Advanced Manufacturing Processes
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Module - 5
Other Advanced Processes
Lecture - 1
High Energy Rate Forming Processes

Welcome to this new module on some new specialized material processing methods under the course advanced manufacturing processes. In the module 4, we have discussed about many advanced welding processes like solid state welding processes, laser welding processes, plasma arc welding processes etcetera. We have seen the working principles, advantages, limitations and applications of these processes. Moving on, let us see some new processes like high energy rate forming process, then rapid prototyping process and microwave material processing techniques. In the first of these techniques, let us consider high energy rate forming process.

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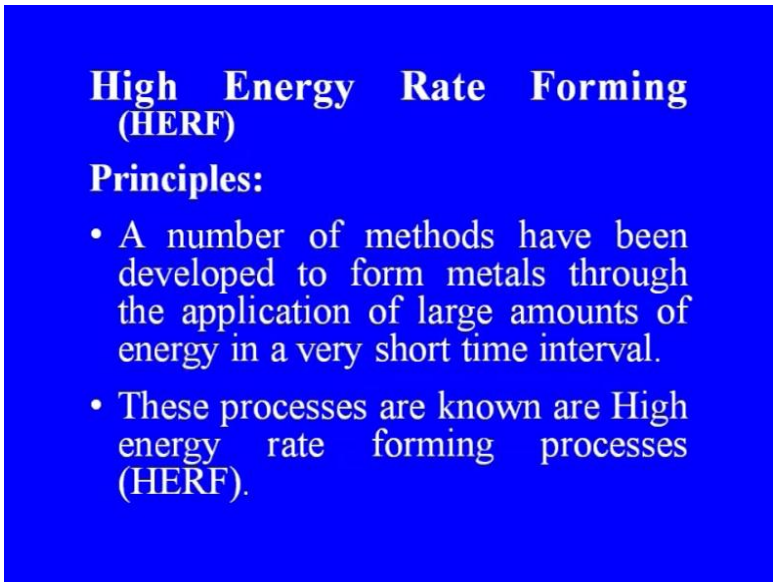

The principle of these processes is like this. A number of methods have been developed to form metals through the application of large amounts of energy in a very short time interval. These processes are known as high energy rate forming processes.

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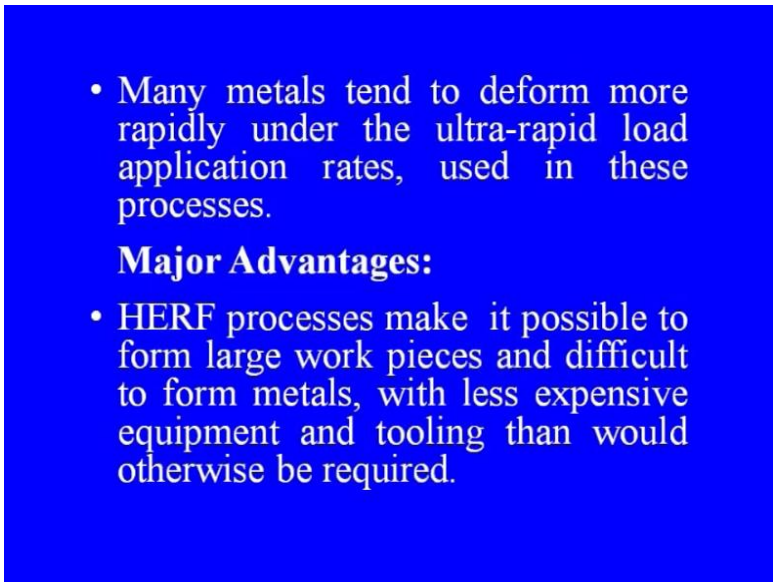

Many metals tend to deform more rapidly under the ultra rapid load application rates used in these processes. Principle of high energy rate metal forming can be explained like this, if we have a ductile material, then this material can be deformed by working on it at a very faster speed and against a die of the shape required, the material can be shaped under the pressure of this applied energy.

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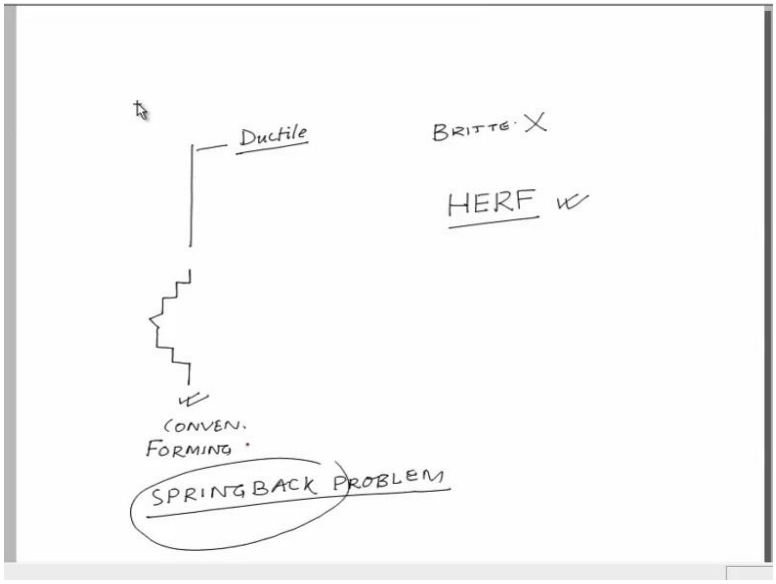

Say for example, we have a sheet of metal which is of ductile in nature. So, this is we can say this is a pre condition for the material to be formed by this process. Generally,

brittle materials, brittle materials are not suitable to be processed by this process. Now, say for example, this sheet is to be given a shape something like this, then we can take help of this particular process, that is high energy rate forming process HERF. Otherwise, if we try to make or form the sheet into this shape, then if we try to cut it from a basic block, then there will be wastage of certainly wastage of material or otherwise the processing time as well.

And if we try to do this with the help of conventional, conventional material forming processes, this is forming, that is called conventional forming processes. Then the problem is the time required will also be high, then and another problem is the spring back problem. This is very much associated with all the conventional forming, most of the conventional forming processes applied to sheet metal forming.

Now, this can be easily overcome by applying this concept of high energy rate forming which very faster and there is no problem like spring back problem also as we encountered in many metal forming, sheet metal forming processes, conventional sheet metal forming processes. So, here the principle is something like this.

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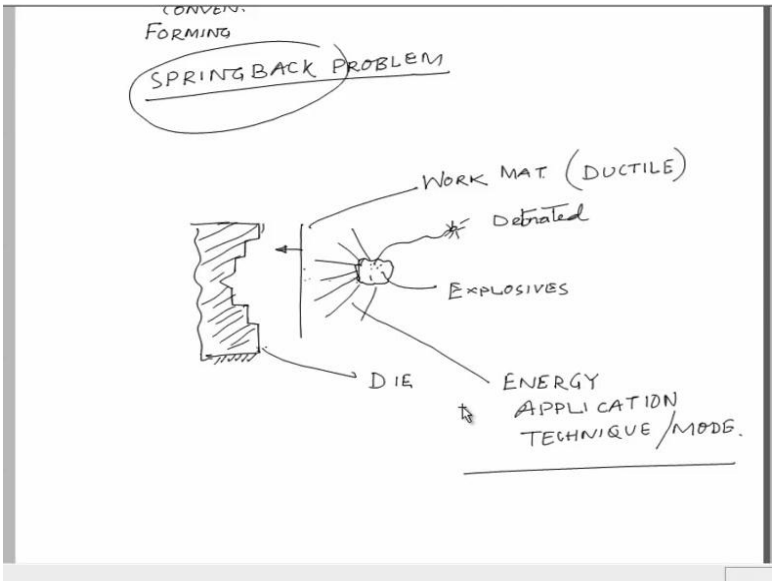

Suppose, we have a sheet to be formed then we have a die here of the required shape that is to be formed. Say, this is the die which, which is reusable of course, this is a die, this is a reusable and this is very firmly held here and this is the sheet, this is we can say, this is the work material to be shaped. Then if by somehow we can provide velocity to this

sheet and allow them to impact this die at a very high rate then it will, it will plastically get deformed and take the shape of this die.

So, this is the, we can say die and this is being used, this principle being used in this process. So, here what is being done is generally there will be some explosive. So, these are explosives being used and they are being detonated suitably, so they are detonated and therefore, there will be shock wave and this will cause a very high energy to be transferred. And this sheet will get impacted on against this die at a very high rate and it will take the shape of this die.

So, this is basically the principle of, this particular processes there are different techniques for this and there are some hydraulic techniques, there are some capacitive techniques which are being employed to achieve this detonation process or this you can say, this is nothing but energy energy application technique or mode. So, only this mode can be different, but the basic principle lies in this in which a material, material which is basically ductile in nature, generally ductile in nature will be formed using this high energy or high speed rate of, high speed of forming.

Thus, if we see the major advantages of this process, high energy rate forming processes make it possible to form large work pieces and difficult to form metals with less expensive equipment and tooling than would otherwise be required.

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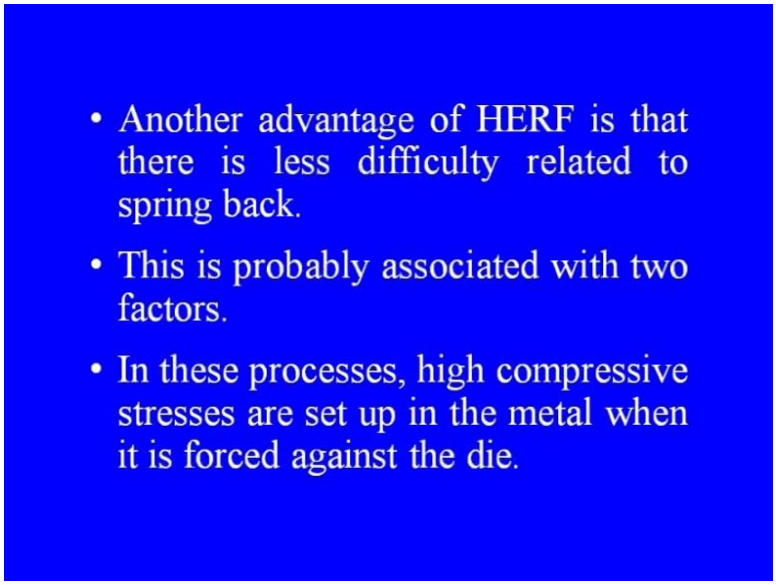

Another advantage of high energy rate forming process is that there is less difficulty related to spring back. This I have already indicated that in conventional metal forming processes, sheet metal forming processes generally, there will be a problem that is called spring back which accounts for actually the dimensional inaccuracies or form accuracies, form inaccuracies. Therefore, this can be, to a large extent can be eliminated in this processes. This is probably associated with two factors. In these processes high compressive stresses are set up in the metal when it is forced against the die as we have already explained.

