Thermo-Mechanical and Thermo-Chemical Processes

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Lecture-02
Conventional

Hello friends, we start with a new topic and the first topic of this lecture that is hot deformation processes. So, in this lecture we will be introducing you to different hot deformation processes which are used in the industry and as you can see that we are going to discuss the conventional one first and then in the next lecture we will be discussing the non-conventional one. The non-conventional one means the new type of hot deformation processes which are now people are devising new ways to give deformation at high temperature.

So, in this lecture we will be discussing about hot deformation processes and I have kept it as a one and in this we will be discussing about conventional processes. So, the one of the most used processes which you can find in any industry which does material processing is what we call as hot rolling ok,

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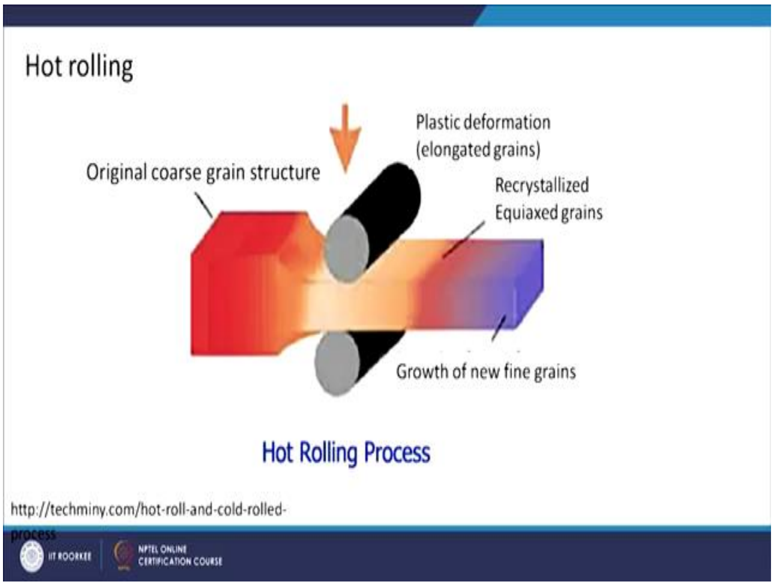

So, the idea is that you have to keep reducing the size of the billet, size in the sense cross sectional area or the thickness of the sheet, after casting what you get is big billets or ingots and those ingots have to be processed initially and you want to impose very high strains to break the dendritic structure. So, when you want to impose very high strain as you can see that or you must be knowing from your basic understanding of stress-strain curves.

That when you impose a strain it the material gets strain hardened and when it gets hard and if you still apply a very high stress then ultimately there will be some instability some cracking in the material. So, I cannot impose very high strain in one pass but for to break the dendritic structure which you get during the casting you have to impose very high strain to break the structure.

So, the initial processing of any material after the casting process is usually done at a higher temperature and that is why these are called hot deformation processes or thermo mechanical processes that means you have temperature as well as some strain is introduced and these processes that is why called as thermo-mechanical processes. So, one of the very important process in this is called rolling.

So, it can be cold rolling or hot rolling. So, right now as we because we are discussing thermo mechanical processes we will be discussing about hot rolling. So, there is a reduction or when you impose a strain there is going to be a reduction in the cross-sectional area and then there will be a lot of microstructural changes going to happen. As you can see here also the original material had some coarse grain structure as you can see here.

It is heated so that is why it is shown as red color and then you are allowing it to go through these roles so these are the roles here. And then the material as you can see there is a reduction in the thickness after the deformation. So, you have imposed some deformation. So, initially whatever you get from rolling after a plastic deformation these will be elongated grains then because if the strain is sufficient and if the temperature is sufficient you may have recrystallization process in the material at that temperature.

And then after recrystallization there will be growth of new fine grains. So, basically the idea is that you have to refine the microstructure and break the coarse grain structure. Also, so there will be multiple stages, first stage you will be you would like to break the dendritic structure then again you have done some annealing you have some coarse grain structure then you go for fine grain structure and so on. And then you will go for cold rolling processes later on.

