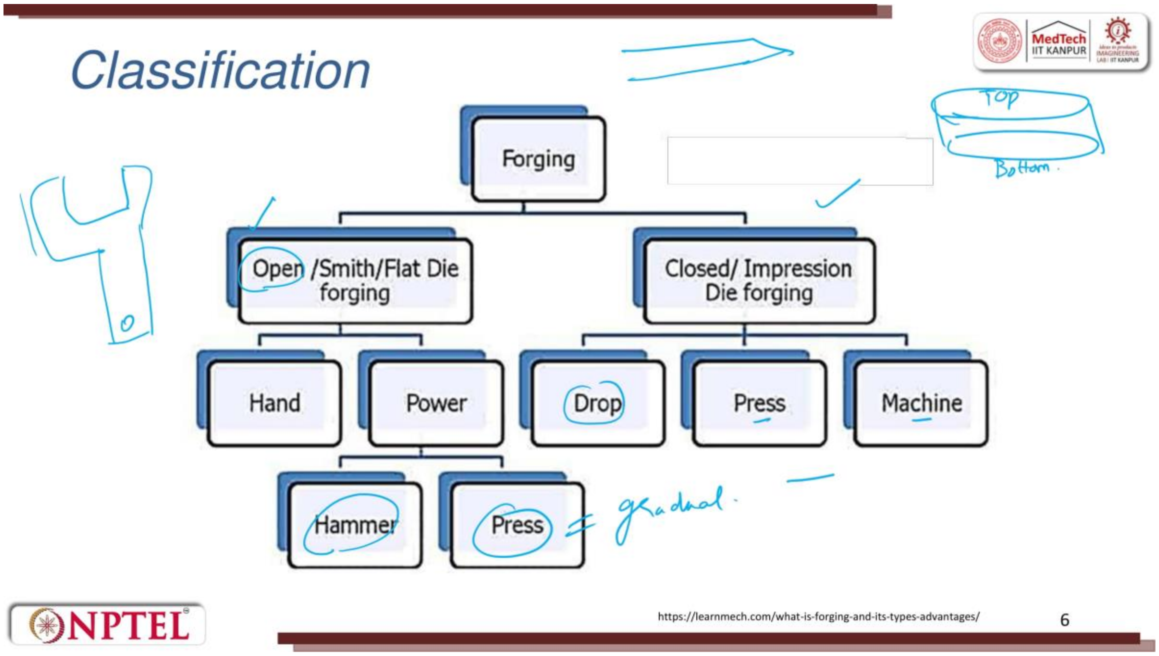


When we look at the history of forging, when they wanted to make swords and other artillery weapons, they used exhaustive forging methods. The forging process dates from the earliest written records of man around 7000 years ago. There is evidence that forging was used by ancient Egypt, Greece, Persia, India, China, and Japan for making weapons, jewelry, and various other implements. Engraved stone patterns were used as impression dies in the hammering of gold and silver in ancient times.

So what they did was, they had a die. In that die, they used to have all the features they wanted. And then they would try to imprint it on a flat sheet or a coin they used to have the engraving. In fact, the gold coins of ancient times were all forged, wherein they had the king's logo or face or whatever it was. And then they also had the worth of money, like the coin value, such as 1 rupee or 1 whatever it is, 1 carat, 24 carat—that's all forged.



Created around 1600 BCE, they evolved into the fabrication of coins by a similar process around 18 BCE. More complicated impression dies were made in Rome around 200 CE. And then the blacksmith trade remained relatively unchanged for many centuries until the drop hammer with a guided ram was introduced at the end of the 18th century. They were able to use this forging.



So, classifications of forging. What are the major classifications? Open die forging, closed die forging. Open die forging means the bottom and the top of an object. This is the top of the object, and the bottom of the object. So, if you have features and if all the features have to be brought into the workpiece, then we always go for closed die forging.

In open die forging, the basic shape alone will be there. For example, this is a spanner. So, you have the features. The top features are not very important. Only these dimensions are important.

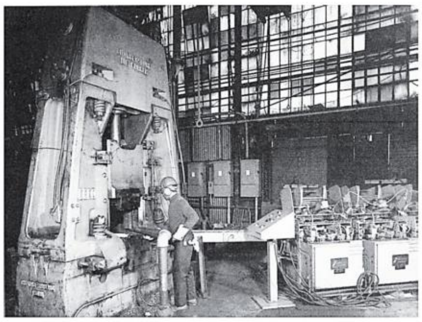
Then we go for closed die forging. Closed die forging is economical. For example, the screwdriver tip is forged. So here, the cost of the die is very economical. Open die forging, closed die forging.

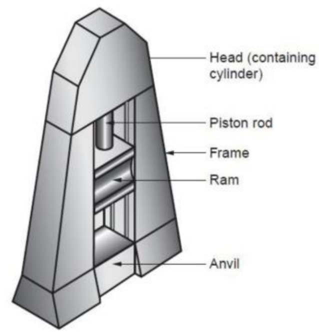
In open die forging, we have hand dies and power. Again, in power, we have hammers and presses. Presses are gradual. Hammers are impact-based. Gradual means, from the top, you can reduce or control the feed rates.

Slowly, it will come down and go up. In closed die forging, you can have drop, press, and machines. Open die is used for components and parts where their geometry is not so stringent and features are not so prominent. In closed die, that is not the case.

Forging Hammer

- Forging hammers operate by applying an impact loading against the work.
- Drop hammers are used for this purpose.
- **Gravity drop hammers** and **power drop hammers** are two types of drop hammers.



