Rheology and Processing of Paints, Plastic and Elastomer based Composites
Prof. Santanu Chattopadhyay
Rubber Technology Centre
Indian Institute of Technology Kharagpur
Lecture 46 : Introduction to FEA based computational fluid mechanics on extrusion 3

Welcome to NPTEL online certification courses on rheology and processing of paint, plastic and elastomer based composite. We are on week 8 today and title introduction to FEA based computational fluid mechanics on extrusion. Actually it is module number 3, actually 3 subsections of it. Again without going into the you know keywords and all. So, let us directly go. This is actually some of the works of my group Dr. Sajeet Sarma's work and two of the work of course he published in chemical engineering journal basically and one was published in manufacturing process. But this particular things is from chemical engineering journal, I mean having now it is about 17, 15 or 17 impact factor. So, let us try to understand coextrusion. So far we have been talking into simple extrusion and direct extrusion, inverse extrusion.

But here see you have a two flow channels and two different polymers are coming getting united and their die swell becomes more complicated. Now this is the entire curing line as I mentioned it to you. Now one thing I didn't talk about other day, how your line speed is defined. So, line speed is defined by the optimum cure time and if optimum cure time is time required for curing up to this is not uncured, is uncured. So, this is the line from it cures.

So, you have a definite you know line length of the hot air tunnel. So, depending on the speed you can decide how much the duration is dwelling in the hot air tunnel. So, depending on that your speed is decided. But most importantly here the complication of the problem, suppose if I have one half here and another half here. So, those two halves when it is combined consolidates there should be a same velocity more or less.

If it is really have a very differential velocity the interface will get distorted. But sometimes it can be little difference that also is some way good. So, that optimum bonding you will be able to get it. But if it is too much that is not a good from the you know finished products morphology or structure point of view. So, here you go two different compound formulation of course are to be coextruded.

Difference in terms of the process well in terms of extent of carbon like you can see from here and after all both are EPDM. As I mentioned in this particular things we have chosen the EPDM best. See you see two q curve of EPDM 1 and 2 means two components of to be extruded. You see optimum cure time, cure rate index is different but optimum cure time is almost TC 90 is almost same. So, that way it does not have that complication I was talking about.

Otherwise what you have to do often you have to change the temperature, change the velocity, change the you know those part of it so that when it converges it should have a equal velocity profile that is the bottom line. So, now once again the same way we do the experiments for both the both the fluids. You try to fit in have a master curve by two rheometric experiments low shear rate high shear rate generate here we try to fit in a carreau Yasuda, carreau-bird we are talking about other day. Carreau-yasuda fits better better it is a more number of parameters five parameters as you can see from here. Those are the parameters you fit in that data your software will do regression and try to give you the solution in terms of those unknown parameters.

$$\boldsymbol{\eta = \eta_\infty + (\eta_0 - \eta_\infty)[1 + (\lambda\dot{\gamma})^a]^{\frac{n-1}{a}}} \textbf{\textit{(Carreau-Yasuda law)}}$$

And you see if you do it across the software has different different models, you see different models starting from Bingham, bird-carreau, Carreau-Yasuda cross, hustle buckley, log-log, power law. So, you can see where it is giving the maximum regression coefficient I mean more fitment. So, you can see carreau-yasuda gives you the best. So, we took it for carreau-yasuda that we fit in the in the console as a fit parameter input parameter. Then again we we try to do log viscosity as a shear rate although it does not look you different in this line it converges, but you really do zoom it in they are different.

