Theory of Production Processes

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Lecture - 36
Extrusion Process: Classification and Analysis

Welcome to the lecture on a extrusion process. So, we will discuss about the classification and analysis of the extrusion process. So, extrusion is a very important process in metal forming, where you have the billet and from the billet you try to extrude the cross sectional mix mostly axis symmetric type of cross sectional products, like you have rods tubes and all that they are extruded. So, what we do in extrusion is that you have a block of metal and that is reduced in cross section by forcing it to flow through a dye orifice under high pressure.

So, in the earlier cases when you have to convert the block of metal into the lower cross sectional products, then you can go for the use of hammer or press. Mostly you go for open dye type of forging, where you apply the force from the top dye and then that will convert that we reduce it is cross section and increase it is length.

So, that way you do it know even you can go for rolling sometimes and if you are making grooves in the rolls and you are trying to push the material through the rolls, then you can get certain shapes. Now here extrusion is another process of forming; where what we do is depending upon the shape of the dye or depending on the cross section you want you have the dye and that will be at one end and from the another end you are forcing you are giving the pressure from one side on the block it is of metal itself normally it is heated.

So, you are basically applying; now what happens that at the corner of the dye you have the stress state in such a way reached that there is plastic deformation and because of that the metal basically because of the pressure, it is tending to go out of that particular you know dye. So, it will go out of it and then you can take the hollow bars or I mean hollow tubes or cylindrical bars of length. So, depending upon the stock dimension, you will get the different dimensions different length of the bars or tubes.

So, it is a forming process and in this case you are getting the better product property because the metal is forced to pass through it. So, in that case it is a type of hardening process and every advantage of a forming process is achieved, because metal is plastically deformed and so, all the advantages related to forming like you have better mechanical properties like welding of the you know cavities inside, and then strength improvement all that occurs. So, this way your property becomes better. Now the thing is that most of the metals are hottest to date only because of the sense that when we do the hot extrusion at that time the flow stress requirement, the pressure which you are applying that will be required is less.

So, that is how most of the peoples most of the metals are normally hot extruded. Now if you talk about the extrusion process, in that you have hot and cold extrusion. So, again it is same way based upon the temperature at which you though do the extrusion. So, if you do the extrusion in the hot working range, then it is known as hot extrusion and if you do in the cold working range then it is the cooled extrusion. So, cold extrusion is also done for smaller parts that we will discuss and then hottest result mostly is the one which is used. So, it is based on the working temperature, this classification is based on the working temperature. Then you have the different types of you know extrusion processes. So, first is the direct and indirect extrusion.

So, direct extrusion indirect extrusion impact extrusion, had the static extrusion, these are the different varieties of extrusion processes; what is the direct extrusion? So, director extrusion means when you apply the pressure, the metal will flow through the dye cavity opening and if the direction of the application of pressure and the exit of the you know a student bar or tube or so, product is same.

So, if you are applying the pressure like this, and the metal also extruded is going in the same direction then you call it as the direct extrusion. So, you are applying the pressure and then the metal is moving, in that case the ram which is on which you apply the pressure or billet is there. So, it will have it will be pressed, and then that way the through the opening from the other side from that. So, you have in between the billet and then it will be pressed and so, the metal will be extruded from that and then in the same direction the metal will be advancing after extrusion.

So, that is a case of direct extrusion. Now there is a indirect extrusion. So, if we look at the figure.

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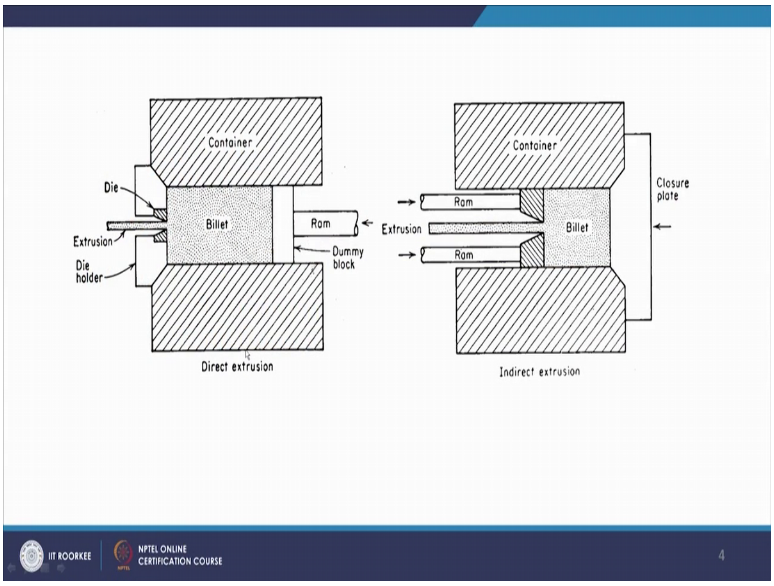

