Rheology and Processing of Paints, Plastic and Elastomer based Composites

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Lecture 44 : Introduction to FEA based computationalfluid mechanics on extrusion 1

Welcome to NPTEL online certification courses on Rheology and Processing of paints plastic and elastomer-based composites. Today we are in week 8 and lecture number 8.2. It is a introduction to FEA based computational fluid mechanics on extrusion. So it has three lectures. Today we are into the lecture number 1.

So now I was talking about other day profile extrusion. So you look it at a car body, automobile body. You understand that only the rubber part that you can see visibly from outside which is made out of rubber of course. It is not solely of course the rubber as I said it has a wire, it has a textile part.

So it is a composite basically. What you do not see apparently which is inside there in the car you have different seals and profiles and those are extruded products. And those extruded products have different types of geometries, channels and different types of material actually. As I mentioned other day it may not be a same polymer, it may be a polymer, solid polymer, rubber, solid rubber, foamed rubber, it may have some metal inserts also. So that complicates the shape and size are numerically different.

And you know what if you do not have accuracy, geometric accuracy it will not fit in. Think about your winter country. You try to put it in a geometry which is not accurate. So there will be gap and that gap will give you some squeak or noises basically. And of course in a cold country the ice will tip in if you have a gap and then you will not be able to open your door.

So not only designing extruder, better designing extruder, computational perfected design is very very important for profile design particularly today's context. If you try to design a small end car, mediocre car then it may not be that difficult as your iterative design to make a die design and then try to perfect it by iterative process, change it, again machine it, put it back and forth. But today that actually you waste lot of materials, lot of cost it incurs. And not only that end of the day you do not get the perfected design. So the computational fluid mechanics is the solution today particularly designing a die of an extruder.

Same is the case for moulds, I mean as I mentioned injection moulds, you know transfer moulds, compression moulds. And the whole gamut of plastic extrusion and you know textile extrusion spinning, spinnerets and its design basically at the flow channels. But we will rather concentrate today the profile extrusion that to rubber, why rubber? You may ask me the question, rubber as a fluid is the most complex one as you understood by now. A plastic is has a ease of flow this complication, but rubber being a long chain, longest chain amongst the polymer fraternity. So in terms of extrusion it has complication over the other, shaping is a really really trick that way.

Once you melt a small I mean small molecular weight polymer like plastic it flows not like a water, but it flows close to that and particularly at high shear rates. But rubber is seldom does so. So challenge is to cut the die, design the die so that you get a desired shape. Now not only it confined to tyre, you can see tyre this bead wire I was talking about the profile extrusion, the trade part of it is a profile extrusion part of it, and this is a wire coating where it is involved. So you see the medical tubing, so let me tell you the complication.

So a catheter or tubing making it below certain diameter is a challenge, making a silicon catheter, polyurethane catheters very small diameter, very very difficult to manufacture. Because you have to not only consider the flow of the fluid by its stability after extrusion, otherwise it will collapse. Cable extrusion and also in construction today's construction a lot many plastic extrusions are made by the process of extrusion and somewhere you have a insert like a metal or within the rubber you may have a you know plastic inserts. So that there lies a challenge and designing a perfected die for all this construction cables biomedical and tyre industry is a challenge and that is done based on computational design today. And those who have adopted fine, those who have not yet adopted try adopting it faster.

So try to see the complication, see as I mentioned it to you if you go through a extruder let us not take into consideration other part of it, let us just zoom it out here that means die line and die. After that if it's a rubber you have a whole gamut of curing, if it's a foam curing and expansion I am not going into the complication for this time being because it is for the beginner and intermediate again. So this is a extrusion channel and finally you are making of a desired shape you are cutting it. So for tyre extrusion this curing part is not there obviously you are trying to make a bead wire and that again you have to make it in a tyre building drum. So you just what you do you cut it at a definite length basically so that is what is represented.

Forget about this all curing part of it. As I mentioned it to you let us try to understand schematically let us concentrate on you know this all this different channels there is a die land and metering zone it is slowly entering into you know the die finally these are the die lands. You see here you have a angular entrance to the die ultimately and this is the die leaf from where you are getting it out. And schematically you can see the one of the complication I told you several times I do not want to repeat it again. So you have a entangled polymer mass that is getting straighten up, straighten up, narrower the channel is going to more straighten up so uncoiling happens and then again it releases pressure drops it coils back.

