Thermo-Mechanical and Thermo-Chemical Processes
Prof. Vivek Pancholi
Department of Metallurgy and Materials Engineering
Indian Institute of Technology-Roorkee

Lecture-23
Microstructure and Application

Hello friends, continuing with our processing maps module, already we have seen about deformation mechanism map and processing map. Processing maps are generated using a model called dynamic materials model and in that the same continuation, we are now going to look at some microstructure and application, how processing map can be used and how to validate it through microstructure and how we can use these ideas of processing map for some application.

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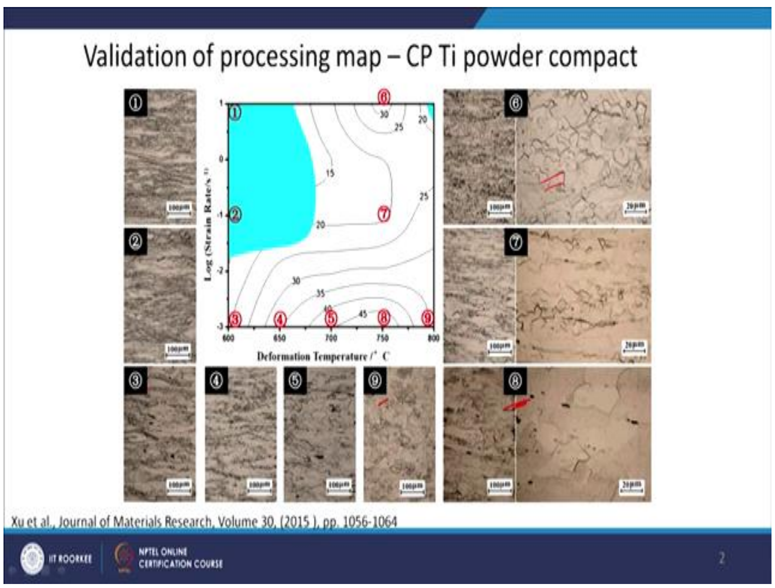

So, you will see how processing maps are used and how we validate the processing map at the same time and how we interpret the processing map. So, you can see here (refer to above figure) that again deformation temperature is on x-axis and strain rate on y-axis and your contour maps are drawn and instable region is shown at these two locations.

And now they have taken samples from different location, wherever they are observing higher efficiency and also the instable region. So you can see that wherever the high efficiency regions are there for example 8 (in above figure), you see more or less nice microstructure. Of course, it must have seen some grain growth also. Similar to here, in this one also you can see some high angle grain boundaries are there (refer to above figure).

And looks like recrystallized microstructure. So, all these regions and in region 3 here I think you can see some partially recrystallized grains forming on the boundary. So, 3, 4, 5 all these are usually high efficiency region, 8 and 9 also, more or less recrystallized microstructure. Whereas if you see the two here, 1 and 2 you can see that there is some flow localization has taken place, you can see some big elongated coarse grain.

And then some very this dark bands kind of thing. This usually happens because of the flow localization. This 1 and 2 you can see some kind of flow localization wherein other cases you can see the relatively nicer microstructure. This work was done in commercially pure Titanium powder compact. Powder was sintered, compacted and then the deformation was performed on this powder compact. And from there these microstructures have been generated.

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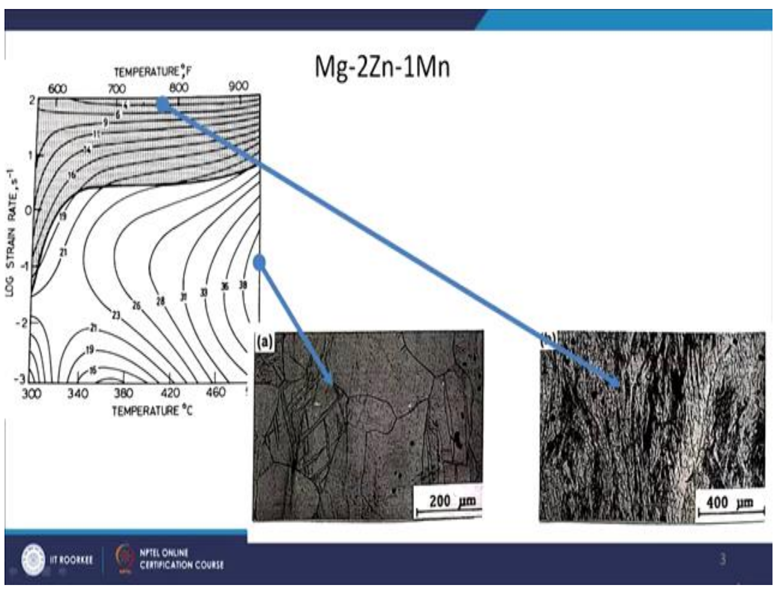

