Heat Treatment and Surface Hardening - II
Prof. Kallol Mondal
Prof. Sandeep Sangal
Department of Material Science & Engineering
**Indian Institute of Technology, Kanpur**

Lecture - 40
Importance of heat treatment practices in real life (with examples)

This is the final lecture in the heat treatment course. And in this particular lecture we will look at some applications of the simple applications on some of the principles that we have learnt in this course. So, the first application that I am going to look at is what is the thermo mechanically treated reinforcing steel bars or they are called commercially as simply TMT rebars. And what are these? These are bars which have specific properties and a use for construction of high rise buildings.

Now this was work of a masters thesis in IIT Kanpur, where we looked at what would be the affect building caught fire. What would be the affect of the properties of these bars? However, in this lecture we will not look into that. But we will look at how these bars are actually produce and you know what are the heat treatment principles you know that become important here. So, here you have, you have these what are called as TMT rebars.

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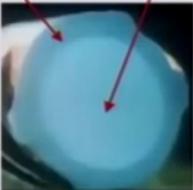
These are of various diameters the particular diameter that we studied were the diameter of 25 mm which are used for construction of high rise buildings. A typical steel composition for such a bar for example, it is relatively low carbon. It is 0.17 percent carbon. And it has some amount of manganese 0.69 or so and silicon 0.19. So, this is just a composition of the specific batch that we were studying. Now if I look at the macro structure of this if I just take an image of a cross section of this, what this has this has a hardened rim and a soft core.

So, I am going to look at what kind of a process was used to produce such a bar, where you have a hardened rim on the outside and a soft core outside. So, you start with the bar of a specific dimension of this particular composition. And this is the process you follow you austenitize the bar again.

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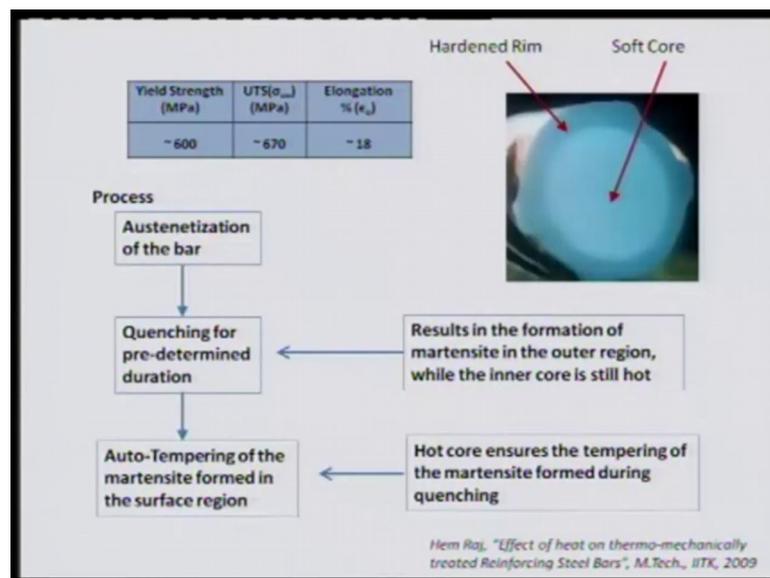
So, go to high enough temperature that you have you are in the single phase austenite region of the iron and carbon phase diagram. And then this bar is coming out of these furnaces that are relatively high speed in a steel mill. It goes through what is called as a quenching box, and hence it gets quenched for a pre determined duration. And we will see why you have you have do you do not want to quench it continuously you want to quench it only for a pre determined durations Such that the surface layers form martensite while the interior is still soft is the interior is still in the austenite region.

If that happens; so it results in the formation of martensite in the outer region while the inner core is still hot. Now when it comes out of the quenching box the cooling is stop from the surface. The inner core of the material is hot enough that heat transfer takes place to the surface and actually tempers the martensite and that is what it calls auto tempering. So, you do not have to temper the martensite separately. It is the same continuous process martensite formation and martensite tempering takes place. So, you end up with the tempered martensite surface which is harder much harder, and a soft core which is a ferrite pearlite core. And hence you get a hard outer region and a soft core. Because you do not want you know the completely hardened region, because if you get completely harden region then this particular becomes very brittle, and it will not be usable for structural applications for in construction business.

If I look at the tensile properties of a such a material. This these are the kind of tensile properties you get you get a yield strength of about 600 megapascal, you get ultimate tensile strength of 670, but you get a very large elongation as well and this is because of the soft core inside. So, this is the simple process of making this material, and as you can see that in order to get this kind of a structure hardenability of this steel is going to play an important role.

So, you and hence you have to know what are the transformation curves, what are the continuously cool transformation curves for such a steel So that you can design properly the quenching medium how long you have to quench, how severely you have to quench. So, that you get just a right amount of variation in the microstructure from the center to the core to get this kind of mechanical properties. If you look at the microstructure of this material, along the radius starting let us say from the surface down to the center you would get for example, near the surface.
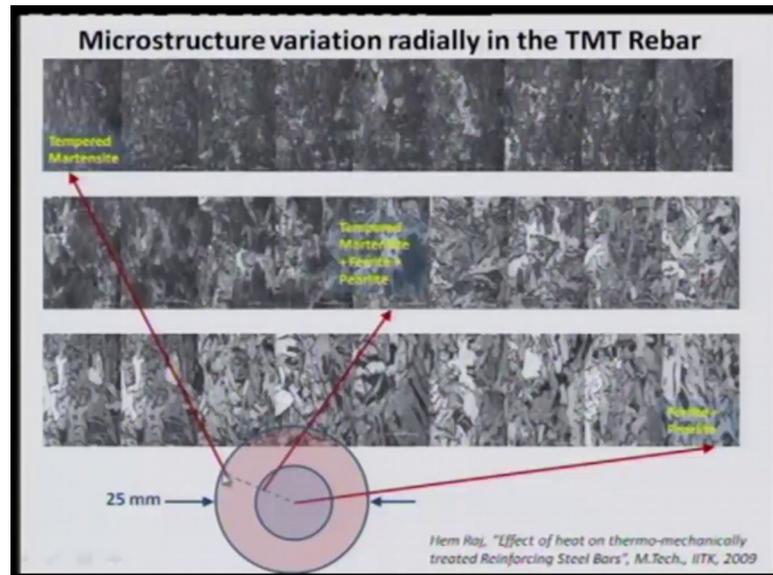
You will get everything 100 percent martensite, but auto tempering makes sure that this martensite is tempered. So, this region is tempered martensite then somewhere in this region you have tempered martensite plus ferrite plus pearlite, and then ultimately if you reach the center you end up with a ferrite pearlite core. So, this is how the microstructure all along the radial direction varies for the steel.

