**Plastic Working of Metallic Materials**
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**Module No # 01**
**Lecture No # 03**
**Temperature Effects in Metal Forming**

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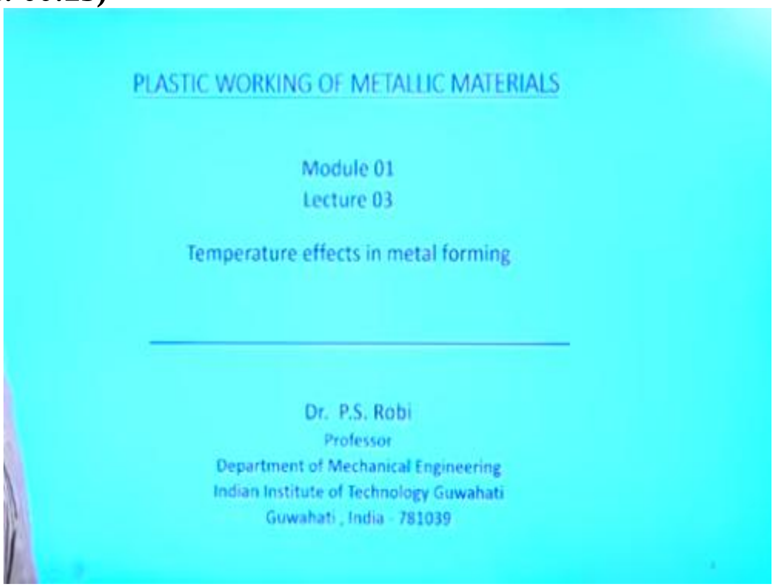


Now let us come to the lecture 3 that is the temperature effect in metal forming.

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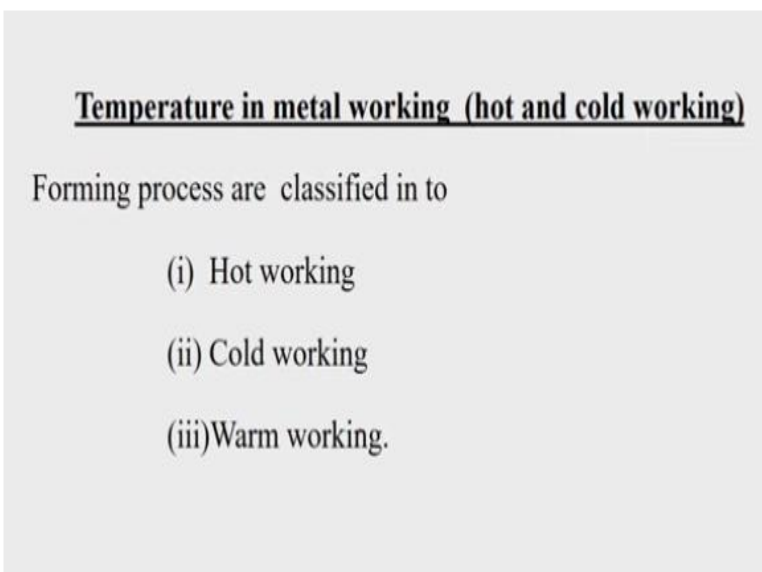

We can say any type of a metal forming that is carried out at under three different temperature. So depending upon the temperature we can say that the forming process are classified into, say one is hot working and another is the cold working and third is the warm working okay. So may be few years back it was only classified as hot working and cold working but recently this third term that warm working also has come into picture.

Let us see what are the advantages. See may material when you are trying to deform plastically deform at room temperature, there is a large amount of strain hardening which is taking place okay.

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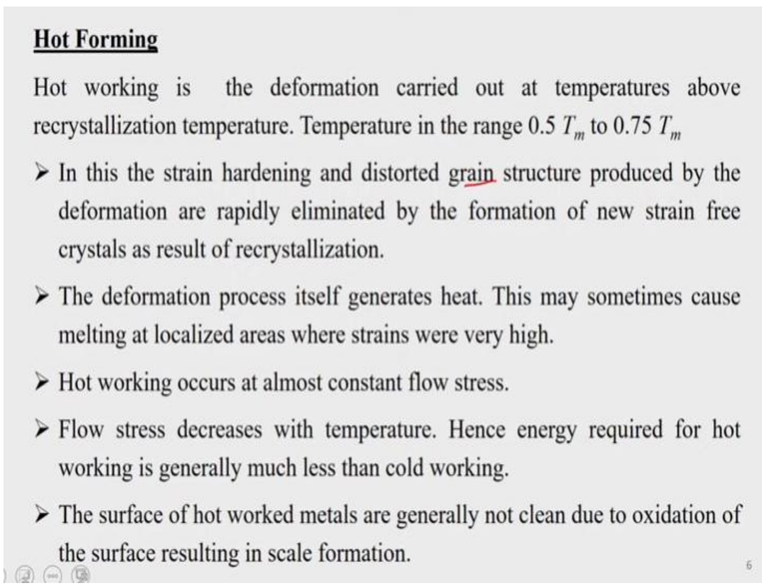


So if you heat it and this strain hardening is due to the interaction of the dislocation inside the material say when you are trying to deform the material, what happens is that, the dislocation are generated a large number of dislocations are generated and for a small amount of strain you will find at the dislocation generation increase is by an order of one or two orders of magnitude. So that much high amount of dislocations are generated.

