Finite Element Modeling of Welding Processes

Prof. Swarup Bag
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture - 03
Fusion Welding - 2

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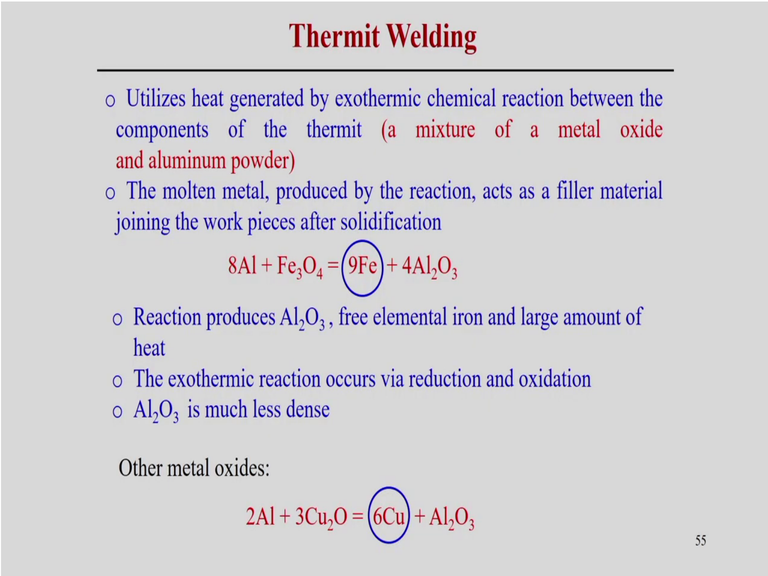

So, in continuation of the different welding processes that we are discussing; now today we will discuss the other welding process that is the different from the chemical source, there is a heat generation and that is responsible for the joining of the two components that is one of that most widely used method is the thermit welding process. So, in this cases, they utilize the heat generated by exothermic chemical reaction during the reaction.

There is a generation of the heat and that heat is basically is responsible to join the two components. So, we can we will see that how, what way we can the reaction happens and that how it helps to join the component. Basically this chemical source utilization of the energy for the joining purposes normally we use a very remote location. For example, there is a huge application of this particular processing railway track; there you can use this kind of particular process.

So, in this case a mixture of metal oxides and the aluminum powder is required, such that it will create some kind of the exothermic chemical reaction. So, we can see that molten metal produced by the reaction; for example, acts as a filler material the gap between these two components and then joining the work piece after solidification.

If you see the first reaction, aluminum plus F e 3 O 4 that iron oxide the aluminum with a certain proportion you can mix it. And then this this is a creation the separation of the iron, pure iron is separated out and that it creates the aluminum oxide. So, it means during this reaction, there is a generation of the heat.

And that heat is basically responsible to melt to create the molten iron and that iron is basically filled up that gap between these two components which is supposed to join. But in this cases, there is a it produces the aluminum oxide and this aluminum oxide is basically lighter in weight. So, therefore, it comes much denser and just come out from the upper side of the weld joint and after that we just remove this aluminum oxide from the surface and then maybe this acts as a; acts as a protect the material from the outside atmosphere.

So, therefore, this is one kind of the reaction that is the principle of the thermit welding process; but if the combination can be aluminum and copper oxide also. In this cases also, we can separate out the copper and that copper maybe join the two components the this thing and this aluminum oxide just separated out and maybe lighter in weight, it just comes on the top of this weld zone.

So, this way we can this by using the principle of thermit welding, it is possible to join two two components or maybe steel components can be joined or maybe almost pure iron or the other metal oxide for example, copper based alloy also that is also possible to join using this thermit welding technique. Now, we have discussed the several welding processes their aspects and their advantage maybe and their principle also we have discussed.