Now, if you measure let us say the hardness of the material, right from the surface along a particular diameter.
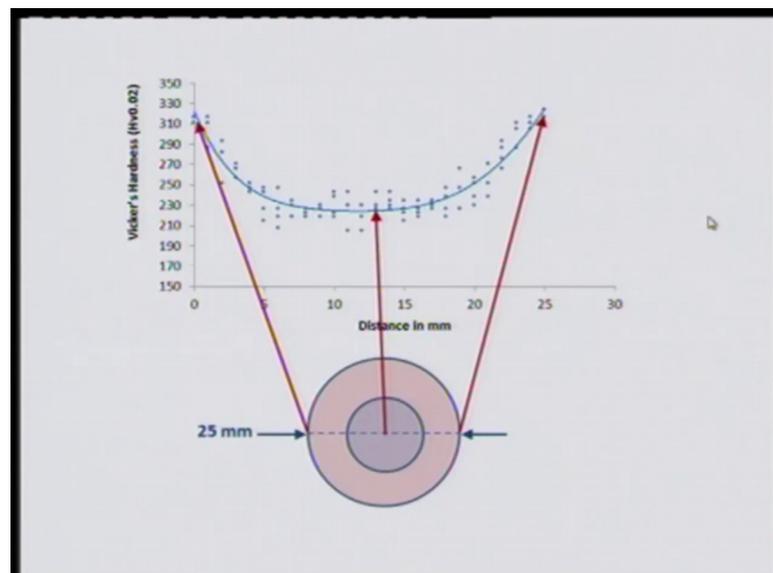
Then this is the kind of a hardness profile you get. So, you have high hardeners near the surface at both ends, and you have a low hardness of the center signifying a soft core. Of course, when this work was done in this work we studied what would be the effect if a building caught fire, how will the microstructure change.

And many of the fires can be so severe that all the properties that have been achieved by having a tempered martensite in the surface are lost. And the strength of the material severely goes down in that case of in many fires, the even though the building may look reasonably, but you may have actually a deuterated the entire load load bearing structure of such a building. This is just showing where the hardness variation is going right from the surface to the core and to the surface back end to the other end.

So, this was one example you know where heat treatment principles can help you design such heat treatment schedules. Now let me take a very different example. Knowledge of heat treatment can help you in designing, low technology stuff as well as high technology it related stuff.

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Improving life of
horseshoes
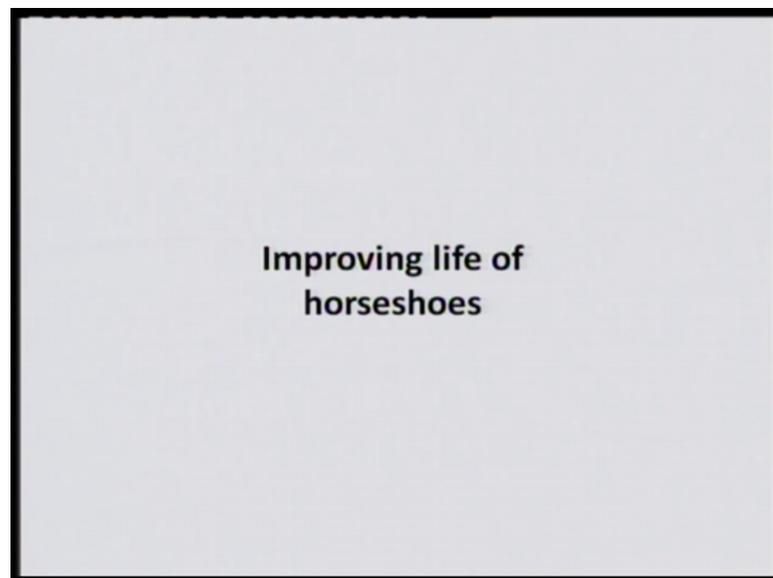
So, here is one particular case study, where we looked at improving the life of horseshoes. You may be aware that horses in India are use for caring very heavy goods, and these horses are moving on hard surfaces. As a result the life of the horseshoe the horse shoe which is put on the hoof of the horse is very poor because this horseshoes of

wears of very quickly. And it falls of and then therefore, the horseshoe has to be replaced very frequently by the horse owner.