So that is manifested in the form of die swelling. Now let us try to understand the problem associated with rubber extrusion. So we are into rubber extrusion not in unlike a plastic extrusion or soft metal extrusion like lead we are not going into that that is much easier let us assume. So what are the problems what are the complications extruded swell I told you several times. Then rearrangement of velocity profiles of the polymer leaves the die that is very very important last class also I believe so I have talked about that.

Uneven die body temperature, die body changes that means viscosity changes, velocity changes, slip changes, so all together a change paradigm basically. In sufficient mixing in the extruder I mean of course for the time being we are not considering the left part of it where all these things are happening mixing, vortexing everything. Non-uniform swelling as I mentioned that you recall garvey die why it was different you know corners just to understand better understand the swelling behavior that can be compensated with the velocity that can be compensated with the temperature as well. Then the high viscosity, high viscosity is always always a problem. Remember when I talk about a extrusion I mean a shear rate of 1000 second inverse or around.

When I talk about injection molding I am talking about 10,000 second inverse. So rubber steel has a sufficient viscosity and not only that after extrusion of course you are cooling it down but it should have a dimensional stability otherwise   all these geometries you make it, it is going to be null and void it is going to be collapsing. So these are the some of the intricacies of a unit process you must understand. So in order to do computational based die design what are our objective first to develop a possible strategy for effective die design. I will show you with certain examples of dies.

Study the die swell behavior of the polymer and to predict the optimum die profile shape and dimension. Now this is what is necessary. So you just computationally design it, give it that CAD file to the you know tooling room and they will make a die out of it. So that is the dimension I will give it. So that particular die I will prescribe this sort of a geometry you will be able to make given this compound details.

So study the swelling phenomena and the mass flow balance affected by different parameters like I mentioned die length, flow rates. So this flow balance fluid mechanical part and most importantly as I mentioned it to you your fluid is not very easy. It is a 4 parameter, 5 parameter type of a fluid and you have a set of momentum balance or mass flow equation. You have a set of you know heat transfer equations. You have to simultaneously solve it because remember one thing as your temperature goes high viscosity changes.

So flow also changes. So unless you just consider the flow in isolation to the temperature effect. It is a wrong design anyway. So study and understand the overall polymer extrusion process and integrate the simulation results with the experimental data to optimize the die design and ultimately to achieve better quality dimension of the, that is the bottom line and prepare the complete design of the die. So you as a technologist what you will be doing if you understand this, if you are expert on this, your manufacturer says look this is the product, this is the dimension you have to come up with for extrusion say.

You consider it continuous. You give me a die for this given type of a material. These are the conditions and you do take care of those essential of the fluid flow. Do it in your computer console. Export that geometry and profile geometry to what is going to be your die geometry to in order to have that profile ultimately. So this is you will be the expert for that and you will be paid for that having this expertise.

Make sense? Now what is the challenge? See I have a compound which has 0 PHR carbon black. Let us say you have a 10 PHR carbon black. I have 20 PHR carbon black. So I have a variegated, obviously the hardness of the material. So but still with the, so rheologically they are going to be so different then.

0 PHR, 10 PHR and 20 PHR. But you have to make the same dimension. What my point, the challenge? Because they are differently filled, their flow property, rheological characteristics is whole lot different but you have to make a die which will ultimately give you the similar profiles. Or you end up having three design of the die with this compound, this die is perfect, this die is perfect, this die is perfect. So this is the complication. How does rheology plays important role there? Meaning design, cost, production rate, product quality.

So you have to look it into some of the parts of it. Surface distortion is one of that. If you make a dimension but if you have surface distortion nobody will buy your product for sure. Strength is important criteria. You have done the extrusion but there is a non-uniformity.

It is not isotropic. Then structure, development and safety. I talked about already bamboo effect and all. So in the sea, in the sitting material how it looks. And this is the aim and you have this distortion.

So those are not acceptable. You see here you have huge melt fractures while you have the very very very good extrusion. So your again point of view will be having how to have a perfected dimension and so that correct rheological characteristics you have to pick choose. Although I am not going into that this is the cross section of it. You understand how complicated it is, corrugated. You have a closed loop that is also fine but if you have open loop structure.

So when open loop is coming out through extrusion if you have a slightest imbalance in terms of flow they will try to get rotated. That rotation, additional rotational force will be introduced. So you do not have, you have, you are going to have distortions like this. So there lies the problem. So in order to achieve weight reduction of the compact part of course foam is very good.