So, you have the, this is the case of directors extrusion. So, the billet is placed in the container. So, this is the container and you have the billet placed here, and then this is a ram. So, the ram is here and you have a dummy block or you also call it as the pressure plate.

So, this dummy block or pressure plate it is there in between the ram and the billet and then that is used for applying the pressure on the billet. Now in in that you have the dye here and you apply the pressure here and the metal will be extruded from this opening in between the dye. So, this is a dye holder and this is supported you know. So, it is housing the dye, and then the metal will be extruded from this portion and then you get the extruded product.

So, this is the case of direct extrusion as we discussed where the application of pressure is in this direction and around the extruded product is also moving in this direction. So, they are having the same direction. So, that is known as direct extrusion product. Now in you have the indirect extrusion. So, by definition indirect extrusion means the pressure in which direction you apply, now in this case what you see is that the, you are moving in this direction. So, you are applying the, if you see that pressure is applied in this direction and then the ability is pressed and the extruded product is coming in the in this direction. So, it is opposite direction. So, that is all it is name is the indirect extrusion.

So, this is. So, here what is happening is, you have a hollow ramp and the metal will come in between the ramp. So, you have the hollow ram you are applying the pressure and in between you have this dye opening here, and the metal will come out of it. So, the container will be closed. So, you have a closer plate here in this case you have this is a closer plate, and then you apply.

What we do in this case normally that the ram which is containing the dye now in this case. So, that will be kept stationary and then the container and the billet. So, this one will be moved. So, what happens there is no you know relative motion between the wall of the container and the billet surface.

So, here in this case here actually there is friction between this village surface and the container surface, but in the case of this indirect extrusion, you have this whole unit is moved in this direction so, that there is no relative motion between these two. So, there will not be that way the friction frictional forces are basically lower as coming. So, in this case you have to overcome the frictional forces, when you apply the pressure the frictional forces are moving in the opposite direction.

So, you have to apply extra more pressure extra force you have to supply, to overcome this you know frictional forces. But in this case as you are this is this whole assembly here this will be moved in that case. So, you do not have that frictional forces present and that will be having a lower value and so, power required for extrusion that will be also be smaller. So, this way the indirect extrusion is you know carried out. Now what happens that, when you have to make the hollow product. In those cases you have to apply a mandrel and this mandrel will be kept at some place and then once you apply the mandrel then the clearance between the mandrel and this dye. So, that will be the thickness of the hollow portion.

So, this way from both the sides the extrusion will go ahead and this way you will get a certain pipe of certain thickness. So, that way use of the mandrels are required your or are advocated for finding these hollow products getting extrusion. So, that is known as the clearance. So, clearance between the mandrel and the dye wall basically technically we call it like this, that the clearance between the and the dye wall. So, that basically will be giving you the thickness of the wall of the tube. So, that way you get such kind of you know product. Now you have another type of extrusion that is known as impact extrusion.

So, as the name indicates in this case you have you make the smaller portions of hollow shapes. So, that way you allow this impact force to go on the seat and then in the opposite direction, the extruded the portion will be you know formed. So, normally for making you know the collapsible tubes toothpaste and all that, this impact extrusion is used. So, this is normally performed on a very high speed type of mechanical presses.

So, this impact extrusion is that we categorized another type of extrusion process which is common is the hydrostatic extrusion.