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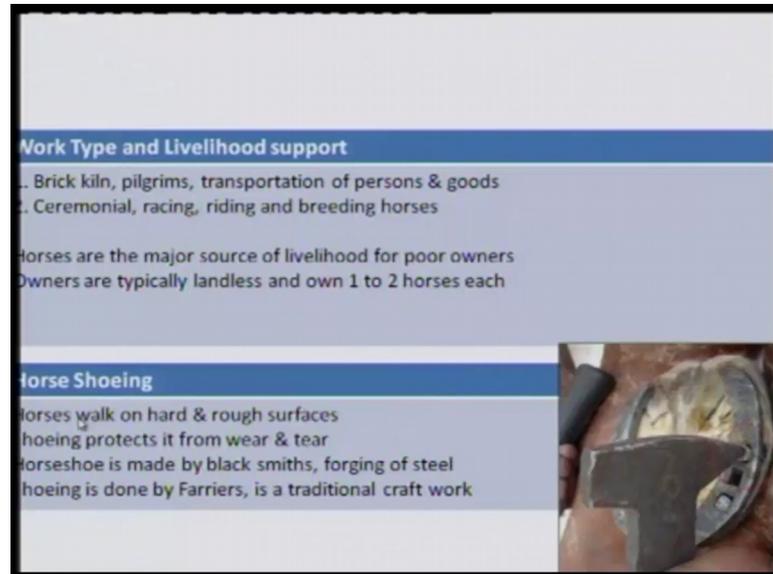
So, these horses just to give you little bit of an idea; these horses are used in brick kilns for ferrying piligrims for transpiration of goods, as well as horses are used also for racing as well as ceremonial horses as well. And this is a example over here of this image showing a horseshoe being nailed to the hoof, by nails into the hoof. And the life of the horseshoes is low because they walk on hard and rough surfaces.

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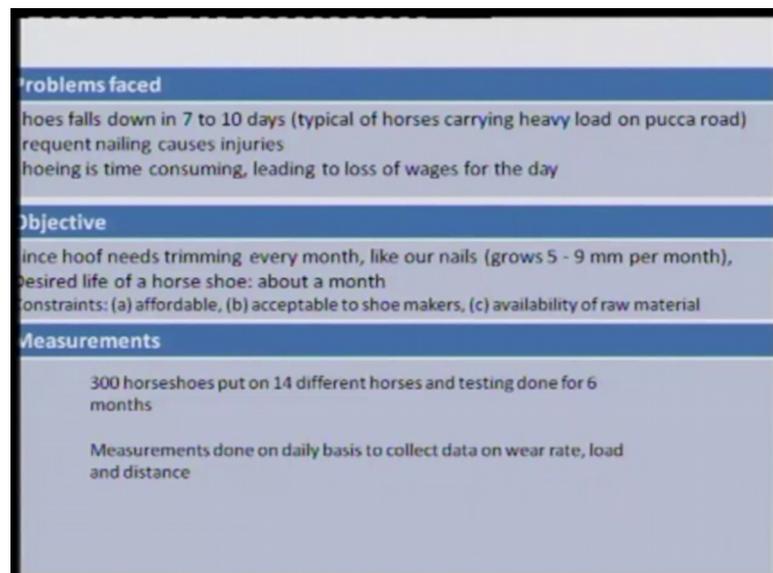
So, in order to let us just look at an idea what is the life of a horseshoe of a typical horse which is being used to carry goods in a typical city in India. It is incredibly low; it is of the order of 7 to 10 days. And hence every week or So the owner will take the horse to a ferryer for a nailing a new horseshoe, and it may cause in frequent nailing may cause injuries.

So, there is a need here for improving the life of the horseshoe to a much longer duration. So In fact, we did this work in which we tried a you know lots of experiments and horseshoes were really put on horses and data was measured on the life of the horseshoe, but before that let us just look at the existing process.

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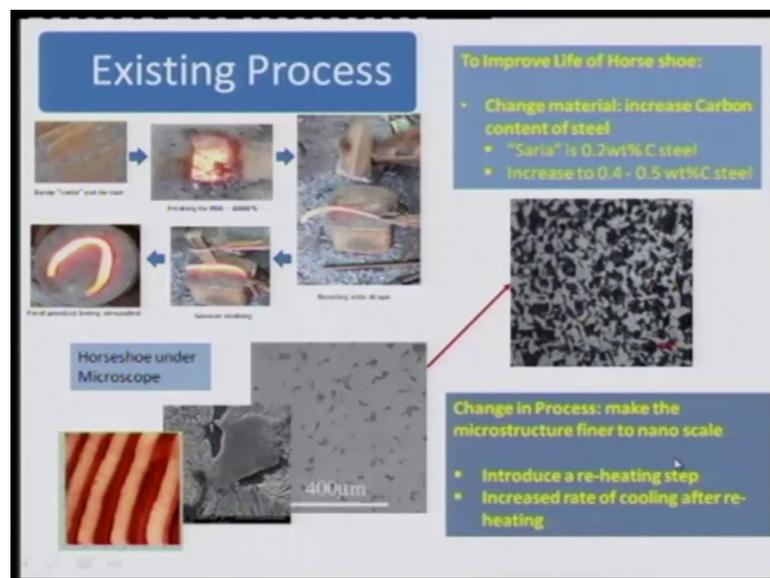
The existing thermo mechanical process of making an horseshoe. The horseshoe is made by a blacksmith by a traditional technique. You start with first bars of certain kind of steel and here the bars that are used, a bars that are called as sarias which are used in many of our construction business. It is essentially a low carbon steel. These bars are heated in the austenite region in a coal fired furnace as you can see in this image, after that the bar the rod taken out of the furnace And forced into the shape of the horseshoe.

If one looks at the microstructure of such a such a material under a microscope, well I will see ferrite pearlite kind of structure and small amount of pearlite because it is a low carbon steel if we if I increase the carbon the amount of pearlite will increase. And as you can see this is a shape of the pearlite that I have shown earlier and this is the pearlite

layer that you can see very clearly here. Now what can we do to increase the life of the horse shoe? Well, we have to improve the wear resistance of such a horseshoe then only we can improve the life. One way of doing it is increase the carbon content so that the amount of pearlite increases. So, that is one change the material increase carbon content of steel instead of point 2 percent carbon which is typically the carbon content of steel saria which is used for making horse shoe increase, it in the range of point 4 to 5 percent carbon, if you do that then look at the change in the microstructure.