So, that way you can see those exponent values in the Arrhenius equation and you see Arrhenius equation for both the cases is more than 96 you know percentage r square value. So, that way you see this is very good. So, alpha and you those exponent you can alpha exponent you can borrow from there basically and it fits in goes to the console. So, overall without going into that so these are the input variables volumetric flow rate come again compound1 to compound2 you see zero shear viscosity, zero shear viscosity infinite viscosity is the requirement for the carreau yasuda model. As you go back and see to the model so you have these two parameters.

$$\boldsymbol{\eta(T) = exp[-\alpha(T - T_\alpha)]} \textbf{\textit{(Arrhenius approximate law)}}$$

So, then other exponent parameters specific heat thermal conductivity like similar way and this is alpha is the temperature part of it temperature dependent part of it and these are the input parameters for both the compounds f2 and f1. So, again the flowchart simulation it is little complex the algo. So, first you have to have this as I depicted already. So, what is that again after meshing you specify the flow domain fluid material property specify the flow and thermal boundary condition specify the remeshing techniques you can go back again and then try to solve it. So, if that does not converge again you go back come back.

So, every stage you have that opportunity to redo basically. On top of that since you have two fluids you have to do specify another yet another flow domain flow boundary condition in the machine. So, that way combining that you get the total profile simulated. If it is a three component extrusion it is going to be three such I mean. So, accordingly you have to plug in just those subroutines.

Then geometry, mesh, boundary conditions. So, flow boundary condition you define the temperature stage wise for that thermal boundary condition 100 degree temperature let us say extruded material which is actually entering into the die and die wall temperature and then interface then the temperature of the outer atmosphere etcetera etcetera. And then also about the die swell as I mentioned it to die swell depends on the velocity ultimately. So, that way these are the boundary condition given at different positions from here to here. So, now so remember this is half half 50 50 half is one compound and other half rest half is other compound and they are getting submerged in this particular design.

So, remember same way what I taught you is being done. Again some of the assumption I already specified the same thing you have to have an assumption while solving. But more precisely you can see the in terms of material data we have chosen carrier Carreau-yasuda model that we feed it. Temperature you choose it and it will ask you for those parameters required parameters. Specific heat thermal conductivity and then boundary conditions you have to put in I showed you just like and both flow as well as thermal boundary condition two conditions you have to do parallelly.

Now in terms of meshing and remeshing see optimize 3D mesh you can choose it as recommended for extrusion and inverse extrusion problems a large deformation of the extruded is expected. So, once you do not expect that much of deformation you go for a 2D mesh technique and that you will give you a edge in terms of less computational time. And remeshing thing as I told you, remeshing and mesh optimization you have a Lagrangian and you have a stream wild meshing opportunities there. So, without going into that if you just have the access of the solver, access of that software your company or organization if you ask your organization to buy it for us IIT Kharagpur has the license with we brought it the full license academic license of it. So, actually what it solves inside that you do not see in the black box it happens.

These are the some of the set of equation in the tensor form it looks little complicated, but nonetheless without going into that I many times I talked about a Fourier law about the you know heat transfer. So, you can see the total part of it dissipative heat, conductive heat as well as total buildup of the temperature those are coined here in terms of you know tensors basically. So, those equations are actually solved in the background. Then let us try to see again we have the simple geometry, but it parted into the two. So, now this is the visualization of that and see if I get it from directly here different geometries you see compound 1 and compound 2.

In top you have a compound 1, bottom you have a compound 2 and you see there they are swelled at a different extent. See upper one you see swelled less, competitive red one swelled more. As I mentioned it to you the go back to the fundamental if you have more filler obviously it is going to be swelled less than that of the less one. So, that way you can see the decide the swelling factor for compound 1 compound 2 ideally it should not swell as simple as that. So, this is what your analysis from the direct extrusion.

So, you see in one compound is 1.09 another compound 1.13 one is 13 percent another is 9 percent. So, obviously different percentages. So, this is the visualization you try to see.

This is how frame by frame animation of the streamline velocity distribution is happening. You can see one case is flowing faster than the other. And this is the frame by frame analysis of that till it freezes basically. And you see how the deformities is happening in each frames. So, from the very first you take frame number 1, frame number 2, frame number 3 till it comes to the equilibrium.

So, this is the equilibrium most distorted one. So, that is how your analysis by frame by frame you can make it. So, you can verification obviously I mean if you do realistic things you know the realistic dimension of the profile. And after this die we are talking about remember the direct extrusion here. So, we try to do the you know verification in one of the industries it is called ALP overseas it is NIMRANA.