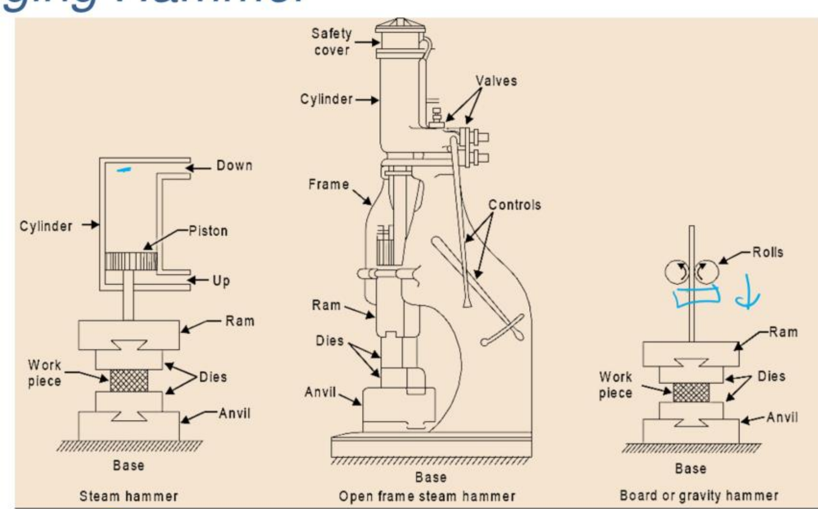


Drop hammer detail

Source: Modern Manufacturing: Mikell P. Groover;2012

The forging hammer. The forging hammer operates by applying an impact load against the workpiece. You try to have a lever, take it to the highest position, and from there, you drop it with impact. Drop hammers are used for this purpose. There are gravity-based and power-based drop hammers. Gravity-based means you pull it up, put a wheel, take the weights to the topmost position, and then instantly release. These are gravity drop hammers. In the power drop, you slowly take it through power and then you do it.

Forging Hammer



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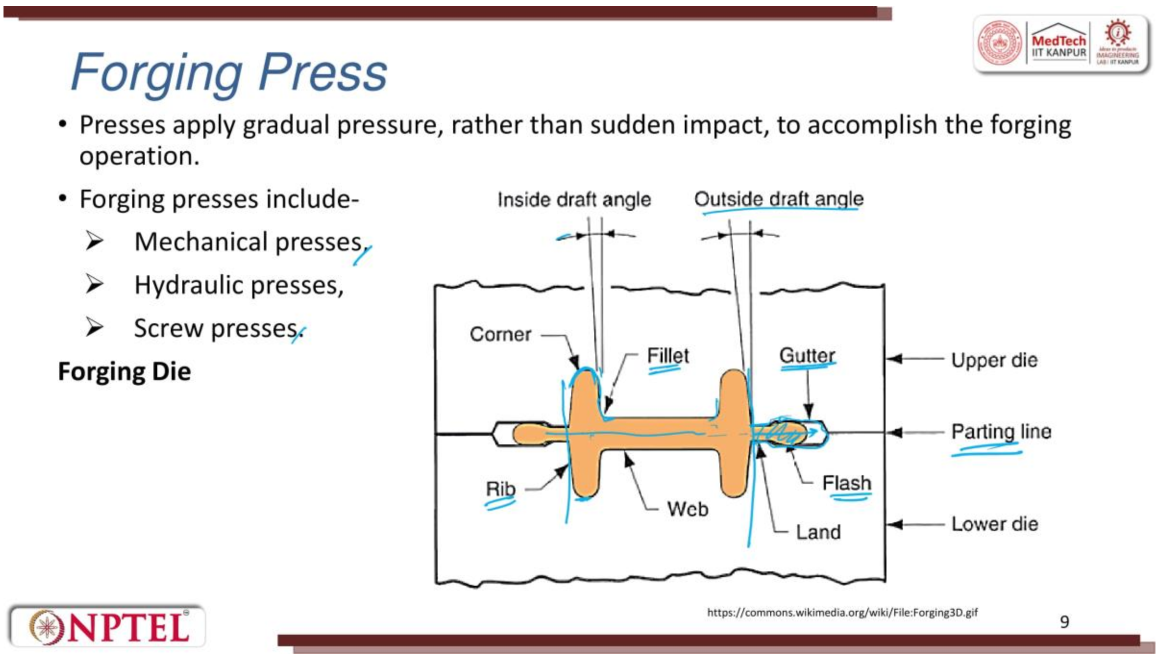
So these are the different types of hammers that have been used. This is a steam hammer. Steam is used to lift the piston to the highest point, and from there it is released.

It can be through gravity, or you can push it down through steam, and then that can deform. The other thing is, an open-frame steam hammer is also there. Then you also have gravity-based hammers. So with gravity, you roll it, it comes to the topmost position, and then you drop it. Impact forging.



So, forging press. Presses apply gradual pressure rather than sudden impact to accomplish the forging operation. So the press can be a mechanical press, hydraulic press, or it can be a screw press. When you look into a die, the cross-section of a die is shown. Like in casting, you have a draft allowance; you also have something called an outside draft angle.

This is the outside draft angle. This is the inside draft angle, which is given so that the component can be released. You don't have sharp corners. You have corners where you try to have the end. Those portions are called corners.

This is a corner. So, from the main web connecting to the corner, you have something called ribs. The main one is called the web. You can see there is a gutter. The gutter size will always be larger compared to that of your component.

For example, when the output of the component is cut like this, the center portion, like a dumbbell, will be the product. For this product, they will always have a land and a gutter. The function of the land is to take the excess metal from the main area to the gutter. And the function of the gutter is to ensure that it resists flow inside this gutter. And it provides enough pressure so that uniform distribution happens in the die.

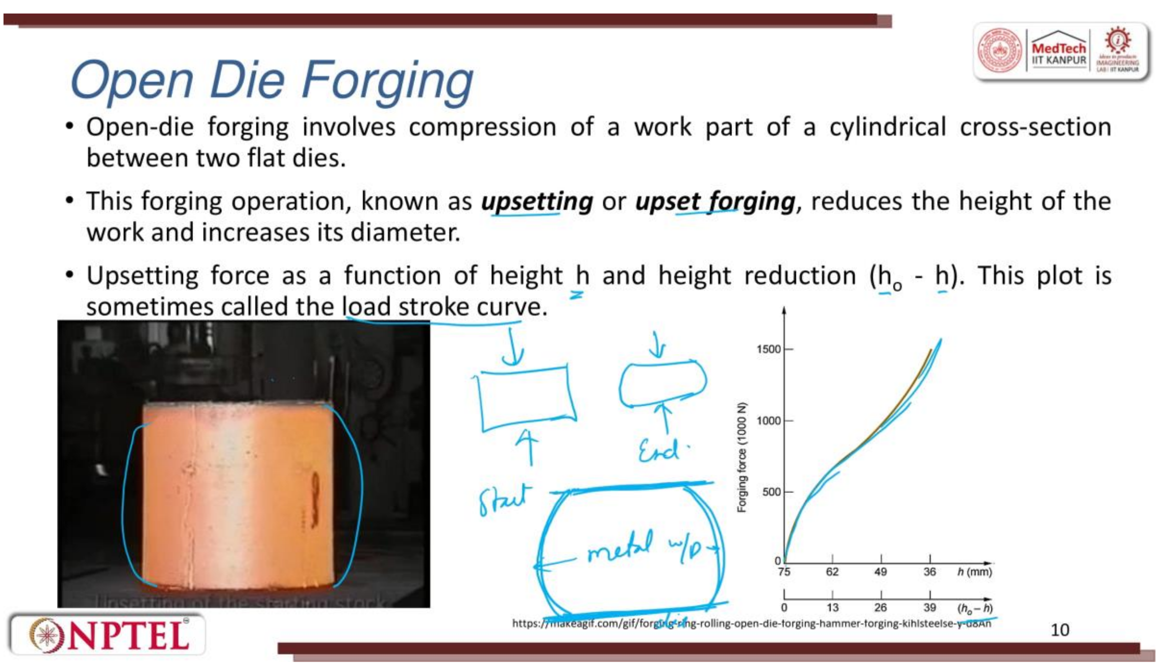
So later what along with the land it is cut down. So this part is a waste. So this projection part is called as a flash. And in between the top and bottom die is called as a parting line. identifying a parting line for any given component is a big challenge.

