Surface Engineering for Corrosion and Wear Resistance Application

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Lecture-30

Heat treatment after carburizing and Nitriding

Welcome to the 30th lecture of Surface Engineering this going to be a brief discussion on the need for post carburizing heat treatment or post nitriding heat treatment usually one a certainly needs to carry out certain heat treatment namely the hardening treatment after carburizing.

What we must realize is that by way of carburizing you actually introduce carbon and make the surface ready for hardening. You are dealing essentially with a stock which has very low carbon 0.1, 0.2 percent carbon. So, even if you subject this whole component to hardening treatment you may develop martensite, you may enforce martensitic transformation on to the surface.

But that martensite will not have adequate strength or hardness because, the amount of carbon is inadequate. You require at least about 0.4 weight percent carbon or more to get the optimum martensitic hardness and it is because of this reason you introduce carbon by carburizing.

But then after the carburizing treatment which is a batch process, you actually when you take the component out of the carburizing treatment, you cannot immediately subject it to quenching simply because, as I said it is a batch process either its back carburizing or liquid carburizing or some gas carburizing in all these cases the chamber is enclosed components are inside.

So, you have to break the vacuum or lift it out of the liquid path or salt path or a break open the solid mass that forms the sintered mass that forms after carburizing. So, you have to open the back and then remove the materials and so, by then they come to room temperature if not at least fair to fairly low temperatures.

So, already there in the not in any longer in the austenitic range so, they are already in the ferritic range. So, you have to bring it to in order to bring it to the martensitic state or martensitic microstructure on the surface, you again have to reheat and then quench.

So, let us look at as to how we do it .

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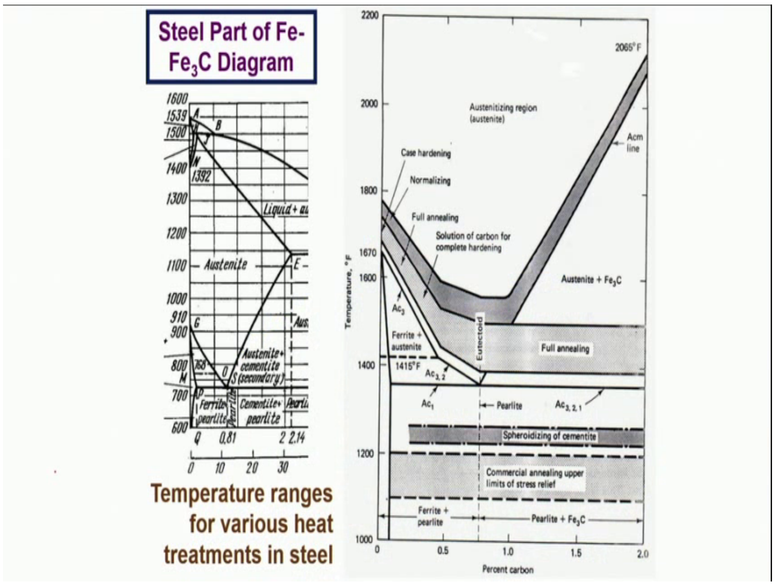
Steel Part of Fe-Fe_3C Diagram

Temperature ranges for various heat treatments in steel

So, in this if we look at the first slide you realize that a, so, this is the steel part of the iron cementite phase diagram and we are primarily concerned so, we are dealing with the an alloy which basically is low carbon 0.2, 0.3 percent carbon and in order to introduce a carbon we took it to 930, 940 in that temperature range in this temperature range.

So, that carbon can diffuse in faster and deeper. So, after that we take it out and then we when we take out of the chamber, this is what I was mentioning in a few minutes ago, that the temperature already drops to fairly low temperature easily below maybe just a few 100 degrees maybe 100, 200 degrees just above room temperature.

So, that is the temperature range when you are in this in the ferritic zone. So, there is no question of transformation ferrite into martensite in order to do that you have to again reheat, go to the austenitic zone and then quench then only you can get martensite.

So, what the this is the general guideline for all kinds of heat returns in steel typically for hardening treatment this is the temperature band and since we are dealing with low carbon. So, this is the region of our interest.

So, we do actually, we carry out the carburizing treatment at slightly higher temperature since, we do it at fairly high temperature and the time period is longer. So, we generally end up getting a very coarse microstructure and that is not very good, that is actually detrimental for mechanical properties. So, when we reheat, we reheat to about this temperature and from there we have to quench fast.

