Theory of Production Processes

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Lecture – 42
Heat Flow in Welding

Welcome to the lecture on Heat Flow in Welding. So, we discussed in the last class about the classification of welding processes. Now most of the welding processes what we see; majority of them are the fusion welding processes. And as we know that in fusion welding processes, you have the application of heat to a certain reason and then that reason is melted, further it is solidified.

So, this way you have the application of heat there is heat source, then there will be transfer of heat from that reason that is weld metal zone to the surrounding areas. So, this way the heat application and further it is dissipation, basically affects the properties of the material, the microstructure or structure of the material changes because of that.

So, in this lecture we are going to discuss about the heat flow in welding, how the heat is flowing in what mechanism the heat is generated, not in a very depth manner we are going to discuss about it, but we just have to have some understanding that how the temperature field is generated, how there will be isotherms generated, what will be the concept of these, how that is useful for further you know in in future if you want to predict the microstructure, then how these concepts will be used in finding those you know details.

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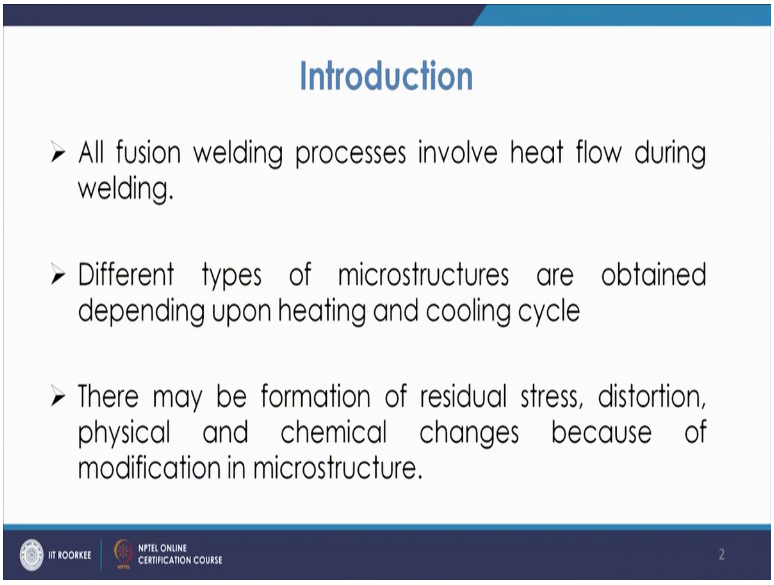

So, as we discussed that all the fusion welding processes, they involve heat flow during the welding. So, fusion welding means you have a zone, fusion zone or you have basically a zone which is basically fused which is melted and then and that melting is normally done by a type of heat source. So, you have a source which apply the heat, and that goes and then when adequate heat is supplied that basically melts the parent metal and if required the filler metal or so, so that way you have the involvement of heat flow during the welding.

Now, because of that you have different types of micro structures which are obtained depending upon the heating and cooling cycle. So, what happens that, when you have a seat or when you have two plates which are joined. So, first of all they are heated and then while heating the temperature is increased.

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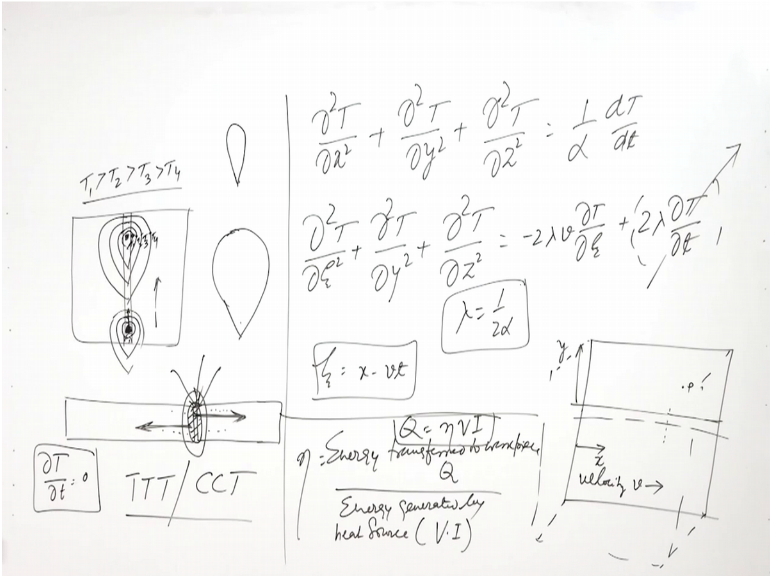

So, suppose you are welding two seats like you have these two seats, and if you want to you know have the joint here. So, what you do is, in this joint you are applying the heat now because of this application of heat this johns temperature goes on increasing. So, this here the temperature is increased, and then these temperatures which is increasing because these are the metals in most of the cases and it has some certain conductivity. So, this heat will traverse to these directions.