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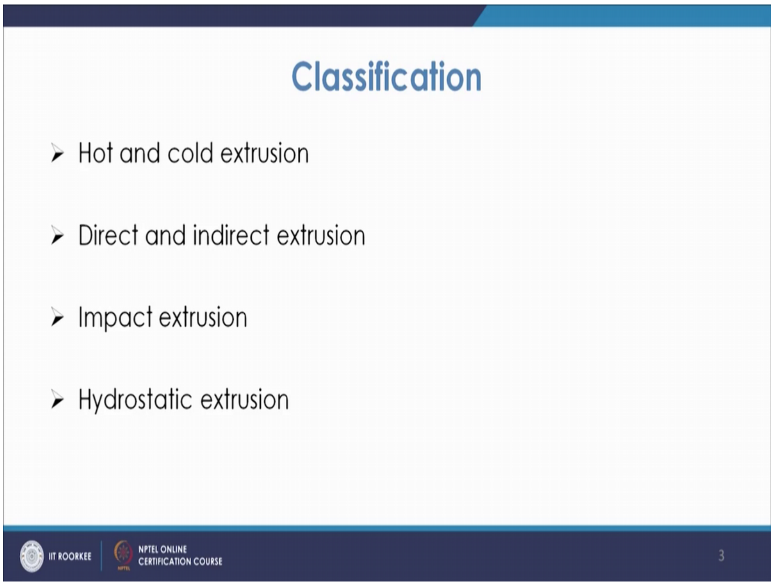

So, in the hydrostatic extrusion what we do is, that the pressure basically is applied the hydrostatic component of stress is used to apply the pressure. So, this way the lubrication which is there the lubrication is better in that sense and. In fact, this says that even and the brittle materials also are extruded in that case because you apply the hydrostatic pressure, and then that because of that pressure of the metal is confined to go through the opening.

So, even the brittle materials also are extruded with the use of this hydrostatic extrusion. So, here what happens you have a geo static fluid, this fluid is applying the pressure from all the sides and then that allows the metal to have a pressure experiencing the pressure. So, that it passes through the opening.

So, that is the case of hydrostatic extrusion. Now we will discuss about some of the terminologies of the extrusion process. Now when we deal with the extrusion process then typically we are going to deal with that the area of hottest extrusion. Now in the case what we have understood that you have one area of billet and this area is converted to another area of smaller dimension. So, A naught will be converted to A f. So, you know if you look at that. So, your A naught a is the original area.

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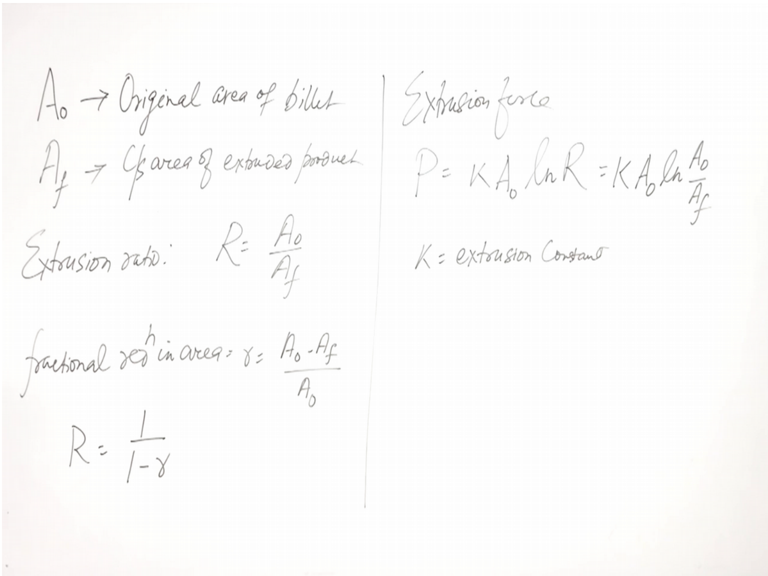

Original area of billet and if A f it is the cross section of area of extruded product. So, final area basically f means indicates the final area. So, basically the ratio of this A naught and A f that is known as extrusion ratio. So, the term extrusive ratio refers to R as A naught by A f. Now if you have discussed about the fractional reduction in the case of if you recall the definitions of the term like fractional reduction in area that is small r.