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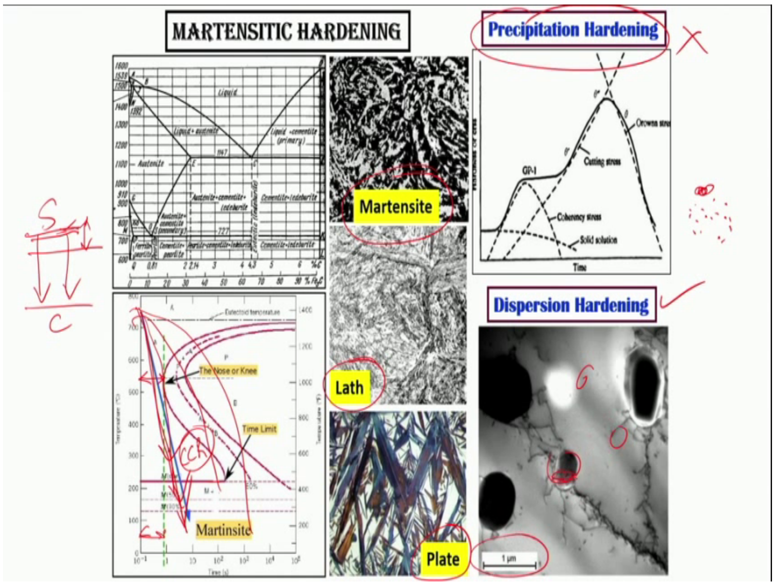

MARTENSITIC HARDENING

Precipitation Hardening

Dispersion Hardening

And while talking about quenching what we must realize is that we have we are aiming a quenching rate which will be at least as fast as this.

That means we must avoid the nose and hence the so called critical cooling rate which is a minimum cooling rate that can avoid intersect intersecting the politic or benedict start line is the so called critical cooling rate and this is what we must adopt. So, in other words we have to adopt some drastic quenching because this time period is very very small.

Now, when we quench then we convert the surface into martensite, that is our desired microstructure product and martensite actually can appear either in lath morphology or in acicular or plate morphology. So, this is a typical microstructure that we aim to achieve onto the surface, but we also aware that the carbon content and cooling rate both actually decrease as we go from the surface to the core.

So, if this is the surface and if this is the core then carbon content is highest here and gradually decreases and the cooling rate also whatever we the temperature to which we expose is of course, highest at the surface, but when we quench then the cooling rate will be the highest at the surface and the cooling rate also decreases as we go deeper inside the interior.

So, In fact, the cooling rate that we make sure is actually applicable up to a certain depth from the surface and not beyond. So, below this the cooling rate will be lower and hence we end up getting a microstructure which can be just purely pearlitic course pearlitic or pearlitic or at the most fine pearlite like this. In addition to well when we talk of carburizing then it is all about martensite it is all about martensitic that strength comes from martensite nothing else.

But when we talk of nitriding then of course, we have precipitates and in ultra finds condition for example, at the very beginning or if the nitriding period is very small or if for whatever reason, we are able to create a condition whereby we have very very high nucleation rate, but very small growth rate; that means, we form a precipitate a nitride, but we do not allow it to grow.

So, if we have tiny little precipitates formed all over then they and they are not allowed to grow, then some of these precipitates actually may maintain very small size and at the same time the surface will be at least semi coherent if not coherent, but coherency is something we do not quite expect in case of nitride because the crystal structures are very different than the ferrite.

So, if you have two phases alpha and beta, where these two I have vastly different crystal structures, you do not expect coherency at the matrix. So, in if you do not have coherency then; obviously, you do not expect precipitation hardening, but what you certainly expect is dispersion hardening,these nitrides actually offered the strength to them to the surface by way of dispersing themselves in very fine form of course, remember this is a very high resolution microstructure and transmission electron microscopy microstructure.

So, typically these precipitates are very very small. So, these kind of a dispersoids or so called the precipitates, which are incoherent precipitates will offer or one strengthening and that is why we call it dispersion hardening. So, that is this side on the right is for nitriding and this column is all for this is all for carburizing.