So, the heat which is applied to this place, because of that there will be basically expansion and there will be associated you know phenomena because of that heat then further that heat once the heat is accumulated here, this heat tries to you know spread in that the transverse direction.

So, in these directions like this, and then once the trance travels to us this direction they will increase the temperature of these zones slowly these zones temperature will be increased. So, at the very far end the temperature may be the room temperature, but here the temperature will be higher than higher and higher. So, this way you have heating, then further after some time they will again start cooling because this starts dissipating the heat slowly and then further.

So, it will be heated and again slowly because it is an environment. So, again it is the (Refer Time: 05:30) dissipating the heat to surroundings. So, slowly again it is temperature will come down. So, you have a cycle, you have you can see that the material passes through a heating and a cooling cycle. Now because of this heating and cooling cycle the different kinds of micro structures are obtained depending upon what kind of heating and cooling cycle is there, how quickly the heat is increased, how quickly heat is decreased temperature is decreased basically how quickly heat is added and temperature is increased or how quickly the temperature is decreased. So, depending upon that you will have the different types of micro structures which are obtained.

So, this all is because of the heat flow or the insertion of heat into that particular zone. Now because of this the other effect is, that there may be formation of residual stresses distortion physical and chemical changes. So, because that will lead to you know here what happens that, because of these differential thermal cooling or heating there will be the formation of residual stresses.

Now these residual stresses may lead to distortion. So, you know there may be and distortion means, the body becomes out of shape, then there may be physical change or there may be chemical changes like chemical in homogeneity may be generated. So, this is all because of the modified structure also, you will have these are the end effects of this heat flow.

So, now coming to the you know thermal distribution in welding.

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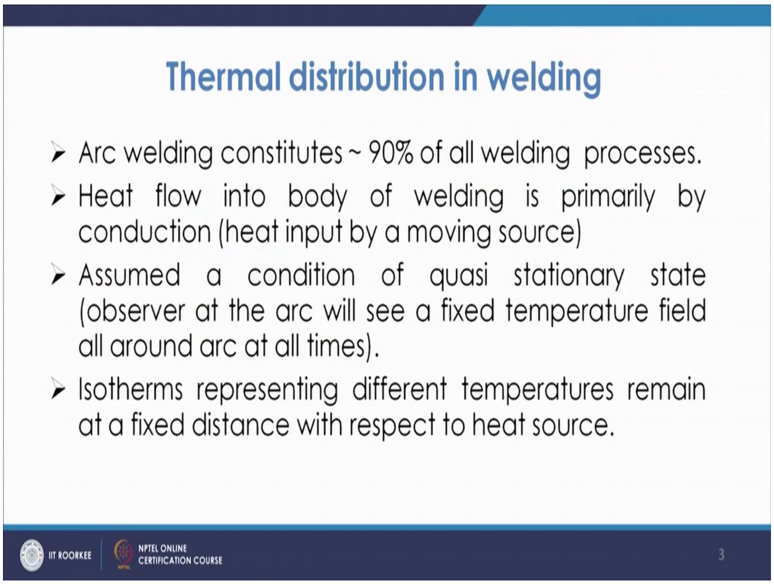

So, what we see that most of the welding processes are. So, about 90 percent of the welding process which we talked about, about 90 percent is based on the arc welding process. So, among the in the all the fusion welding processes, you have about 90 percent is you know from the arc welding because arc welding is simple and it is very effective. So, normally we use the arc welding process.

So, now what we see is that the heat flow into the body is primarily by conduction. So, as we see that when we are having the heat flow, now that goes into the body by mainly by the conduction and partly very very small percentages by convection. So, the you know by radiation also it goes into atmosphere and even by convection, but that percentage is quite small.

