Rheology and Processing of Paints, Plastic and Elastomer based Composites

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Lecture 48 : Concluding remarks and commentson applied rheology for advanced learners

Welcome to NPTEL online certification courses on rheology and processing of paints, plastic, and elastomer-based composites. Today on week 8 and the penultimate lecture, the last lecture, last but not the least I should say. It is all on concluding remarks and comments on applied rheology for advanced learner. If you remember, I tried to design the course in the line of like for the taking care for the beginners and you know intermediate learners. So this is all about what you have to do being an advanced learner or kind of expert in this domain, subject domain. So without going into the contents, I will give you some of the glimpse of it.

So I will give you some of the works which you can get it here it is actually given. So in this case, you see the die for example, this is where you can see the entrance basically and this is where it fits in this part of the extruder after it the skin pack and all as you can understand. But what is given the die land from here to here is given a length of say 10 millimeter and that is the geometry typically as you can see one to one. So now very interestingly you can see again I mean here to here now you try to understand that way.

So you try to see in this work particularly they again did the ANSYS based poly flow based simulation. So in that the distribution of shear deformation as you know shear deformation is related to die swell, higher the shear deformation more is going to die swell. So this is a kind of a scale it is normally for your convention is starts low and the color sets represents to high, red is the highest so blue is the lowest. So when it comes you can see some of the spots where you have still high deformation. So obviously the velocity profile is going to be different higher velocity obviously shear deformation is going to be more.

So ultimately having the high I mean larger die length it actually equilibrates and at the end as you can see it comes out the shear deformation more or less going to be uniform. So more important is the same way if you try to locate from the entrance to end the frame by frame how it is going to be the velocity profile. Even though towards the end last frame I showed you there is little gradient I mean compared to wall where it is the velocity is minimum. But still then you can see it is more or less homogenize the velocity from low to high. So that represents 10 millimeter I mean is okay for us to giving us a good distribution, but how do I know? Question is how do I know whether 10 is optimum or I have to give some additional length or I can reduce that.

Reducing length you understand that its productivity increases and increasing the length again the other part of it, but still then you have a better surface finish. So there is a dilemma basically you have to optimize. So here in CFD simulation what they have taken care the thickness and width and of the original profile somewhere it is 3 millimeter and you know with this also you are getting from the original profile that is what you are going to get. And width also you can see what is the distortion because of the die swell you can see it there and dimensional difference percentage this 33 and 3.0 it is merely 2.

7 percent. So if your product specification really really allows that the 22.7 percent you know variation or in terms of width 6 percent variation you are well to do with that. Otherwise as I mentioned you have to change with the other parameters say die land and angular entrance say for example or even the material of construction of the die so that you can play with the friction coefficient. So that's what I wanted to emphasize upon and this is how your logic and your programming goes like that.

So geometry of the flow interior head and outlet and the green part is actually already extruded. So that way here also you can see the pressure distribution from you know die entrance to the end. So this is very very important to understand you see somewhere initially you have angular entrance also here embedded here. So now one part remains so far so forth we have been trying to focus on only the die land and die part of it after the following the metering zone. But point is that that is not all for a detailed design of an extruder.

So you have to take care of the screw and you have to take care of the what happens from the feed to the end basically. And of course for plastics you do not have to consider after it equilibrates that is it but for rubber you have additional consideration while curing also. And specially if it is a foam it expands actually during the curing and there is a balance there. So there are two types of geometry as far as plastic extrusion is concerned one is a co-rotating type another is a counter-rotating type as you can see from the geometry and volumetric flow rate which is represented Q and N is the you know RPM of the rotors of the screws more precisely. Now point is that again I mean there mathematically the simulation becomes little complex.