So, and there will not be any sharp corners, they will always be fillet. So, that is the fillet we give. So, here, friends, in a die, we have the same thing like what is there in the mold. You will have draft elements. There we had a shake elements.

Here we do not have shake elements. Here we have a land and a gutter. So through which the filling happens. So when it tries to flow in this direction, there is enough of resistance. So the metal distribution happens here.

Inside the die area, there is proper filling of metals. Suppose I do not give this land and the gutter; you will not have proper filling of the material inside the die portion. So gutter—you know the function of a gutter. What is flash? The flash will be trimmed.

Land to gutter, you know fillet, which is given, web, and then you know rib. So all these things will be part of a die.



So if you look at open die forging, it is something like a compressive load that is applied. So the workpiece, whatever is here, when you apply force, it tries to bulge and tries to get reduced.

So this will be the start, and this will be maybe the end. So you see here, there is bulging happening. And why is this phenomenon happening? Why is uniform bulging not happening? What happens is, at the top and the bottom, there is huge friction between the metal workpiece and the die, which is made out of metal.

So, because of this friction which is there, it does not allow the material to flow easily. Whereas, in the center portion, the material is allowed to flow easily. That is why we get this bulged portion while doing open die forging. So, open die forging involves compression of the work part of a cylindrical cross-section area between two flats. These two flats do not have any geometry.

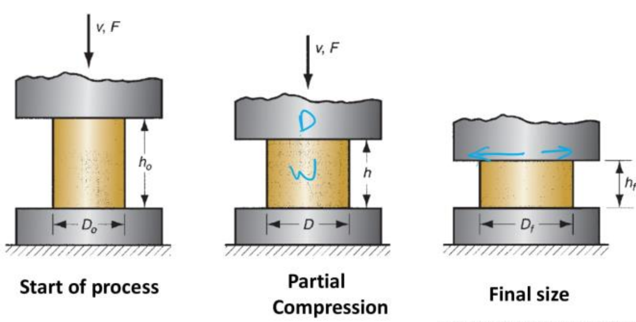
The forging operation known as upsetting or upset forging reduces the height of the work and increases the diameter. Because it is a constant volume process. The upset force as a function of height and height reduction from h0 to h is given in the plot. Here, you can see what H is and then what the reduction we are doing, H0 minus H. What is the forging load?

So, you can see there the response of the curve. The upsetting force as a function of the height h and the height reduction from h0 to h. This plot is sometimes called the load-stroke curve. Spanners are open forged. Your chisel, your knife, and all the agricultural implements when the blacksmith hits are all open die forging.

Open Die Forging

Without Friction

- Under ideal conditions there is no friction between work and die surfaces, then homogeneous deformation occurs.
- It results uniform radial flow of the material throughout its height.



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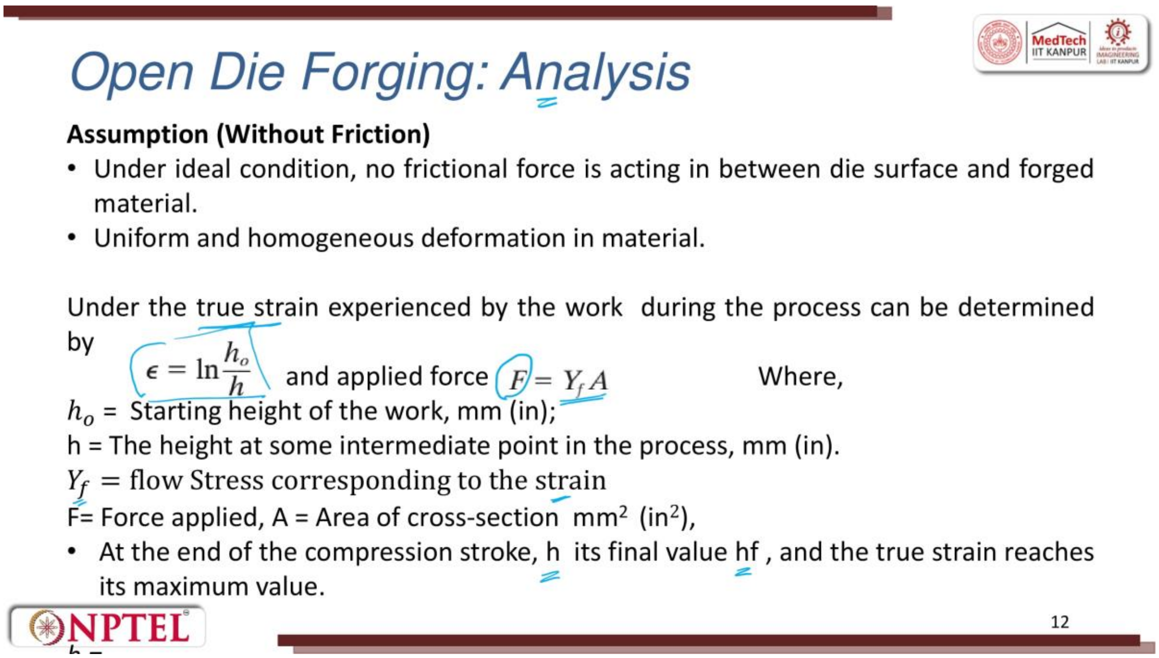
So without friction, what will happen? Under ideal conditions, there is no friction between the workpiece. This is the workpiece and the die surface. Then homogeneous deformation will happen. There will not be any bulging.