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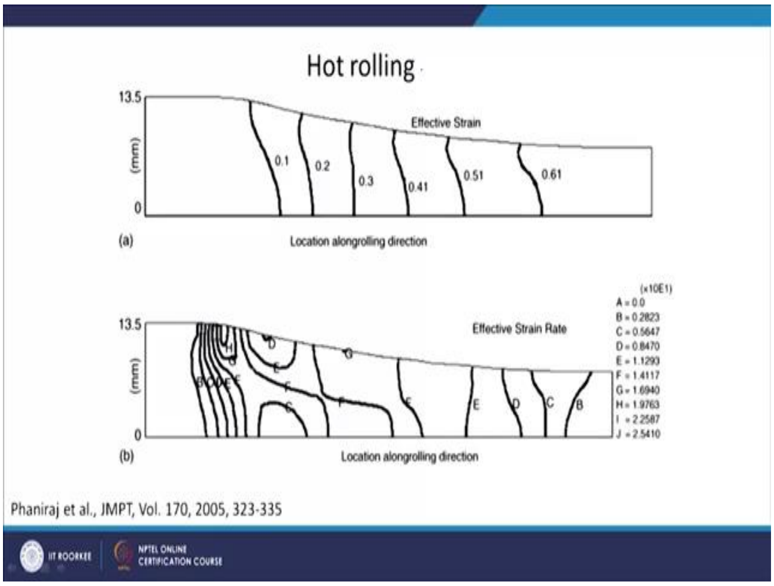

If you see a typical deformation process during hot rolling. So, basically I can say that here I am talking about the strain distribution. So, you can see that x-axis along the rolling direction and y-axes is where you have the thickness of the material and these are some work I have taken from journal called journal of material processing technology. So, basically what they are trying to show here is that; what is the strain distribution at different stages during the rolling.

So you can see that roll must have started somewhere from here and somewhere here the roll must be coming out so it must be something like this. And you can see that how much strain is introduced at different stages. So, from 0.1 strain you are going up to 0.61 strain. And in the second slide they are also trying to show you that what are the strain rate distribution and the values are given here.

So, from a which is 0 strain rate to 2.5*10^1, so 10^1 is written here so it is 2.5*10^1. So, that kind of strain rate can be introduced during the deformation process. So, maximum strain in this particular case is around 0.61 and the maximum strain rate if I can show you here it is somewhere let us say I is somewhere or may be H, H is somewhere here.

This is H, that means the strain rate must be maximum around here. And this combination of temperature, strain and strain rate is going to bring out the change in the microstructure.

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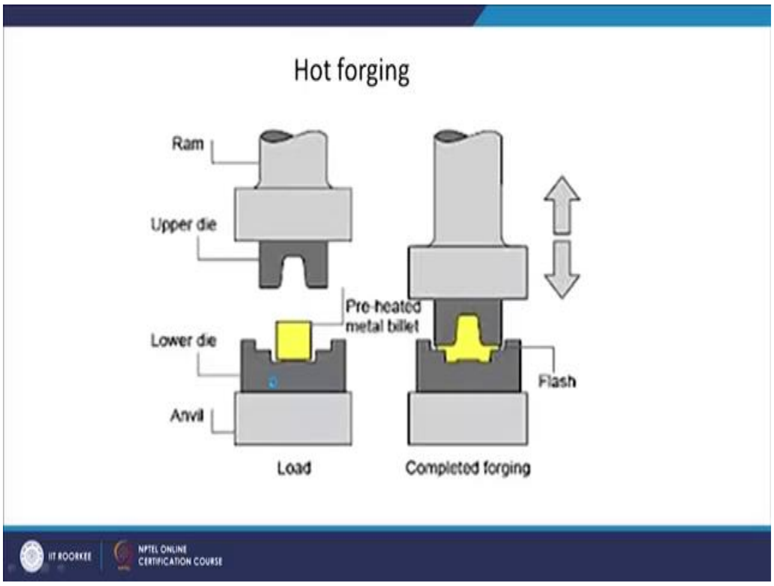

The next process is what we call as hot forging so very simple process basically there are two rams. So, this is a fixed ram then there is a moving ram here and then you kind of bang the material at a very high strain rate. Strain rate you can choose depending upon the rate at which you are hammering the material. So, it is a similar process like a hammer which you must have seen any blacksmith doing next to a road who is working on material or steel that they are hammering the material.

So, this is a similar process. Only thing now in this case the machines must be very large and these are in few thousand tons. And the process can be two type either it can be an open die forging or closed die forging. As you can see here it is a closed die forging the material is confined in a particular die and it is kind of forged. In an open die forging basically it is very simple you have a fixed ram some material is kept here and the top ram is hammering it.