Now, if you look at the welding process what is there. So, you have two plates, you are welding in a particular direction with certain velocity. So, you will have a direction of welding. So, in each direction you are moving. So, you will have a direction of welding. Now when we try to analyse this welding process, there in that case what we see is you can assume it as a conduction problem with a point heated source and that is movie. So, what we see is that you have two plates. So, you have suppose this is the plate and you are basically doing the welding along this direction suppose. So, this is your welding direction, in that case if you look at it is nothing, but this is a problem of conduction, but then you have a heat source here.

So, you have a heat this is a heat source and this heat source is moving. So, basically you can assume this is primarily by conduction heat flow or body flow into body of welding is by conduction and heat input is by a moving source. So, that is what that soon what that way we define this welding process, then again this is assumed a condition of quasi stationary state. So, what does that mean that means, that the observer at the arc what he sees that he sees a fixed temperature field all around the arc at all times. So, basically dou T by dou t.

So, that will basically becomes 0. So, that that is a case of quasi stationary state. So, basically if you look at any point, what he sees is that all the point is distant to it now these points are at the fixed temperature. So, what he sees is that there is a fixed temperature field all around arc at all the times. So, that is a case of quasi stationary states and this way you will have the formation of isotherms. So, isotherms are nothing, but you have the lines of constant temperature. So, that is known as isotherm.

So, you can draw these isotherms for the process, and you may have these isotherms which will represent the different temperatures remain at a fixed distance with respect to the heat source. So, what we see is normally when we talk about the case of such quasi stationary state, and which when we talk about the isotherms you can see that suppose if you are looking here, you will see that your temperature will be here it will be like this then it will be coming like this way it will be going and that way ok.

Now, similarly if after some time it goes here. So, in that case you will have a temperature line here then you will have this type of. So, this way these are known as the temperature isotherms. So, this is nothing, but if you look at this point where the, his source is there, there the weld pool is there at that particular time now at this point this temperature is highest here.

So, this temperature if you look at this is point 1 2 3 4 or 4. Now if you this is T1, T2, T3 and T 4. So, like this is T 1 this is T 2 this is T 3 this is T 4 in that case T 1 is greater than T 2 greater than T 3 and greater than T 4. So, this way these isotherms are drawn which basically talk about the temperature, different temperatures which are at a fixed distance with respect to the heat source. Now we will talk about the metallurgical effects.

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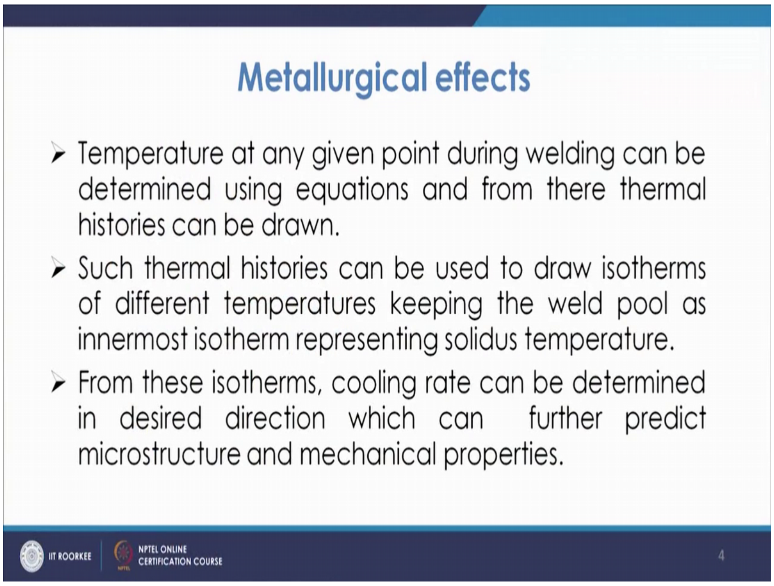

Now, before that let us see how these conditions come, now the thing is that if you talk about this thermal distribution building where we talked about the different kinds of you know I now how decisive terms are drawn basically as we discussed that basically it is the solution of a problem of conduction, and this conduction is having a source also that is heat source. and if you talk about the law of conduction, then there is very renown the equation of conduction that is furrier law of conduction.