You get lots more pearlite all this dark regions are indicative of lots more pearlite in such a steel, and pearlite would improve the wear resistance of the steel. In addition or alternatively one can make some changes in the process. When we studied this process we found that this process was producing non uniform heating So that In fact, the properties all along the horseshoe was vary. And in fact, the horseshoe would wear out at the point where the properties were a minimum. So, what we did to improve the uniformity of the property? Well, we introduce the reheating step. So, that once the horseshoe is finally, made it is put back at the furnace and reheated to the austenite region.

And then instead of simply cooling and still air we increase the cooling rate, but we did not increase the cooling rate. So, drastically that martensite would form we increase the cooling rate if you remember the c curves that we showed in the last lecture. You increase the cooling rate in such a way that you got much finer pearlite, now what would that do to produce much finer pearlite that would increase the wear resistance of the material it would increase the strength of the material. So, both of them increasing the carbon content and changing the process should improve the life of the horseshoe. Using this we did the following. We also look for a material which is easily available for the blacksmith.

So, we found some grades that are available commercially EN 8 steel EN 9 steel which should have higher carbon content, and which are also available is scrapped with these grades and with the faster cooling rate.

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Now, how did we improve the cooling rate? Well we put a fan in front of the hot horseshoe after reheating it was dropped in this basket with a fan in front of it to cool it faster, So that you got much finer pearlite; alternatively another technique which was developed in which the horseshoe was put in a graphite powder. Now graphite powder also produces faster cooling, because graphite is a good conductor of heat. And In fact, this is a this was developed as a completely due metallurgical process of rapid cooling. Without cooling so drastically that you produce martensite.

As a result of all this if I look at it this is how carbon is increasing on my x axis If I go this way I 3 different materials one is saria here then I have EN 8 and EN 9 and carbon is increasing in this direction.

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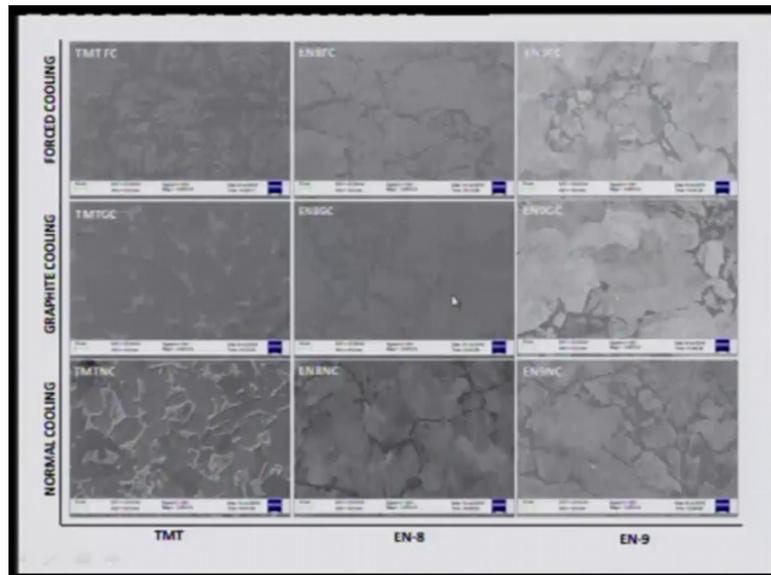
How the microstructure would change if I use simply normal steel air cooling? How the microstructure would change if I had graphite cooling? How the microstructure will change if I have forced cooling under a fan? Doing this these were the final results of such a study.

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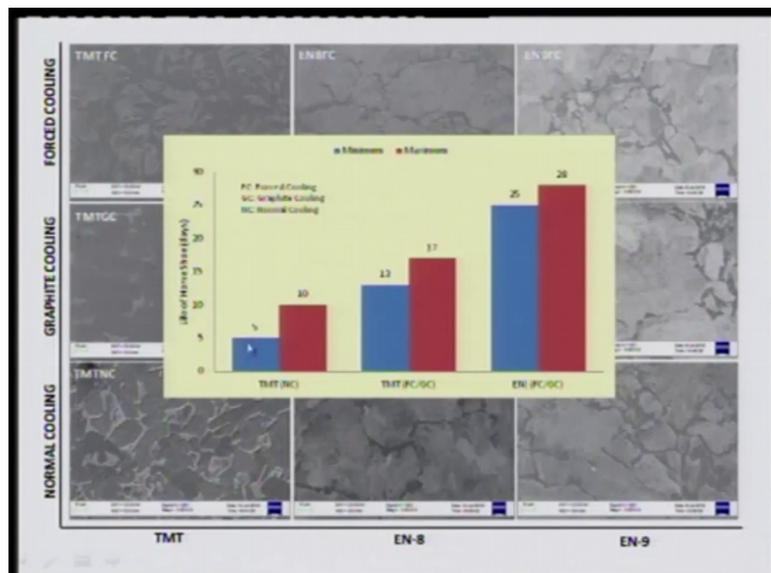
Where if you notice for a given material 2 ranges are given; so for example, saria here TMT normal still air cooling the range is 5 to 10 days. The same material low, the low carbon TMT steel either force cooling under a fan and a graphite cooling the life changes

from 13 to 17 days. Now I change the material to one of those EN b material EN 8 EN 9, fast either cooling under a fan or graphite cooling my life change from 25 to 28 days.

So, essentially we are able to increase the life by a factor of 4 by properly adjusting the heat treatment of the manufacturing process of horseshoes; now coming to the next case study which was for the wheels of the wheels of the coach of trains: coach wheels of trains.