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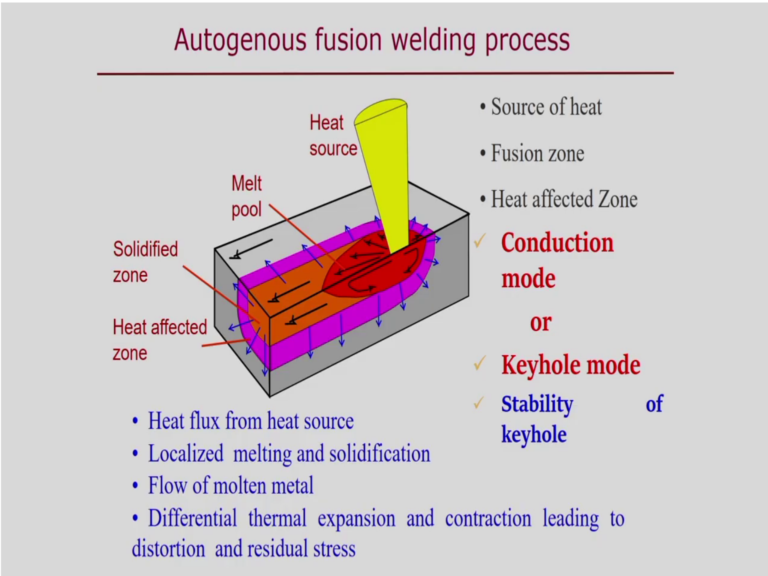

And basic principle we discussed on different front; but what maybe the approach to look into all these phenomena welding process or different welding techniques?.

In a single platform; that means, I am talking about the mathematical representation of this different welding phenomena that has to be understand at this stage. Then that will help to develop some kind of the numerical model or maybe other kind of the model for the particular welding process. So, that is that we will try to explain in this slide.

So, autogenous fusion welding process; in autogenous fusion welding process there is a source of the heat. So, maybe the source of the heat can be arc, can be laser or some other; that means different welding technique we are representing in the single platform, what are the different physical phenomena happens in a welding process and what are the difference of the different welding techniques that may be necessary to implement in the form of mathematical model or finite element model in this case?

Now, the what physical phenomena happens in fusion welding process and autogenous fusion welding process it is like that only; the heat source moves from the work piece and heat source is responsible to melt the substrate material. And subsequent there may be associated with the heat transfer and the molten material flow within the small weld pool.

And once it advances on particular direction the heat source; then solidification happens and it creates the different solid different zones for example, solidified zone, heat affected zone.

Now, this is the general representation of the fusion welding process. Now, there are several fusion welding techniques. So, we can follow the similar strategy to develop the model here in this case. So, first is the source of heat can be different for the different. So, in that sense, there may be source of heat can be represent in different way.

For example, if there is a arc welding process; we can represent the heat source in the particular situation, we will explain this in later on. And if it is laser or electron beam welding process, if there is a formation of the keyhole; then we can represent the heat source in the different way. But then in terms of different technology, although they are the same category of the fusion welding process; the representation of heat source can be different.

Second part is that, it creates the some kind of the fusion zone. So, within fusion zone heat transfer material flow, mixing of the material in case of alloy system are there, that kind of involvement is there. And but fusion zone is only define the only the molten zone or melting point temperature is isotherm can define only the fusion zone.

And then heat affected zone, which is affected within the heat affected zone, some solid state phase transformation may happen within the heat affected zone that zone. So, that transformation we can look into all these physical phenomena is involved in the welding process.

Now, how it happens in this cases the, we can look into this aspect the heat flux from the heat source; that is the representation, how heat flux has to be considered from the particular heat source.

Then localized, particular localized melting and subsequent solidification also happens; in this cases flow of molten material is also associated within the small weld pool. At the same time differential thermal expansion and coefficients; expansion and contraction that actually induce some amount of the distortion and residual stress in a welded structure.

So, that different font we can analyze these things for example, if we analyze the heat transfer analysis. So, it get a lots of information, if we do simple heat transfer analysis by solving heat conduction equation with the appropriate boundary condition in the fusion welding process; simply we will be getting the temperature distribution in a particular welding process.