When you are deforming a material at room temperature so with this and finally when you are trying to basically the plastic deformation in metallic material is by a phenomena strip, where the dislocation form inside the crystal it moves to a surface but when large number of dislocations are generated the newly formed dislocation itself act as a hindrance for the movement of the dislocation.

And then these dislocation will interact each other and finally it form a dislocation substructure and all those things will happen you will see that the strain hardening is taking place. So the material then become brittle, the ductility keeps on decreasing with the increase in strain. So these are the thing the typical flow curve is because of that only the strain hardening region. Now if you heat it to a higher temperature, to some slightly higher temperature may be something in the range between 0.5 $T_m$ to 0.75 tm where $T_m$ is the absolute melting temperature.

That means in kelvin so into that region if you do it, then you will find that okay this strain hardening effect is reduced. And sometimes in some cases there is no strain hardening itself the material may behave as elastic perfect plastic material in some cases above certain temperature. So hot working, so in that case you call it as hot working, so hot working is the deformation carried out at temperatures above the recrystallization temperature of the alloy okay.

See now this term recrystallization, say it is not constant for an alloy recrystallization temperature will keep on changing, it also depends upon what is the amount of pre strain you have given to the material. The higher the amount of strain you have given, the pre strain you have given the activation of the plastic flow will be reduced. So you means that the recrystallization temperature will get lowered, so with a more and more restrain you have given into that material you will find that the recrystallization temperature comes down.

So that is what, so that is why there is range of temperature depending upon what is the amount of pre strain you have given to the material and there are various other factor also on which recrystallization temperature depends but this is one important thing. So when you are heating when you forming the metal, at temperatures above recrystallization temperature, what really happens is that new stress free crystal starts nucleating in the material.

So in the initial case, it was a highly with the high amount of internal residual stresses, the grain will be a having lot of internal residual stresses because of this high amount of dislocations which are generated. But when you are heating to the temperature above the recrystallization temperate this new stress free crystals are nucleated and the driving force for this recrystallization is nothing, but the change in the free energy of this internal energy of the stress of the crystals, so that is what.

So in this the strain hardening because of this new stress free crystals are nucleated at temperatures above the recrystallization temperature, the strain hardening and the distorted grain structure. Distorted grain structure maybe found during the deformation, produced by the deformation are rapidly eliminated by the formation of new strain free crystal and of course that is stress free also as a result of recrystallization.

So what happens is that there is no strain hardening, so it reaches a particular value reaches the yield strength and remains constant or maybe only slightly a slight increase in the flow stress will be there depending upon what is the temperature and other thing but normally if it is at higher temperature it will show a plato a flat curve it will show. So that but in that process you can have a large amount of deformation, that is the biggest advantage when you are doing the hot forming.

The deformation process itself generates heat when you are heating that itself because 90% of the heat with or 85 to 90% of the energy which has been given into the material during the metal forming process is converted into heat. So in this case the deformation process itself generate heat. This may sometime cause melting this is one drawback. So though you are heating it in a higher temperature and if it is the strain rate is high amount of heat generated is very high also.

And then what happen, in that case inside the material somewhere inside the temperature may shoot up and then it may result in incipient melting. So the upper limit of hot deformation is the temperature at which incipient melting may takes place or many times not only incipient melting you may not go to that level itself, sometime where excessive grain growth is taking place, that also specially when you are using at lower temperature when you do not want a coarse strained temperature.

And sometime you know if it is above that burning and other thing may taking place so that people do not prefer to that but mostly as a thumb rule, we can say that upper limit is that temperature at which incipient melting of the alloy can take place or very rapid coarse grain coarsening takes place okay. So hot working up to occurs at almost constant flow stress that is the biggest advantage, there is no strain hardening since it has a constant then we saw that in the previous days lecture that large amount of strain is possible.

So in flow stress decreases with a temperature, so as I was telling at lower temperature the flow stress will be lower sorry, at higher temperature the flow stress will be lower hence energy required for hot working is generally much less than the cold working. So that is one thing. If you look at super plastic deformation the flow stress is very low, so maybe something of the order of 10 or 15 mega Pascal you can deform a ceramic material also.

So flow stress gets comes to gets reduced very low value but normal engineering material when you are doing the hot working you may not go to that level. So here the energy required for hot working is generally much less than the cold working and the surface of the hot work metal are generally not clean, this is the another disadvantage due to the oscillation of the result surface resulting in scale formation.