Some more pictures, again this is a kind of a collected large number of processing map and microstructures were collected and in a book was written by the author was Y.V.R.K. Prasad and from there I have taken all this (refer to above figure). Earlier also we have taken all the processing map from that book. This is magnesium zinc manganese alloy, you can see some processing map is generated, some efficiency contours are there and you can see the instable region. So, one microstructure is from this region where you have high efficiency 38% and one microstructure is taken from the instable region. So, you can see very clearly a very nice recrystallized microstructure here whereas here you can see lot of flow localization has taken place in these areas (refer to above figure). So, this is where the instability must have been occurring.

This of the same alloy this was in different condition. I think this was homogenized and this was in as-cast condition. So as-cast condition you can see that there breakdown of dendritic structure is taking place where you have got this high efficiency. So, this area is where you got the high efficiency so, from this particular processing condition microstructure is taken.

So, you can see nice wrought microstructure whereas at a higher strain rate and lower temperatures you can start seeing some flow localizations here and in the instable region you can see maybe some kind of void formation here, some these dark regions. So, this kind of the microstructure also looks like acicular microstructure. You can see this kind of long elongated grains or acicular structure.

Whereas in this case you can see very nice recrystallized equiaxed microstructure. This is for the same alloy but in as-cast condition, the earlier one if I am not wrong it was in homogenized condition.

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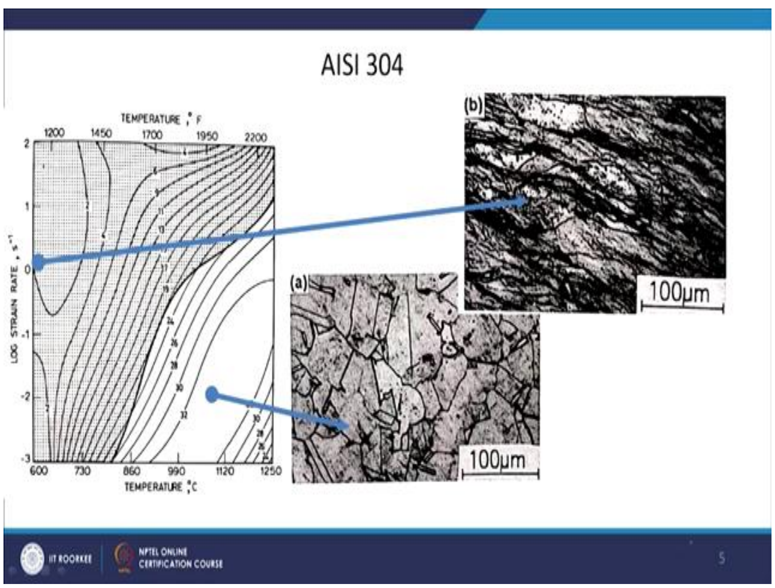

This is another alloy, a stainless steel 304, you can see a very large instable region is shown here (refer to above figure) and the efficiency is high in this particular area around 32% or so and there you can see microstructure. Of course, it has lot of these straight boundaries and these are actually twin-boundaries these are not defects, sometimes defects also looks like that but these are of course twin boundaries in austenitic stainless steels.

And of course, the microstructure is again recrystallized so there is no issue with this microstructure we should get an in this processing condition. I should get this kind of microstructure in the instable region where it is at higher strain rate and lower temperature. You can see lot of flow localization has taken place, all these dark regions. So, flow localization means the deformation is concentrated in few weak areas of the material (refer to above figure).

So that is what you can see here flow location in the material whereas in this microstructure I do not see any defect like that.