Foams are very good for thermal insulation etc. But at the same time in comparison to the compact polymers such foams lead to a significant reduction of raw material, decrease thermal conductivity as well as mechanical properties. The problem is that how you make a foam? You have a blowing agent. So that blowing has to happen after you extrude. So that means whatever shape you make, pre-shape of the die and that shape like a parison because you have to take another blown out form that has to be taken into the design addition also.

I am not going into that foam design right away of the die. So it is further more complicated that way because that expansion part in addition to dies swell will come into the picture, into your consideration. Now problems and remedies associated with foam extrusion. Let us try to understand. I mean still various screws can cause gas loss.

And then fine screens can disrupt the foam structure. You see screen you have end of the day. So you have a contradiction. A conventional die not optimized for foam can produce eddy currents that will create ultimately pressure drop. Then according to this sort of a problem where you can see carbon deposit problem, the pressure drop in a conventional non-foam die causes premature foaming before it exists.

So you already have muscle as you have already have spices there that is the blowing agent. So if you have a little thermal imbalance before you get the final shape it has to blow out. You do not want blowing at that stage. A properly designed foam die offers streamlined passage leading to the direct exit to the die. So this is kind of a design that gets rid of all these eddies, carbon deposition, premature blowing, etcetera, etcetera.

So for the time being let us not consider that. It further complicates the situation. But for a regular simple polymer extrusion what are the problems associated with? Sticking to the screw. I mean I am considering little bit before the die at this stage. Because everything will be incomplete if I do not take it into consideration. So due to the green tack property because tack you need because after extrusion you are trying to assemble it.

So if tack is not there your bead wire, bead portion will not fit into the entire assembly of the tire which actually will take the load basically. I mean fit it to the rim. And then dusting of the compound with the talc. See in order to in the processing stage get rid of the tackiness.

Tackiness of course you want. You use zinc stearate or talc on the compounds. So that is also we will try to invoke other problems. Torn edge is a problem when you do not have a sufficient strength in the material as I mentioned it to you. You extrude it but still it will not be, you remember one of the garvey I was showing you the edge was not good particularly 234 or 224 that variety of 324 I suppose so was giving you a torn edge. So it is insufficient reinforcement is responsible for that.

Loading higher proportion of filler may suffice solve the problem. Incorporation of some resins can solve the problem. So these are the some of the problems which we can really circumvent. Then rough surfaces due to improper mastication of the rubber inferior or poor rubber blending presence of agglomerates. And of course if you try to see any patches repetitive flaws is due to the dead spot.

That means you have a dust sticking to the dye or somewhere. So increasing die temperature may solve the problem many times but not always. So these are the throwing back, flash back what I taught you already about the extrusion. But let us try to understand the problem.

Let us try a try to see this sort of a design. That you are extruding this line says we have already missed that by a finite element way. I am not going to the details again for the finite element. But nonetheless when it is coming out from the die leaf you see there is some sort of a rotation happening. And it is a open loop structure and they try to rotate basically and collapse finally.

So let us read it out. In any of the molding process the most important equipment is the mold again going back to the mold. Therefore molds are carefully designed and finished to get the products correct dimensions of surface finish. That is also true for molds also.

Not only in die. We are in the context of die today. So it is well known that materials deforms right after a die leaf. You see here it is happening. And the extruded shape deformations are the key issues for the die designer. If the die shape has to avoid and compensate for undesired phenomena.

Let us try to understand one by one by one. We are not using the same material always. It can be a combination of material or a single die multiple material may not be possible. Again see depending on the material you are considering the extruded shape differs. And for a given material different grades will lead to different rheological behavior that you must understand.

And your company manager must understand. Two compounds having 5 PHR of difference of filler rheologically they are different. And you see after exiting through the die I see that swelling and deformation. And you see the blue one and you know this one this is the die shape the magenta one. And ultimately what you are landing up with the black shape.

It is full whole lot distorted shape. This is going to the die swell phenomena. As I mentioned adherence is very very important. See as I mentioned at your slip when I talk about a slip on the wall the velocity was minimal. If you have a slip it is not going to be minimal. So if you introduce a slip you are leading towards a uniform velocity that way.