So, for your law of conduction can be applied in this case also now in that as we know that q will be minus of k into a into dou p by dou x. So, that is your you know amount of heat that is q you know in case of conduction. Now if you talk about the three dimensional furrier law. So, fuller equation of three dimensional heat conduction in solids what we get is that dou sqaure T by dou x square plus dou square, t by dou y square, plus dou sqaure T by dou z square it will be nothing, but one by alpha d T by d t.

So, that is what the furrier equation of heat conduction is. So, then where alpha is nothing, but k by rho c p. So, that is what the furrier law of heat conduction is, but in this case you have a moving source. So, if you take that example where you have a moving source in that case in the x direction, if suppose it is moving in the x direction the x coordinate has to be replaced with certain other parameter. So, you will have a welding velocity based on that you will define another parameter, that is and basically what you see is that if at any point this is the x, then if it is moving with speed b then the distance will be x mind in after time t it will be x minus v times t. So, x distance will decrease by that.

So, that way another parameter will be defined. So, if you. So, first of all what we see is that you can use initially the three dimensional foolish law of conduction, that is dou sqaure T by dou x square plus dou sqaure T by dou y square plus dou sqaure T by dou z square equal to 1 by alpha and d T by d t.

So, that is what the furious love three dimensional heat conduction is now the thing is that if you have a plate if you have such plate. So, in that and if you your weld bead is like this. So, in that case suppose you are going to add some distance x and if you have any point p. Now the thing is that your source is moving with velocity v. So, you know once it is moving with velocity v in that case this x. So, if this is the direction x this is the direction y and your thickness.

So, it has some some thickness. So, it has certain thickness like that now the thing is that this is the thickness. So, in this thickness it moves now the thing is that once it is moving in that particular x direction. So, what you do is you have a new you know coordinate system with respect to the tip of the electrode. So, that is moving in s direction. So, what we do is we define and it is moving with velocity velocities v in this direction. So, we define zeta as x minus v t. So, that is basically because the source is basically moving in the x direction with velocity v, now in that case the you know equation for quasi stationary you know state of welding, comes to it comes in terms of zeta in place of x it comes there.

So, it will be dose sqaure T by dou theta square plus again dou sqaure T by dou y square plus dou sqaure T by dou z square and that becomes equal to minus of 2 lambda v into dou t by dou jita plus 2 lambda into dou T by delta t. So, that way it becomes that. So, that will be dou sqaure T by dou theta square plus dou sqaure T by dou y square, plus dou sqaure T by dou z square.

So, this will be on the left hand side on the right hand side again you will have another terms coming that will be function of alpha as well as v. So, first term will be minus two lambda v and that will be dou T by dou g t. So, minus of two lambda v plus 2 t by dou theta and second term will be the transient term d T by d t and for that you will have 2 plus 2 lambda and dou T by dou t. So, so that is basically a transient term u that basically gets cancelled because of the quasi stationary condition this is cancelled because of the quasi stationary condition where dou T by dou t is taken as 0.

Now, in this case the lambda is 1 by 2 alpha. So, this equation is solved and you can get the isotherms because here you have depending upon the v. So, this v is also coming into picture you have alpha that is coming here. So, it is all because of the you know define meant of this another parameter that is zeta, that is x minus v t.

And this way you can have the you know formation of these temperature contours or isotherms and these isotherms are further used for the prediction of microstructures. Now the thing is that you this can further be solved with the boundary conditions and you get another equation. So, that is t equal to t naught plus again is raised to power minus lambda then v then jita and then again phi of zeta y jet like that. So, that way what we mean to say that you will have this equation which needs to be solved.

So, you must have an understanding of how these equations are coming. So, you know that this you directly get it, this is this you are getting by direct non normal analysis in a pure heat transfer problem and then you get this by using or by replacing this x with jita that is x minus v t. And in this way you try to get the solution of these heat flow equations.

Now the thing is that based on that when you try to draw the isotherms, then you get this particular type of isotherms and these isotherms talk about the kind of temperature history in a particular type of welding process and then based on that you can predict the properties or microstructure in the welded specimen or so. Now, you will talk about the metallurgical effects of the welding process, the thing is that temperature at any given point during welding can be determined using equations that we already discussed.

So, we discussed that you can find the, what will be the temperature at different points and then there from the thermal histories can be drawn. Now these thermal histories are used to draw the isotherms of different temperatures keeping the weld pool as the innermost isotherm representing solidus temperature. So, here once you draw these isotherms the, this temperature is nothing, but it will be near the solidus temperature and then all these temperatures are the from there. So, depending upon the shape of the isotherm the isotherm may be of this shape or the isotherm may be of this shape now both these shapes have a different meaning. So, in this case this temperature is on this periphery you have same temperature whereas, in a very small periphery you have this temperature.