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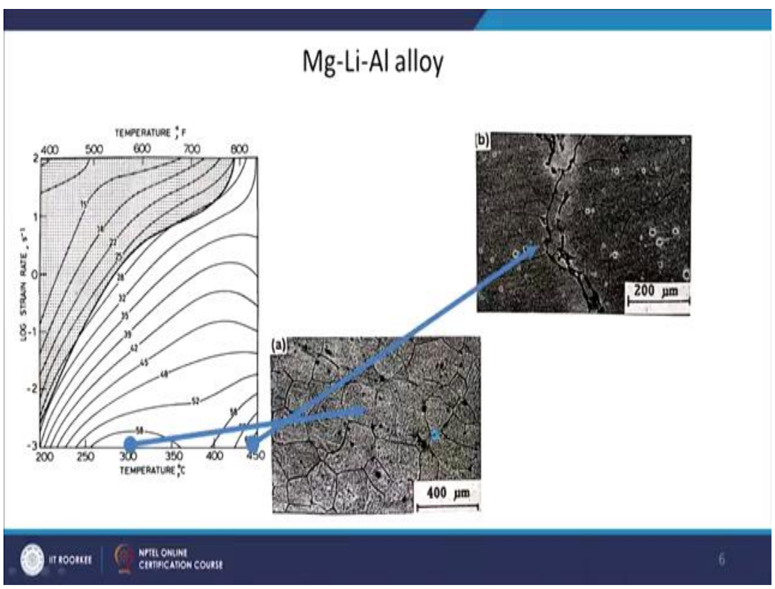

Another example microstructure and how processing maps are validated. So, this is one region where you have high efficiency (refer to above figure). Again, a very nice recrystallized equiaxed microstructure of course, grain size is large. This is again a magnesium lithium alloy. Whereas if you see at higher temperatures, you can see some cracking at the grain boundary, some void formation, void must have nucleated and they have kind of connected with each other, some cracking has taken place at the grain boundary.

So, although it shows high efficiency again, we should be concerned about this that it shows high efficiency, but there are defects in the material. The efficiency is around 60% here whereas it is 58% here at lower temperature. So, with increase in temperature you have a new type of defects, you can also see if I am not wrong that there are some cavities I have found here and maybe on the grain boundary or so.

And you can also see this kind of cracking or kind of cavities joining together and you have cavity coalescence kind of phenomena and maybe some wedge cracking also must have taken place. So, the idea here is though it does not show instable region and it in fact shows a very high efficiency region but still you can get defect in the material. So, for any processing map it is usually advisable to do a validation.

So, you should take microstructure of all the high efficiency zone as well as few microstructures or few samples from the instable region or unstable region. And one should do a good microstructural analysis before this processing map can be used.

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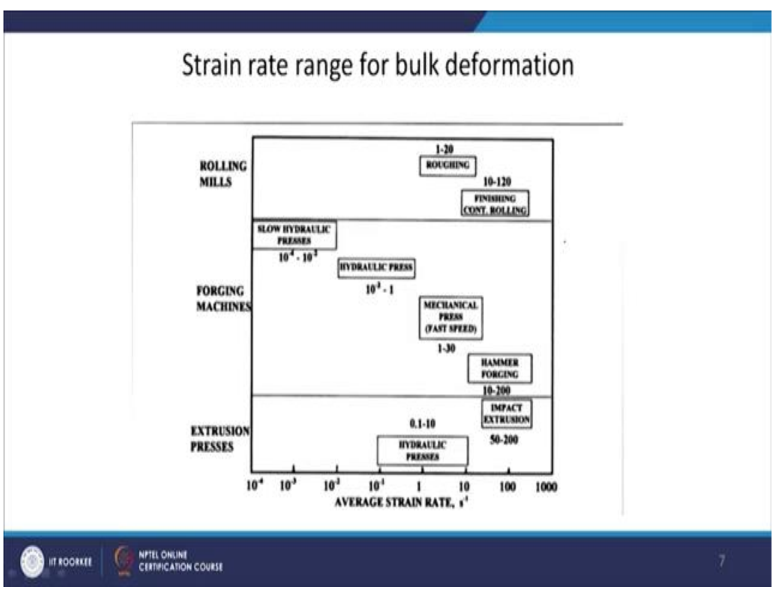

Now there are some applications we are going to see for processing maps. Before coming to that I just wanted to show you that what are the strain rate range for different bulk deformation processes. So you have rolling, you have forging and you have extrusion process and the average strain rate of these three processes is given on the x-axis (refer to above figure). So, for extrusion, if we are using hydraulic press, the strain rate is in the range of 0.1 to 10 s^{-1}.