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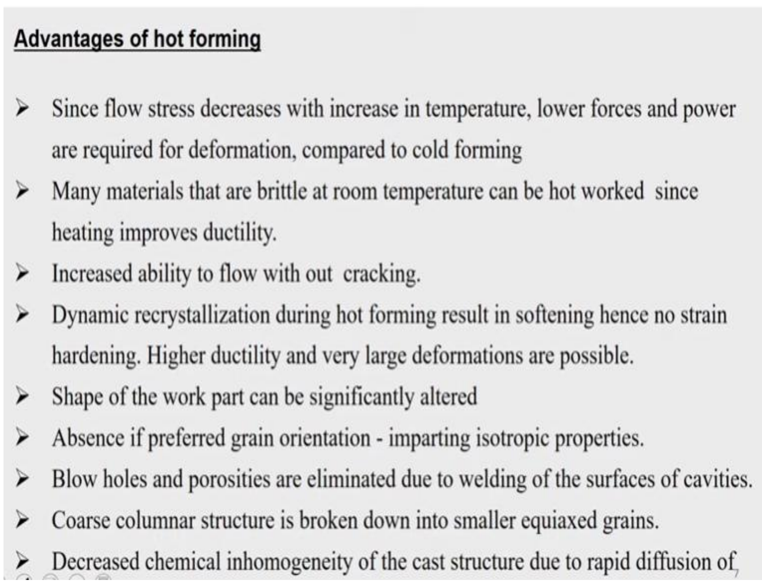


So if you look at the advantages of hot working, since flow stress decreases with increase in temperature low forces and power are required for the deformation compared to cold working. So in one thing, at higher temperature flow stress is low yield stress is low and second thing is that at higher temperature your ductility is much higher, so all those things are coming. So your forces which are required by the machine for the deformation is very low.

So that means energy which is required for the deformation is much less than compared to cold working. So you may not have to go to a very high capacitive machine also. Many material that are brittle at room temperature, brittle means not very brittle but where poor ductility is there at room temperature, it can be hot work at higher temperature since the heating improves the ductility this is another advantage.

So if you have somewhat slightly lower ductility, you may not be able to extend it to a large deform it to a large extension. So after some strain again you have to take it and then take it in a furnace anneal it, what you call as process annealing, so those type things will be required but in this hot working that is not working because ductility decreases, so you may get a higher amount of deformation which is possible.

Now increase ability to flow without packing, so at higher temperature since the material is almost coming to a fully plastic stage, so you will find that this cracks and other things are generated under certain condition say if it a very high rate and other things crack may form. But under normal condition the formation of cracks and other things will be, the chance is very less. So then dynamic recrystallization during hot forming result in softening, hence no strain hardening.

So higher ductility and very large reformations are possible, this is what I already mentioned. Then shape of the work is can be significantly altered. So that means when it is very plastic, it can just flow into some very complex shape areas and other thing integrate areas and fill up the die cavity that is another. So in the plastic deformation that is also possible here. So that way you can say the shape of the work is can be significant altered.

Now in cold working, when you are deforming the material, say you end with preferred orientation of the grains okay, with that will result in isotropic say you end up with preferred orientation of the grains okay, with that will result in an isotropic properties so that is one thing. But along certain direction you may get an improved mechanical properties but along the other direction, it may not be that high.

So you will find that under at cold work cold formed materials have preferred orientation and in that is somewhat advantages for some cases but in some case it may be disadvantages but sometimes you know you do it for obtaining the preferred orientation. The grains the crystallography planes, in that polycrystalline materials so, individual in individual grains the while deforming will orient in such a way that some particular planes are always arrange along certain direction maybe along the rolling direction or something or deforming direction so that is what is called as the preferred orientating okay.

So because if the preferred orientation at higher hot deformation, this preferred orientation is somewhat absent that means you get somewhat isotropic properties are achieved, so not iso anisotropic properties. Specially that is obtained at much higher temperature. Now during this hot forming, the blow holes and porosities are eliminated by cold welding of the surface of the cavity, that is another advantage.

So metal can easily flow, it can cold welded much easier this cold welding will be there in colded deformed piece also but it will not be welded together okay. But it will get eliminated or maybe its effect will be reduced but it will not get welded cold welded. But whereas in this case you know it will be cold welded, so you will find that improved properties are there. Coarse columnar structure is broken down into smaller equiaxed grains, that is also there.

Then decreased chemical homogeneity, at a higher temperature may be in a cast structure, you will pay, you will always observe that you cannot avoid in a cast structure. If specially if the freezing range is very large, for large freezing range alloys, you will find a severe effect of coring and segregation that means the chemical homogeneity is lost inside a grain itself you will find from the center of the grain to the surface, there is a variation in the composition of the elements inside that grain itself, from the center to the surface.

And at the same time, at grain boundary regions you will find large amount of segregation of specially that will be of low melting point that alloys have, you take this under the which comes into picture. So when we are heating this to a higher temperature the deficient comes into picture. So rapid efficient comes into picture and then you will find that, okay this chemical homogeneity is obtained or inhomogeneity is reduced when you are doing the hot deform.

Plus this, due to the deficient as well as due to combined effect of deficient and the breaking of the structure you will find that there is a better homogeneity in the crystal in the structure.