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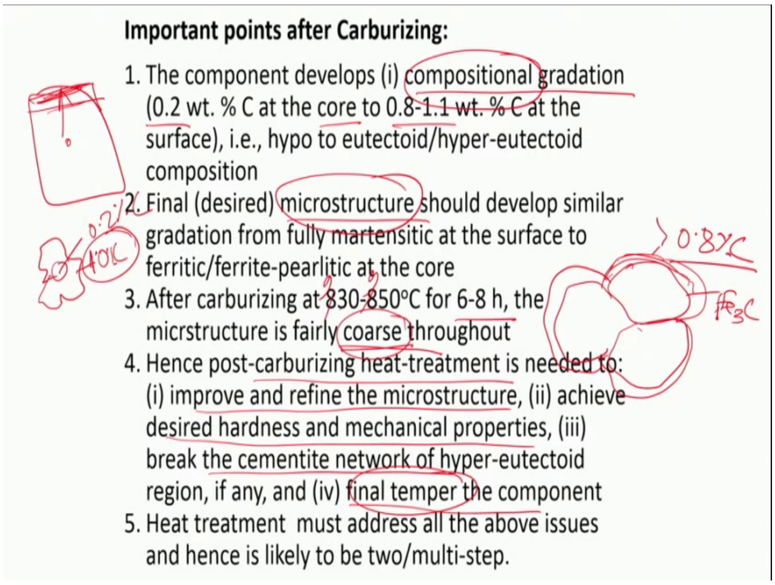

Important points after Carburizing:

1. The component develops (i) compositional gradation (0.2 wt. % C at the core to 0.8-1.1 wt. % C at the surface), i.e., hypo to eutectoid/hyper-eutectoid composition
2. Final (desired) microstructure should develop similar gradation from fully martensitic at the surface to ferritic/ferrite-pearlitic at the core
3. After carburizing at 830-850°C for 6-8 h, the micrstructure is fairly coarse throughout
4. Hence post-carburizing heat-treatment is needed to: (i) improve and refine the microstructure, (ii) achieve desired hardness and mechanical properties, (iii) break the cementite network of hyper-eutectoid region, if any, and (iv) final temper the component
5. Heat treatment must address all the above issues and hence is likely to be two/multi-step.

We need to take a look and sort of review the situation as to, what happens after carburizing? What is the state after carburizing? So, first thing we realize that we have developed a compositional gradation. So, which can be easily from 0.28 percent to about 0.8, even 1 point weight, 1.1 weight percent of carbon at the surface.

So, from the core to the surface so, if this is the sample and if this is the core; so, from the core to the surface particularly at the top layer, we have a gradation of composition. We also desire a gradation of microstructure because, we want full martensitic on the top surface and certainly fine pearlitic at the core. So, that we actually maintain very high toughness at the core and very high wear resistance at the surface.

So, both compositional gradation and micro structural gradation are desired. Now, after carburizing well I am sorry, this actually should be higher almost above 930, 950 of course, carburizing is possible at 800 range as well, 830, 850 range as well, but usually for larger components you exposed to 930, 950 temperature range for about 6 and 6 to 8 hours.

What you develop throughout is a very coarse microstructure. So, the typical crystallite size would be fairly coarse. Now, this is good for converting into martensite, but not so good for introducing or retaining, toughness in the core. So, this core microstructure is not is to be broken and needs to be converted into final microstructure.

So, we need grain refinement and so, for all these reasons course and structure and then taking care of the gradation of microstructure and composition, we require certain post carburizing heat treatment. So, that we improve and refine the microstructure we achieve desired hardness and mechanical properties, we break the cementite network.

Now, generally if you go to 0.8 and above or let us say 1 percent carbon or something then the the austenite will be covered by a cementite network like this. So, this will be your Fe_3C, if the composition of the steel is hyper eutectoid; that means, greater than 0.8 percent carbon.

So, this cementite network actually is very hard and also very brittle. So, if you already create such network then, you cannot do machining, you cannot do any post processing. So, this is not desirable and also it actually creates a sort of conflict with the martensitic post heat treatment martensitic microstructure.

So, in order to break this hyper eutectoid microstructure or cementite network, we also need a heat follow up heat treatment and we also need a final tempering of the component because if otherwise the fully hardened microstructure is very hard and brittle. So, in order to actually match this difficult demands of having pearlite at the core, martensite at the surface and yet there should not be any very large grain size and also should not be lot of stress gradients.