So, fractional reduction in area, area it is basically r. So, it is A naught minus A f by A f. So, what we see is it will be A naught by f minus 1 that way. So, you get that this is not A f basically this is A naught. So, from here what you see is you can find R will be equal to 1 by 1 minus r. So, if you do 1 manner by 1 minus r it will be, 1 minus r will be 1 minus 1 minus A f by A naught and then. So, that is why it is A f by A naught and then if you do the inverse of it. So, it will be A naught by A f. So, this is the this x to some ratio term will mostly be coming in the case of the extrusion. Now what has been seen is that in the case of extrusion the pressure which is applied, it is normally directly related to the natural log of extrusion ratio. So, basically the pressure is equal to you know that will be proportional to the natural log of extrusive ratio.

So, the extrusion force will be equal to. So, it will be proportional to area multiplied by that natural log of the extrusion ratio. So, as to some force. So, this will be a constant times area multiplied by because you are talking about the pressure, pressure was directly proportional to LNR. So, r is nothing, but A naught by K and this k, K is known as the you know x to some constant and it will be covering all the factors. So, these factors are like for the flow stress friction or inhomogeneous deformation.

So, you can further write it as K a not l n in not by A f and K is extrusion constant. So, it will be depending upon these factors like flow stress, frictional conditions and you know the inhomogeneous deformation all that taken into account this m and the value of K will be varying. Now further the extrusion for extrusion to go on, you need to know that at what temperature you should do the extrusion. So, there is certainly the upper limit of the temperature at which you should do the extrusion and the upper limit is basically governed by the temperature at which the hot shortness occurs.

So, we have discussed that when the temperature will rise, it may lead to a temperature K mean at the stage when the hot shortness will occur near the melting temperature. And in case of metals basically pure metals this is the melting temperature of the materials. So, in that case and when we talk about the alloys you have different phases. So, some of the phases may get melted at certain point.

So, in the case of pure metals it is the melting point. So, basically you have to be I mean aware that the temperature should not reach near the melting temperature of the body. So, that is the workable range for the extrusion processes, you cannot oh to lower values also because in that case the flow stress requirement will be quite high. So, you have if you go in that upper range in that case the flow stress requirement will be smaller. So, that is how you have to see that how you have to do the extrusion. Now we will be doing some analysis of this extrusion process.

Now, what we see in the case of extrusion you have you must know that how you will find the extrusion pressure or extrusion force. So, if you use the uniform deformation energy, but you have been we have discussed or we have basically we had highlighted the different approaches by which you do this analysis the approaches, we are like slab method you had you had the deformation energy approach, you had the slip line field theories.

So, these are the different you know methods by which you do the analysis and then you try to find the expression for the stresses and the forces. So, if you use the uniform deformation energy approach, in that case your plastic work of deformation per unit volume that you can find as the average value of the stress. So, mean stress and then integral of the epsilon.

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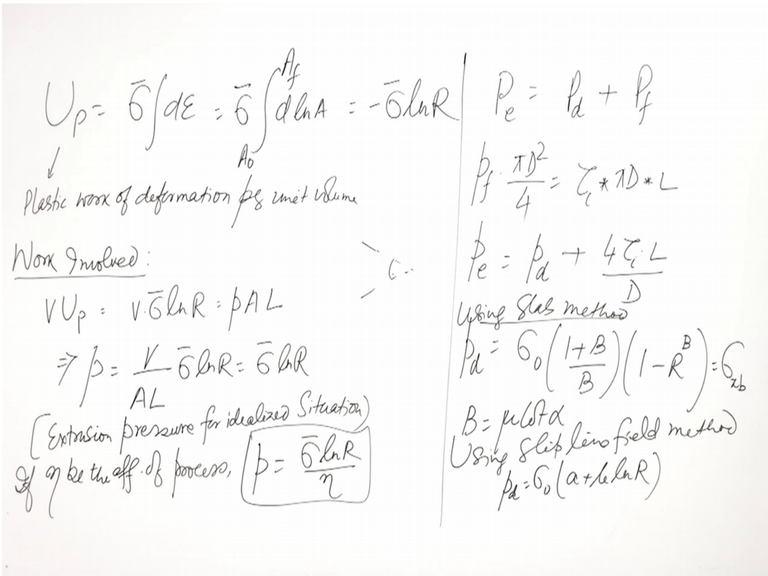

So, your U p, U p will be this one and the epsilon. So, that is your expression for basically work of deformation.