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**Disadvantage of hot forming**

- lower dimensional accuracy hence higher tolerances required.
- higher energy consumption since the work piece has to be heated
- Surface reaction between metal and furnace atmosphere results in oxidized surface
- Metals like Ti, Mg are reactive to oxygen and results in embrittled surface
- oxidation of the work piece surface - scaling and loss of materials
- Embedded oxides on the surface and poor surface finish
- Shorter tool life
- Possibility of grain growth at the centre since center region is exposed to higher tempearature for longer periods

But their disadvantages of hot working, there that lower dimensional accuracy because you are heating there is an expansion under the things comes and at different section your you may having you may be having different thicknesses, so but when it cooled room temperature lot of distortion will come and then okay dimensionally inaccuracy comes into picture and all those things comes. Hence you may have to give higher tolerances for the parts during hot working

Then higher energy consumption, though energy required for deformation is lower you may need higher energy because you have to heat the sample for which you need a furnace. So that disadvantage is there. So overall you will find that the energy is high because the furnace you have to heat it you have to heat the sample from the room temperature to the higher temperature soak it there specially for with even labor force also will be slightly higher than that of the cold formed during cold deformation.

Now, many of the metals say you know may get oxidized at a specially at higher temperature, most of the metallic except a few all other thing there is a tendency for getting oxidized when it is exposed to higher tolerance mainly at the surface. See like if you take aluminum naturally, aluminum even at room temperature or also after exposing sometime, you will find there is an oxide layer.

So steel if it is get for sometime it may oxidized okay all those. So when you are heating it a higher temperature there is always a chance that it reacts with the furnace atmosphere and form some oxides okay surface may be oxidized. So when you are trying to deform this oxides, which is very high temperature like in steel also you will find that scales are formed, so that will get embedded into the surface during deformation.

So you may have to adopt some other technique to remove this scale form or if the scale as such is not there also this oxides get temporary into the material during deformation. Now there are certain metals like  titanium, magnesium and other things, which are very active to very highly reactive to oxygen and then they and this results in embrittled surface. So when you are when you wanted to deform this state materials, hot deformation, you require a special furnace atmosphere is required, inert atmosphere is required.

So some metals and that is one major headache actually for deforming this type of materials. This embedded oxide on the surface it comes and then you end up with the pure surface finish. So surface finish in hot deformed metal is never good, okay. Now you may put some lubricants also that may vaporize and resides also get embedded into the surface. So that way in all those cases, the hot work material surface finish will not be good.

Now because you are going to deform the material at higher temperature and the hot material is going to come in contact with your die. Die surface gets heated up it becomes soft and maybe due to the friction you may get eroded. So you will find that the tool life gets reduced very fast okay. So shorter tool life is there for hot deformed material, many times you know what happens it gets eroded very fast.

Now at higher temperature possibility of grain growth at the center because as I said when you are deforming the material lot of heat is generated inside, which is not conducted away to the surface that fast. So with the result that this energy which has been supplied it gets accumulated and in the it gets converted in the form of heat and inside you know the temperature may go up, so either as I said it may melt also if it is not melting also at higher temperature the grain growth may takes place at the center region.

And especially that is a case which is exposed to higher temperature. So in that case also you will find that the variation. There is a variation in the mechanical properties from center to the surface also. So these type disadvantage are therefore for hot working.

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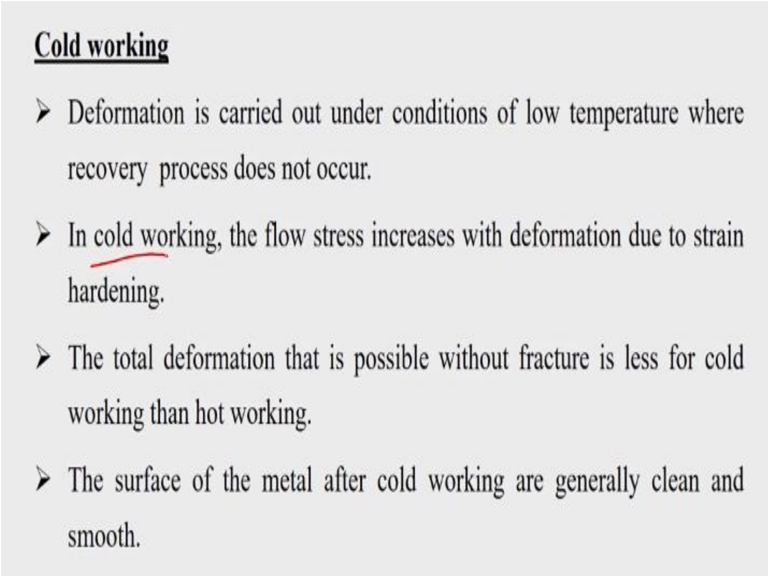


Now let us come to cold working. So cold working is the deformation if it is carried out under conditions of low temperature where recovery process does not occur, recovery or recrystallization does not occur we can say that it is cold working this. Now these all depends upon the temperature of the material. See for example, if steel to consider it as the hot deformation, you have to go somewhere around 450 or 500 degree centigrade 450 degree centigrade.