But of course, we want residual compressive stress on the surface and high hardness and yet if we want some post processing machining or other treatments. So, we want certain amount to restore certain amount of machinability. So, keeping all these things in mind, we may require post processing heat treatment, but that is a final tempering treatment, but in general you know if we now look at now imagine that this is a component that we have carburized and the core is 0.2 percent and the surface is let us say 1 percent carbon.

So, obviously, we are talking as if talking about as if two different steels merged into one. So, for this 0.1 percent carbon, we do harden from above the AC 1 eutectoid temperature, but for 0.2 percent, we harden or normalize or whatever we do it from above AC 3 which is fairly higher than that.

So, how do we match these two conflicting situations, we do it in this way.

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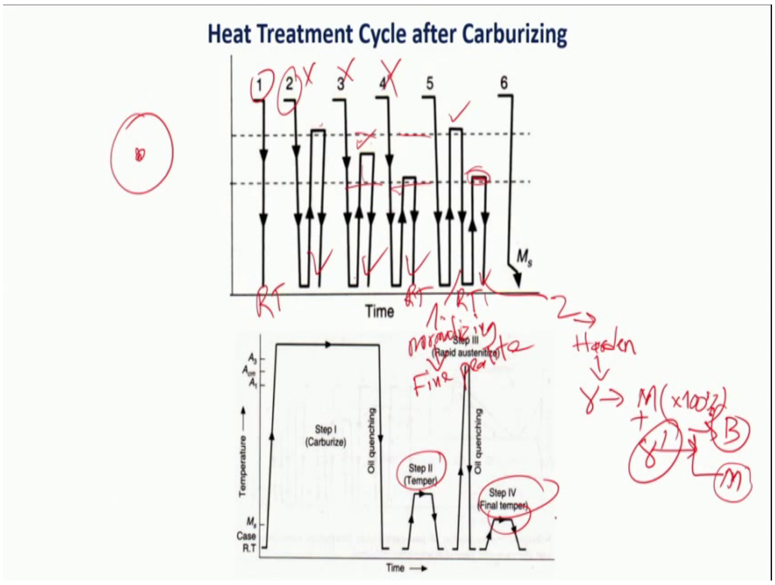

Heat Treatment Cycle after Carburizing

So, first of all, this is the hardening this is the typical carburizing treatment. So, after carburizing we bring it to room temperature.

Then we want to carry out typical hardening treatment. So, if we do a single stage hardening treatment then, we have to go to above the eutectoid temperature and then quench, but since we are dealing with two different steel is almost merge into one the surface is at a fairly high carbon content and core is at a low carbon content.

So, we now have to so, this single treatment is not adequate. So, this is not adequate. So, then what we do is, first we take care of the core because, the core is at a higher carbon content. So, we heat to above AC 3. So, we so, if we do separately then we might do something like this that we can heat treat.

So, first we heat the surface to much higher temperature and then we can do a repeat a similar hardening treatment for the surface which could be either between AC 1 and AC 3 like here or just above AC 1 and when we quench in all the cases we actually are quenching sharp quenching so that there is no time lag and we come to room temperature drastically so that we actually are able to convert austenite into martensite.

But when we do it we can do it separately for two different parts of the component, so, in the sense we cannot separate the component into two parts and then carry out two different treatments so, all these are hypothetical situations and not quite applicable because, we are dealing with a single component.

Now, in order to actually carry out the heat treatment, to convert austenite into convert or obtain martensite onto the surface, we do a composite treatment like this so, the component is the same. So, we first heat to above AC 3 and then normalize, we do not necessarily quench, we just cool in air still air. So, that the coarse microstructure at the surface now converts into fine pearlitic or fine ferrito-pearlitic microstructure, good enough to give us fair amount of toughness.

We do not want to develop very high hardness at the core. So, the core is not meant for very high hardness is only meant for providing toughness. Now, we reheat so, we bring to room temperature and then we reheat, but we do not reheat it to above AC 3, we reheat only above AC 1 because, the micro structure here is hyper eutectoid so, 0.8 and above.

So, this requires does not require heating above AC m, it requires heating only above AC 1 and from AC 1 temperature just above AC 1 temperature we need to quench. So, in the first leg if this is the first leg, which is meant for normalizing and what we get is fine pearlite in the second leg, when we heat from above AC 1 and not above AC 3.