But from that temperature distribution it will be able to estimate what maybe the cooling rate in this particular zone. So, from the cooling rate, it is possible to predict what maybe the expected microstructure in this particular zone; that kind of information we can get from the heat transfer analysis.

Similarly, if we do the fluid flow analysis also, fluid flow analysis basically enhance the heat transfer basically temperature distribution in a weld zone. More correctly it can predict; because actually if you look into the welding process; that within the small weld pool that the molten material can flow from one point to another point depending upon the driving forces acting on this particular weld process.

But why fluid flow important particular situation? Because material flow is significant, once we try to analyze what may be the effect of the surface active elements; that we know in a weld pool how it change the weld pool behavior. For example, different change the weld pool dimensions; that kind of analogy or that kind of analysis can be done by incorporating the effect of the material flow in a structure.

Similarly, once we do heat transfer analysis and these things fluid flow analysis; then we normally do the stress analysis to understand the what is the distortion and the residual stress generated in a welded structure. So, that from the stress analysis, we will be getting the distortion field; that means what is the magnitude of the distorts in a particular zone and what is the amount of the residual stress generates during this process.

But of course, if we want to do the stress analysis part; then the input may be required to the in the form of a temperature distribution is the input. So, temperature distribution is necessary to explain the or to do the stress analysis model. So, in general we say, this is called the thermo mechanical model and in that cases, we do the temperature distribution as well as the stress analysis or distortion field in a welded structure.

Similarly, we can do a thermal fluid analysis. So, temperature distribution as well as the material flow field in a particular welding process; that kind of phenomena we can explain, we can get from a mathematical point and that mathematical model and from that point of view, we can explain the welded structure and finally the welded structure.

Of course, there are several phenomena also associated with these things; one thing is that what maybe the free surface profile, because most of the welding profile may not be the flat. So, you have to do explicit the free surface profile modeling. Apart from that, we normally look into the what are the mode of welding process in the say conduction mode or keyhole mode; this conduction mode is different maybe depending upon the heat intensity is basically we are talking about the heat flux.

So, what is the intensity of the heat flux supplied to the substrate material that can be in the mode of conduction mode or in in the mode of the keyhole mode.

And of course, this conduction most of the cases conduction mode of welding we normally do; but if we do the keyhole mode welding processes also, the intensity is very high. So, it creates some kind of the keyhole in a structure. And the if you want to achieve the very good depth of penetration this thing; then we can use the keyhole mode laser welding process.

But one of the issue can be the, what we can analyze the stability of the keyhole that we will see that whether it is conduction mode, keyhole mode and what we can analyze all these phenomena.

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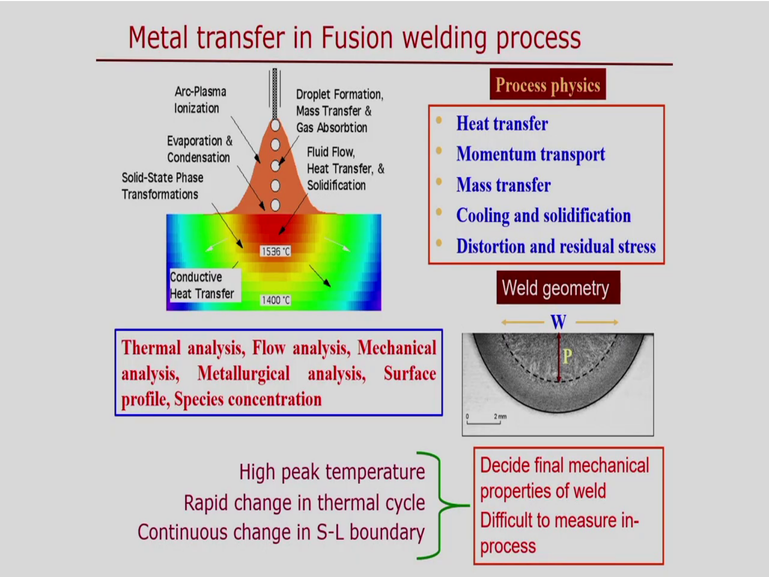

Now, apart from that there is other part also that, previously autogenous welding process, boiling process may be associated with some kind of the metal transfer. Now, if we look into the metal transfer in fusion welding process and there are several physical phenomena involved in this case; for example, metal droplet transfer from the electrode consumable electrode.