This results in uniform radial flow of the material through the height. So whatever the height reduction, the radial flow will be there. But in reality, friction does not disappear.



Assuming no friction, we are trying to do a small analysis to find out the required force. Under ideal conditions, no friction force acts between the die surface and the forged material.

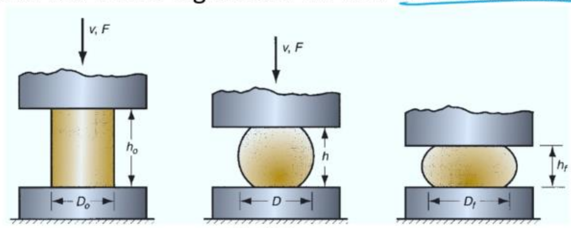
Uniform and homogeneous deformation in the material occurs. So, through the strain curve, we find the strain is nothing but the natural logarithm of H0 by H. And we are trying to apply a force $F = Y_f A$. Where h0 is the height of the workpiece, and h is at some intermediate point when it is being reduced. Flow stress is given for a corresponding strain as Ys.

The force whichever is applied is F, A is the area on which the flat surface of the workpiece is getting hit. At the end of compression stroke, the h is a function of hf and the true strain reaches a maximum value.

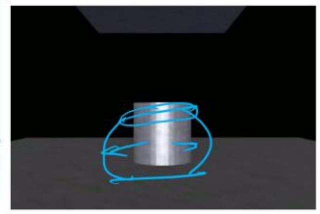
Open Die Forging

With Friction

- In this case friction opposes the flow of work metal at the die surfaces. This creates the barreling effect.
- The hotter metal in the middle of the part flows more readily than the cooler metal at the ends.
- These effects are more significant as the diameter-to-height ratio of the work part increases.



Start of process | Partial Compression | Final size



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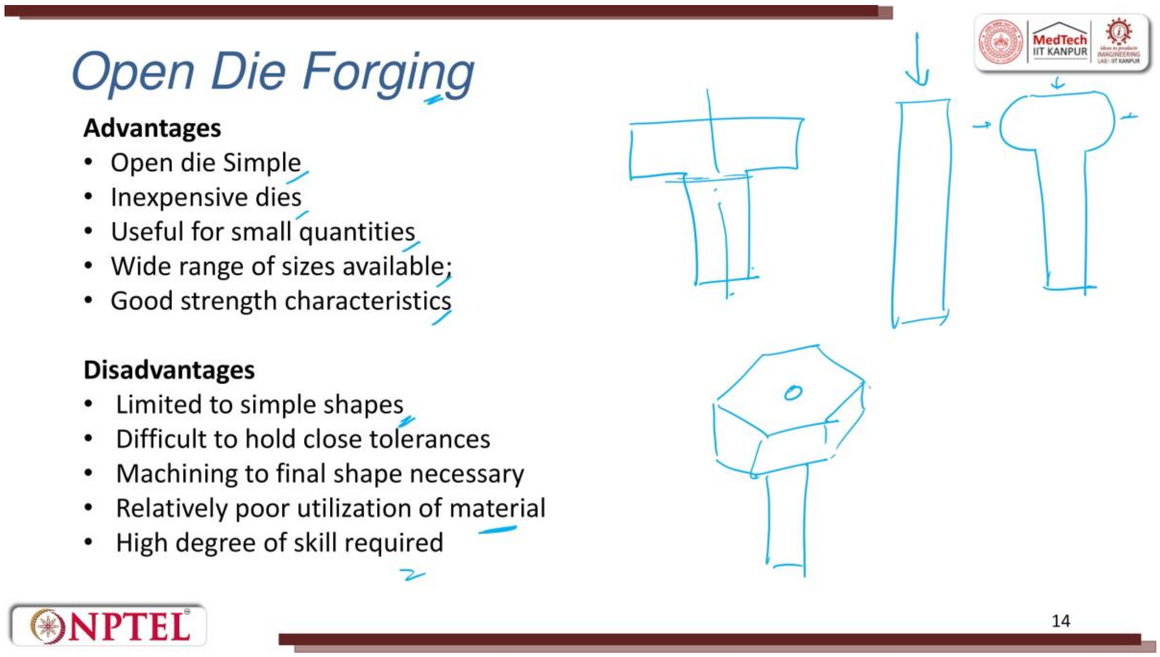
When there is a friction, what happens? In the case when there is a friction, the flow of the material or the metal at the die surface is opposed by the friction. This creates a barreling effect.

This is called as a barreling effect. The hotter metal in the middle of the part flows easily, readily than the colder portion which is touching the top surface. These effects are more significant as the diameter to height ratio of the workpiece increases. This is start of the process. This is partial compression.

This is final compression. So, friction and barreling effect you should remember. And what is the cause? We have discussed.



So what are the advantages of open die forging? In open die forging, it is very simple. The die is inexpensive. It is useful for small quantities. A wide range of sizes is available. Whatever the output, it provides good strength.

Disadvantages: limited to very simple shapes, like a screwdriver or spanner. The bolt head, by the way, gentlemen, the bolt head. This head is made by forging. They start with a large material. Then a force hits it.