For impact extrusion, very high velocity extrusions, the strain rate in the range of 50 to 200 s^{-1}. In forging, you have different types of forging. So, you have slow hydraulic presses, through hydraulic press you are applying the compressive load. The strain rate in the range of 10^{-4} to 10^{-3} s^{-1}. For hydraulic, press it is around from 10^{-3} to 1 s^{-1} or I think it is 10^{-2} to 1 s^{-1}. Then there are mechanical presses used, means they must be using some cam or some gear arrangement. So, these are not hydraulic. So, in mechanical presses you can achieve higher speeds and the strain rate is in the range of 1 to 30 s^{-1}. Then there are Hammer forging. So, under the gravity force a hammer is kind of dropped on the material, the strain rate in the range of 10 to 200 s^{-1}. So, again a very wide range of forging strain rates. Then there is rolling mill or rolling. So, there are two rolling operations usually one is called what we call as roughing. There the strain rate is in the range of 1 to 20 s^{-1}. And then there is a finish rolling in which case the strain rate is around 10 to 120 s^{-1}. So roughing you usually do in the initial phase of processing. So, after the ingot casting you have made big ingots, you want to roll it. So, initial these are done usually at high temperature. So there you have roughing. You want to impose higher strain to the material and then when it is coming to the final shapes which is now going to go out to sell in the market, there we do finishing operation.

The strains are usually low in this case. Of course, the strain rates are high but the amount of strain you put in one pass is quite low. And the deformation is usually at low temperature or usually it is cold rolling, so room temperature rolling. So, just to maintain the good finish of the surface, you apply a very small amount of strain and you try to give whatever shapes you want to give to the material. So, these are called finishing operation to give a good surface finish to the material. These are the strain rate range.

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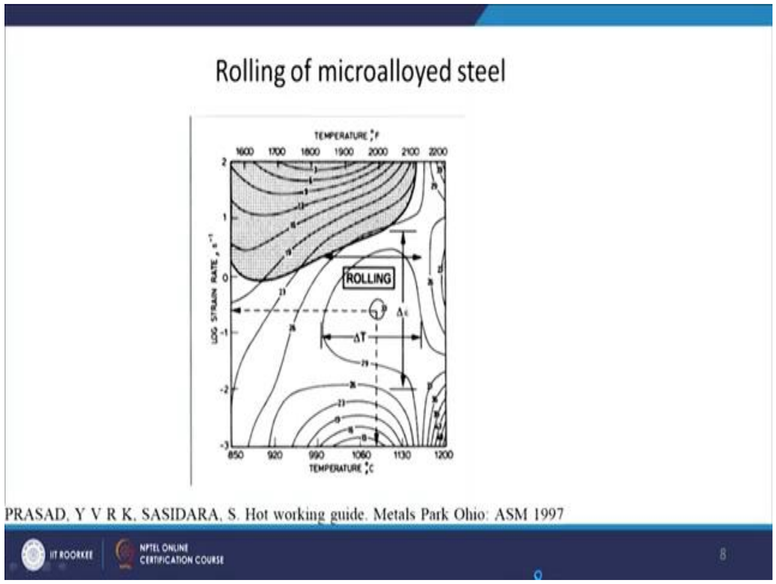

So, now we have established that processing map are able to predict the microstructural changes which we want. So, it is able to predict that where you will have recrystallization, where you will have a defect formation in the material. So, that is now established, so I do not have to keep looking at that again and again. So, now I can use the processing map for my other purpose that how I can apply this processing map in actual application for example rolling of a micro alloyed steel is if you are trying you can contact a processing map first, you can look for high-efficiency regions. So, of course again you have to look about the cost of any process.