And then you can see that so many the when creating the arc, the arc plasma ionization is there, evaporation of the material, condensation at the same time may happens, droplet formation, mass transport to the system, gas absorption by this metal droplet to some extent. And then of course inside the weld pool the fluid flow heat transfer and solidification is associated outside that molten pool.

Solid state phase transforms are within the heat affected zone also happening; but at the same time from the boundary, their convective and radiative heat losses from the boundaries also associated. So, these all are phenomenon basically associated with a welding process that makes it is a very complicated to analyze in the single platform to by considering all these physical phenomena; that maybe the difficulty or in the developing of a particular model of welding process.

So, most of the cases, we analyze the welding process from the by considering the particular aspect and then we analyze in the or we do the develop the model in the welding process. See physics processing involved in general if we categorize in this way also; the heat transfer is the involved in this case, momentum transfer because of that material molten flow occurs within the small weld pool.

Then mass transfer, because of the molten metal droplet out from the consumable electrode. Then definitely cooling and solidification is also associate and finally, it generates some amount of the distortion residual stress. All the elements are associated with the or we can say the process physics is involved in case of the welding process.

Now, if we look into that, what are the different analysis we can do? Simple thermal analysis; that means only your interest will be getting only the temperature profile or temperature distribution in a particular domain in the weld zone. So, that is associated only thermal analysis. If we do the only fluid analysis, but normally with the thermo fluid analysis; only fluid analysis we need the information from the temperature.

So, we can say the thermo fluid analysis or fluid analysis will give you the fluid flow field inside the molten pool. And actually this fluid flow analysis is sometimes maybe helpful and can be improved by incorporating the effect of the solidification behavior for a particular alloy system.

Then we can do the mechanical analysis. Mechanical analysis simply understand the what is the stress distribution, strain distribution or distortion field in a welded structure; that is responsible to predict the residual stress and distortion in a welded structure. So, that can be done separately mechanical analysis.

Then metallurgical analysis means, sometimes we can do some constitutive relation between the by looking into the microstructure development where this process or phase transformation effect can be incorporated in the thermal analysis or thermo mechanical analysis, so that prediction of the residual stress can be improved.

So, that is why sometimes with the metallurgical analysis that is incorporated with the thermo mechanical analysis. Then surface profile is also important in this in this aspect; because prediction of the surface profile is one important phenomena. And we can predict; because we can see we can observe that in a practical welding process after deposition of the material, the surface profile may not be the flat.

So, free surface profile prediction can be one kind of one analysis can also be done and there are some volume of fluid method can be incorporate here to analyze the free surface profile.

Finally, the species concentration, so distribution of the species concentration or either dissimilar metal welding can be joined; what is the distribution of the species concentration within the weld zone, because there is a mixing of the molten material that can be predicted using the particular the species concentration, we can use the particular governing equation associated with that.

So, this that the different type of analysis normally done and all the cases it is possible to develop some kind of the finite element model, a particular to stick with the particular analysis. Now, if we look that, how it looks like this thing the weld geometry one figure has been shown here; the depth of penetration which is also has been defined, but this we can define purely looking into the microstructure.

Under the microscope how the changes happens accordingly, we can decide what is the depth and penetration of evolution and what is the size of the heat affected zone. And this measurement is necessary or this when you the same thing what you observe in the experimentally and that same thing can be represent in the mathematical model, such that if you see in the dotted line here in this weld geometry, that dotted line should be represented mathematically as a melting temperature of a particular alloy system.

Similarly, heat affected zone the solid line and dotted line is corresponds to the particular temperature which we can get as output from a thermal model. So, this way different isotherm can define the different zone in the from the mathematical model and that can be compared with the experimental analysis.