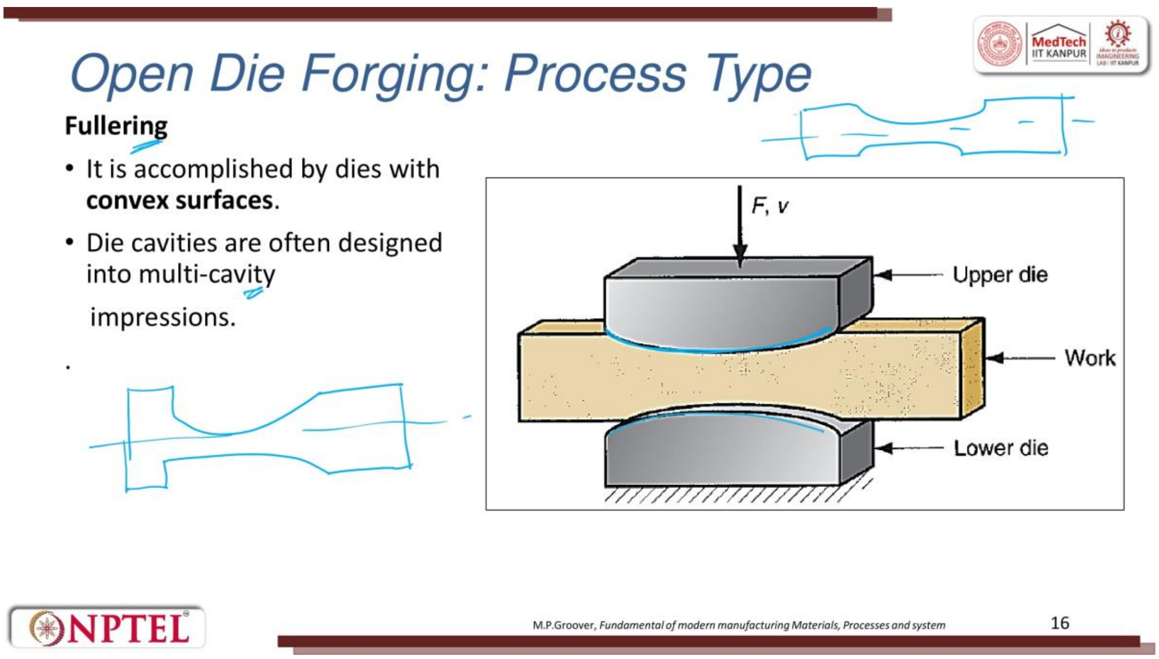
So it tries to take a shape like this. Then they move to another one. And then they give an impact shape to form a hexagon. This hexagon is formed at the top. So, this is done by the forging process.

So, machining of a final shape is necessary because it is open die; it is not a tighter torsion. Sometimes, it is necessary. Poor utilization of material can happen because there can be material that gets oozed out as flash. Then, finally, you trim it, and it needs a higher degree of skill. So, now, the first thing we did was analyze without friction.

Now, we will try to add friction to the analysis and see how the analysis changes. When performing hot work with cold dies, the barreling effect is even more pronounced. The hotter metal in the middle of the part flows more readily than the colder part at the end. These effects are more significant as the diameter-to-height ratio of the workpiece increases. So, due to a higher contact area at the workpiece-die interface, there is a huge impact of friction.

The applied force here is going to be F = KYA. Y is the flow stress, A is the area, and K is the strength constant ratio. So, mu is the friction. So, K is again a shape factor. So, that in turn depends on μ.

So, μ is the coefficient of friction, d is the workpiece diameter, and h is the height of the workpiece part. So, with that, you try to calculate Kf. From Kf, you know the flow stress and the area which is there. You can try to calculate the applied load.



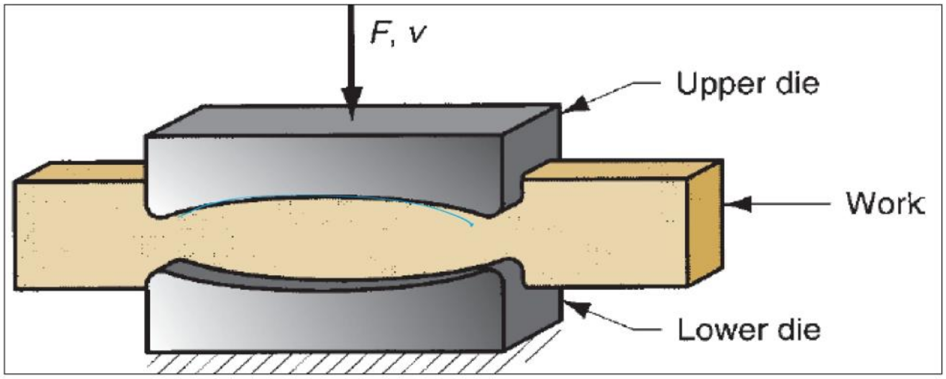
So, in open die forging, there are process types. In the fullering process, what happens is it is accomplished by a die with a convex shape. So, if you want to have any shape like this, something like this, if you want to have. So, then you will try to use the fullering operation. Or you can try to have something like this. Like this, also you can try to have.

So here, it is accomplished by a die with a convex surface. The die cavities are often designed into multiple cavities and impressions. Multiple cavities in the sense, like in lost-form wax casting, you can have multiple things attached.

Open Die Forging: Process Type

Edging

It is accomplished by dies with **concave surfaces**.



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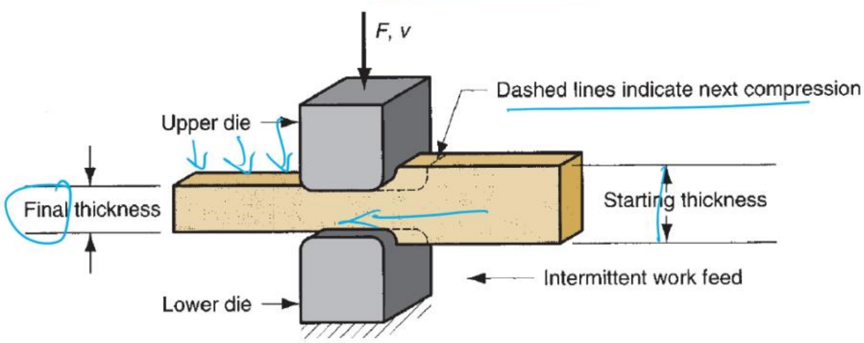
So, edging is another process. So, edging is accomplished by a die with a concave shape. Concave, the previous one was convex. This is called as edging process.

Open Die Forging: Process Type

Cogging

It is a sequence of forging compressions along the length of a workpiece to reduce cross-section and increase length. Its also called **incremental forging**



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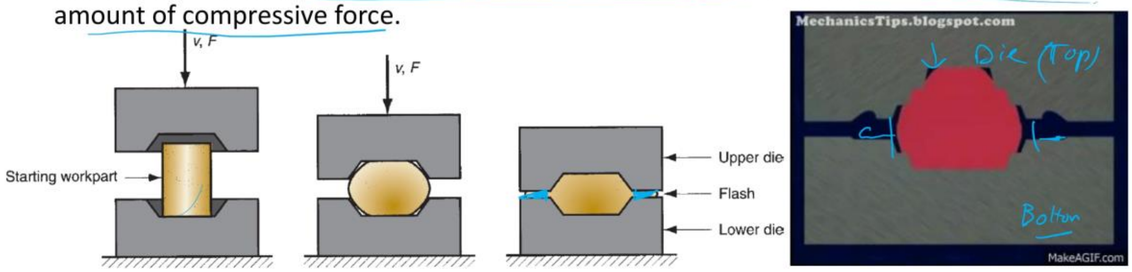
Cogging process, it is a sequence of forging compressions along the length of the workpiece to reduce the cross section area and increase the length. For example, it taps here. It keeps moving.