But on the contrary if it adheres then it is almost close to stationary. But worst part is stick and slip. I talked about while talking about extrusion. As a result if this is the die shape you see what happens the comparison extruded difference see slip coefficient.

Just slip coefficient we are considering. So full slip is the red one. You see you are getting almost perfected cross section after extrusion. But if you have a complete adherence the blue one what it shows all this deformities because of the non-uniformity of velocities. See now you consider this velocity profile from the die lip. this is the die land and this is the dye lip and this is coming out. And now at some point of time try to see the velocity at the central position from the metering zone faster particles.

Let us say particles or the I am trying to say not only particle polymer with the all its ingredient flowing the mass flow I am considering. So at the stationary walls velocity is minimal. At the center velocity is high. So if it remains here you can understand what is going to happen is going to be swell more in the higher velocity size. So I have to make a design of the die and die land in such a way that after it exit through the die lip it must have uniform velocity no imbalance in terms of velocity.

So that how do you do it? Either you play with the entrance angle. As I mentioned different geometries different you know restrictions. So accordingly try to have a longer die land. So that is how it can be compensated. And of course the wall slip not only by angle by choosing different material of construction of die you can actually achieve that. But ultimately bottom line is that I have to have a uniform velocity in my design of the die and die land.

So velocity redistribution is very very important. So I have what I mean by velocity redistribution. So this is the distribution I get it. So redistribution has to happen within this channels and I have a uniform distribution of velocity that is the bottom line. And consider if it is a coextrusion duplex or triplet where you have two or three different polymers are getting extruded. So it gives you rather more complication think about when these two polymers are submerging at a single line of flow one is running at a higher velocity another is a less of velocity.

So interface will be distorted. So slow particles must speed up to reach the constant extruded that is the most sluggish person is like you are teaching in a class you are very brilliant person goes very faster than you teach. And there are some people who receives 10 percent what you teach. So you have to make a mechanism at least to take them to certain uniformity of course, there will be certain deformities in nature one will be faster anyway two will be faster anyway. So if you have a gross velocity or average velocity you have to take it into consideration it must be as uniform as possible by playing with the temperature by playing with the pressure by playing with the geometries by playing with the other parameters. So local contraction the first particle will slow down to a constant extruded speed and slower speed is reached by increasing locally the flow section that is what I mean by velocity you know.

See here see if you have this sort of a die see you as a result its flow is more you may have a contraction here. So ultimately what you try to see from this die design is going to be entirely different that you get ultimately. So ultimately you have to have a flow balance and this is what I was talking about induced torque specially for the open loop structure. If you have a closed loop structure it will never happen but if you have a open loop structure there will be sufficient chances because of the high velocity, low velocity, velocity distribution there will be obviously a induced torque and this imbalance comes from the again from the velocity imbalance basically and those are called instabilities of extrusion.

So again you try to see bad design or a good design in terms of velocity. So again the same design you remember last lecture I talked about this sort of a design just again have a symmetry cut out this part so you end up having this. See you are having if you happen to have this sort of a structure and same die length you end up having a velocity profile just like this velocity here is the maximum here is the low but if you can make it at a split angles angular entrance I am not playing with the die length here what I told you earlier just angle up entrance. So I have a velocity distribution almost both the extremities similar. So velocity difference is less see what happens if you have a bad design good design this is the bad design and slowly you end up having playing with the die length and die entrance angle you pacify you have a uniform products. But it is up to you whether you can afford to have a more die length in your design or you have a angular entrance that way you can take care of the mass imbalance that was happening.

So hope it gives you some idea how we can take care of let us try to see next class how we take care of in a computational method. So how to reach our goals goal is again having a perfected design with that die whatever shape you desire that you are going to get. So in order to do that how you do that understand the kinds of flow and deformation effects exhibited by a complex system and observing this very system. So rheometry I will take it forward from there to understand what type of a fluid it's that fluid I will put it in I will try to see the velocity distribution and that this velocity distribution I will try to make it as uniform as possible with my finite element methods and CFD methods. Taking into consideration mass balance I mean momentum I mean mass flow as well as your you know heat transfer part of it.

So that is how we are going to achieve it and let us stay tuned how we are going to do it in the next class. Then some of the references of course I will be demonstrating the poly flow part of it I will of course acknowledge to them because our IIT is licensed to the ANSYS platform as well. So I will be using for the demonstration purpose of course with giving due credits to them. Thank you up to this see you soon next lecture.