If it is aluminum, then to consider, it as a hot working condition your temperature, you may have to go to say something around more than 200 or may be more than 150 because it all depends upon this one otherwise below that it is always consider as (()) (18:59). But if you take the case of led and tin its melting temperature is low, so like if it take at 0.55 to 0.75 obsolete melting temperature, then room temperature, what you are doing at it room temperature is a hot working temperature because they are recrystallization temperature is below the room temperature.

So that difficulty is their actually. So it all depends when you are talking about the recrystallization temperature you have to talk in terms of, you should also have it in mind what is it melting temperature so when it is taking place at such a temperature where recovery or recrystallization is not taking place, then you call it is as cold working. In cold working the flow stress increases with deformation due to strain hardening.

So when you wanted a material with a high stress then this cold working is the solution to that, so earlier you know you use to get the twister bars for RCC reinforcement okay. Nowadays you get what is called as TMT steel, the surface is deformed not at the center. So the surface is strain hardened, so like that. So many times you know when you wanted a higher strength material, then you call say cold working or cold forming is the answer to that.

This is true with the materials which are not going to undergo any phase transformation, say like steel when you wanted to you can increase the strength by strength or hardness by say hardening heat treatment or normalizing heat treatment, if you wanted to make soft we can make it by annealing treatment and other thing. Because there is a phase transformation which is taking place but in those materials where it will not undergo any phase transformation then it is a strain hardening.

Say for example, austenitic stainless steel, even at room temperature is austenitic structure and its higher temperature is also austenitic temperature. So when you are heating to a higher temperature and deforming there is no phase transformation which is taking place. So you cannot strengthen by say other type of heat treatment. So in that case where the material cannot be strengthened by heat treatment, then you go for, if you wanted to strengthening then it is only by cold forming may be cold rolling, cold extrusion, cold drawing, any of those things are cold forging, you can do any of this cases.

So in that the flow stress increases with the deformation due to strain hardening, the total deformation that is possible without fracture is less for cold working then for hot working. In hot working because your ductility is enhanced and there is no stain hardening you may get extended ductility. So without failure you can deform it to a larger extent but in hot working that is a limitation you cannot extend it because after some amount of strain it becomes completely brittle and then it will start failing. The surface of the metal after cold working are generally clean and smooth.

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**Advantage of cold forming**

- greater accuracy, meaning closer tolerances can be achieved
- better surface finish and clean surface (absence of oxidation)
- higher strength and hardness of the part due to strain hardening
- grain flow during deformation provides the opportunity for desirable directional
- properties to be obtained in the resulting product
- no heating of the work is required
- If the finished product must be stronger than the annealed material, the final operation must be cold working to the desired amount to result in the largest strength followed by a stress relief annealing heat treatment.

Advantages of cold forming, greater accuracy, you are getting it because there is no thermal effect coming into picture like it is not being brought from higher temperate and it means at closer tolerances can be achieved, better surface finish and clean surface you are getting, that is another advantage because there is there is no presence of oxidation on the surface at cold deformation, condition which is not getting oxidized.

And higher strengthen hardness of the part due to straight hardening, that we already discussed, grain flow during deformation provides the opportunity for desirable directional properties to be obtained in the resulting product. So that is one advantage, in cold deformation you get a preferred orientation of crystallographic planes and then this, it will have the directional properties also along the direction of flow that is why you know when you wanted a nut and bolt.

Say you go for thread rolling there it is work hardened that, say head of the thread you will find at the metal flow is there due to that the it gets hardened at there because due to impact forging with is taking place, it gets work harden and other thing. So you can very clearly see this and in forged gear tooth and other things, you know you will find the metal flow is there so that gear teeth is made stronger by hot forging and cold forging and other things.

So grain flow is taking place, so you get directional properties and for the resulting products of that is some cases it is very advantageous and no heating of the work is required so you end up in saving lot of energy. If the finished product must be strong other than the annealed material, the final operation must be cold working to the desired amount to result in the largest strength followed by a stress relieve and annealing heat treatment.

Stress relieving is required because cold deformation or cold forming will result in large amount of residual stresses in this and the material. So you may have to give an annealing heat treatment or stress reliving heat treatment but in stress relieving heat treatment the micro structure is not going to change, it is only the stored internal residual stresses are only relieved okay by the process of recovery and other thing, so that is what it is happening.

So you will find at so in that case, if you wanted to have a material which is stronger than annealed material, then the final operation should be cold forming and then to remove the residual stresses you have to, it has to be it should be subjected to stress annealing heat treatment and that that is how people go for it.