Closed Die Forging

Impression die forging

- Impression-die forging, also called closed-die forging, is performed with dies that contain the inverse of the desired shape of the part.
- Flash is formed by metal that flows beyond die cavity into small gap between die plates.
- Flash indirectly helps in close and complete filling of die cavity and it also increases the amount of compressive force.



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Sequence of forging compressions. Workpiece to reduce the cross section and increase the length. It is also called as incremental forging. In steps we increase the height or decrease the height. It is called as incremental forging.

The process is called as cogging. So it can keep hitting, hitting, hitting and moving. So this is the starting thickness, final thickness and here the dashed lines indicate the next compression.

Close die forging or impression die forging. In impression die forging, you see very clearly that there is a volume of material kept in the center.

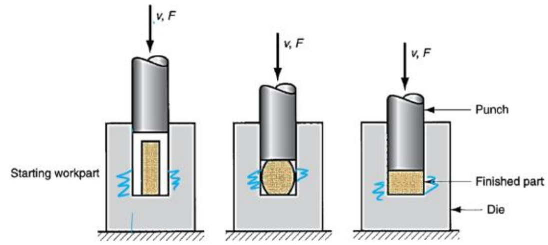
So this is a die on top. This is a die bottom. So when the compression load is applied, you see here there is material flowing along the land to the gutter. So, these things are called as flush. Or also called as closed die forging, is performed with die that obtain the inverse of the desired shape of the part.

So you keep this, press this, you see, and here you see the flash. The flash will be removed and then you get the final part. Flash is formed by metal that flows beyond the cavity into a small gap between the two flat plates. The flash is very important. If there is no flash, there is not much of proper filling, proper filling of the material.

Because there is a friction, the realignment of the material flow will happen and every portion is filled here. Flash indirectly helps in close and complete filling of the die cavity and is also increase the amount of the compressive force. So this is very very important. Gutter and flash are very important.

Flashless Forging

- In flashless forging, the raw workpiece is completely contained within the die cavity during compression, and no flash is formed.
- In this operation work volume must equal the space in the die cavity within a very close tolerance.
- Too large or too small blank may result breaking of the die/press, or incomplete filling of the cavity respectively.
- Flashless forging is often classified as a **precision forging** process.
- Suitable for simple, symmetrical parts, and to work materials such as aluminum and magnesium and their alloys.



A flashless forging is also possible. So in flashless forging, what happens is you have a punch and a die. And then, when the punch tries to hit the material, the material itself fills all the area around, and there is no flash here. So in flashless forging, the raw material is completely contained within the die cavity. There, you will have a top and a bottom. So, parting line decision is very important.

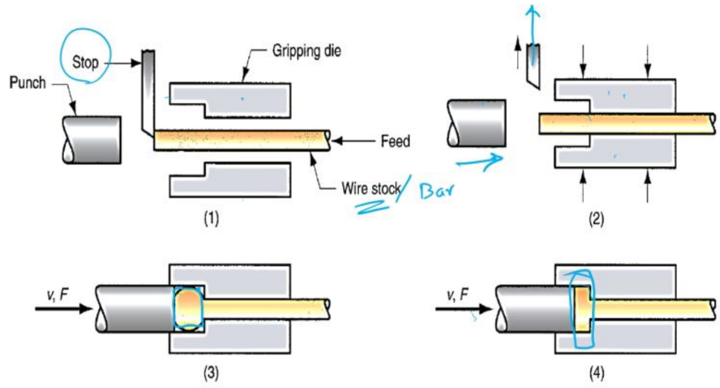
Here, the parting line is different. You don't have a parting line. In this operation, the work volume must equal the space of the die cavity within a very close tolerance. So whatever you need, we try to make the mold here, put the component, hit it here, it tries to fill and get the material. Too large or too small blanks may result in breaking the die and press or incomplete filling of the cavity, respectively.

Flashless forging is also classified as a precision forging process. So, if at all there are any features, the features will be exactly filled, and you get fine control over the output. Suitable for simple symmetrical parts, and work materials such as aluminum, magnesium, and titanium alloys are used here.

Other Forging Processes

Upsetting and Heading

- Upsetting (also called upset forging) is a deformation operation in which a cylindrical work part is increased in diameter and reduced in length.
- It is widely used to form heads on nails, bolts, and similar hardware products.



The other upset forging methods are, as I told you, the bolt can be done. In upset forging, what we do is we try to have a feed.

This is done by automatic machine. There is a feed which is there. There is a stopper. Feed comes from a bar. The material is fed inside.

The material is fed inside the die and you put a stopper there. So this is a stopper. So here now what happens is then comes the two dies. So if you see in the next step, the top die, bottom die grips the bar. Then the stopper goes away and once the stopper goes away there is a free hanging bar here.

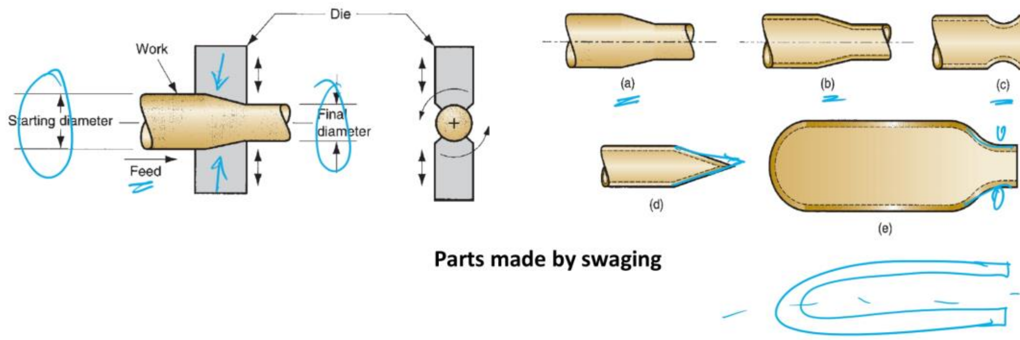
Now there is a punch there. This punch impacts on the bar. So when it impacts on the bar there creates a head. And this head when the punch is pushed inside the material filling happens. And you have a forged head in place.