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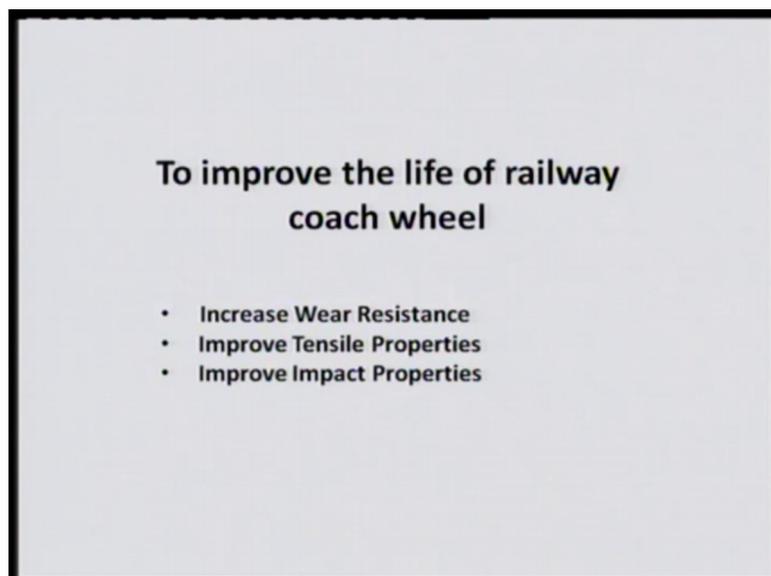
Here also we wanted to improve the life of the coach wheel also, and now what would be the factor that can improve the life of the coach wheel. So, this is one the earlier study was a fairly low technology study this is a high much higher technology study, but again the same principles get applied in the life of the railway coach if we look at the factors which are important are what kind of a wear resistance it has what kind of a tensile properties it has what kind of a impact properties this steel has. If I can increase all these 3 I will end up increasing the life of the railway wheel.
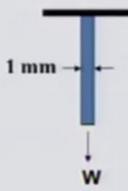
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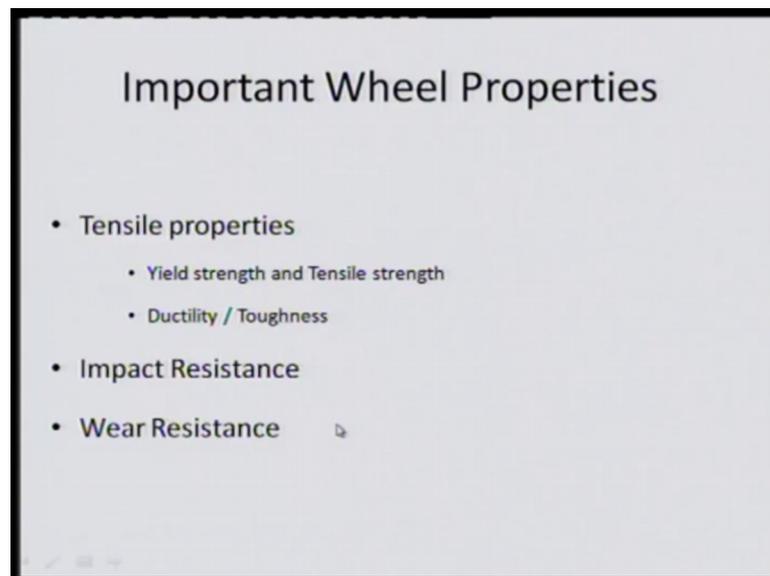
So, here again just to if I look at the tensile properties a properties I am interested in are in strength and tensile strength ductility and toughness; I will measure impact resistance, and I would also wear a measure wear resistance.

Now, here if I look at what are the properties of the wheels that are being used, the yield strength of the wheel is of the order of 540 megapascal, that tensile strength is of the order of 900 megapascal. Elongation is of the order of 14 to 15 percent. Just to give an idea what does this 540 and 900 megapascal mean? If I take a one millimeter by one millimeter cross section rod, 540 megapascal means it can take a load of 54 kilo grams, this one millimeter by one millimeter rod 900 megapascal Means this rod can take up a load of 90 kilograms.

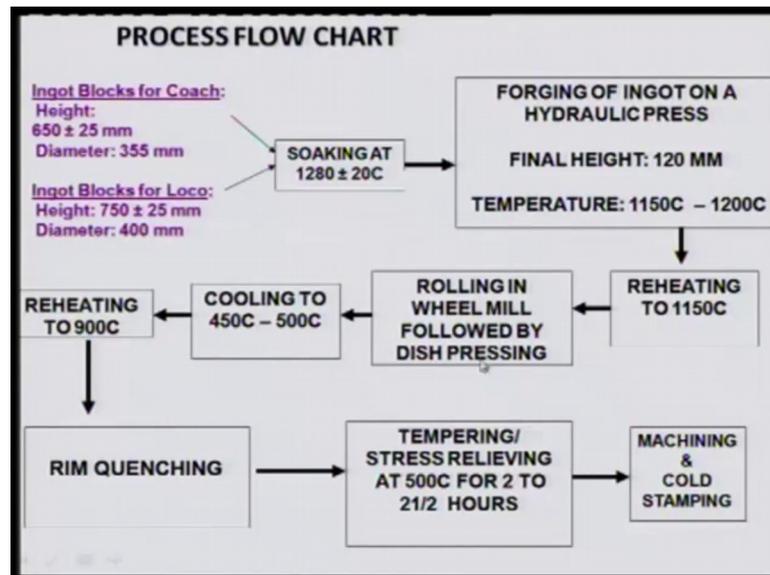Now, just to give you a first a good idea a brief idea of the how such a wheel is produced. So, you start with ingots like this. These are large steel ingots with a specific composition. And from these ingots you produce these railway wheels. How it is produced well this is a flow chart Here?