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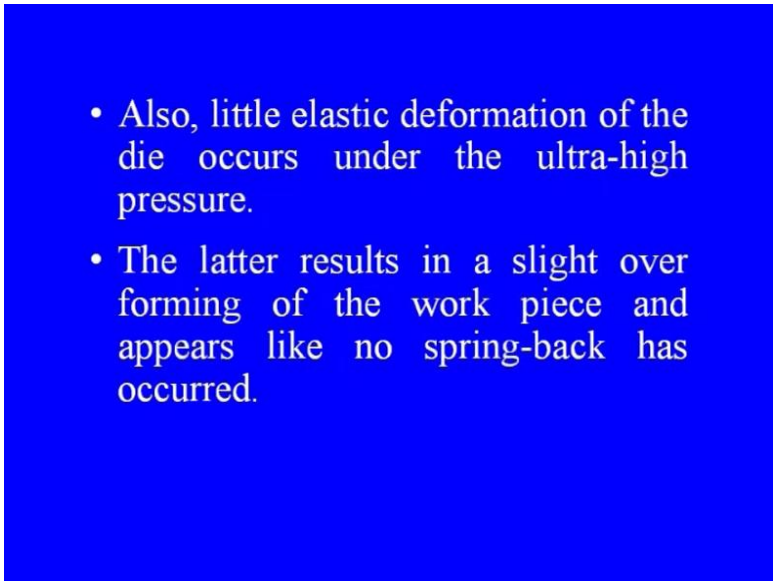

Also little elastic deformation of the die occurs under the ultra high pressure. The latter results in a slight over forming of the work piece and appears like no spring back has occurred. High energy rate can be obtained by five distinct methods as we have already indicated; there are different techniques or modes to obtain high energy rates.

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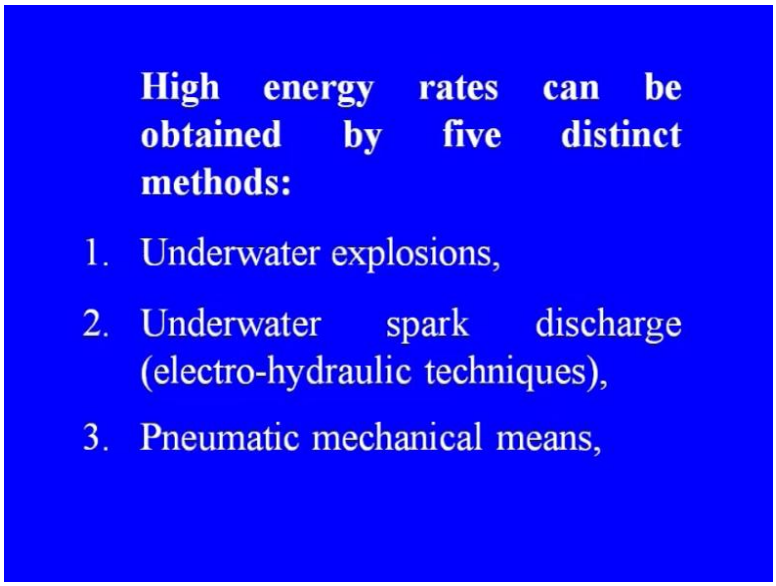

So, these are number one underwater explosions, number two underwater spark discharge which is also called electro hydraulic techniques, then pneumatic mechanical means…

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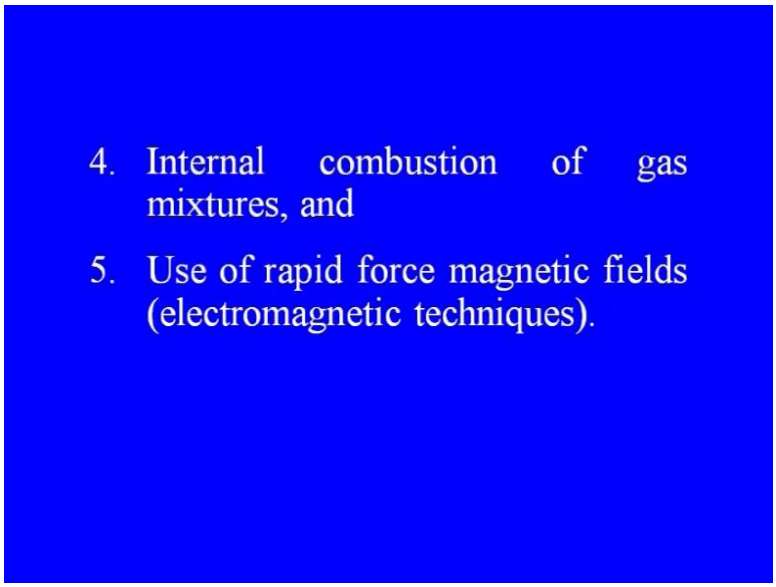

Then number four internal combustion of gas mixtures and number five use of rapid force magnetic fields which is also called electromagnetic technique. Let us first of all discuss the underwater explosion technique.

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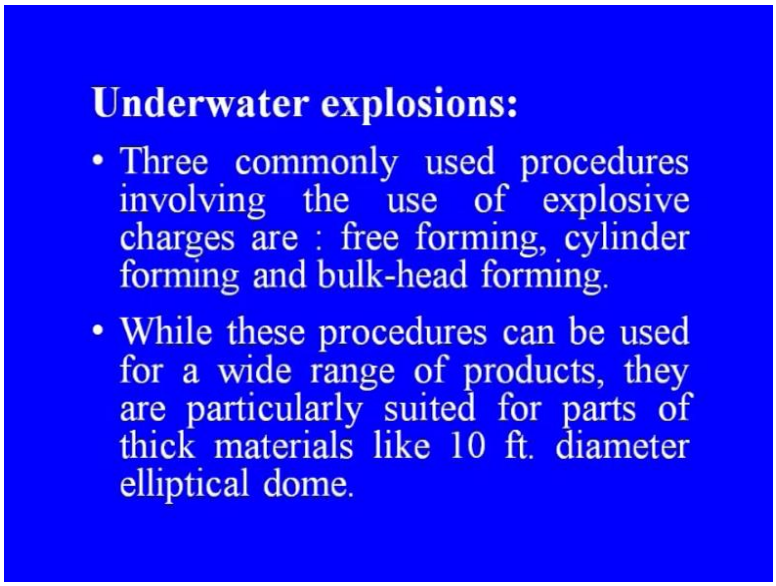

Three commonly used process procedures involving the use of explosive charges are free forming, cylinder forming and bulk head forming. While these procedures can be used for a wide range of products, they are particularly suited for parts of thick materials like 10 feet diameter elliptical dome which is considered to be a very big piece, material piece to be formed. And this process is found to be suitable for such huge parts to be produced.

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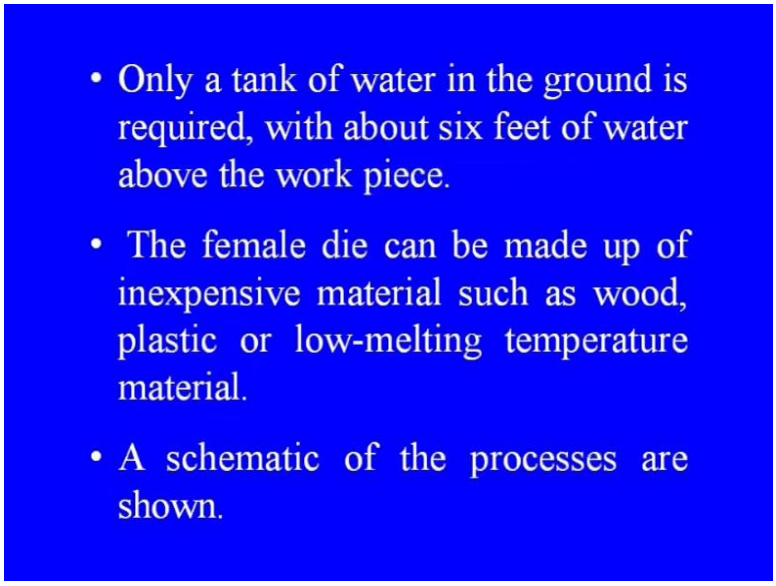

Only a tank of water in the ground is required with about 6 feet of water above the work piece. The female die can be made up of inexpensive material such as even wood, plastic or low melting temperature materials. A schematic of the processes are shown like this.

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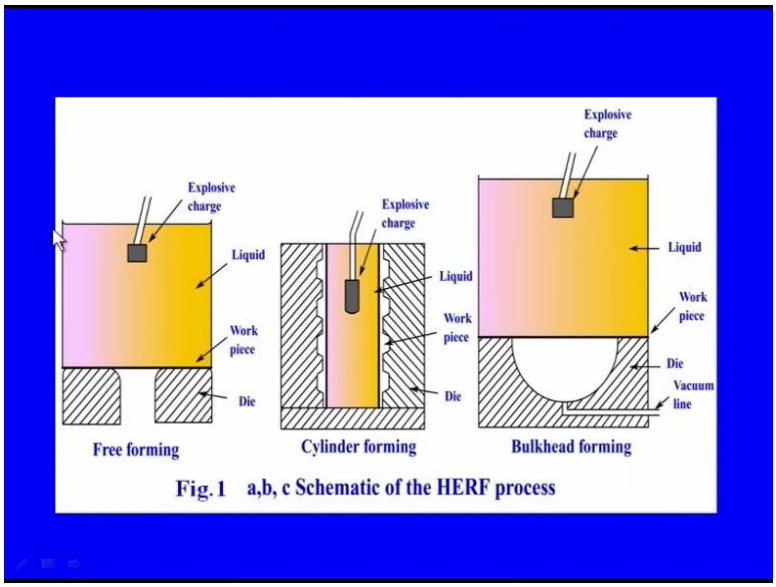

So, this is the, this entire process shown in the screen. So, this is the tank, underwater tank we can, we can talk about and this is where the explosive charges are put and it will be detonated later on. So, this is the work piece or the plate to be shaped. These are the, this is the part of the die. Now, this can, once this explosive charge is exploded then the energy will be transferred in all directions and this energy will cause this plate to deform and take the shape of this die. This is the basic principle of this process.

Similarly, as I have already indicated earlier if the die is like this and a cylinder having some features like this need to be produced. Then what we can do is one plain cylindrical cylinder can be placed like this, then this consist of the explosive charges can be exploded in the middle and because of the pressure applied on this or we can say the energy being transferred because of this explosion to take place, there will be a sudden expansion of the gases or the medium in contact with and that medium, the energy through that medium will be transferred to this sheet of material to be worked upon and it will get plastically deformed to take the shape of this die.