So, that is plastic work of deformation per unit volume. So, this is your plastic work of deformation per unit volume there is nothing but the, if you look at the energy of this stress strain diagram you have. So, this is nothing, but the area under that.

So, if you take the average value of this stress, then multiplied by integral of d epsilon. So, that way you can find this now further you can write. So, that will be sigma bar. So, that is your average stress then then that is the epsilon you can do as l n of a. So, that will be n or 2 f. So, it will be d of l n A and A is varying from n or to A f. So, that is how you define the true strain. So, true strain is is that and that can be again it will be d of l n a. So, it will be A f by A naught. So, A naught by A f is the extrusion ratio. So, you can write minus of this and l n of R.

So, this is how you get the plastic work of deformation per unit volume, because it comes as A f by A naught and that will be. So, l n of A f by A naught it will be nothing, but minus of l n of A naught by A f, and A naught by A f is the reduction ratio. So, extrusion ratio basically. So, that is how it comes as minus of sigma bar l n of R. Now work involved will be basically U p multiplied by v that is volume.

So, U p you have been knowing. So, it will be v of multiplied by you know sigma bar into l n R. So, that will be coming. So, you look at the work involved. So, it was per unit volume. So, it will be v times U p. So, it will be v times sigma bar ln R. Now if you look at this value this will be nothing, but the pressure and multiplied by area. So, that is force and then and force into distance is the work done.

So, you can further write it as pressure multiplied by area and multiplied by distance. So, that is nothing, but the force into distance. So, that is what the work is done in in driving that much. So, you are basically not considering the friction into account you are assuming that there is no friction. So, the pressure applied multiplied by the area over which the pressure is applied.

So, that will be force and then how much distance you are covering. So, that is l. So, this way you can have this equated. So, pressure can be computed from here and pressure will be equal to v by a l into sigma bar l n R. So, it will be pressure will be V by A L and then sigma bar l n R. So, this is what you get the pressure and it is nothing, but V by A L is nothing, but the volume. So, that is sigma bar l n R. So, this is the pressure that is known as extrusion pressure for idealized condition. So, this is the extrusion pressure for idealized situation.

So, you are neglecting basically the friction at this point, because you are assuming that there is no friction. Now if the efficiency of the process is eta in that case and the pressure will be this much divided by eta. So, if eta be the efficiency of process, now because of many parameters because of many conditions the efficiency will be less. So, in that case the (Refer Time: 26:48) p pressure will be sigma bar l n R divided by eta. So, this is how if you know the average stress value, you know the extrusion reduction extrusion ratio and if you know the efficiency of the process in that case you can find the expression for the extrusion pressure that is sigma bar into l n R divided by eta.

Now, there has been the prediction of these extrusion pressure or force differently by different kind of researchers and one of the researcher was d pyre. So, basically he has shown that he has what he has tried to say, that the total extrusion pressure it should be equal to the dye force that is you know extrusion force total pressure p e capital P E it should be equal to the because of the dye force that is p d, then you have the frictional force between the container liner and the upset billet and then also you have other terms like you have a container liner and the follower.

So, they are there. So, that basically we are neglecting. So, basically the buyer has tried to show that according to him the total extrusion press force P e should be equal to P d plus P f. So, so P d P e total extrusion force it will be equal to dye force because of that and then because of the friction. So, this friction is basically between the container liner and the upseter upset billets. So, billets, which is upseted it.

So, there that friction which is acting because of that although there is another term of friction and that is basically neglected. So, this is the expression for this is the consideration which was done by the d pyre, and now further if you assume that the for the billet the frictional stress will be equal to tau I will be K in that case. So, you will have p f into you know pi by 4 of d square, that is it will be equal to you know pi d. So, you will have the diameter and your tau I is acting. So, pi d into tau I into l. So, that way you are getting the expression for that. So, this way P f you can have the expression. So, p f into pi D square by 4 which is acting, on that basically then that will be equal to further you have if you are taking that as equal to tau y. So, so tau y frictional stress will be tau y that is equal to k.