And there we did it and we published jointly with them. And you see this is the deformities showing As I told you see the blue one the lower compound lower one is actually deforming more than that of the upper one. And here also in that contour design also is happening in a similar way you see the deformation. So, by this process you can understand that if I have that particular die design it is wrong it will lead me to erroneous product set. So, that is what across all this type of we not only confined ourselves a single design, but we did it across different simple geometries vice versa complex geometries.

So, here you go you can see it from here. So, this is how again the animated version other day I talked about. So, although we try to show you initially this particular die which is much simpler, but of course we did it with the complex ones as well. So, more complicated ones is again which we did not cover here, but example if I remember is a T header cross head extrusion. So, here in this case wire is going and then your you know polymer is submerging on that and giving you resultant thing with the swelling part.

And this is the another one you have a same die the blank one is the metal insert. It is extruding with the metal strip. Here is a wire it is a strip and frame by frame you can analyze. This is another one interesting design it is used in your automotive doors I mean door closers in the cars basically. So, there are many many many designs which you can actually do it with the cross head extrusion, but nonetheless I am not going into the cross head extrusion, but staying in the same co-extrusion or single extrusion inverse extrusion gives you a very good idea.

Again your direct extrusion you have a die and you have a deform shape getting and you have a shape and shape driven die design you will get it from the inverse extrusion. So, always dimension analysis you see as I told you if you just do direct extrusion in the corner regions you get more deformities. Why? Again tell me shear rate or shear stress is going to be more. So, if shear stress or velocity is going to be different definitely it will show you variegated you know dimensions.

So, again from this animation. So, this is how you actually get that die design and it fits in rest of the part fits in the die head basically. So, this is the inverse extrusion way how you better design. So, again comparison of the product shapes here you can see it from here it's repetition what I told you, but try to realize the complication of the problem from the point of view of co-extrusion where you have two different compounds and they are embedded in a single design single shape. So, that is what you want to look for again I am showing you some of the you know videos taking care of the inverse extrusion into account and that shows you clearly frame by frame the velocity profile of it and why you are wrong. So, I will not go into the details further, but what I wanted to convey you message by now you understand your understanding of rheology your understanding of processing ultimately enable you designing a die design a mold although I did not talk about and of course, so given a material you will be able to assess whether given a process it will be suitable or not suitable remember the Garvey die.

Garvey die is a very initial assay, but in a computational way it will be much precise analysis point to point corner by corner geometry by geometry you see all those velocity profile pressure profile and what not and that will give you a more precise idea about why it is what is going on. So, to conclude quickly material properties are characterized by standard instruments geometrical thermal instruments as well as you know thermal conductivity by guarded hot plate or other means. Those material properties are to be analyzed like rheological properties you put in the master curve overlay it and try to fit in with a suitable you know regression techniques to a suitable fluid model and then all above parameters are used as a input parameter into the console of poly flow here example there may be other commercial software also available, but otherwise you have to write the whole code for solving all those differential equations giving the set of boundary condition. In post processing section what you do ultimately what you are concerned with shape of the product is predicted which help you to reduce the die development type energy consumption and manpower. So, this is going to be our industries including rubber, plastic, fiber, adhesive and paints they should quickly adopt sooner they adopt more sustainable their industries will be otherwise the fear competition what you call in one hand the other industries they are equipped with the computational design minimizing the time having better accuracy there you would stand no higher compared to if you just be in the inertia and follow the same tradition.

So, better quicker way you adopt better it is. So, in the next lecture of course, so I mean without practical demonstration it remains I just showed you some of the results and showed you how it is done. That demonstration will be given and the last and penultimate lecture will be all about solving some numerical problems that we missed it and of course, about the way forward what to learn after that of course, as we promised that we are going to float a advanced course, but not now for the 3 to 4 years from now meanwhile you can read it from different resources. So, thank you very much see you in the next class.