You have to give some boundary condition like from the inflow point from the outflow point as well as in three Cartesian coordinates basically. So it is while doing it for the co-rotating while doing the counter rotating I'm not going into the very details of it how do you do it but it is again I mean you have to give it remember I just tried considering the you know die land and die you know leap and die part of it. So again you have to put different different position different boundary conditions not only boundary condition in terms of you know flow rheology but also in terms of the thermodynamics part of it temperature part of it. So here the distribution of shear rate as you can see again and different parts of the screw as the volume conveys basically in co-rotating vice versa in a counter-rotating analog of it. So you can see two frame frame by frame what is the distribution sort of a say co-rotating have gives you some sort of a distribution while counter-rotating shows you some sign of uniformity rather or in terms of velocity distribution of course so in terms of you know counter rotating screw its velocity is much higher than the co-rotating of course there are certain points where the there is velocity gradients as well.

So I am not going to into the details of it how do you analyze how do you design a screw and also the screw I mean you know the distance between the top wing of the screw between this two are very very important as well as the wall because that there it demands a high shear dispersive actions basically. So again going into the little details part of it because pressure and volume as I mentioned earlier one I showed you the volume part of it. So you can see the you know pressure part of it in both I mean twin screw extruder co-rotating vice versa counter rotating counter part of it. So again these are the some of the distribution as I was showing you repeatedly somewhere in the velocity distribution somewhere with respect to a specific axis y x and z. So that way you have to give a consideration make sure all the things you intend to do in your machine is properly balanced in terms of mixing as well as conveying and finally giving it to the shape.

So these are the very very important component that you must consider but of course you do not keep temperature in isolation because temperature plays very very important role since you are dealing with a material whose viscosity or rheological behavior is whole lot changed across that I mean temperature you are considering and remember the temperature is generating inside because of the viscous dissipation in addition to y conduction whatever you are giving from outside the temperature and that will resultant of which will give rise to the you know rise of temperature. Remember here the radiative heat and rest part of it we are trying to you know ignore it rather. So this gives you a pressure distribution. So always always I will say in a typical type of a mixing case you should not have a confinement you should have a distribution distributed emotion and that is also important end of the day while considering the distributive mixing part of it otherwise somewhere it will be very well distributed somewhere it will not distributed. So this plays very very important role although this will be taken care at the advance level each graph each signature of it will be typically taken care of and explained and given the interpretation for the final design.

So CFD simulation of screw is really really very very important what is going to be the design like what is going to be the flight length say for example what is going to be the wing size its width its gap with the barrel as well between the two screws if it's a twin screw sort of a geometry single screw is between more of like a between a screw and a barrel basically. So again this is the work depicted here in a published in MDPA journal and there you can see this geometry is the twin geometry how the pressure distribution across the accesses it happens and the velocity distribution ultimately is velocity and pressure as I mentioned it to you repeatedly while talking about bit of applied rheological sense of it. So that is what is important. So CFD simulation of screw again they have taken care this people this is another another paper basically the detail is given here appended here and you can always click and go to that publication which deals with the modeling of extrusion process of polymer is a review I mean and this kind of a things I mean I will say I mean being a going to be advanced learner. You must look into the some of the state of the reviews basically many of the things you will not find it in a very good way even in a book many a times because this has lot of you know many of the things are confidential design people do lot of business on that but at the same time being a good learner you have to go step by step follow the state of the reviews and try to understand every basics that is giving bibliography given in the bibliography and that you try to cross read basically and do yourself.

Otherwise for a beginner do not go for anything high fighter do not try to envisage that you are going to write your code. Code is a second part of it initially try making you comfortable with using a standard platform where you give input output that data and finally end of the day you get some design that you try to you know accept or not accept. So once having that you can use the subroutines to make your you know that platform itself smarter and end of the day I must say if you have a program written of your own then maybe somebody in the software did not take care of some of the considerations say for example as I mentioned it to you simply taking the velocity as a measure of you know die swell will not suffice rather if you can go from the little bit of detail analysis I mean in the sense of you know the tension what is the normal force difference and that you try to implement intelligently into the system piece by piece in the entire mass flows of it. So here it shows they have taken into consideration a non-Newtonian power law which is very common and simplified then Carreau as well as cross model that I mean already deliberated and in that you can see across the screw what is going to happen in terms of the viscosity contours velocity and pressure gradients. So you have to do your analysis I mean while it's no slip or with the slip what is happening basically.