So upset forging, also called upsetting or upset forging, is a deformation operation in which a cylindrical workpiece is increased in diameter and reduced in length. It is widely used for making nails, bolts, and other similar hardware. So nails are also made this way. So instead of wire, as I said, we are using it for nails.

Other Forging Processes

Swaging and Radial Forging

- It is forging process used to reduce the diameter of a tube or solid rod, it is often performed on the end of a workpiece to create a tapered section.



Parts made by swaging

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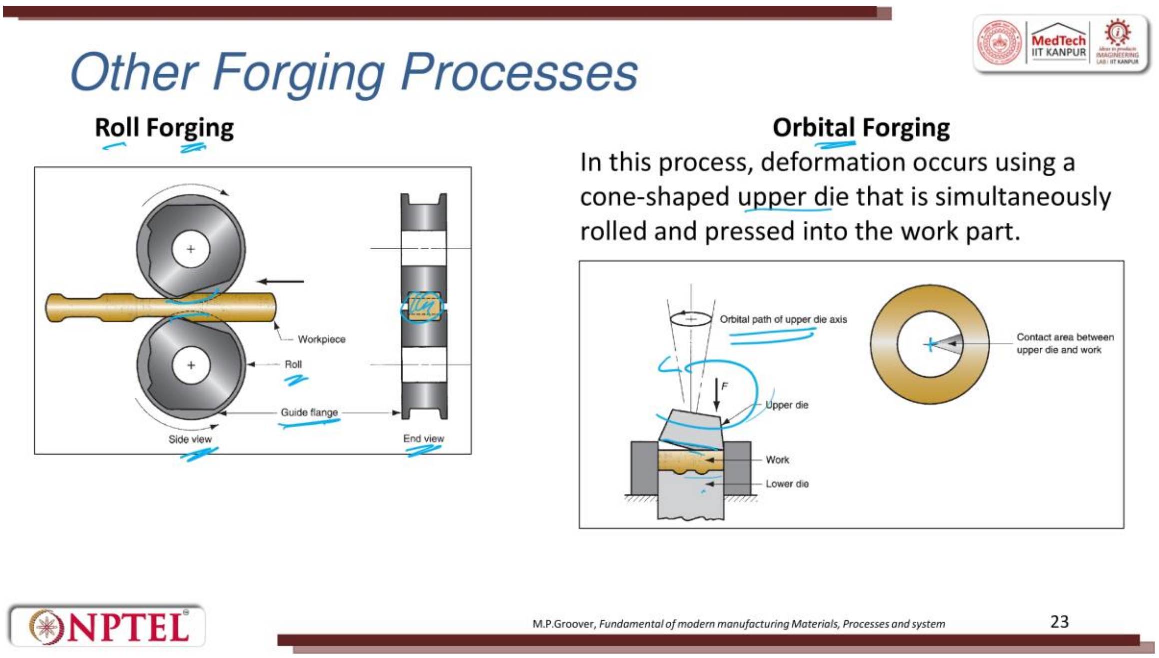
If you replace it with a bar, you can use it for bolt swaging and radial forging. If you want to have uniform reduction in the diameter, then what happens? You push the workpiece into a die, and in the die, there are impact loads that keep hitting it, which will try to reduce the diameter uniformly. So this is the starting diameter, and here you see there are dies, and this is a workpiece. It is fed through this direction. So this is the starting diameter, and this is the ending diameter.

Here the impact load is applied on the die. So here the workpiece is also rotated so that you try to get a uniform cross-section. So this is what it is. So if you look into it, there will be radial dies and there will be a cam. The cam will be rotating.

Each time the cam comes in contact with the die, it hits the workpiece. It is a forging process that is used to reduce the diameter of a tube or a solid rod. It is often performed on the end of the workpiece to create a tapered surface. So you can try to have such cross-sections by using swaging, or you can also have a sharp tip by using the swaging process. If you want to form the flask's internal surface, this is also done by the swaging process.

So initially, it will be like this. It will be like this. Now, you do swaging and try to reduce this diameter. It will be like a bottle. So, swaging and radial forging are interesting processes that are part of closed-die forging.



Then you also have something called roller forging. So, I roll using a roller. Two rolls, and then the roll shape is given a special shape. When this roll rotates and tries to hit the workpiece, it creates an impact. That is why it is called roll forging.

So this is the workpiece; this is the roll. The roll has the shape, whatever it is, and then it can create the shape, whatever you want, on the workpiece. This is the side view. The side view is what you see when looking from here. This is the end view.

When you see the end view, you can see this is the workpiece, and you can see the guide flange, whatever it is. Orbital forming is another interesting process. In this process, the deformation occurs using a cone-shaped upper die that simultaneously rolls and presses the object. This will roll and impact. So you see here; this is the orbital path.

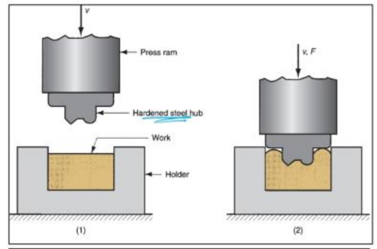
So it goes like this. It goes like this and then hits it. So, you can try to create parts like this. So, this is the lower die; this is the upper die. The upper die rotates like an orbit and also hammers.

So, you can try to have such interesting workpieces made out of the orbital forging process. So, the contact area between the upper die and the lower die can be seen here.

Other Forging Processes

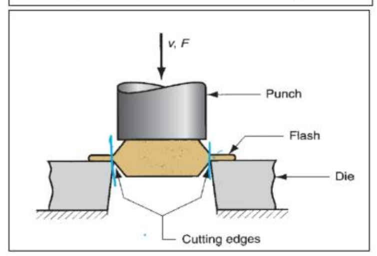
Hubbing

- In this process a hardened steel form is pressed into a soft steel (or other soft metal) block.
- The process is often used to make mold cavities for plastic molding and die casting



Trimming

- Used to remove flash on the work part in impression-die forging.



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Hubbing process: In this process, a hardened steel form is pressed into a soft steel. So, this is the work. This is a hardened steel. This is a soft workpiece. So, the shape is given to the workpiece. In this process, a hardened steel form is pressed against a soft steel to create the desired shape. The process is often used for making mold cavities in injection molding and die casting. Trimming is another process.