So, as you can see here there is no confinement in this direction. So, material is free to flow in this direction. So, whatever shape it is going to take it can take. Whereas in this case you can see that there are die around it so it is going to give a particular shape to the to the billet. So, a pre heated metal billet will be kept and then you will hammer with the upper ram and material will be kept on the lower ram.

So, it can be done at a repeated cycle so it would not be a one short process you keep hammering till the material take the shape of the die.

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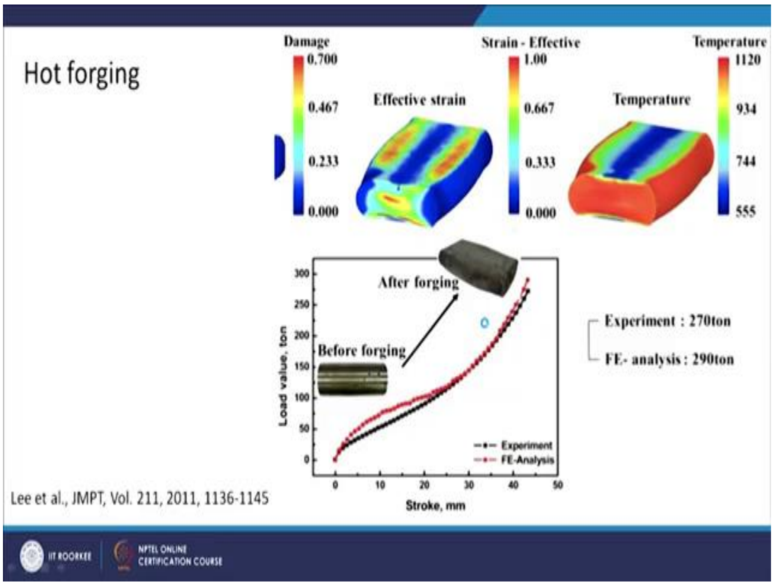

Again, people have done studies and some experimental, some FEM simulations. Just to show that what kind of strain rate and temperature you can attain in the material as you can see that effective strain is plotted here and the color coding is given here. So, blue is very low strain, red is very high strain and they are trying to show that where the high strain is achieved. Basically, the idea is that in the same deformation process you achieve different level of strain and strain rate in the material.

So, understanding of thermo-mechanical process is very important to know whether you are reaching deformation condition which can introduce a defect in the material. So, we have to be very careful about that. Also, you can see that there is a temperature profile here. So, rest of the billet as you can see still at a higher temperature it is around 1100, 1120 °C. And the blue color is where the ram comes in contact with the bullet.

So, because ram must be at low temperature compared to billet you can see that lot of heat must have been dissipated from there so that is why you see this all low temperature region on the top. So, that also we have to account for that there can be temperature variation in the same material, strain variation, strain rate variation and again they have compared the experimental and their modeling results. So, they have plotted stroke on the x-axis and load on y-axis in tons.

Then trying to show that how the load variation takes place as a function of stroke. So, before forging the material had this kind of shape after forging it became something like this.

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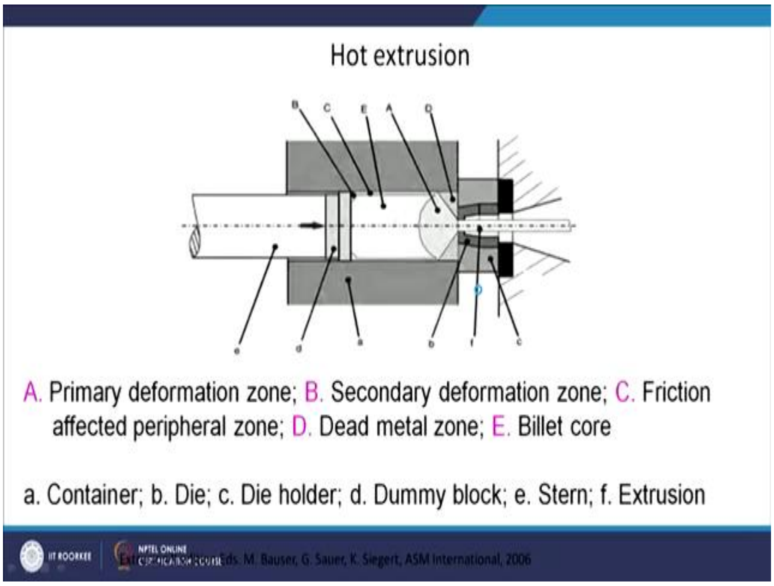

Then another very important process that is called hot extrusion. You must have seen some of these kind of process at home also in kitchen. There is one dish which we make in some part of the country which is called Chucklee. So, basically you put dough of gram flour and then you have to kind of force it through an opening and then it takes that shape. Similar process here, you have a small opening here of course you have to give some angle to the material so that you can introduce the strain in the material at different levels.