But remember one thing I am considering here only the flow through the screw. So if you screw and die part you combine together you can design yourself a screw and then you ask your manufacturer or design team or they will try to make the screw design and then you try to have your own single screw extruder or twin screw extruder and that is where we pretty much lack actually in our country. But days are going to come where we will be designing our own machines and following this computational techniques. So other things processing things are elaborated are giving you more or less elaborated means although that elaboration is not sufficient enough. But again blow molding I talked about and particularly stretch blow molding giving you a recall we will make a preform first a parison I told and that parison has to be stretched and again blown to make a bottle here.

Again in a finite element way people try to model it the paper is appended here. Again they have messed it the whole geometry whole length of the bottle and as I mentioned across there will be some variegated thickness part of also in the parison itself and that is taken care of and finally a paid bottle making how is going to be designed and they have done with time I mean starting from the parison is made it stretched and blown whole course of this action at a time t equals to 0 point remember this is a very fast process 0.54 second and by 0.62 second it is blown and taken a step and during the course in a paid bottle you try to see what is the pressure what is the velocity at different times the snap shot. So that is kind of the work and you will try to design the cavity for the mold that way.

So mold design is also extremely very important and earlier it is to be again is going to be computation based design. So another one is a rim reaction injection molding is a important process I mean by the way rim is actually very close to additive manufacturing today which is adopted say for example 3D printing it is after all you have to print I mean you call it a ink the polymer which is in flown basically. So it is actually the microfluidic part of it or rheology part of it is not that different except the channel you know width. So it becomes kind of a microfluidic approach more or less otherwise it is a great dynamics after all. So again in a rim particular polyurethane is filling in inside a mold through the various channels and different profiles like a velocity, pressure, shear, viscosity and temperature can be actually simulated and therefore ultimately looking at those contours, contours means the pressure distribution, shear rate distribution, velocity distribution you come up with a better design that will give you least mold shrinkage.

In one of the numerical problems I showed you what is the basis calculating the new in a mold shrinkage. So that shrinkage part also can be taken care of so that you can design well and end of the molding you have a perfected sample easily come out release from the mold very easily. So that kind of a design is going to be the subject matter for the advanced learner and that I as I told I am going to plug in ultimately. So that way the degree of cure see injection reaction injection molding is a typical of it in unlike injection molding your job ends you try to fit in the material as far as plastic is concerned just flow it takes the cavity shape and then cool it down pressure has to be released and you release it that is what I talked about. Here on the contrary there are two processes you have to do simultaneously first of all it has to fill in and second it has to be cured.

So again you can do the mold filling for different design and you see the temperature profile or cure profile of it how after filling it is getting actually cured there. So degree of cure for two different actually mold design I mean although apparently you do not see any different but of course it is a circular it is a rectangular type of a shape close to rectangular I will not say. So how the mold fillings happening and how the you know resin volume fraction changes basically there. So that is what it is can be done. But again coming back to the extrusion, extrusion has its own complication as I mentioned it to you I already covered you know the profile extrusion that too with a single material and a you know co-extrusion process where two different materials are converging or conferencing in a single channel ultimately.

I told you that the complication of it some of the simulation that our group we have done it and using poly flow and this is appended here it is about the foam. Foam molding is important because again I mean for the rubber extrusion like you have a curative there so you cannot afford to have a high temperature. Similarly so for you know making a foam you have a blowing agent which actually decomposes at elevated temperature giving rise to some defects and some sort of a cellular structure. But that cellular structure you actually exactly do not want its initially happen. Even if it happens it should happens where is very small nucleation part should happen.