So, in this case this, there will be a cylinder having some features like this will be produced. Similarly, suppose a dome is to be produced, hemisphere sort of dome then the

sheet is placed like this, this is the medium in which the explosion will be taking place and the sheet will take or will plastically get deformed and take the shape of this die like this. However, if the volume of this is large then the air or the gas entrapped in this needs to be evacuated otherwise, there will be non uniformity on the shape. Therefore, there will be some connections where through which the gas or the air interrupt here will be evacuated prior to the process, so that there will, the shape inaccuracy will be minimized.

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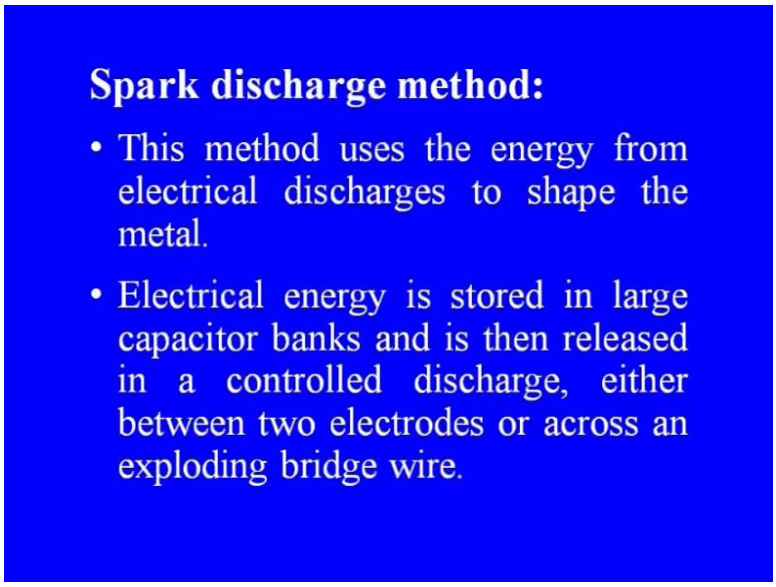

Now, let us discuss another method, so that is spark discharge method. This method uses the energy from electrical discharges to shape the metal. The electrical energy is stored in large capacitor banks and is then released in a controlled discharge, either between two electrodes or across an exploding bridge wire.

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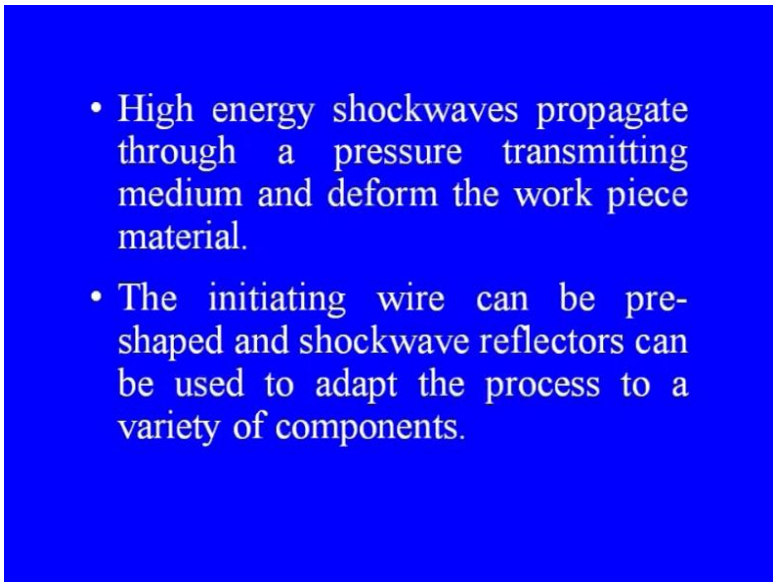

High energy shockwaves propagate through a pressure transmitting medium and deform the work piece material. The initiating wire can be pre shaped and shockwave reflectors can be used to adapt the process to a variety of components.

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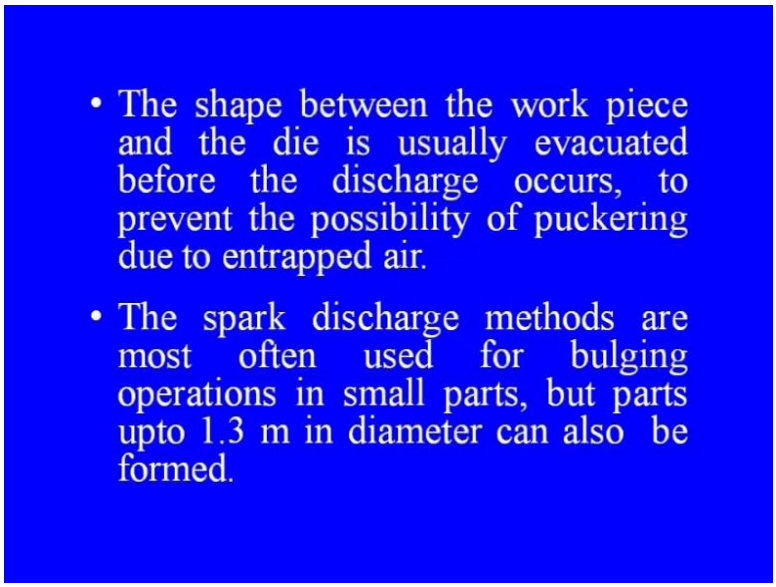

The shape between the work piece and the die is usually evacuated before the discharge occurs, to prevent the possibility of puckering due to entrapped air. The spark discharge methods are most often used for bulging operations in small parts, but parts up to 1.5 meter in diameter can also be formed.

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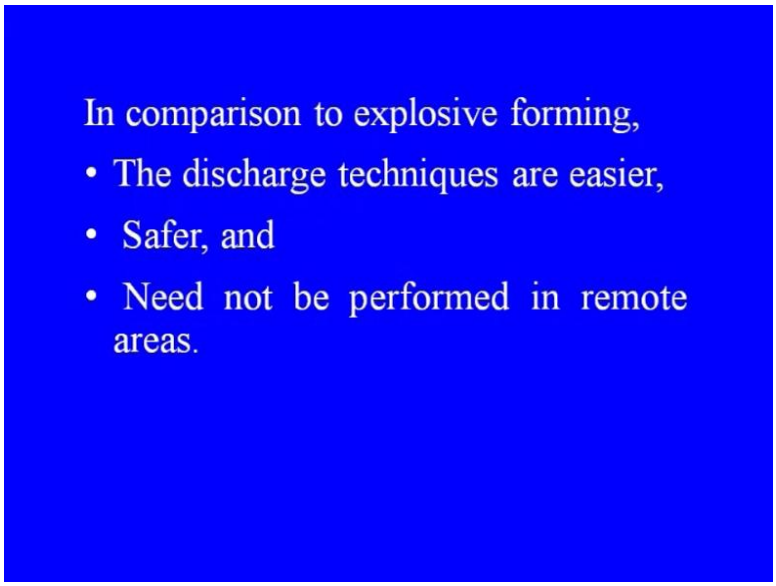

In comparison to explosive forming the discharge technique, techniques are easier, safer and need not be performed in remote areas because that is explosion will be generally allow to take place inside a medium that is liquid medium or so. Therefore, it will be generally safe to operate.

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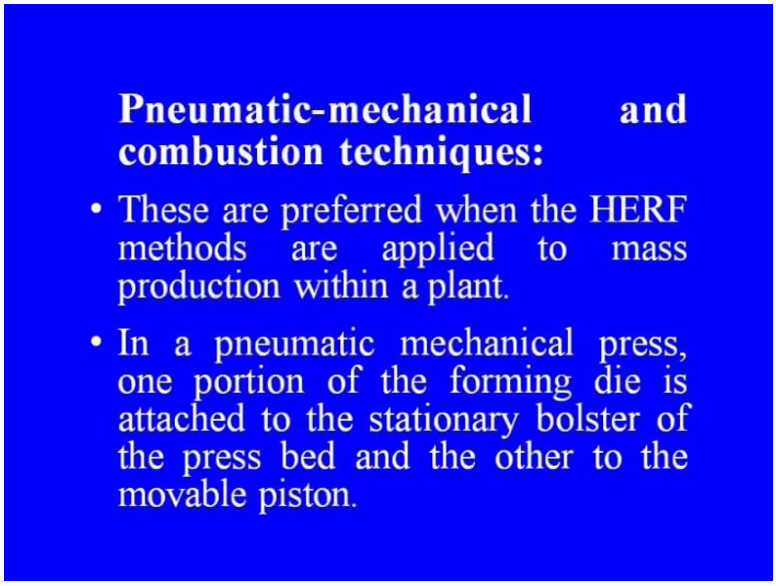

Now, let us look at pneumatic mechanical and combustion techniques that is used for forming processes. These are preferred when the high energy rate forming methods are applied to mass production within a plant. In a pneumatic mechanical press, one portion

of the forming die is attached to the stationary bolster of the press bed and the other to the movable piston.

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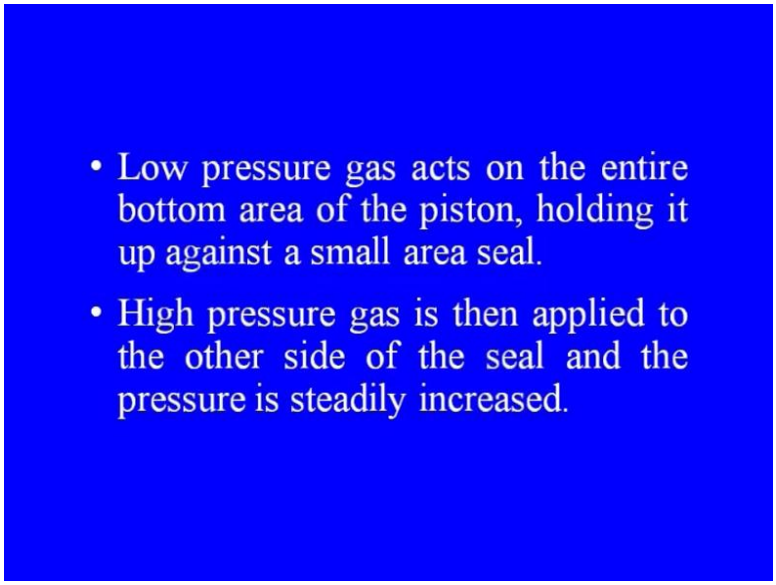

Low pressure gas acts on the entire bottom area of the piston, holding it up against a small area seal. High pressure gas is then applied to the other side of the seal and the pressure is steadily increased.