Now, depending upon the different types of welding conditions whether you are going at a fast rate or a slow rate you will have the different types of welding isotherms temperature isotherms. So, the innermost isotherm will be representing the. So, it is temperature and then the outermost items will be the temperatures at lower values now. So, from these isotherms you can have the cooling rate determination.

So, once you know these isotherms are different points, then cooling rate can be found and once you know the cooling rate then from there you can predict the microstructure and mechanical properties, because you know that you have different types of curves you know that when there is transformation, then depending upon the cooling rate you will have the transformation products like you have TTT or CCT diagram which are they available.

So, how is the you know isotherm looking at, how you see the isotherms and depending on the spacing at different points or. So, you can predict the microstructure of and the mechanical properties in such cases. So, this way you can say that here the property will be or the phases will be like coarse pearlite or fine pearlite or (Refer Time: 25:32) marten site or so, so depending upon that you can that.

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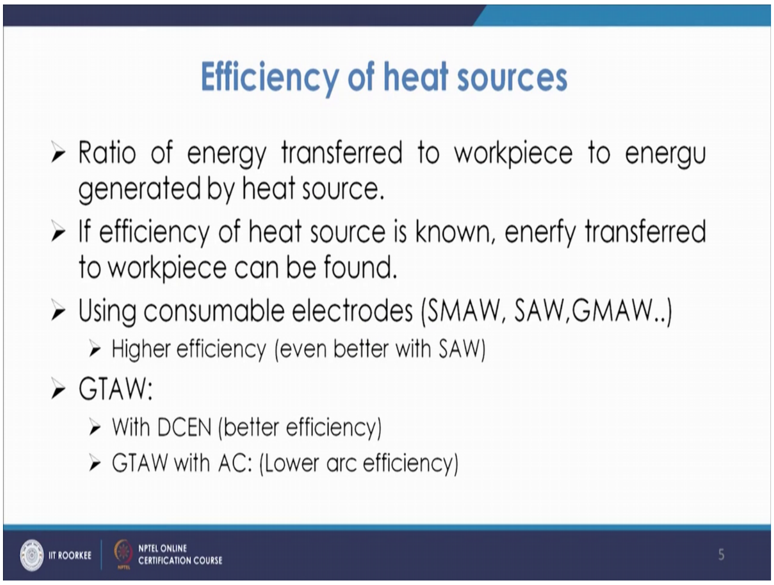

Now coming to the efficiency of heat sources, what is the efficiency of heat source now it is that we use the heat source to basically transfer the energy to the work piece. So, you have certain energy which is of the heat source, and how much energy has been used by the having transferred to the work piece. So, that energy which is transferred to the work piece, at that divided by energy generated by the heat source that basically is known as the efficiency of each source.

So, if the efficiency of the heat source is known in that case the energy transferred to the work piece can be found. Now the thing is that the efficiency is denoted by the formula that is eta. So, this eta will be basically energy transferred to the work piece, and divided by energy generated by the heat source. So, so that is energy transferred to the work piece and. So, you can write energy transferred to work piece.

So, if it is Q and then you have the energy generated by heat source. So, if it is V into I in that case the energy transferred to work piece Q may be taken as equal to eta v i. So, that is what we mean to say that q can be found by eta times v into I. So, we if you use the electricity as the source of energy in that case v into I multiplied by eta that may be giving you that is voltage and current which is used. So, that may tell you that that is typically in the case of electro slag or electron beam welding cases.

So, where you use that electron electricity. So, in that case voltage and welding current if you have v and I. So, second table may be used as q may be used equal to eta into v into I. Now the thing is that this efficiency of the welding process is vary different welding processes have different efficiencies. Now let us take the example of consumable electrodes like SMAW, SAW or GMAW like see the shielded metal arc welding submerged arc welding gas metal arc welding. Now in these cases what happens that you use you know either of the polarity now in that case ultimately the heat goes to the work piece. So, the efficiency is quite higher, now if you talk about the gas tungsten arc welding.