So, in that case this tau y will be multiplied. So, that frictional stress this is acting on the peripheral side. So, peripheral side will be pi D, and then that is multiplied by the length of extrusion. So, this way you are getting the expression. So, if you look at that. So, total pressure I mean P e if you look at p will be P d plus p f. So, p f will be tau i into. So, this pi will be cutting. So, there will be 4 into tau i into L upon D. So, that will be that. So, if you look at the pressure term P e. So, this is the force this is was the first component, if you talk about the pressure component this will be basically.

So, you will have the dye pressure which you are applying, then you have this will be going to this side. So, 4 tau i that will be tau i is equal to K, and then this pi and this pi will move this d and this d will move. So, into L upon D. So, this is the expression for this small p e and a small p d. So, p d that is your dye pressure, now the tie tau I it is basically the uniform interphase shear stress between billet and the container liner.

So, that is your tau i. So, that is basically the interphase shear stress between the container liner and the billet. You have l is the length of billet in the container liner and d is the internal dia of the liner. So, this way you can have the calculation of the pressure and once you calculate the d, and p and p d can basically be measured and you can find the frictional value of the shear stresses.

So, once you get that you can find the extra some forces. Now this dye pressure p d can be calculated using the slab analysis where you we have already done the slab analysis and where we assume the homogeneous deformation and basically that is same as that for obtain for the wire drawing or so. So for that basically p d is computed as the expression that is a sigma of x b and that comes out as sigma naught multiplied by 1 plus b by b, b mu cot alpha and then that is one minus r raised to the power b.

So, that this expression we will further see in our coming lectures, how we find that earlier we have done the forging strip analysis, and then once we do the wire drawing analysis there we will do the this expression. So, this p d can be obtained using this slab method. So, p d can we can have the analysis we will see the analysis later on when we do the y drawing, and that will be basically equal to sigma naught multiplied by 1 plus B by B into 1 minus R raised to the power B. So, and B is basically mu cot alpha.

So, alpha is the semi dye angle and that basically will tell you. So, this is nothing, but also this is also known as sigma x b. So, that here we must know all the terms b is mu cot alpha, alpha is the semi dye angle. So, the dye which is there it will have certain angle. So, like the dye is going like this. So, this will be semi dye angle. So, here from you get this alpha you know that is semi angle and then b we know mu is the certainly we know that mu is the coefficient of friction between the liner and the billet.

So, this way you get another using the slab method of analysis this has been found. Even using the slip line field theory methods it has been suggested that p d is basically sigma naught multiplied by a plus b l n R. So, this is using slab method and using slip line field method, you can have p d as sigma naught a plus b l n R. So, this way and we have different values for different semi dye angle. So, for that basically a and we values you have to take and accordingly you can find the value of p d.

So, this is how you find p d you should calculate that then you can find the extrusion pressure. There has been another you know expressions also using the upper bound and lower bound methods and that further again comes out as sigma naught multiplied by a plus b l n R and then you have the extra term that is plus m K cot alpha into l n R.

So, that these expressions can be you know seen and according to that you can find the this expression for the extrusion forces. Now many a times when we talk about the extrusion. So, we have also the concept of strain rate many a times and then in that case the velocity you know comes into picture or the strain rate basically comes into picture. So, in that basically the average strain rate is found out and the average strain rate you know average mean strain rate is defined and that is basically defined as equal to. So, that is computed and that is equal to 6 times v and then multiplied by l n R by d b.

So, that is how this mean strain rate is also defined and this way you can have the effect of strain rate analysis also in the case of these extrusions. So, you can this you can further study this effect of this mean strain rate, how that mean strain rate is computed and if you have the values of all the parameters the mean strain rate can be computed basically you have the auto dial for entire or and inner I mean initial dia, and based on that basically you can see and you can use these values further and doing some simplification analysis. The average mean strain rate is computed and that is further used when we do the extrusion analysis. So, this is about the cases of hot extrusion you know analysis then you have the cold extrusion as we discussed. So, the cool extrusion is basically something like cool forming of the stock or bars.

So, that was necessitated while during the world war two the steel countries cases, that was required to be you know manufactured. So, in that time this cold extrusion process was basically developed and started, and you know in the case of cold extrusion you require to have proper lubrication.

So, that zinc phosphate or soap they are used as the lubricating medium for the coolest to some cases. Then we already discussed about the hydro static type of extrusion. So, these are the different aspects in extrusion analysis you can further read from the book of George dieter or other standard books.

Thank you very much.