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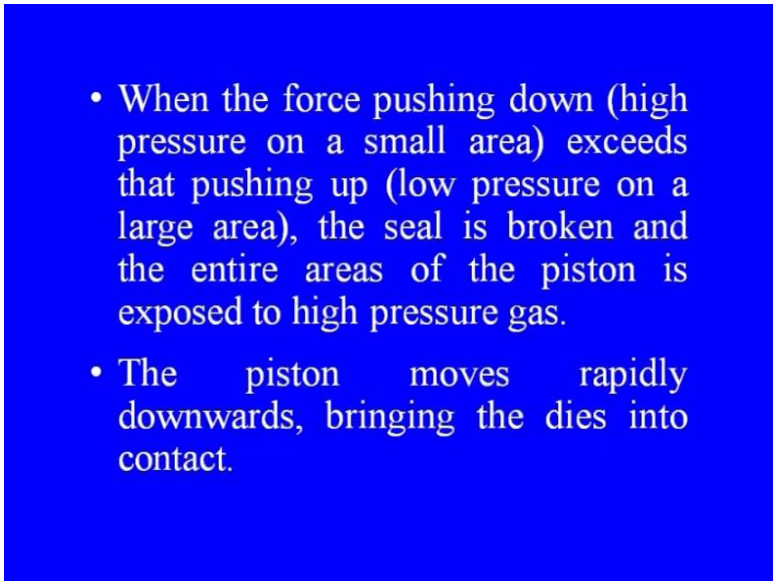

When the force pushing down high pressure on the small area exceeds that pushing up that is low pressure on the large area, the seal is broken and the entire area of the piston

is exposed to high pressure gas. The piston moves rapidly downwards, bringing the dies into contact.

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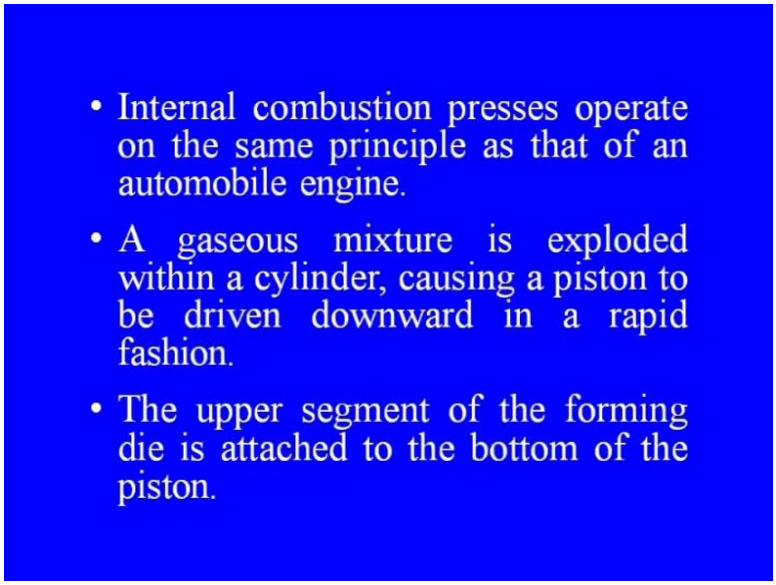

Internal combustion process operate on the same principles as that of an automobile engine. A gaseous mixture is exploded within a cylinder causing a piston to be driven downwards in a rapid fashion. The upper segment of the forming die is attached to the bottom of the piston.

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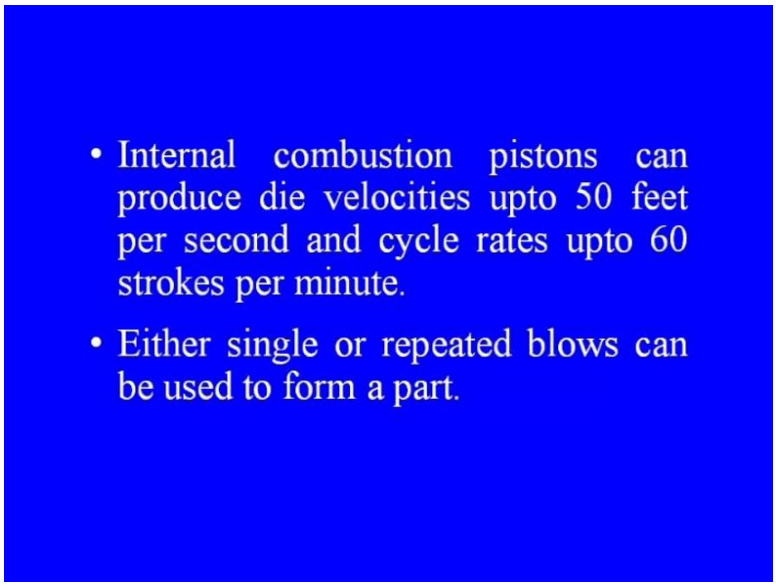

Internal combustion pistons can produce die velocities up to 50 feet per second and cycle rates upto 60 strokes per minute. Either single or repeated blows can be used to form a part. Now, let us talk about another important variation in this high energy rate forming process that is electromagnetic forming also known as EMF.

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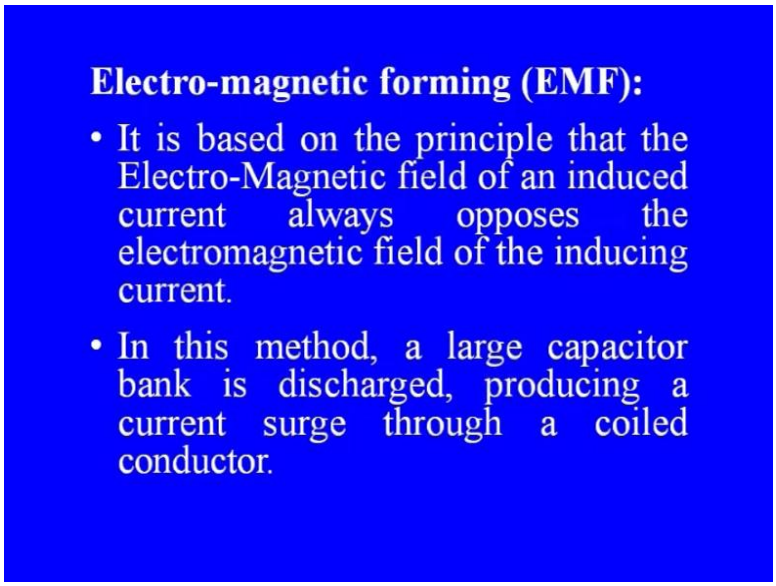

This process is based on the principle that the electromagnetic field of an induced current always opposes the electromagnetic field of the inducing current. This is a very basic principle that we know. In this method a large capacitor bank is discharged producing a current charge through a coiled conductor.

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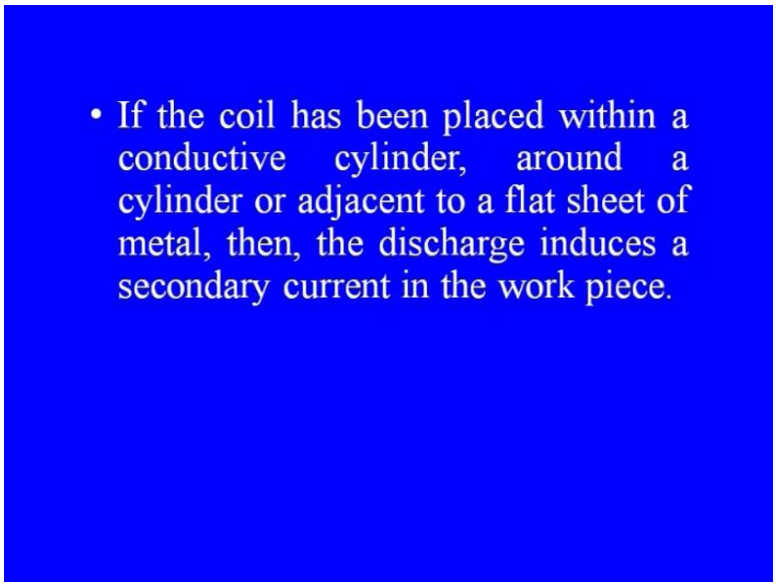

If the coil has been placed within a conductive cylinder, around a cylinder or adjacent to a flat sheet of metal, then the discharge induces a secondary current in the work part.

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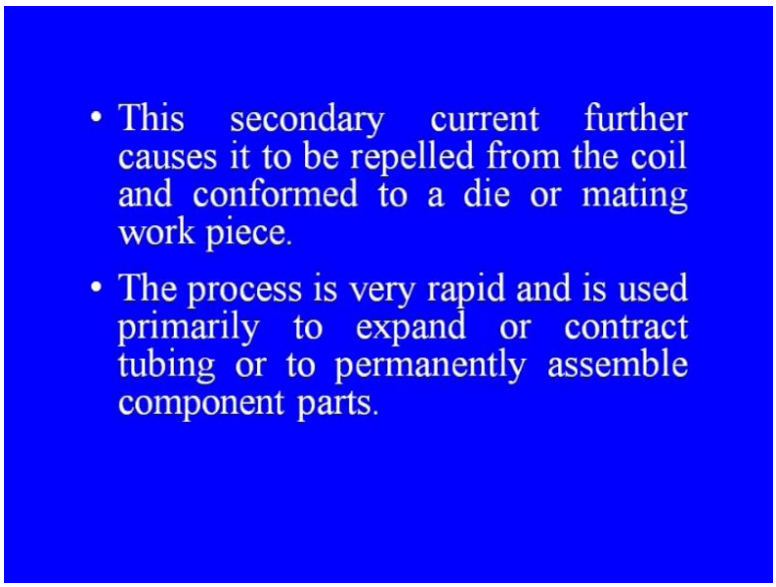

This secondary current further causes it to be repelled from the coil and conformed to a die or mating work piece. The process is very rapid and is used primarily to expand or contact, contract tubing or to permanently assemble component parts. The next figure shows some product examples of electromagnetic forming.

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- Fig.2 shows some product examples of EMF.
- Some others examples of Electromagnetic Forming process are :
  - Coining,
  - Forming and
  - Swaging

Some others examples of electromagnetic forming process are like coining, forming and swaging.

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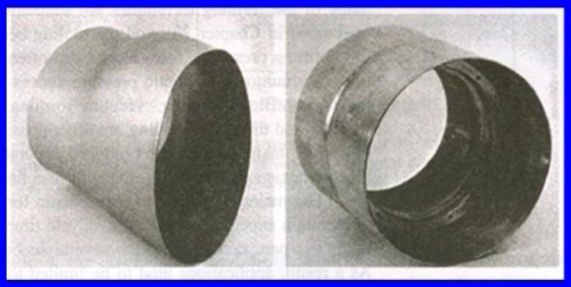

Fig.2 Parts shaped by Electromagnetic Forming, dia 125 mm.

So, these are the parts formed by using electromagnetic forming process. Then, let us discuss about another process that is known as electro forming. So, the principle of the, this particular process goes like this.