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PROCESS FLOW CHART

First this ingots either for the coach or for that metal for the loco motive the same process is used. You have a ingot of that dimensions 650 millimeter and height and 355 millimeter in diameter. They are soaked to a very high temperature. So, that everything is dissolved and it is 100 percent austenite. And then it is forced in an hydraulic press So, that the final height for the coach for example, reduces from 650 millimeter to 100 and 20 millimeters you get a disc out of this.

Then it is followed through other processes. It has to be reheated and then it goes into a rolling mill followed by dish pressing that gives you the shape of the wheel. Then it is subjected to cooling to about this temperature and then it is reheated again So, that you get austenite again. And then the wheel is subjected to rim quenching. So, you have a wheel in which this wheel hot wheel is placed in a rim quenching apparatus, and there are waters prays all around the wheel.

And this wheel is rotating these water spray the rim. Here again the objective here is to produce a hardened rim, but not So hard that you produce martensite you produce only fine pearlite and it is possible because this structure is So large that in order to achieve

cooling rates to produce martensite are very difficult. So, you end up getting very fine pearlite on the rim and then eventually all of these quenching etcetera produces lots of internals stresses.

So, it has to be stressed relief. So, this tempering is actually for stress relieving there is no martensite temper here and then finally, the wheel goes to the machine shop for final machining.

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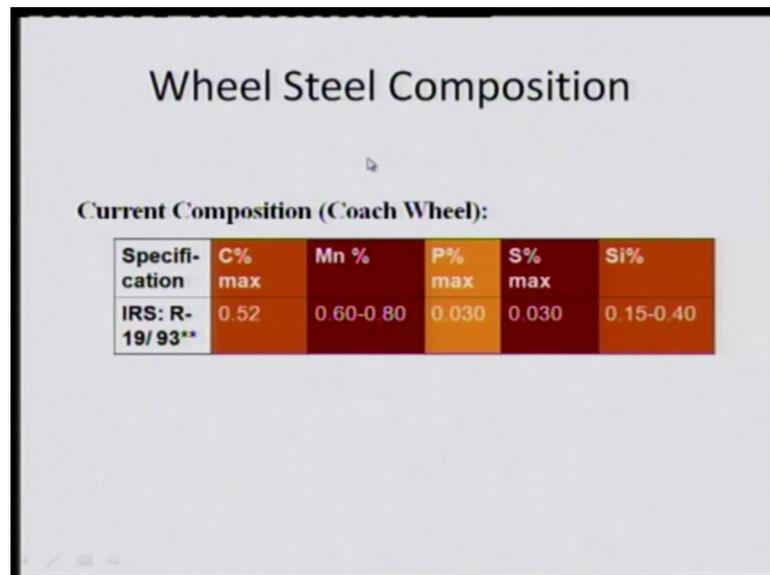
Wheel Steel Composition

Current Composition (Coach Wheel):

Specifi-cation	C% max	Mn %	P% max	S% max	Si%
IRS: R-19/93**	0.52	0.60-0.80	0.030	0.030	0.15-0.40

The composition of such a wheel is has a about 0.5 percent carbon, then it has certain amount of manganese and certain amount of silicon. So, it is essentially a plain carbon steel. Now when you looked at this problem and we wanted to increase improve the life of the wheel in terms of improving it is wear resistance it is strength it is impact resistance and all. Well, one thing is clear that before In fact, before you even do this we also looked at the microstructure these are typical microstructure of ferrite pearlite that you get in such materials.

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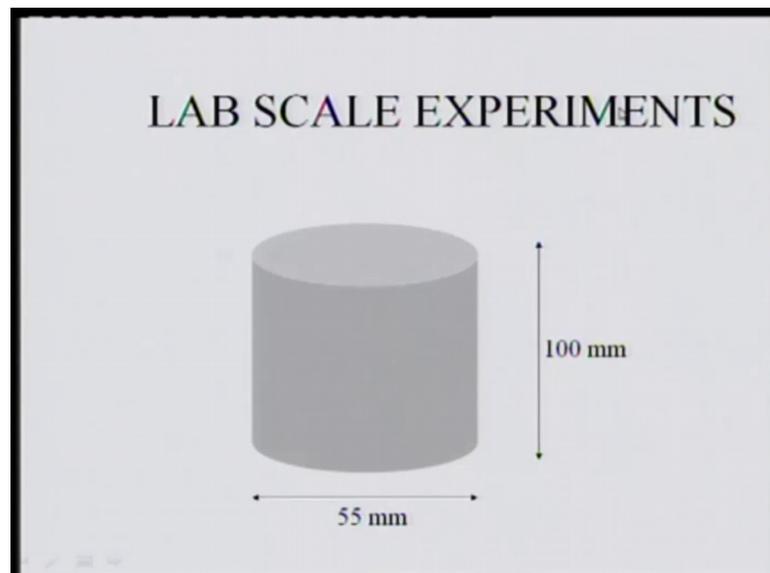