And then after it should go through it should cure and you know it should be blown. So it is a two kinetics happens simultaneously one is blowing another one is curing. So unless it is think about the situation it is not curing but it's blowing what will happen it'll try to pierce through the matrix you will not have a I mean closed set sort of a closed cell sort of a geometry. So it has to be cured so that the you know air pockets or blown gases probe gases should expand giving rise to cellular structure. But at the same time they should be isolated from one each other they should not be inter communicating that way.

So if you take it into consideration your boundary condition your consideration for the screw length everything will change. So in this example you know people they have taken certain geometries of L by D and length of the screw. And at the same time a slit die they have used and the pull up unit they have taken care of and frame by frame the polymer made two phase mixture single phase mixture nucleation in both part as I talked about nucleation is nucleation of the you know initial gas pockets and that will ultimately be blown and this is the finally form so form the form. So, these things actually has lot to do with the cell diameter cell growth number of cells density that actually decides the ultimate properties of it. So you can understand on top of the screw design I mean a small I mean a simple material like say even the rubber compounds it adds further complication.

So that has to be taken care of in that because we do profile extrusion of several sort of items starting from automotives to constructions. So extrusion of foam is a complicated process as I told you. So here you see one of the die is used in this particular work once again another journal is happened here. So initial processing parameters you know saturation condition flow modeling foam modeling inside the die and foam modeling outside the die while cure and the ultimate result is taken care of. It is a they call it console a finite element method they have developed and temperature pressure drop and matlab they have used simultaneously.

Matlab as I mentioned in this course initial is very very important the subroutines I was talking about you can easily write it there not only that the visualization many of the software does not have your own written program does not have a visualization. You do not know from somewhere whether to stop the simulation or redo it that you can figure out very easily getting a live plot using you know Matlab and that is those who does simulation often it is nothing new for them. Here they have used carbon dioxide as a probe gas by the way. So carbon dioxide many times nitrogen is also probe gas or the you know mixture of that. So they try to do a coupling between the FEM you know platform with that of the Matlab and they try to solve the simulate the foaming process you can use the Semuling as well that is embedded in Matlab.

So for example I am not going into the details at this juncture. As I mentioned it to you if you have a metal inserts both in the point of view of molding as well as extrusion is very little complicated than that of a you know molding a polymer alone. So if you have a rubber or polymer you have a metallic insert. So you may have ultimately certain cracks happening you have a contours. So you can have get as I mentioned it too often is just thumb rule wherever you have a sharp angle you try to get rid of that you can reduce the angle stress concentration will be definitely low there.

So that way it is taken care of in this particular example. This is another extrusion sort of a die and structure which takes care of metal inserts here and then with that you will get it and this is the finite element model of it while slow. And this is a molding part of it may be a compression molded items or transform molded items with the metal insert you can often make it. So you probably you understand the complication part I am talking about the boundary condition followed. These are the some of the results in terms of velocity distribution in terms of shear stress distribution with the metal inserts both in the in terms of extrusion as well as molding.

So you have to take care of various zone by zone you try to generate again the contours in terms of velocity in terms of shear stress and ultimately what you have to consider the effect of the die structure effect of the metal inserts particularly in terms of the velocity. However I mean in a molding process your metal is stationary but while in extrusion metal is also moving an angle of insertion plays very very important role. Otherwise you will have a again stress concentration velocity redistribution part that will give you excessive die swell and therefore stress concentration point. So again that particular paper is embedded appended here you try to look through and if you try to be advanced learner first. Sooner you begin better it is so at the end I will say without untiring a force of some of my you know TA's say Miss Ramya Devi, Piyush Gupta of course in the practical component Dr.

Debabrata Ganguly and Rajesh they have done a great job and you give your feedback feel free. We are going to interact in two sessions particularly and of course last but not the least the people who have recorded in the background you never see them say for example I will mention one name Mr. Rajiv Bhattacharya who was through and through very active in this event. Thank you very much.