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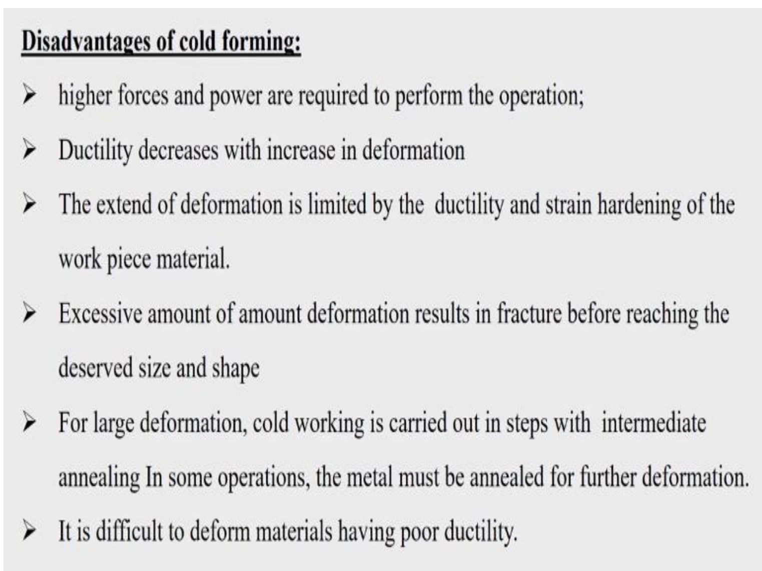


Disadvantages are because it is strain hardening, you will find that higher forces and power requirement are required for your machine. So machine should have a higher capacity. Say if you have a press, you should have a higher capacity press that is one advantage and when that happens it becomes lot of other practical difficulties also comes into picture. Ductility decreases with increase in deformation, so after some amount of deformation see what happens because of the strain hardening the ductility decreases and so you may have to stop in between and give heat treatment to soften the material.

So that is another disadvantage which is, which is required a change okay, in this one because large amount of plastic deformation is not possible with this. Excessive amount of deformation result in fracture before reaching the desired size and shape. So you may have to intermittently, you have to stop it and do a process annealing and other thing. For large deformation cold working is carried out in steps with intermediate annealing.

In some operation, the metal must be annealed for that deformation. Now, there are large number of material which is difficult to deform because of the poor ductility at room temperature or at lower temperature. So in that case, you know that becomes very difficult okay, especially if you look a tool steels and die steels and other things if you wanted to deform then it becomes a real problem.

Now finally the thing is that, when you are doing the cold deformation because the material gets hardened the die life may be affected if you are not providing sufficient lubrication okay, good lubricants if are not provided then die will whereof very fast. So that is another thing so that is the this is another disadvantage with this.

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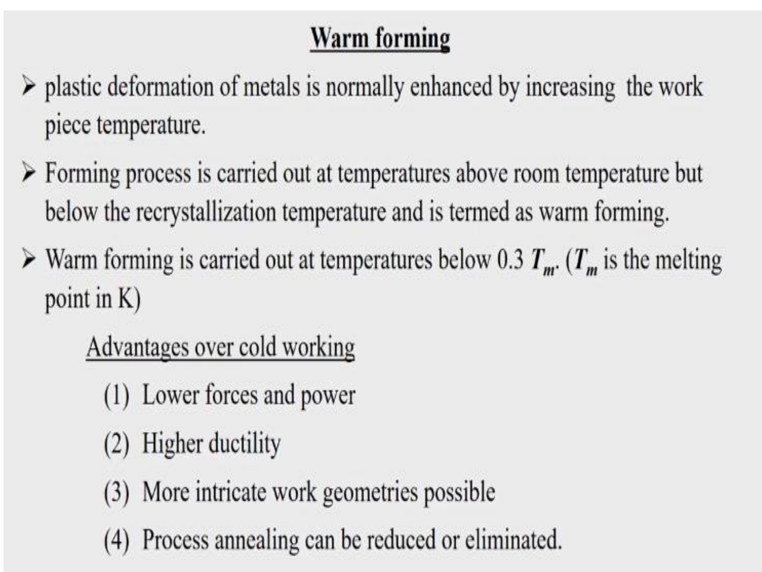


Now in between this cold working or and cold forming and hot forming is the warm forming which has come very recently may be few decades only it has come. Say because as you know that the plastic deformation of metals is normally enhanced by increasing the work piece temperature that is very common thing. So you do not have to go to that very high temperature so that any structural changes are taking place, so it just get soften so that your force requirement or power requirement for the deformation can be reduced.

And plus, a slight increase in ductility will be obtained. So that is the case so here see in that if it is above the room temperature but below the recrystallization temperature then it is called as warm forming. And it is carried out generally at temperatures below 0.3 $T_m$ where $T_m$ is the melting temperature in Kelvin. So advantage of cold working, advantage of the warm forming or cold working are lower forces on power compared to cold working condition, cold forming and you get a slight higher ductility.

So that we can deform it to much more compared to cold forming because ductility is improved, so more intricate work geometry can be achieve so work piece geometry can be obtained you can get it compared to the cold working and process annealing can be reduced or eliminated by this process.