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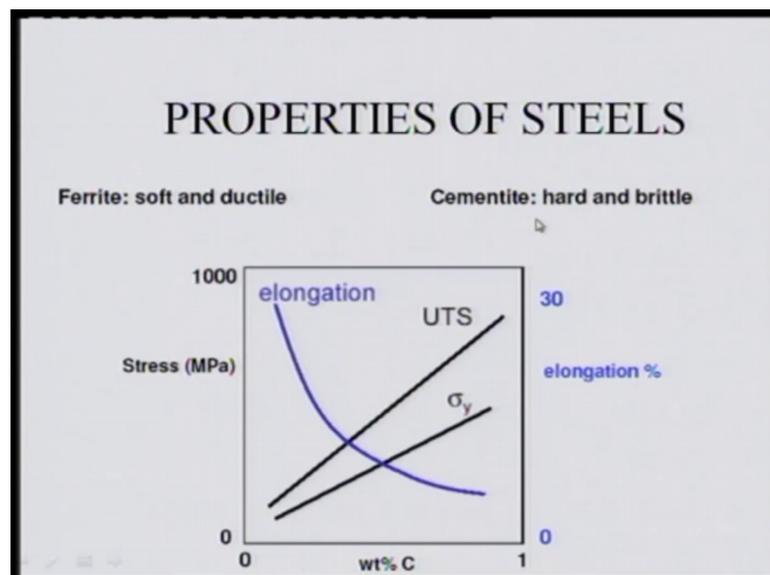
Now one way to simply increase the strength is to increase the carbon content. Well, In fact, in increasing the carbon content would be increasing the tensile strength as well as the yield strength, but the elongation will plumb it down ductility will go down. So, this wheel would become harden brittle. So, carbon increasing carbon is not an option. In fact, we decided to reduce the carbon. Now when you reduce the carbon what you add? Because if you reduce the carbon the strength goes down the wear resistance goes down everything will go down.

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So, we decided that modified the composition and replace it with a micro alloyed steel, and we decided to reduce the carbon and add some of amount of vanadium, in micro alloying quantities to of set the reduction and carbon. And get the benefits of micro alloyed.

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So, what we did? We first did lab scale experiments. So, we reduce that entire ingot into the lab of dimensions height of 100 mm and diameter of 55 millimeters.

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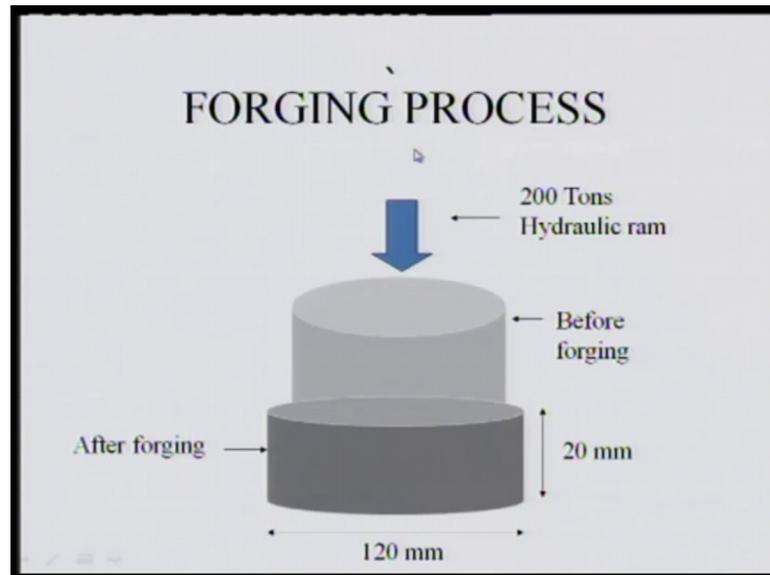
And we force the material in exactly the same way as one would force the wheel in an hydraulic press. Forced it from 100 m millimeter height to 20 millimeter height and it is diameter increase to 120 millimeter after forging and it was done after heating it to more than 1200 degrees. After that it was subjected to rim quenching at this was basically the flow chart in the lab.
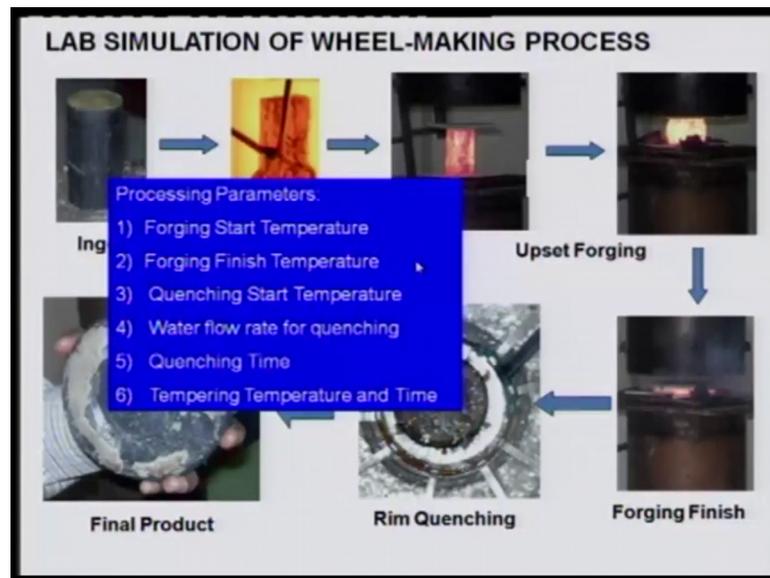
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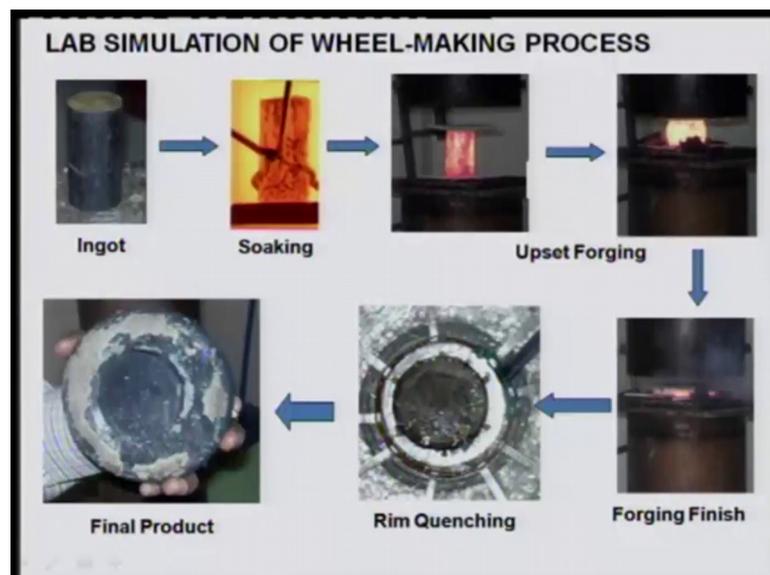
So, you start with this ingot, you soak it to a high temperature and then you forge it. So, this up forging is taking place here finally, it forms a disc and then we designed an

apparatus where you could do rim quenching of this and this is the final shape one gets of the final product.