Now, high peak temperature rapid change in thermal cycle this is mostly associated with the welding process and there is a continuous liquid interface change, boundary change. This because of this all this phenomena is associated with the final mechanical properties of the; because we are interested after welding process what is the mechanical properties of a weld joint.

But all these things is basically very difficult to measure in the process, because it is very difficult to track what is the solid liquid interface during the welding process

And there is a continuous change in the thermal cycles also and very high peak temperature, all these phenomena is very difficult to measure by simple experimental setup. That is why we need development of a particular welding process model, such that we will be able to predict all these what is the peak temperature, what is the thermal particular zone.

In that way the mathematical model or finite element model actually helps to get all this kind of the information. And this once we get this thing, we will be able to predict what is the residual stress in the structure and what is the expected microstructure; but direct correlation to microstructure is not possible.

Rather we can say that, we can link with the microstructure with the different cooling rate from that prospective; we can predict something in a welded structure. So, this all kind of benefits we can get from a mathematical model that is why these things.

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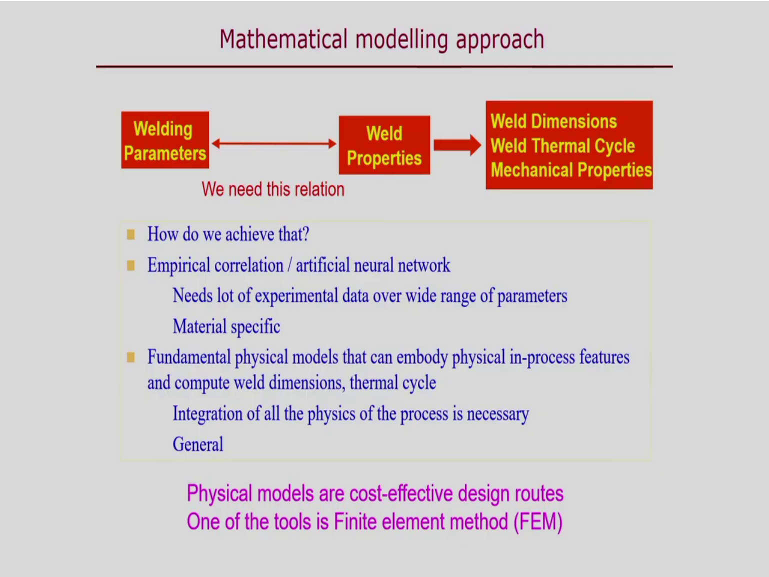

Now, this slide will help you to understand that, why we should go for the mathematical modeling approach or maybe in a welding process.

So, definitely in a welding process, the welding parameters are involved; we can set the different welding parameters. For example, in case of arc welding the we just said the current voltage all these kind of phenomena, all these kind of parameters we set it.

But finally, what we are looking for? The we are doing setting the input parameters and then we are getting some weld properties, weld properties means after welding we will get the we evaluate the properties; that means what are the weld dimension and what are the weld thermal cycles and basically what mechanical properties, that means what is the strength of the weld joint, what is the hardness distribution fatigue behavior all these kind of testing we do after doing the welding's.

And engineers are always interested to know what should be the input parameters and such that we can get a very good properties or we try to find out the relation; this is the input parameters and this is the weld characteristic or weld properties in a particular material. So, to do this relation; there are several approaches to achieve this kind of relation, the welding parameters to the weld properties.

It can be possible to simply empirical correlation or maybe you can follow some artificial neural network model; but in this cases, it needs a lots of experimental data and this we does not understand that the what is the physical phenomenon is associated in a welding process, it is simply knows that data available of the data and the correlate the data by the different techniques.

So, that is why this empirical correlation or artificial or any kind of statistical model or data driven model maybe needs a lots of experimental data to correlate between this thing and over a range of parameters. And this range of parameters, experimental data is basically material specific; for example, if you change the material, then you have to evaluate all these parameters once again.

So, there is a huge number of experiment is needed to these things; but if you look into the other way also mathematical modeling approach, fundamental physical models that can embody physical in process features. And compute the weld dimension thermal cycle; because it consider any kind of fundamental physics based model, consider all the physical phenomena associated with this process.