What we do is harden and by hardening, we convert austenite into martensite, but actually this martensite what we believe is to be martensite is not 100 percent if it is not 100 percent then, what else does it have? It is likely to have retained austenite, which is not very conducive for dimensional accuracy or the volume of the material because, during heat treatment or during subsequent use an operation due to the mechanical activation this retained austenite can convert either into bainite or into martensite depending on the path it follows.

So, in either case there is a possibility of again expansion or contraction, volume change and; that means, it can, it may develop cracks onto the surface which is what is undesirable. So, after the quenching we actually after the final quenching, we actually can carry out tempering to convert part of the martensite into tempered martensite and then we carry out the final tempering, final hardening and then we do a final tempering at a lower temperature which is only for stress relieving.

So, by and large, what we need to understand is that carburizing is a treatment is a process to introduce carbon so, now, you make it ready you convert a 0.2 percent carbon steel and make it ready with certain enrichment of carbon up to the level of 0.8, 1 up to 1 percent carbon and with such enriched carbon in carbon enriched surface, what we now need to do is to take it to only above AC 1 and then quench and convert it into martensite then its hardened.

Then, we can talk about all the improved mechanical properties, but the core since it is at 0.2 percent, we need to heat above AC 3 and then air cool which is normalizing to get fine pearlitic microstructure.

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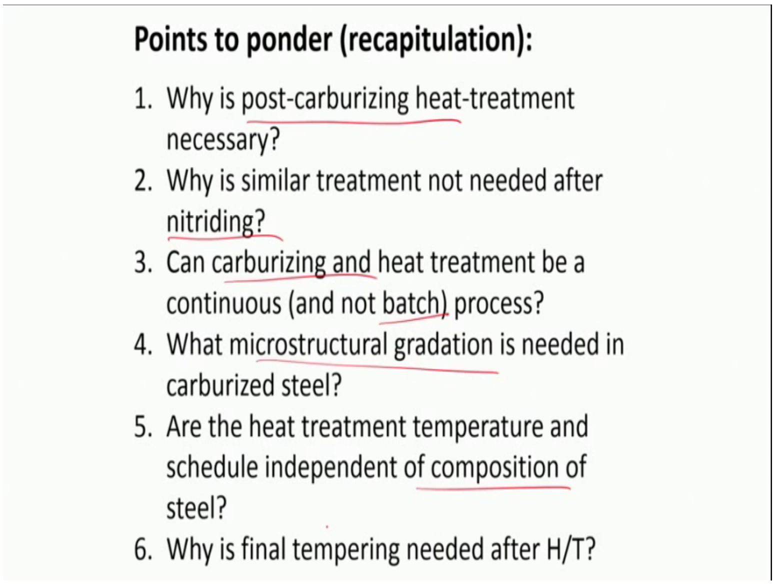

Points to ponder (recapitulation):

1. Why is post-carburizing heat-treatment necessary?
2. Why is similar treatment not needed after nitriding?
3. Can carburizing and heat treatment be a continuous (and not batch) process?
4. What microstructural gradation is needed in carburized steel?
5. Are the heat treatment temperature and schedule independent of composition of steel?
6. Why is final tempering needed after H/T?

So, what all we have discussed briefly here? We have discussed the post carburizing heat treatment, that is needed because of the requirement to develop the complex graded microstructure and also because we have widely varying composition from the surface to the core.

We do not need a similar treatment for nitriding because, the hardening is coming not from martensite is coming from nitrides, which are already formed during at the nitriding process itself. So, the material is ready for use just after the nitriding treatment the carburizing treatment unfortunately is a batch process it is not a continuous process because, you need to break the atmosphere, you need to break the carbon rich atmosphere and then take it out and then you do carry out the heat treatment.

So, it cannot be a continuous process except, in very rare cases of some gas carburizing treatments the micro structural gradation we need because, we need martensite predominantly martensite to or at the end maybe tempered martensite predominantly martensitic or tempered martensitic to all the way to simply pearlitic or ferrite-pearlitic microstructure. The composition does play a role if you are dealing with alloy steel you treat in a way if you deal with plain carbon steel then; obviously, the temperature and time requirements are little different and we certainly need a final tempering treatment so, that the stresses are relieved and some amount of machinability is restored.