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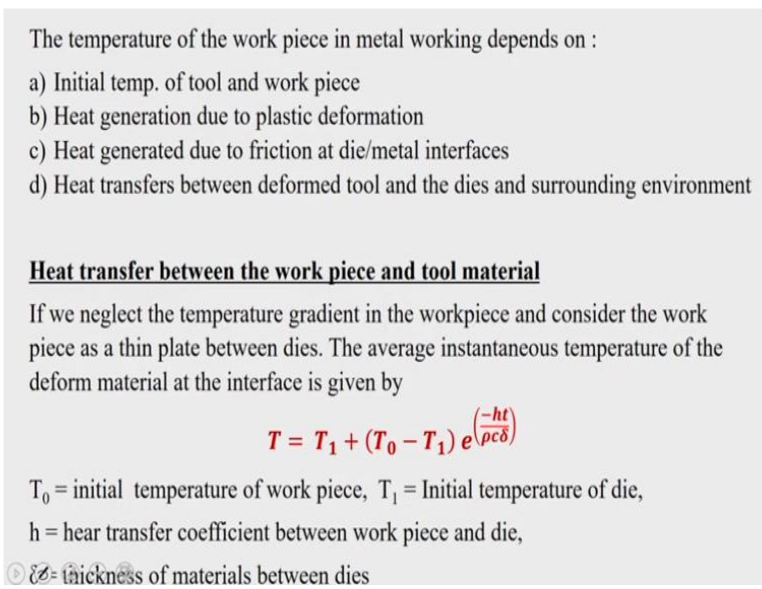


So after having discussed about this three cases like hot forming, cold forming and warm forming let us now look the effect of temperature on the deformation. Because most of the cases when you are doing the metal forming process, hot deformation or any deformation processing whether it is hot forming or cold forming, these deformation is carried out inside a die. Most of the cases it is carried out inside a die whether it is the die cavity is confined to a particular shape or it is not confined it is different but all most of the deformation are carried out inside a die.

Except may be stretch forming but there also you need some shapes okay. So when you are going to heat the material when you are doing the hot deformation processing, your work piece temperature is higher and that is generally above the recrystallization temperature of the alloy and die temperature, die surface temperature will be lower than the melting temperature, otherwise you know what happen that die will get worn off very fast okay.

Or die strength also may get lost that also may get soften and other thing all those things will come, so normally die temperature will be lower than the temperature of the work piece. But over a prolonged time when you are using it in a continuous basis that die temperature also get heated up, die surface also get heated up and then you may when you are applying this one okay that will not get heated up to that high temperature of the work piece material because very frequently you are removing it and there is a time for there is a time lag for the next piece to come inside that and you will be cleaning and other things all those things are coming.

So normally what happen it will be maintaining at a constant temperate almost, so but that temperature is lower than the work piece. Now that is coming in contact with the hot object, so there is conduction. Now when you are deforming the material, the temperature is high but due to a plastic deformation the heat is generated okay. And then when the metal is flowing inside the die so at the die metal interface, there is friction which is going to come.

So all these things will contribute to the temperature raise in the work piece. So let us see that the what are the parameters on which their temperature of the work piece metal, work piece in the metal working operation depends upon. One is the initial temperature of the work piece and the die, so that is fine secondly the heat generation due to plastic deformation, third is the heat generated due to friction at the die metal interface.

And next is the heat transfer between the deformed tool and the die’s and surrounding environment and you have the initial temperature the tool and the work piece is already decided for a particular alloy. Now the other things will be depend upon what is your shape, what is quantity of the material all those things will come into picture. So let us look at that part, say for example, heat generation due to plastic deformation so heat transfer between the work piece and the tool material first.

Say if we neglect because there will be heat transfer from the work piece to the tool material. So if we neglect the temperature gradient in the work piece because when we are heating the work piece in a furnace, you will have some temperature at the center of the work piece because heat as to conduct away into the work piece material. So there will be a temperature gradient from the center to the, when you move from center to from the surface to center of the work piece material.

So temperature gradient work piece will exist and if you neglect that if you assume that can be obtained why, by soaking at that temperature for sufficiently long period of time for sufficient time then you can say that, you can neglect the temperature gradient. And then if you consider the work piece as a thin plate between two die's then how the heat transfer takes place. The average instantaneous temperature of the deformed material at the interface is given by this expression

$$T = T_1 + (T_0 - T_1)e^{\left(\frac{-ht}{\rho c \delta}\right)}$$

where $T_0$ is the initial temperature of the work piece. And $T_1$ is the initial temperature of the die and $h$ is the heat transfer coefficient between the work piece and the die and this $\rho$ is the density, $c$ is the specific heat and $\delta$ is the thickness of the material between the die. So you can get it by this expression, you can calculate after some time T when it is in contact for a sometime period T, now what will be temperate of the material at the interface at the work piece metal interface that way we can calculate it.

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**Heat generated due to plastic deformation**

During metal working, almost 90-95% of the energy supplied is converted in to heat . The remaining is stored in the work piece material and caused up for the metallurgical changes.