And finally, it will give the output as a temperature distribution as a weld temperature distribution either in the form of a thermal cycle also and weld dimension. Even it can gives the output the stress distortion all this distribution we can get from the physics based modeling approach. But in this case, integration of the all physics of the process is necessary in general.

So, that is means, if we can develop a very good mathematical model, probably not necessary to do lots of experiments; but once we develop the mathematical model is the validate the model with this with the few experimental data, then utilize the model to predict the intermediate behavior of the welded structure.

So, that is why physics based modeling is most cost effective approaches and one of the tools to analyze, to develop of this physics model is the finite element methods. And I think that is the objective or aim of this particular course to understand; what we can apply the finite element method to develop the physics based model of the welding process.

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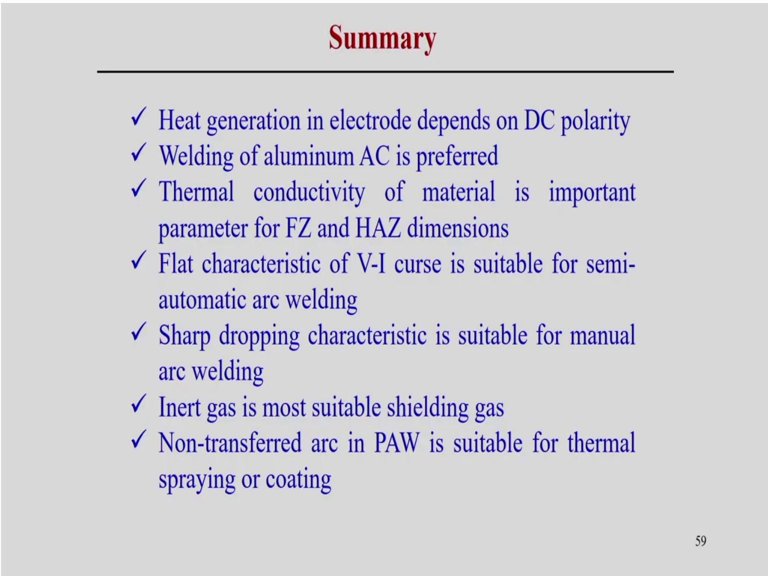

Now, in summary this particular module we can say that, heat generation in the electrode depends on the DC polarity. We have discussed the what are the different polarity associated with that in a welding process. So, heat generation in the electrode depends on the DC polarity; that means whether it is electrode positive or electrode negative accordingly you can choose the polarity.

Welding of aluminum AC is preferred. Once we there is a need of low melting point maybe specifically the aluminum, the cleaning action is required; then we normally use the AC current in during the welding process. Out of the different properties, the thermal conductivity of the material is most important parameter that mostly define the fusion zone and heat affected zone dimension.

But of course other parameters having some influence; but my point is that the thermal conductivity is the most influencing parameter to decide this fusion zone and heat affect in dimension.

Now, we have discussed the different characteristic of the voltage ampere that power source characteristic of a welding machines. So, there we can see that, volt ampere characteristic is suitable for the flat characteristics of the volt ampere relation; that is mostly suitable for the semiautomatic arc welding process this thing. And other cases sharp dropping characteristic is mostly suitable for the manual arc welding process.

So, basically if we know the what are the power characteristics available in this particular welding machines, accordingly we can use utilize this power characteristic mode to do whether it is manual welding or whether it is some kind of semi automatic welding process.

Inert gas is the most suitable shielding gas; because we normally use the shielding gas in a fusion welding process. But inert gas out of other gases, inert gas becomes more suitable shielding gas; because it hardly react with the molten pool.

And plasma arc welding we have seen that, there are two different modes of the arc transfer is there; but non transfer arc is mostly suitable in plasma arc welding to develop some kind of thermal spraying or coating process. So, this is the end of the module one, part of the module 1.

So, thank you very much for your kind attention.