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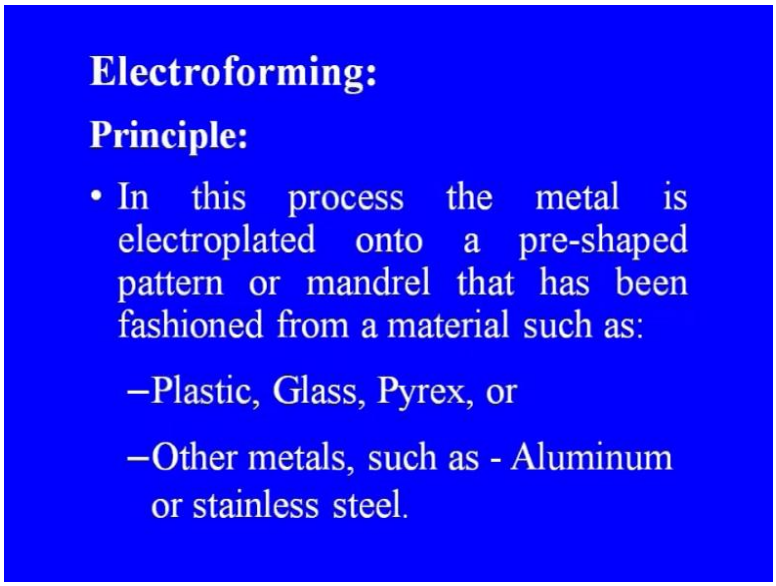

In this process, the metal is electroplated on a pre shaped pattern or mandrel that has been fashioned from a material such as plastic, glass, pyrex or other metals such as aluminium or stainless steel.

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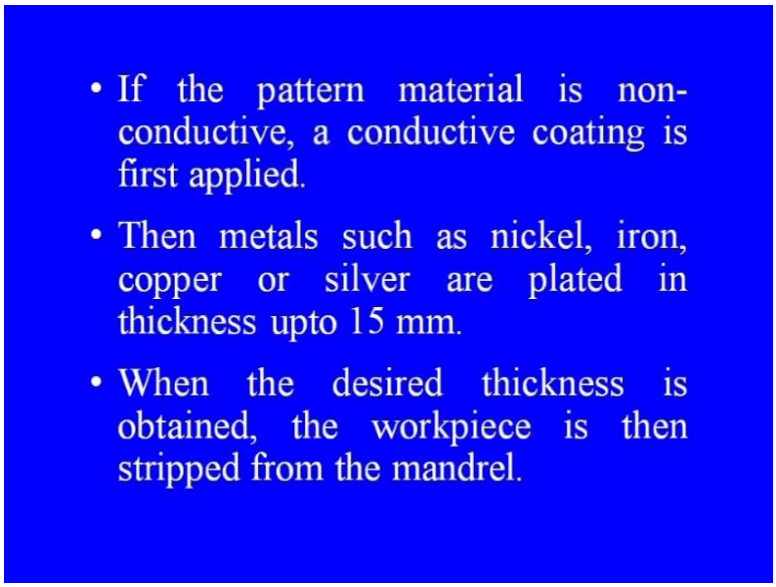

If the pattern material is non conductive, a conductive coating is first applied. Then metals such as nickel, iron, copper or silver are plated in thickness up to 15 millimetres. When the desired thickness is obtained, the work piece is then stripped from the mandrel. Now, let us look at the the different explosives that are used in these processes.

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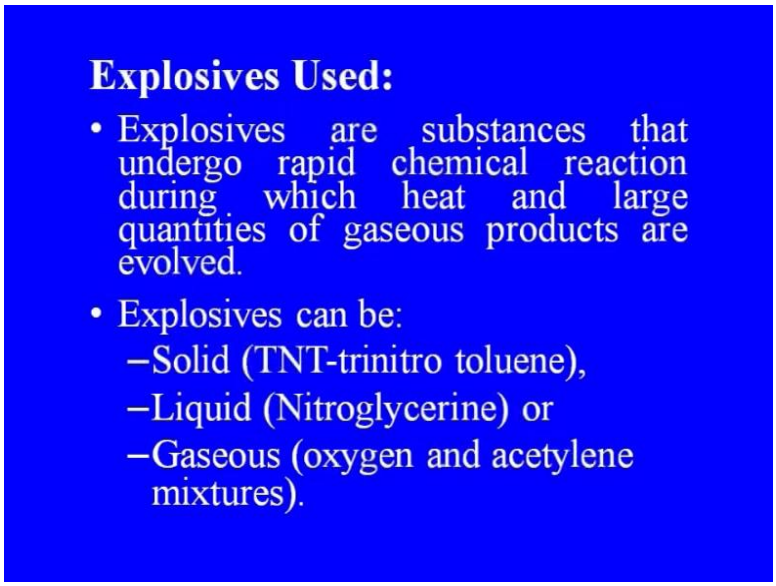

The explosives are generally substances that undergo rapid chemical reaction during which heat and large quantities of gaseous products are evolved. That, all these explosives we we are well experienced of like most of the explosives which are of very low energy, we have been using for different purposes like in different cracker, fire crackers etcetera also, some of the kinds of explosives are used. Of course, they are of low power.

However, for metal working purposes we need high power explosives. So, this explosives are can, this explosives can be solid like TNT which is a very popularly known as TNT, the full name is tri nitro toluene, then it can be in the liquid form like nitro glycerine or it can be in the gaseous form as well like oxygen and acetylene mixtures. This oxygen and acetylene as we know, they are being often used in welding purposes. However, at certain particular conditions both of them can be, can cause very high explosions. Explosives are generally divided into two classes.

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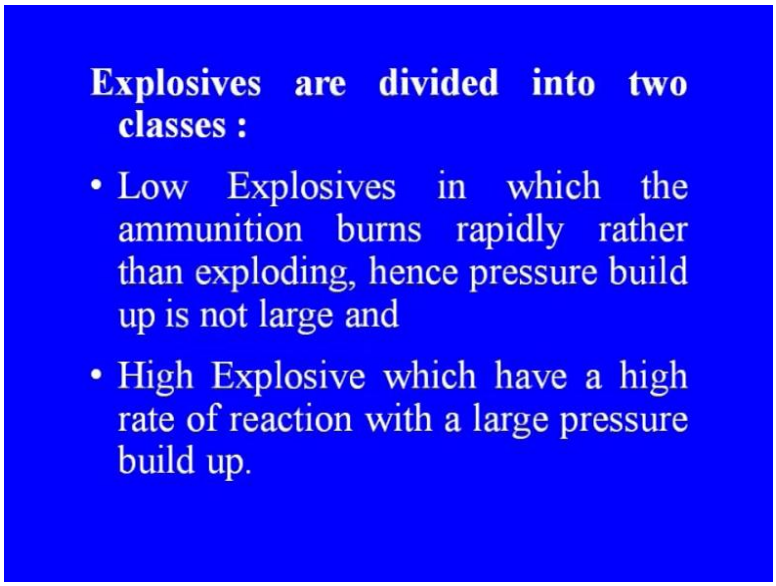

One is low explosives in which the ammunition burns rapidly rather than exploding. Hence, pressure build up is not very large. It is only, you can say one way of burning out the fuel. The other category is the high explosives. In this category, this explosive have a high rate of reaction with a large pressure build up.

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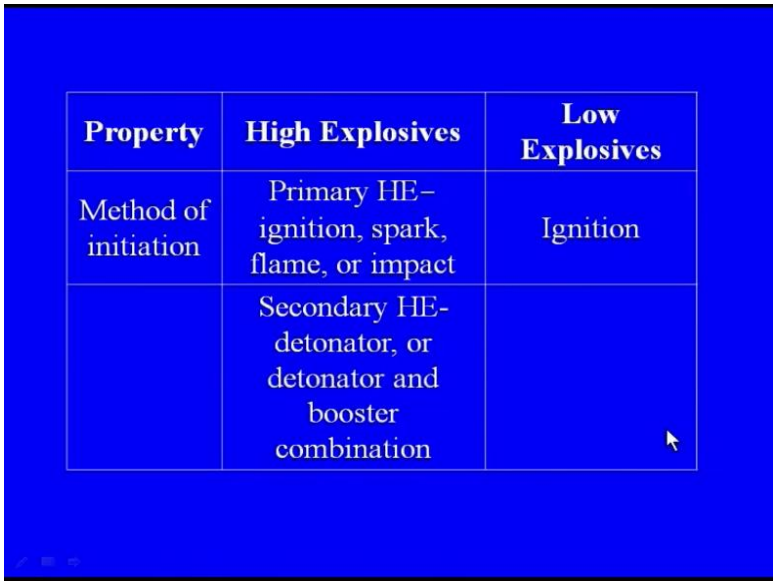

Now, let us see some of the properties of different explosives. High explosives are like primary high energy ignition, spark flame or impact. So, this is how they are being initiated, the flame is initiated or the ignition or explosion is initiated. And in low

explosives the, it is caused by the ignition. In high explosives, secondary high energy detonator can be used or detonator and booster combination can also be used for initiation purposes.

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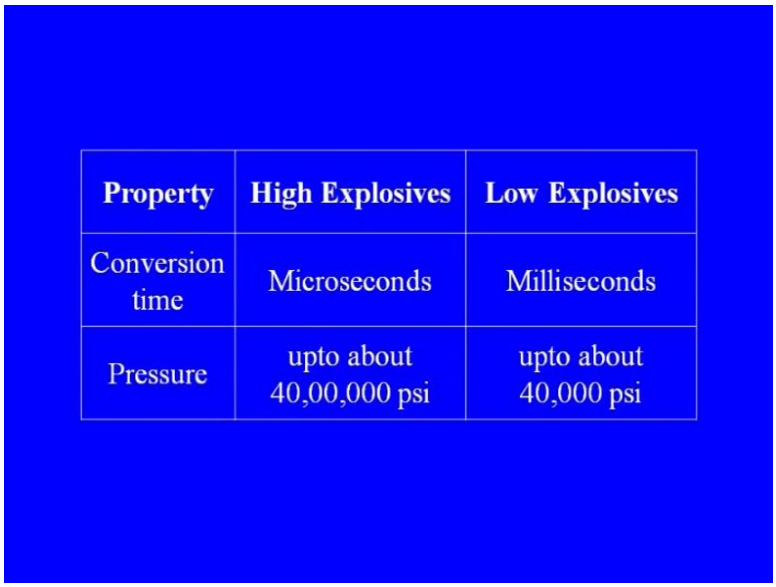

Then as far as the conversion time is concerned in high explosives the energy is converted within microseconds whereas in low explosions or low explosives it may take milliseconds for the conversion of energy. As far as the pressure developed is concerned in case of high explosives up to 40,00,000 pound per square inch can be obtained, whereas in case of low explosives energy pressures up to 40,000 pound per square inch can be obtained, which is we can say, much lower than that of high explosives which in fact around 100 of the high explosives.