So, I cannot do at high temperature because cost of heating the material will be involved, I cannot do at very low strain rate because then my productivity will be affected. So, you can see that a temperature range and a strain rate range is kind of defined for rolling. Because you can also understand that when you are doing any operation, unlike a laboratory experiment, the strain rate, temperature keeps changing during the deformation process.

Because these are continuous deformation sometimes, so I have to have a large window in which I can do the rolling process or any deformation process. So, one way to use processing map is like this.

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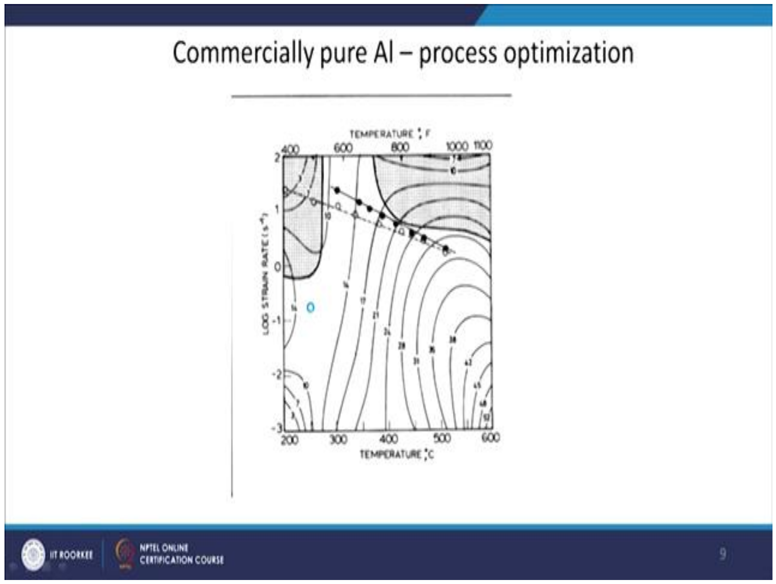

Another in this process optimization was done in commercially pure aluminum. So, as I was telling you that these are continuous processes, so the material is heated in the furnace and then there are couple of rolls, maybe three four rolling mills are there, so the material is going from one rolling mill to another rolling mill. So, the temperature is continuously coming down during the deformation process.

So, this open circle (refer to above figure) is the initial process applied in an industry to do the processing of aluminium and after the processing map was generated it was found out that the two conditions are coming in the instable region. So, again to have good productivity and you do not want to have large heating. So, the first pass is here and this is the last rolling pass (refer to above figure).

So, from high temperature my material is continuously getting cooler and cooler. At same time the strain rate of the deformation is also increasing, as you are going to multiple passes. So, the temperature was more here, strain rate was low and then the temperature is coming down and that strain rate is increasing. So, this was the initial process. So, you can see that the instable region is there in the last passes.

So, maybe there a defect can be introduced at in this particular condition. So, to optimize the process another process was proposed, these dark circles (refer to above figure). And again, you can try to see that they are trying to maximize the productivity by going to very high strain rate. And they are starting from a temperature of 500°C and going up to 300°C and just trying to avoid this instable region here and not entering into this particular instable region.

So, that is how you can design a new process if you notice that the earlier process is going in the instable region.

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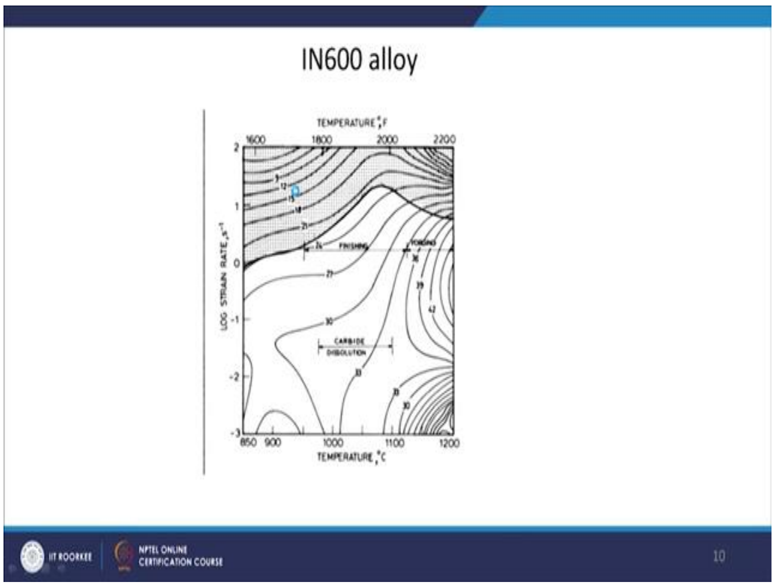