It is used to remove flash on the workpiece in impression die forging. So, in trimming, you keep the workpiece, punch it, and hit it. Now, the component is cut here. Then, the component falls down. You can use this component for your real-time application.

The flash is trimmed. Used to remove flash on the work part in the impression die forging.

Forging Defects

Forging defects	Area of action	Corrective action required
Overlap	Crankpin / web	Remove deformation of blocker die by dressing with template.
Underfilling	Temperature	Modify burner position and calibrate furnace for temperature.
	Die deformation	Grinding of blocker die as per template.
	Delay	Preventive maintenance of conveyors and manipulators for smooth movement of billet from furnace to die.
	Die design	Modify blocker die design by mapping unfilled zone.
	Lubricant	Select the best lubricant for die.
Pitting	Scales	Remove scales in blocker forging or finisher forging through preventive maintenance of descaler.
Foreign body	Unwanted material	Remove foreign body from sawdust through checking of sawdust while mixing with water.
	Chips	Air should be blown properly before placing hot billet both in blocker and finisher die.
Shop scrap	Temperature	First zone temperature to keep higher side for better soaking.
	Delay	Preventive maintenance of conveyors and manipulators for smooth movement of billet from furnace to die.
	Billet	Place billet properly at bender and check billet to touch stopper on flange side.

NPTEL

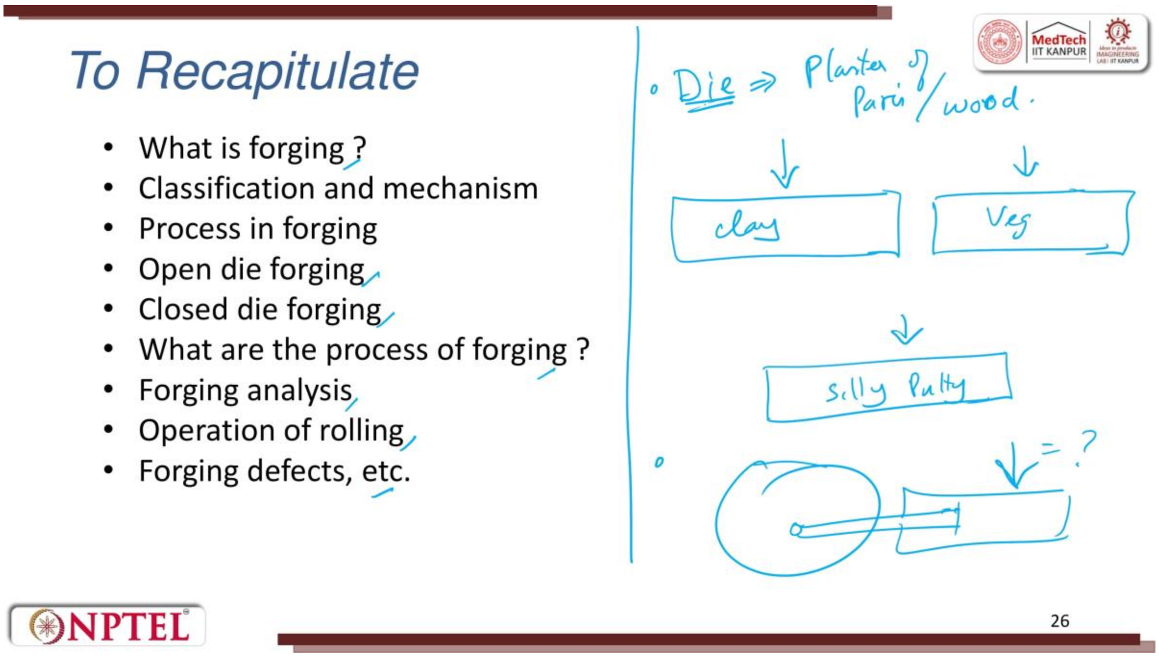
https://www.researchgate.net/figure/Actions-required-overcome-vital-forging-defects_tbl6_228825736

Forging also there are lot of defects. So these are the defects. So overlap is a defect which the area of action is crank, pin and web. Remove deformation of blocker die by dressing with template. Under filling, the action taken is temperature, die deformation, delay, die pressing and lubricant.

So these are all action to be taken such that the filling of the die happens properly. Pitting are nothing but scales which are formed because of metal to metal friction. And then foreign objects, unwanted material and chipping, the oxides which form a hard layer and then it is formed here.

Then shop scrap is the action area is temperature. The first zone temperature to keep higher side for a better soaking. Delay is prevent maintenance of conveyor and other things. Billeting is place the billet properly at blunder and check billet to touch the stopper and the flange side. So these are some of the defects.

These are the areas of action. These are the corrective actions which are required to remove the defects present in forging.



So, before we recap this lecture, I would like to give you a simple exercise. The exercise is, you will try to make a die, okay. You will try to make a die, assuming that this die is made out of plaster of Paris, right.

Or wood, you carve it and then you make wood, right. Now what you do is you try to take a soft material. Let it be clay. Then let it be some vegetable which has it. And then the third one is you try to have another clay or one vegetable.

Then you can try to have sili putty. Which is used for sealing glass windows. Try to take three of them or you take M-seal. Now you try to take a die which is made out of plaster of Paris. In this die, what you do is you try to give an impression.

Now you try to press this as against three of these workpieces. Now you remove the dye and then allow this fellow to cure. And then see what is the amount of shrinking which is happening in the final impression what you have created there. If you do this exercise, you will try to understand the forging, how important the workpiece and the impact force is, right. Then the next one is, I would like to say, you try, you have seen many a times in the trucks, where when they wanted to remove the tyre, right.

When they want to remove the tyre, they always put spanner, right. and then they put a long spanner, whatever it is, and a person jumps on top of it every time. So my question is, why does he jump? Why do people not pull it around? He goes, stands on top of it and he jumps.

Why does he jump? While doing so, what happens to the nut and bolt contact, whatever is there? So if you understand this, then you will understand what is the effect of impact load. So, in this lecture, we have seen what is forging, classification and mechanism of forging, process in forging, open die forging, closed die forging. Then what are all the processes of different processes of forging.

Then, analyze with and without friction, then operations of rolling and forging together. Finally, we have seen the forging defects.

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Friends, we have used these many references to prepare the slides, and the exercises I have given are only for your self-understanding.

Thank you very much.