Strain will increase as material is going through the die and a large cross-sectional area material can be reduced to a very small cross-sectional area and in that process you will be introducing lot of strain in the material. And some zones are shown here. So, A is basically primary deformation zone, B is your secondary deformation zone basically where it comes in contact with the ram and the boundary of the die, C is where you will have frictional affected peripheral zone.

So material will be kind of rubbing against the die wall so there will be lot of friction or friction frictional effect there and frictional heating also. Then you have a dead metal zone somewhere here where there would not be any deformation. So, deformation will be constrained only in this part of the material. And E is the billet zone or billet core. Small alphabets are showing, a is your container in which you are putting your die, b is your die here, c is a die holder, d is dummy block, so this is your dummy block here and e is stern and f is extrusion which is happening through the die.

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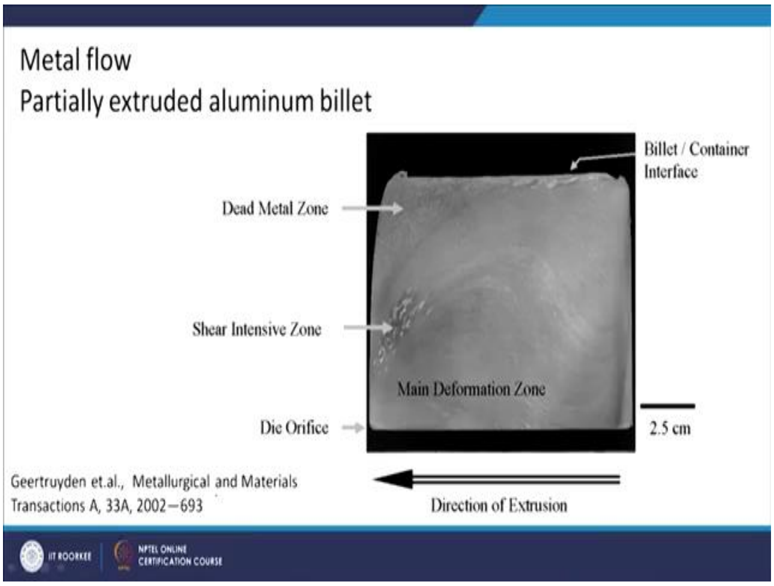

If you want to see how the metal flow during this kind of extrusion process, this is one example again taken from a literature. Actually, what they have done they have started the extrusion process stopped it and took the billet out and cut it in half and then they are trying to show that how the material flow has taken place. As you can see here this is the dead zone you do not see any microstructural change here. Here you can actually see the material flow direction, the flow lines, how the grains are flowing.

Here actually is where you have a very intense shear zone. Lot of shear strain is going to be imposed in this part of the die which is just where it is going to come out. As you can see orifices itself somewhere here it is just before coming out it experiences maximum strain here. And lot of flow lines you can see are going like this. So, you can see that in the same extrusion again there are lot of variation in the microstructure and the strain-strain rate.

And at the at the edge of the billet where it is coming in the contact with the die or the container because of the frictional effect you can see lot of coarse grain is there the temperature must be high at that point.

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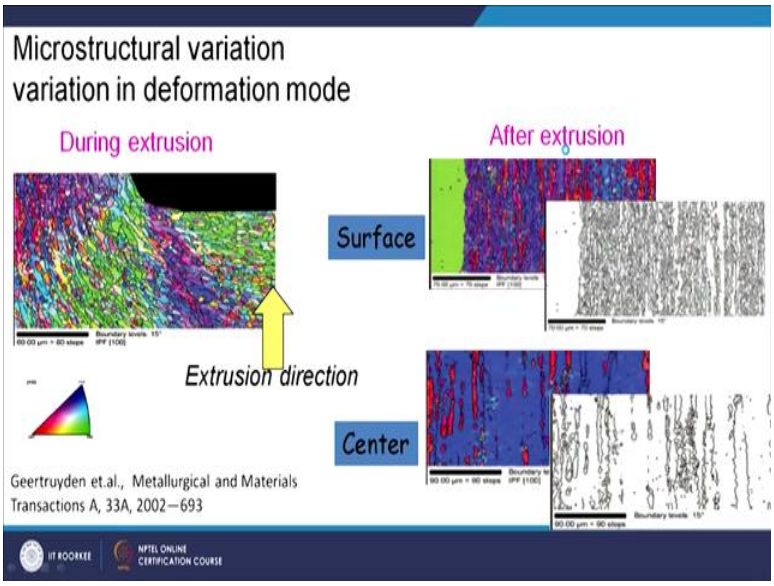