So, this is what we can do as process optimization. This is for an Inconel 600 alloy (refer to above figure); you have different operation. So, forging will be done at high temperatures as I told you rough rolling or forging will be done at high temperature. And then the finishing operation will be done at lower temperatures. Again, you can see we are just avoiding the instable region and trying to have maximum strain rate we can achieve in this particular process.

The carbide dissolution is taking place somewhere here (refer to above figure). So, knowing all this microstructural changes, now you can design the process that what should be the my forging or finishing operation so that there should not be any microstructural change, which I do not want, avoiding the instable region and so on.

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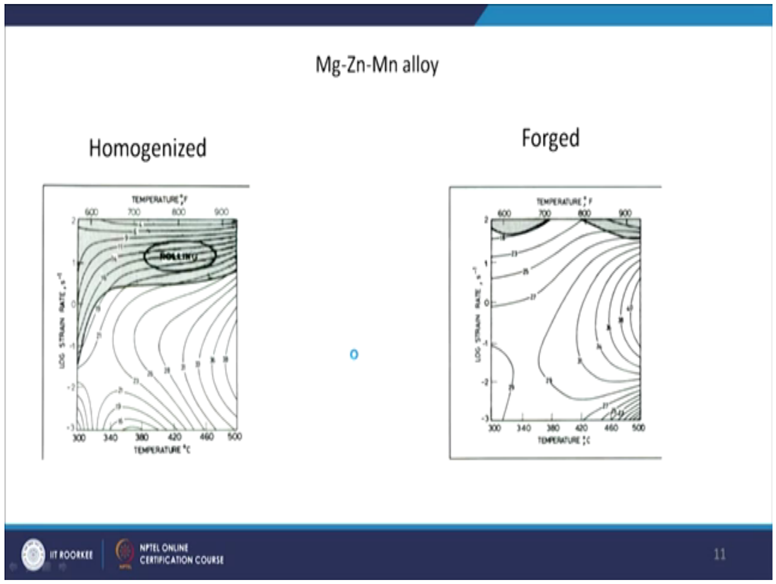

This is for a magnesium zinc manganese alloys (refer to above figure). So, you can see the difference between a homogenized alloy and the forged alloy. So, you please understand that, this is a homogenized material. So, after casting you have done the homogenization. So, still the dendritic structure will be there but the homogenization what it will do, it will homogenize the material; the chemical composition will be same throughout the material now but still the dendritic structure will be there. And with that kind of as-received material you have done different test to measure the stress and strain as a function of the strain rate and from there you have developed this processing map. Same material after homogenization you have forged it. So now this is forged first and then you have again done the same kind of test as you have done here, compression test, measured stress at different strain rate and temperature and from there you have generated the processing map.

So, as you can see that as you have done one forging, so now you have brought the material into a wrought condition. Your instable region has shrunk. Here the instable region was very big covering a large processing window whereas this instable region is now kind of limited to a very small processing window. So now it has opened my processing window for the alloy by doing a forging operation. So, you can understand that by doing this kind of initial operations, what we are trying to do is, we are trying to have material in which you will have less chances of having defects. So, my instable region is reduced by doing a forging operation and again processing map is generated for this forged material. So later processing now can be done using this processing map.

So what we have done here now, is we have used dynamic material model to develop processing maps and using that understanding and by knowing that this processing maps are able to predict the microstructural changes from the efficiency map and instability map, we have now confidence in that and now we have used those processing map for different applications to design a process, to find out the processing window for different material and to identify that what type of processing should be done for the material. You can use it very dynamically and it will be very good input for a process engineer, if you give this processing map to him, he will be able to understand where he has to done the processing.

So, this is important application of processing map. So, in the next lecture we will try to see there are some other models which people have proposed to develop processing map and then we will do again a case study in the processing map. Thank you.

Keywords- Processing map, microstructure, application.