And then we looked at it microstructure and it is properties to determine, you know under what conditions we get what the type of properties we want. And what are the processing parameters that would be important forging start temperature forging finish temperature quenching start temperature water flow rate for quenching time.

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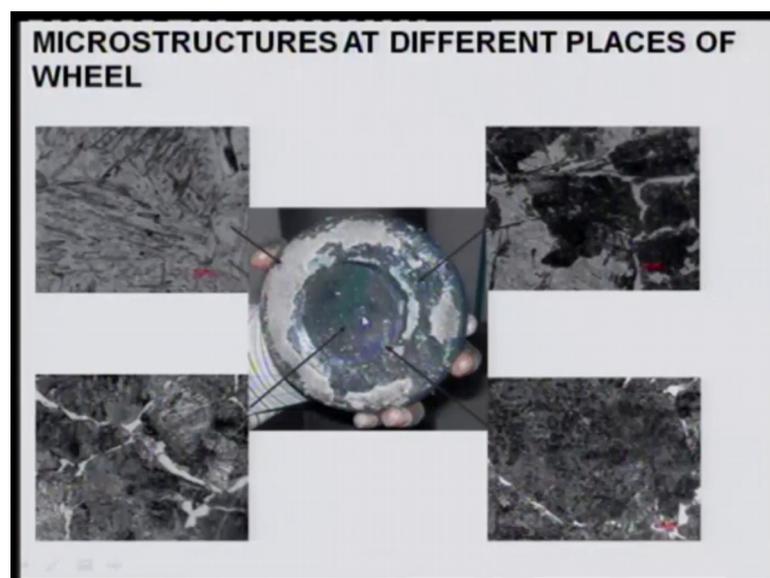
And then finally, stress reliving through a tempering treatment one looked at the microstructure at different regions. So, these are basically showing different regions and essentially in the center you can see it is all reasonably coarse ferrite and pearlite present. Then eventually we came up with certain operating parameters for this.

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DSP Parameters   *DSP Trials*

- Soaking Temperature: 930°C (*current: < 900°C*)
- Quenching Temperature: 800°C (*current: 760°C – 840°C*)
- Quenching Time: 7 minutes (*current: 5 minutes*)
- Tempering Temperature: 500°C – 550°C (*current: 500°C*)

Wheel Properties

	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	YS/UTS Ratio	Elongation (%)	U-Notch Impact (J/cm²)
MAS-5	666	970	0.69	15.3	48
R-19	540	855	0.63	16.3	25
R-19/93 Spec.	Min. 60% of UTS	820 - 940	Minimum 0.60	Minimum 14	Minimum 17

And we went to a production place where wheels are actually produced. And they produce the micro alloyed steel to a specification. And these were the processing parameters that were used. And like eventual wheel properties that we obtained was yield strength which was if I compare it with a with a existing composition. Then instead of about 540 megapascal as a strength in strength this strength jumps to about 660 megapascal, instead of tensile strengtheight 50 megapascal it becomes 970 megapascals and elongation remains roughly same.

And in fact, the impact strength goes up of such a material. And this is been possible because of adding this micro alloying vanadium. And how does it help us it help us in shifting our transformation diagrams to produce much finer microstructure.
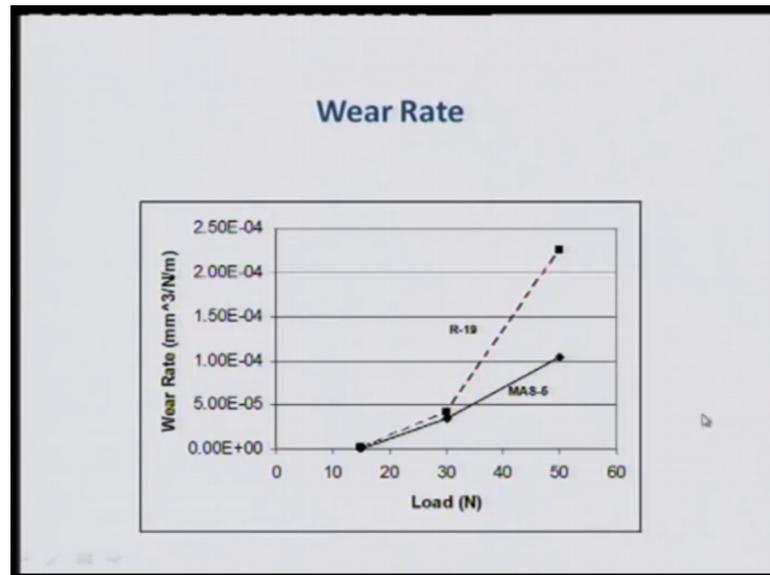
And if I look at the wear rate this is the existing wheel and this is the modified wheel. And you see that were resistance of the modified wheel is much lower than the wear resistance of the existing wheel simply because one obtained a much finer microstructure much finer pearlite in the rim.

And with this I have shown you that the principles that we have done in this course can actually be applied to real life problems. And, with this I come to a close of this lecture and In fact, come to the close of this course.

And I wish you all the best.