Now, in the case of gas tungsten arc welding it is seen that if you use the d c current and if you use this DCEN electrode negative end work positive in that case more heat is because of the electron bombardment is at the work piece. So, you will have more heat generated at the work piece. So, that gives you a better efficiency whereas, if you use the gas tungsten arc welding with a c, in that case you know you have half of the cycle only effective. So, ultimately you will have arc efficiency lower as compared to d c case d c in case in the case of gas tungsten arc welding. Now coming to suppose the electro slag welding now in the case of electro slag welding what happens that it is a lesser than SAW.

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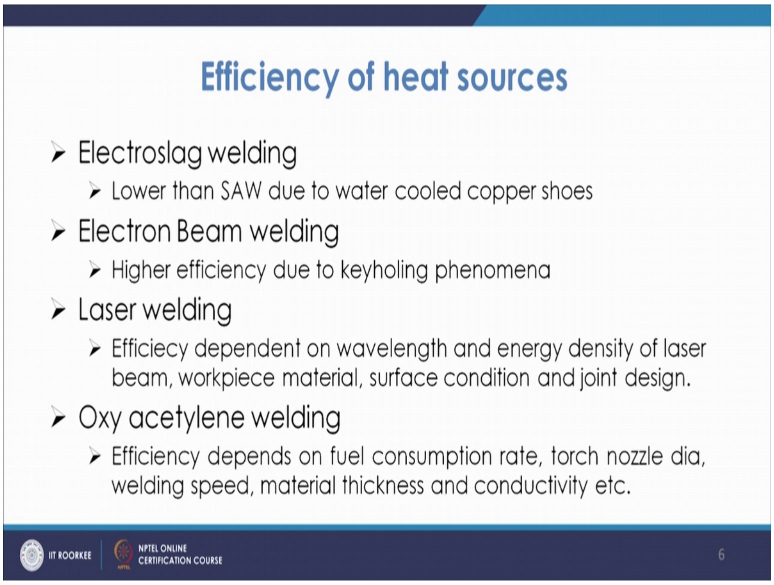

Now, if you look at the these consumable electrode welding in that the SAW is even better as compared to others because in the in a SAW case as we know in the submerged arc welding the arc is under the blanket of flux. So, the dissipation of heat from that arc to the surroundings is lesser. So, in that case the arc efficiency or thermal efficiency of this process is better as compared to other processes. Now what we when we compare it with electro slag welding then it is better, but then it is not as good as SAW because of the water cooled copper shoes in this case use.

So, that way it has some adverse effect on the and the thermal efficiency or the efficiency of the process are. Then if you talk about the electron beam welding now electron beam welding this has a very high thermal efficiency and this efficiency is normally of the order of close to 100 to me it may go. It is because of the key holding phenomena because it makes the whole and that works as a black body type of you know property.

So, that basically does not allow the heat to dissipate and so, this welding is very very effective in the case of these electron beam welding and all. So, they here they are trapping most of the energies and that is why the efficiency is quite high. Now if you take the example of laser welding now this laser welding here, the efficiency will depend on the wavelength and energy density of laser beam. So, that is work piece material laser beam surface condition and joint design.

So, many a times what happens that if you take very polished surfaces like aluminium or copper, in that case the reflectivity is quite high and then you have very low efficiency it also depends upon the type of laser beam what is the density power density and all that. So, that weight it k it can have very small value of efficiency also. So, then in the case of oxy acetylene welding you have the you know other parameters like nozzle diameter, then you have you have welding speed then material thickness all this conductivity. These are the important parameters which decide about the thing efficiency.

So, in a nutshell if you try to see the efficiency the GTAW varies from 50 to 80 for d c and it varies from 20 to 50 for normal a c similarly submerged arc welding will be about 65 to 85 percentage then you have some submerged arc welding if you look at it goes from 80 to 99 percent quite higher among the arc welding processes. Then electro slag welding if you see it will be 55 to 82 percent is reported then a tron beam welding will be closed from 80to 95 percent of efficiency is reported and then you have laser beam welding, you will be about it starts from 1 to even 70 percent of that efficiency is seen oxy acetylene welding is from 25 to 80 percent.

So, now again depending upon the different parameters; so, this way these efficiencies of the heat sources vary. So, this is in a nutshell about the heat thermal aspects in the welding, and typically the heat flow and they about the efficiency of heat sources then about the isotherms and all that we will discuss about other aspects in our next lecture

Thank you very much.