Now if you want to see the changes in microstructure some very nice beautiful pictures are here again taken from a literature. And you can see now they have also shown microstructure and their orientation information. Maybe you would not be able to see this key here I can write a bigger number here it is 111, this is 101, there is 001 ok and this is for 001 inverse pole figure map.

So, basically what these colors are showing which is given as key here. If any grain is red colour that means 001 axis of that grain is coming out, so it is coming out from the surface here. If it is a green colored map that means the 110 axis is coming out, if it is blue color then it is basically 111 axis is coming out. So, you can see again very nicely how the variation is taking place, how the orientation of the grain is changing during the deformation process. So, this is your extrusion direction is shown here by the arrow.

And you can see at this point you have very high values of strain and then somewhere here. I am not sure about the strain values because it is not shown here but what you can see very nicely is that how the orientation is changing there are different zones of orientations. So, basically the texture is changing during the deformation process.

Similarly, another very nice example of variation in the microstructure because of the variation in the strain in the extruded billet. So, this particular microstructure is at the center of the billet and this one is at the surface. So, you can see that in the center you have a different type of grains only blue and red ones. And at the surface if you see the microstructure is more refined because maybe the strain is higher there. Also, you can see a very coarse grain structure here by this green color grain, a very big grain is there and the rest of the them are very fine that means more strain is seen by the surface and less strain is seen by the centre. So, again a very nice microstructural variation you can see in the same extruded billet.

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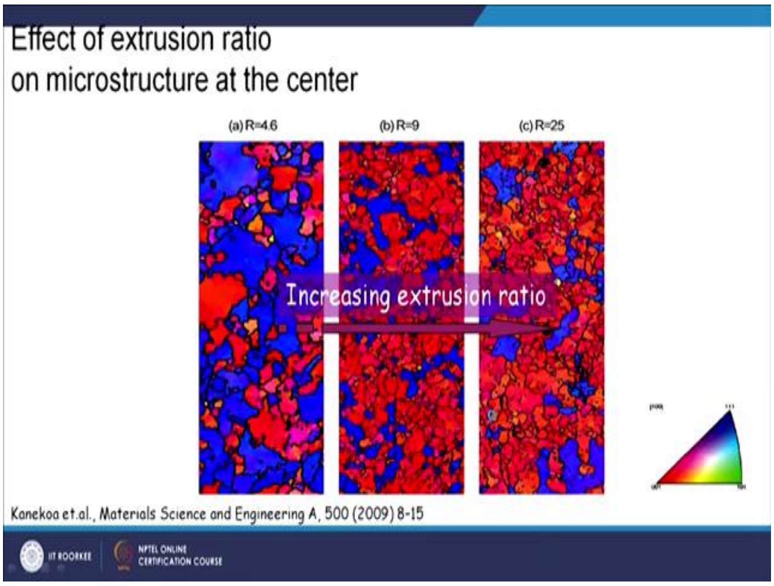

This is the effect of increasing the extrusion ratio that is the ratio between the what is coming out after extrusion and what is you are putting in. And as you can see as the extrusion ratio is increasing because you are putting more strain. The grains are very coarse here big grains are seen. Again only two type of grains one is red one that means 001 axis is coming out or blue one that means 111 axis is coming out.

So, combination of 001 grains and 111 grains and then as you are increasing the extrusion ratio you can see the microstructure refinement which is taking place. And also you can see that the number of red color grains are increasing. So, that means you are introducing a texture also in the material a crystallographic texture which gives a it a predominantly one type of orientation to the grains.