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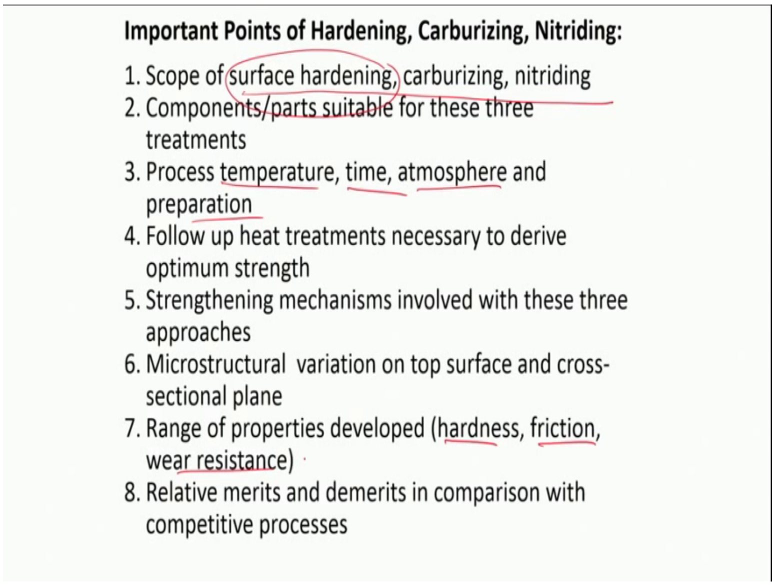

Important Points of Hardening, Carburizing, Nitriding:

1. Scope of surface hardening, carburizing, nitriding
2. Components/parts suitable for these three treatments
3. Process temperature, time, atmosphere and preparation
4. Follow up heat treatments necessary to derive optimum strength
5. Strengthening mechanisms involved with these three approaches
6. Microstructural variation on top surface and cross-sectional plane
7. Range of properties developed (hardness, friction, wear resistance)
8. Relative merits and demerits in comparison with competitive processes

Now, it is also time that we take an overall view of all the possibilities of hardening that we have discussed so far, with regards to primarily steel. So, we have discussed three types of approaches hardening, carburizing, and nitriding hardening is without changing composition.

So, it is simply micro structural modification carburizing and nitriding is thermo chemical treatment, where we change the composition of the surface, in carburizing we introduce carbon, in nitriding we introduce nitrogen. So, the components and the parts that we actually subject for such treatments need not be exactly the same type.

For example, compositionally one can easily say that for hardening, we actually require carbon rich or at least the component should have adequate carbon easily around 0.4 percent carbon for minimum whereas, carburizing, nitriding is done with very low carbon. The parts and their utilities will determine what kind of treatment you actually take and the effectiveness of the treatment will depend upon the temperature, time, atmosphere, and various surface preparation methods that you adopt.

The heat treatment is required only for carburizing and in hardening treatment is itself a heat treatment process. So, there is no separate heat treatment required, there is no post processing hardening treatment required for hardening, but carburizing does require one, the strengthening mechanism in hardening, carburizing is the same is the martensitic hardening, but in nitriding its different it is the presence of these nitrides.

The micro structural variation from top surface to the along the cross sectional plane is a a smooth one is to be understood is to be developed carefully. So, that final purpose is served, but end result or the end aim is hardness, lowering of friction coefficient, improvement in wear resistance and in some cases even corrosion resistance for nitrating cases.

So, we actually at the end of these last few lectures may be starting from 21st or one of those lectures, where in we started discussing all these hardening processes and in fact, even before hardening processes we discussed the shot peening, shock peening processes.

So, now, is the time for all of you to sit down and take a stock of, what all you have learnt, what are the purpose, what were the purpose, what were the end results, what microstructure, what mechanism of strengthening, how do they compare with each other in terms of process difficulty or ease, the process parameters, time, temperature atmosphere, various other implements necessary, what is a level of property changes that you bring in, what are the merits, what are the demerits and finally, the applicability for various industrial practices.

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References

- David A. Porter, K. E. Easterling, Mohamed Y. Sherif Phase Transformations in Metals and Alloys, 3rd Edition, 2009 CRC Press Taylor & Francis Group, Florida
- Y.Lakhtin, Engineering Physical Metallurgy,1998,Mir Publishers ,Moscow

So, I hope you have picked up some good threads for self study and I would definitely implore upon you that lectures are only supplementary tool are only to expose you to the subject, but in order to derive the required knowledge, you must do self study and refer to the textbooks given at the end of the lecture series.

Thank you very much.