For a frictionless deformation process, the maximum increase in temperature can be determined by the relationship [*Courtesy: Altan et.al. 1983*]

$$T_d = \frac{U_p}{\rho c J} = \frac{\bar{\sigma}\bar{\varepsilon}\beta}{\rho c J}$$

$U_p$ = Work of plastic deformation/unit volume; $\rho$ = density of work piece

C = specific heat of work piece ; J = mechanical equivalent of heat, 4185 J/Kcal

$\beta$ = fraction of deformation work converted into heat typically $\beta$= 0.95

Next is the heat generated due to plastic deformation, say during metal working almost 90 to 95% in some books you may find it 85 to 95 depending upon the severity of the deformation, we can say almost 90% of the energy supplied for the metal forming operation is converted into heat and that is because of the plastic deformation which is taking place, the whatever energy is there when it is used for plastic deformation which is converged it.

Remaining energy may be 10 or 5% that energy will be stored in the work piece material and that causes, that will be stored it cannot be relived because that energy is used up for changes in the metal microstructural metallurgical changes which is taking place okay. You may have all this dislocation generation and interaction then dislocation, so sub cells forming all those things may happen in that.

And these are irreversible process, this which is due the metallurgical changes there a irreversible process by a proper heat treatment, we can reduce it but not dealing the deformation process okay. So that but we can say that the majority of that is stored in the work piece material. So for a frictionless deformation process, the maximum increase in temperature can be determined by the relationship Td is equal to a work for plastic deformation per unit volume Up divided by your density of the work piece, a specific heat of the work piece and of course that is you wanted to convert it into this one.

So this is J is the mechanical equivalent of heat, so you can write it in this form that is, the average stress and average mean stress and mean strain into a beta by this one. So because the full amount will not be converted only some amount will be converted. So what is the total stress area under the stress strain curve is what you give it and then convert it into a heat energy this is what it is coming.

So this beta is a constant, which depends upon the efficiency of your process, so that means how much amount of that heat which is generated really energy which is supplied is converted into the heat that is what this beta stands for. So that is what that way we can calculate this the maximum increase in temperature by this method we can calculate it we can determine.

$$T_d = \frac{U_p}{\rho c J} = \frac{\bar{\sigma}\overline{\varepsilon\beta}}{\rho c J}$$

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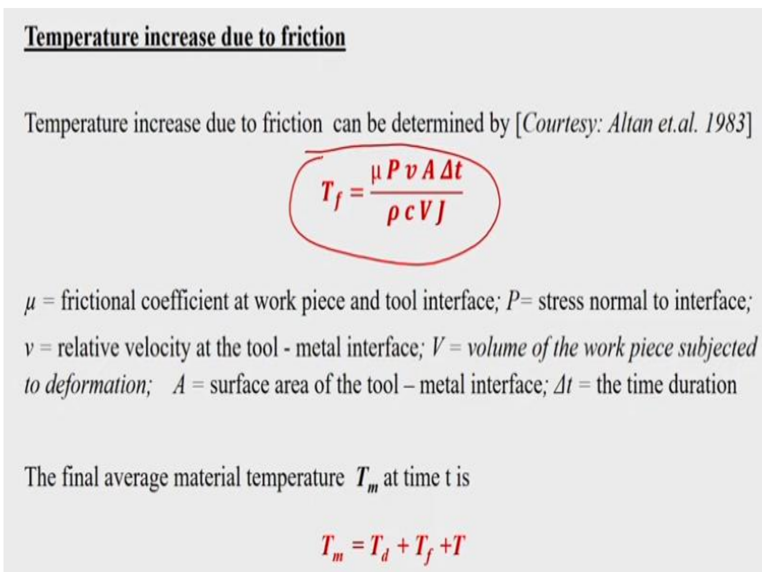


Now the next thing is that temperature increase due to the friction. You have a work piece material whether it be under a hot condition, you have a die may be sometimes two die’s are there and the work piece is kept in between that and then you are subjecting to deformation there may be compressive stresses, there maybe tensile stresses anything can happen bending stresses, anything can happen depending upon what type of metal forming you are doing.

So what happens is that, when you are trying to deform between two die’s there is going to be a relative motion between the work piece and the die because metal is trying to flow and metal will flow in a direction lateral to your application of the load. Say if it is compressive stress you will find that it is just moving sideways like a barrel it comes all those things will take place. But naturally because there is going to be compressive stress at the interface of the die and work piece material, the friction is going to come into picture.

So that the temperature increase due to friction, we can just determine by this relationship that is your coefficient of friction at the work piece tool interface into a the stresses normal to the interface T and the relative velocity at the tool metal interface into say surface area of the tool A into you have time duration, how much time you are deforming this material divided by Rho C into you have the volume of the work piece how much it is there and then your mechanically equivalent of heat.

$$T_f = \frac{\mu P v A \Delta t}{\rho c V J}$$

So that way you can find out this temperature increase due to friction and this is generally at the interface region because of relative motion between them. Most of this say whether it is rolling whether it is wire drawing or script drawing or extortion or say forging this frictional effect is very important in that and you will find that not only the heat is generated some other thing are also happening, many times you know it also decides your die life also.

So but it any case the temperature increase due to friction we can get it by this one so the final average material temperature after time T can be obtained by all the sum of these Td + Tf + T okay. So that way we can determine this.

$$T_m = T_d + T_f + T$$