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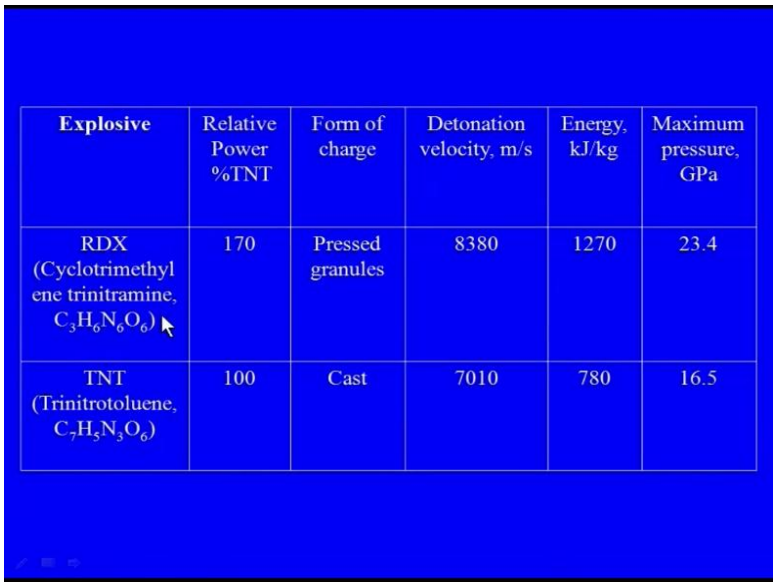

Explosive	Relative Power %TNT	Form of charge	Detonation velocity, m/s	Energy, kJ/kg	Maximum pressure, GPa
RDX (Cyclotrimethylene trinitramine, $C_3H_6N_6O_6$)	170	Pressed granules	8380	1270	23.4
TNT (Trinitrotoluene, $C_7H_5N_3O_6$)	100	Cast	7010	780	16.5

Then a very popular explosive is like RDX which is the chemical name is cyclotrimethylene trinitramine C 3 H 6 N 6 O 6 and this has got relative power with respect to that percentage TNT is 170. And this can be found in the form of pressed granules, it has got the detonation of velocity as high as 8380 meter per second and energy can be developed or released is 1270 kilo joules per k g and the maximum pressure obtainable is 23.4 gigapascal.

So, that is, that is the indication of how powerful these explosives are. Then another popular explosive it TNT, already I have indicated the chemical name is trinitrotoluene, chemical formula is given by C 7 H 5 N 3 O 6 and this is relatively 100 percent power as far as the power ratings are go, are compared with the TNT. It is 100 percent almost and then the form of charge can be found in the cast form, detonation velocity up to in excess of 7000 meter per second can be obtained with energy level 780 kilo joules per k g we can obtain and then pressure also, maximum pressure also can go up to 16.5 gigapascal's. So, this is another popular as well as very high performance explosives we can say.

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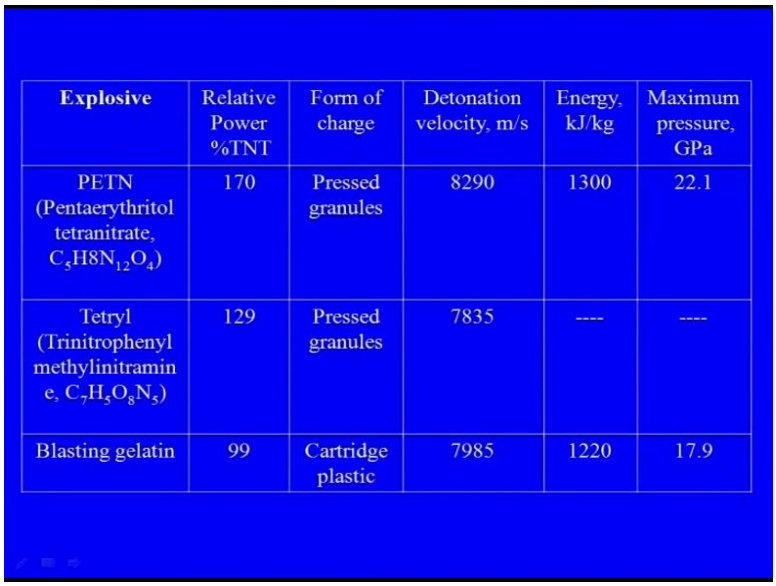

Explosive	Relative Power %TNT	Form of charge	Detonation velocity, m/s	Energy, kJ/kg	Maximum pressure, GPa
PETN (Pentaerythritol tetranitrate, $C_5H8N_{12}O_4$)	170	Pressed granules	8290	1300	22.1
Tetryl (Trinitrophenyl methylinitramine, $C_7H_5O_8N_5$)	129	Pressed granules	7835	----	----
Blasting gelatin	99	Cartridge plastic	7985	1220	17.9

Another category is PETN penta erythritol tetra nitrate, this is what its chemical name is and then relative power is 170 percent of TNT can be obtained in pressed granules forms and detonation velocity can be obtain almost at the same level of RDX that is 8290 meter per second and energy is also comparable to RDX which is 1900 kilo joules per k g and maximum pressure obtainable is 22.1 gigapascal. Another explosive used is tetryl which has got relative power is something around 129 percent of TNT.

Then pressed granules forms it can be obtained and detonation velocity can be obtained close to 8000 meter per second, to be precise 7835 meter per second can be obtained. Another form of like very common explosive used is blasting gelatin. So, this is almost equivalent to the TNT power, 99 percent of TNT. It can be obtained in the cartridge plastic and detonation velocity is close to 8000 meter per second, 7985 to be precise and energy also can be obtained very high that is 1220 kilo joule per k g and the maximum pressure can go up to almost 18 GPa. Now, let us quickly look at the advantages of explosion forming processes.

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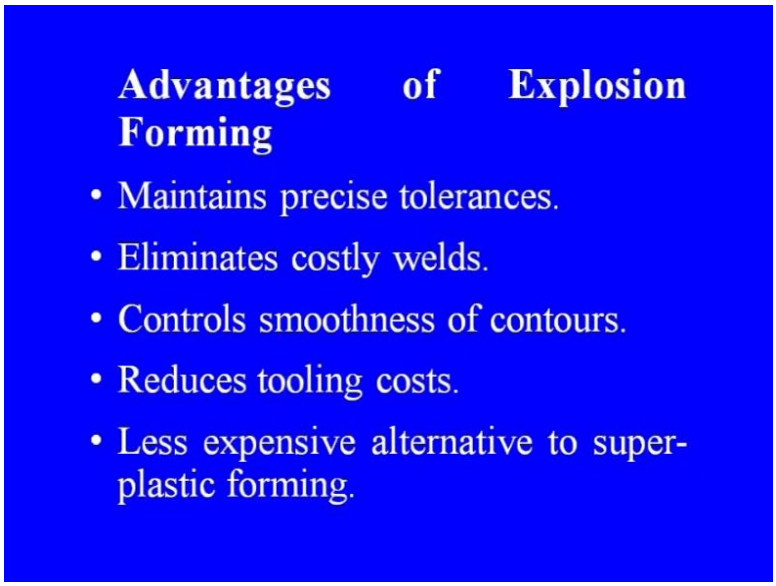

Number one, it maintains precise tolerances of the work part. It eliminates the costly welds. The controls smoothness of contours, then it reduces tooling costs. These processes are less expensive alternative to super plastic forming. Now, let us quickly look at the die materials that are being used in these processes.

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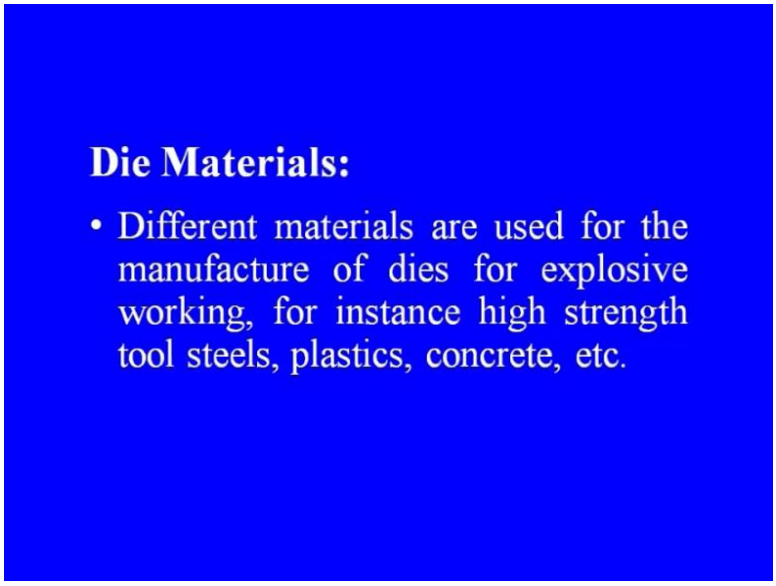

So, different materials are used for manufacturing of dies for explosive forming processes for instance high strength tool steels are used, plastics are also used, concretes

are also used, even woods the low energy material sorry the low strength material like wood can also be effectively used for as a die material for HERF processes.

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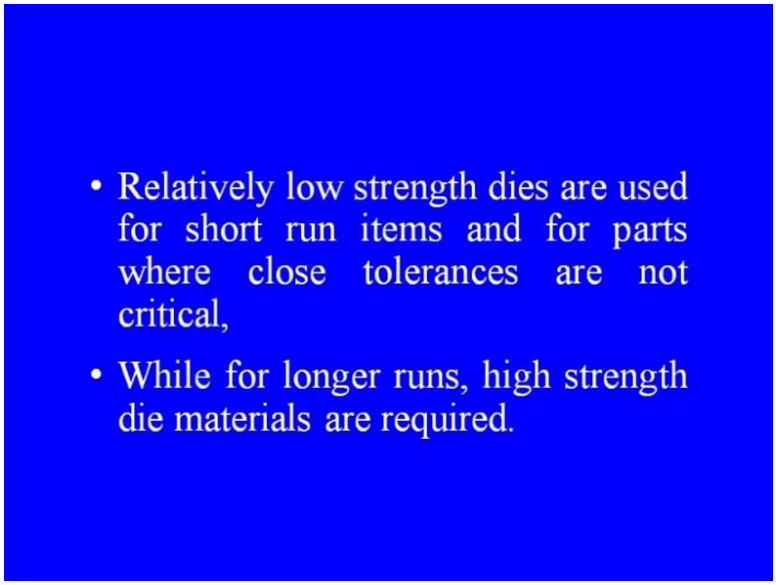

Relatively low strength dies are used for short run items and for parts where close tolerances are not very critical, while for longer runs, high strength die materials are required.

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Kirksite and plastic faced dies are employed for light forming operations, whereas, tool steels, cast steels and ductile iron are used for medium requirements.