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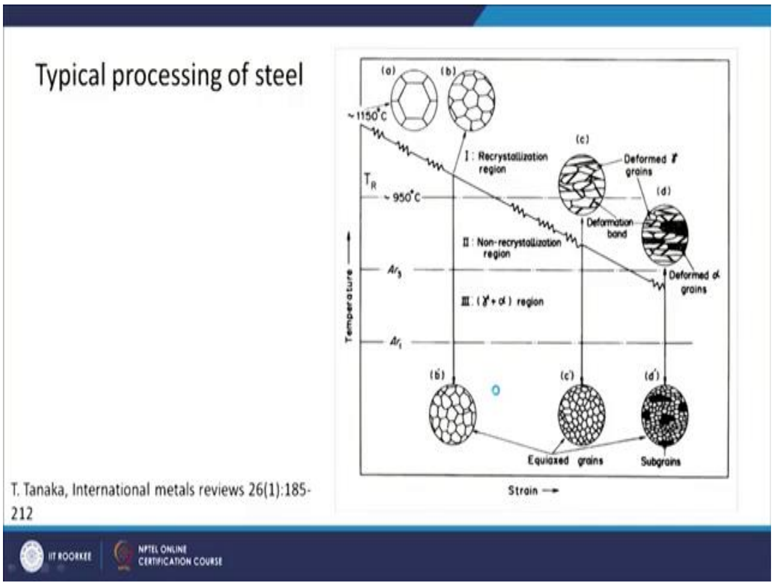

Now this is a typical processing of steel and just to show you that when you do a processing in industry what are the different stages of processing the material has to go through. So, as you can see the deformation or the material is starting somewhere from 1150 degree Celsius and these hatched regions here these are the regions where you have imposed strain in the material. So, as you can see understand that these are all continuous processes.

So, you heat the material and then it goes through the different stages of deformation. So, as you can see these hatched regions here, here, here these are the regions where you have put the strain. Suppose there are number of rolling mills are there so first rolling mills has introduced strain here another one here and another one here. Also, very important to see here is that because you have heated material at one point and then it is going through this stages, the temperature is continuously dropping.

So, this is a steel, also the different critical temperatures are also shown here. AR_3 is here, AR_1 is here and this is around 950 °**C,** above that T_R means where it recrystallization can happen in the austenite phase. So, first recrystallization region will be here. So you start with a very coarse grain, then the recrystallization is happening. So, this is my first recrystallization region and then you can see that it is the temperature is continuously coming down.

And this is a non-recrystallization region that means there cannot be any recrystallization in this particular region. And then again you are putting strain at different stages and then the microstructure is something like this after deformation. So, deformation in the γ phase that means the austenite phase. Again, the temperature is continuously dropping and then you are putting deformation here.

So, these are deformed α grains now because you are coming into the α region, $\alpha + \gamma$ region. So, you can see that the deformation, the actual thermo mechanical processing in industry is very complex. Your temperature is continuously dropping and because temperature is continuously changing phases in the material are changing. So, you start with the austenite phase then you come in to a two-phase region where the austenite plus ferrite phase both will be there.

And then you go into the ferrite region also maybe where only ferrite grains will be there. They have different crystal structure, their deformation behavior will be different. So, there are lot of microstructural information and this kind of deformation processes have to be combined to get a very good understanding of the thermo mechanical processing.

Also, as we have already seen that we have to see the temperature, strain and strain rate, and at the same time now as you can see here there will be information about phases. Now phases can be of different type if we take only metallic material most of them will be only in this region. So, maybe some phase will be BCC, some phase will be FCC, some phase will be HCP and they will be having different type of deformation processes at the same temperature, strain and strain rate. Also, we have seen earlier that strain, strain rate and temperature will also be different in the same material.

So, if you look at all this condition and all these scenarios you can understand that the whole thermo mechanical processing is a very complex process and understanding of that is very essential for a defect free final product and to understand that you have to do a lot. For example, if you are putting any new alloy in the market. You have designed a new alloy or you are working on a new alloying system.

So for each of these alloying system or alloy which you have developed you have to first devise an optimum thermo-mechanical processing to get a grain size which you want, to get a texture which you want and to get the strength and ductility in the final material which you want. And for getting that you have to control all the deformation processes before that.

So, I think with this lecture you must have been able to understand the complexity and the requirement to understand the whole thermo-mechanical process, the inter-play of different mechanical parameters strain, strain rate and temperature and microstructural parameter like phase and their behaviour under those conditions, thank you.

Keywords- Rolling, Forging, Extrusion, Microstructure.