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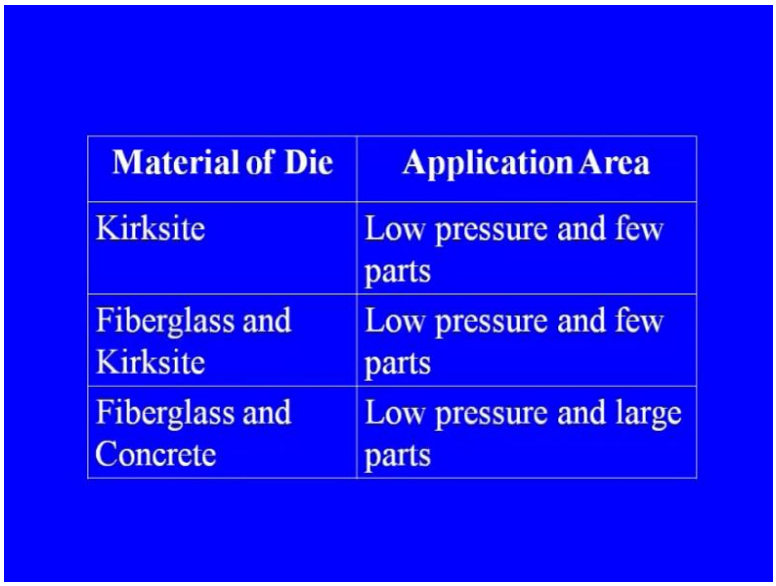

Here are the some die materials that is shown in the screen. One is kirksite as I have already indicated. So, this is for low pressure area and for few parts only because of life of the die will not be that longer. Then fibreglass and kirksite, they are also again used low pressure and few parts only. Then fibreglass and concrete, again for low pressure, but since concrete is there, they can be durable and therefore, for large parts it can be used.

Epoxy and concrete can be used, that is for low pressure applications and of course for large parts. Then ductile iron that is high pressure and many parts, so many parts it can be durable. Then concrete, that is medium pressure and large parts. Now, let us see the common characteristics of this process.

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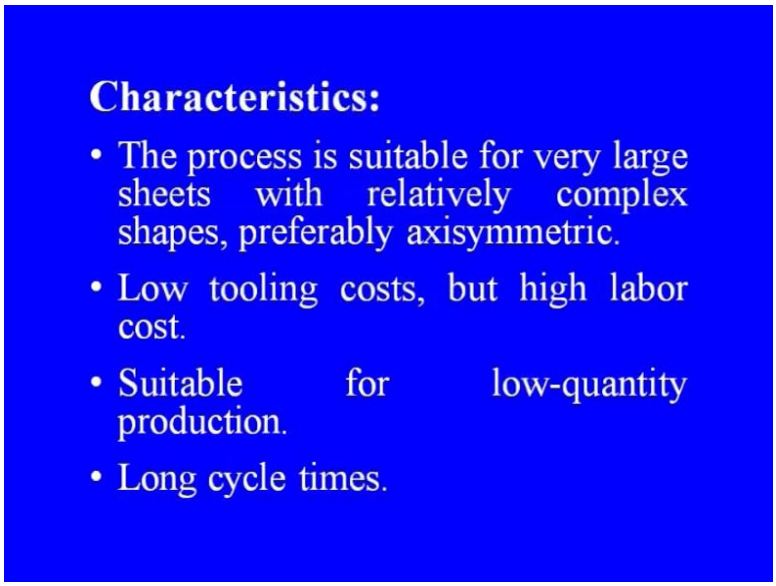

The process is suitable for very large sheets with relatively complex shapes, preferably axisymmetric parts, low tooling cost, but high labour cost, suitable for low quantity production, long cycle times. Now, let us talk about the transmission medium used for transmitting the energy. The energy will be produced by the, by detonation of the explosives. Now, this energy is to be effectively transferred to the work part which will be ultimately formed.

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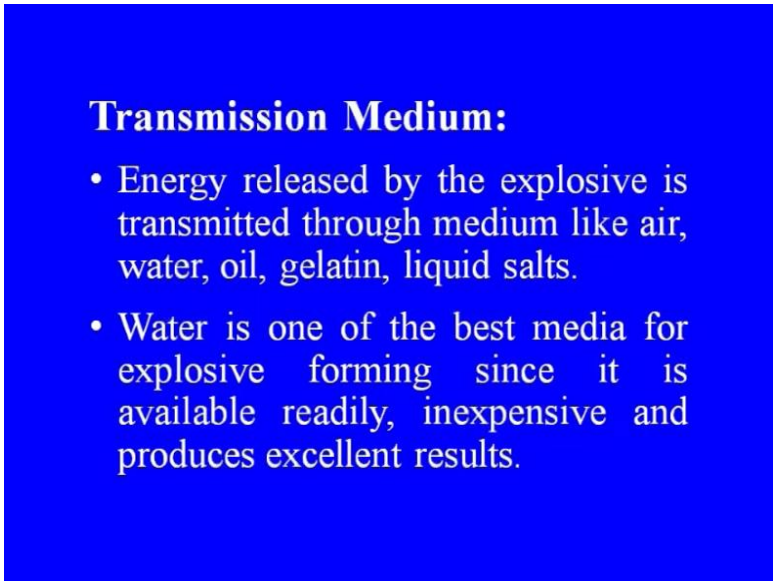

This energy released by the explosive is transmitted through some medium it can be air, it could be water, could be oil, gelatin, liquid salts and so on. Water is one of the best media for explosive forming, since it is available readily, inexpensive and produces excellent results.

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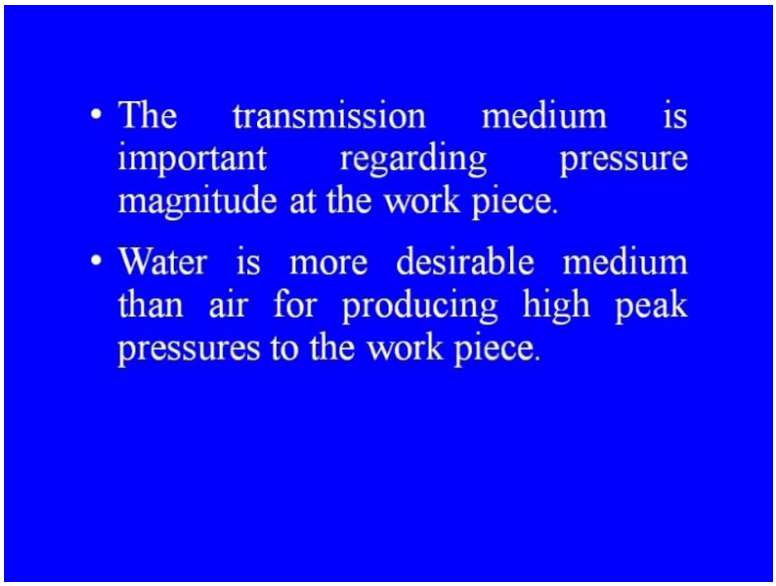

The transmission medium is important regarding the pressure magnitude at the work piece. Water is more desirable medium than air for producing high peak pressures to the work piece. Now, let us look at the formability aspects of the material.

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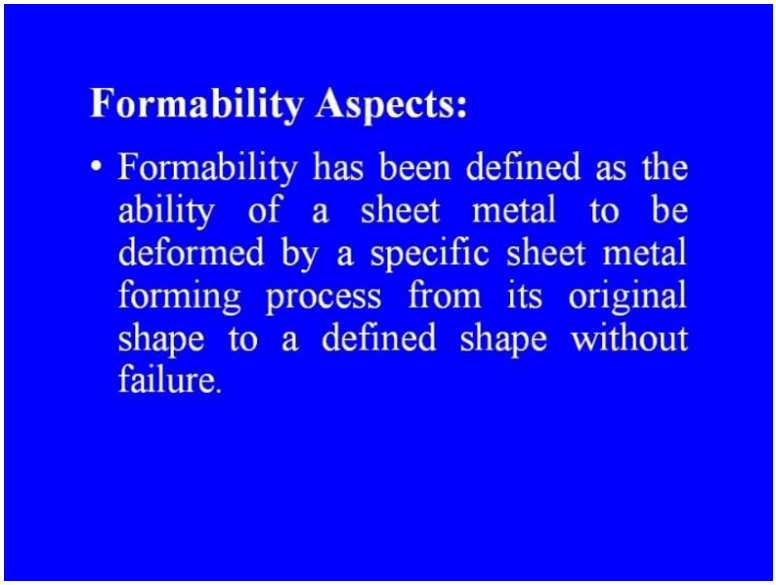

So, formability has been defined as the ability of a sheet metal to be deformed by a specific sheet metal forming process from its original shape to a defined shape without failure. If during the forming process cracks are initiated or the material fails then the material is said to be having very low formability. Generally, the ductile materials have got better formability.

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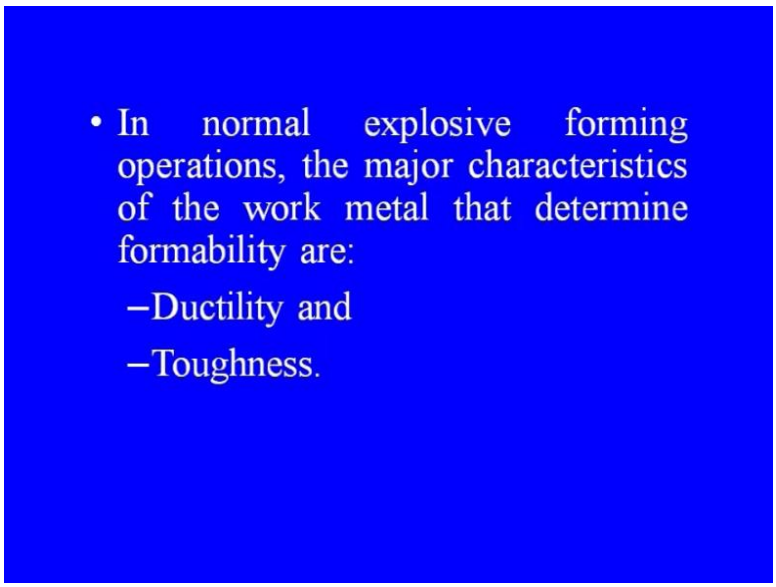

In normal explosive forming operations, the major characteristics of the work metal that determine formability as I have already told are ductility and toughness.

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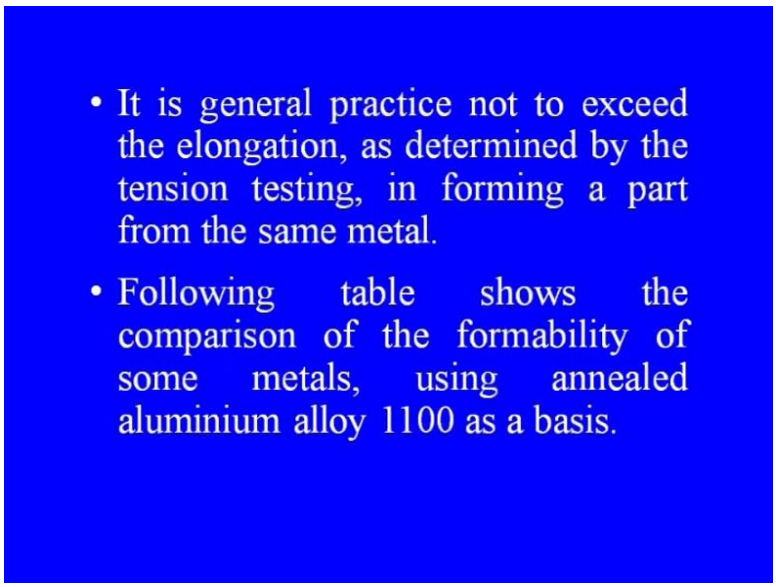

In general, not to exceed the elongation as determined by the tension testing in forming a part from the same metal. The following table shows the comparison of the formability of some metals using annealed aluminium alloy 1100 as a basis.

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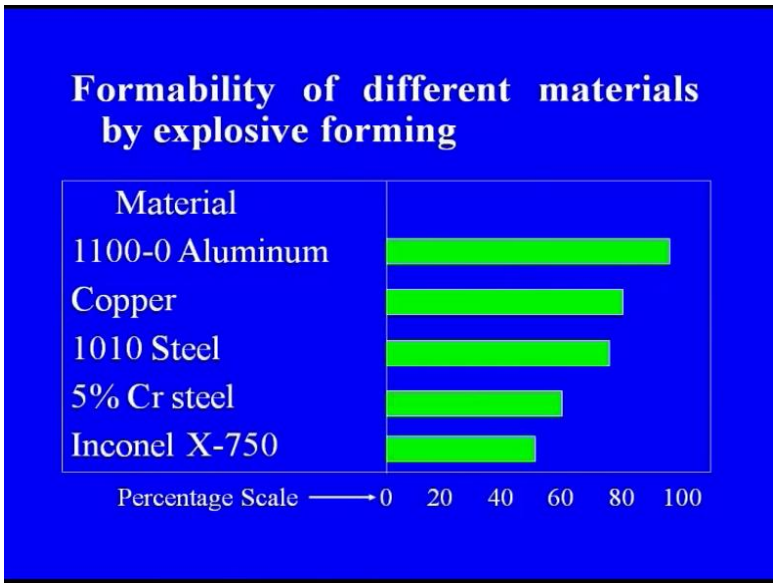

This is being shown in the screen, formability of different materials with respect to 1100 series of aluminium, aluminium alloy. So, copper has got very good formability, almost matching to the standard base alloy of aluminium 1100, then followed by almost similar is the 1010 steel followed by 5 percent chromium steel followed by inconel 750 X 750 which has got among this the list something around 50 percent of that of aluminium 1100 series.

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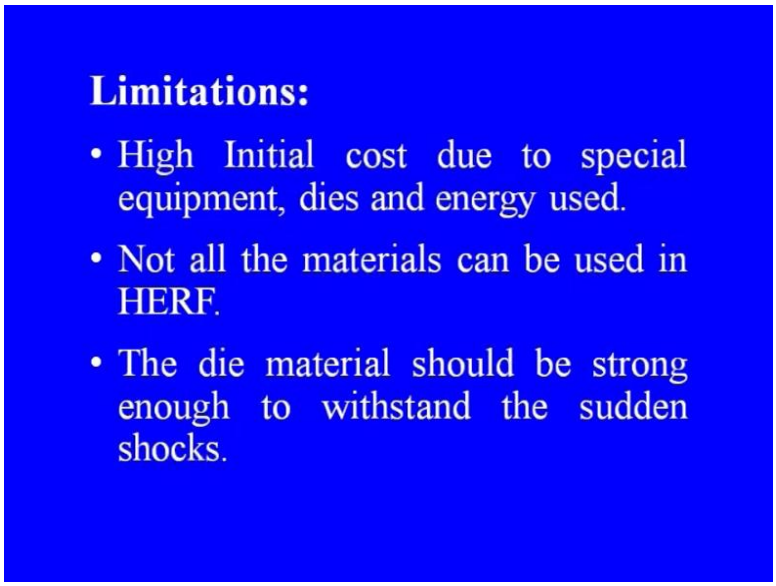

Now, let us quickly note few limitations of this processes as well. These processes have high initial cost due to special equipment, dies and energy used. Not all the materials can be used to be formed through HERF, high energy rate forming. The die material should be strong enough to withstand the sudden shocks.

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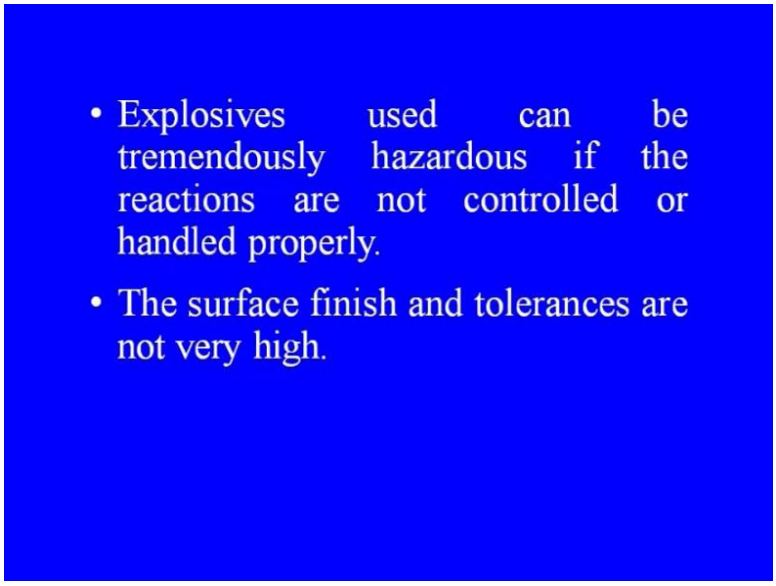

The explosives used can be tremendously hazardous if the reactions are not controlled or properly handled. Therefore, it is generally required that the explosions being carried out inside certain medium which will at least restrict the explosions to be spread or to the, to

affect some other systems nearby. The surface finish and tolerances are not very high. Here mostly the shape is the concern, not about the surface finish or the tolerance.

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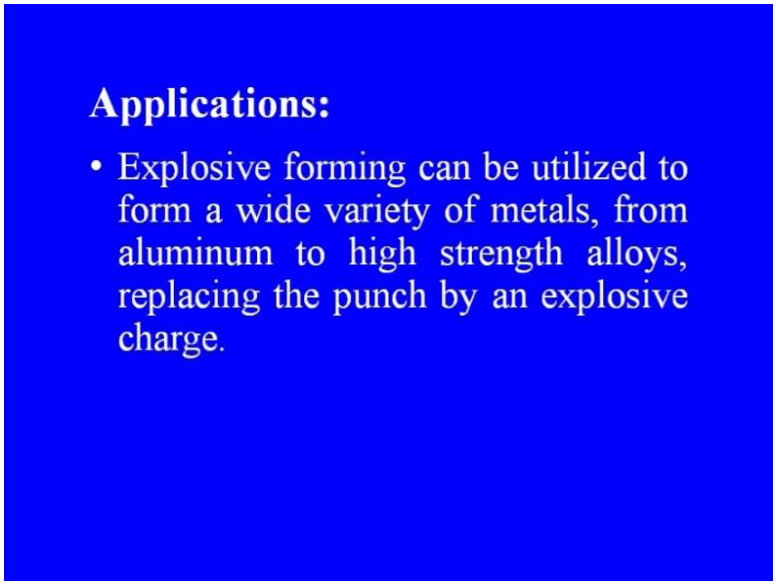

Now, let us look at the applications of the process. Explosive forming processes can be utilized to form a wide variety of metals, from aluminium to high strength alloys replacing the punch by an explosive charge.

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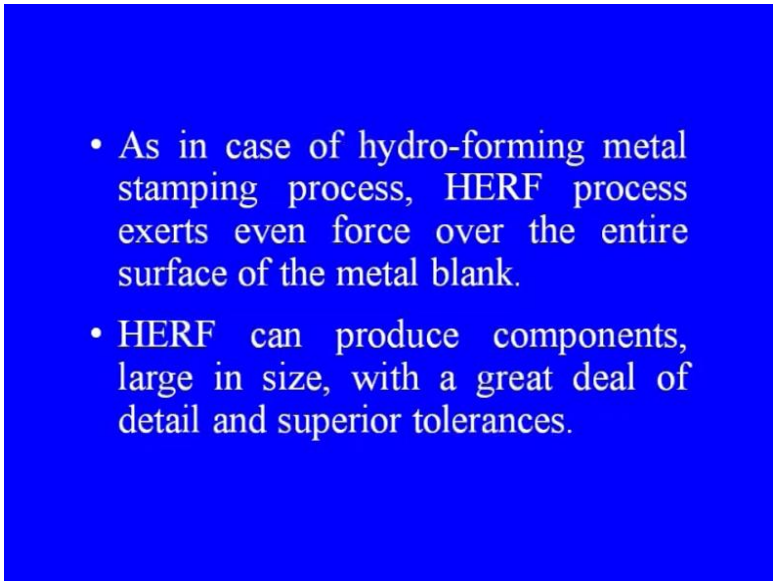

As in the case of hydro forming metal stamping processes, high energy rate forming processes exert even force over the entire surface of the metal blank. This is an

advantage of this process are clearly an edge the uniform application of the forces over the entire sheet of the work piece. High energy rate forming can produce components large in size with a great deal of detail and superior tolerances. As in the case of hydro forming metal stamping processes, high energy rate forming processes exerts even force over the entire surface of the metal blank.

This is clearly an advantage of the process in which the forces applied will be even on the entire work piece sheet. This helps in reducing spring back as well. Then high energy rate forming can produce components large in size with a great deal of detail and superior tolerances. It is particularly useful for a very large parts like domes etcetera etcetera.

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The high energy rate forming processes are employed in aerospace and aircraft industries and has been successfully employed in the production of automotive related components as well. So, this is a typical component being produced by high energy rate forming processes.

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The dimension of the tank can talk about the complexity of carrying out or the manufacturing of this particular product, but this can be very easily manufactured by this high energy rate forming process. Of course, the tooling required becomes expensive, but the shaping becomes easier, because of the process principle that we have already discussed about.

Now, let us summarize what we have discussed in this particular session. In this session, we have seen the high energy rate forming processes, the features of these processes in details, the working principles, different variants of these processes we have seen, then we have seen the applications of this processes also. We have noted the limitations of this processes and then the advantages of this processes as well. We hope this process was, this session was informative as well as interesting.

Thank you.