Advanced Concrete Technology
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Lecture – 26
Fresh Concrete - Part 1

So, today we will begin the subject of the fresh concrete behaviour, of course, this is something that you know quite well about, you also done experiments to measure the workability of concrete through different techniques, you have tested the setting time of cement but not many of you would have tested the setting time of concrete. Any idea, how you test the setting time concrete?

You have to sieve the concrete through 4.75 mm sieve, to extract the mortar from the concrete and use what instrument to determine the setting time; you use a penetrometer, you use a concrete penetrometer, which is used to determine setting time, it is done on the mortar fraction that is sieved out of concrete; wet sieving is done of the concrete and you determine the setting time, you have to realise that the setting time of concrete and setting time of cement may not be the same.

Cement as we tested as per the normal consistency and Vicat apparatus and so on, in the case of concrete, you are testing it in the presence of aggregate, so it is going to be quite different as compared to regular cement paste itself, so the values that you get for concrete are usually going to be be much higher than that for cement. When cement sets typically in 2 to to 4 hours, the cement and concrete may take a little bit longer to set.

It may take about 4 to 6 hours, that would be the typical initial setting time of the concrete, so you need to understand that penetrometer test can be done with the concrete that is supplied on site, you do not have to rely on the setting time of cement numbers, what are the tests do you think can be done? Slump retention, workability retention, of course that is again repeating the workability tests at different intervals, just to understand how long the workability can be retained.

But that is something of an extension of the workability tests itself, in some cases you may also want to look at the rate of hydration of the cement or rate of strength development of the concrete, in other words rate of hardening or stiffening of the concrete and that can be done using some techniques like the maturity method and that is an interesting technique, we will not talk about this in this course but I just want to bring that out.

Maturity simply talks about measurement of the temperature of the concrete as it is hydrating, you know that concrete will; cement will evolve liberate heat, when it reacts with water, so when you study the temperature of concrete over time, it gives you the ageing of the concrete that is why we call it maturity of the concrete and the more the concrete matures or ages, the most strength it will develop.

So, by just monitoring the temperature of the concrete, you can study the maturity, so what are the tests are done in fresh concrete; measurement of temperature, so you need to measure temperature. When is temperature critical; as far as concrete production or placement is concerned? Placement in extreme conditions like cold weather or hot weather, you need to ensure that the temperature of the concrete is controlled carefully.

Especially, for mass concrete when you are facing the difficulty of temperature rise with the concrete, which can cause thermal cracking, control on the early temperature of concrete is absolutely essential and that is generally brought about by the use of low heat cement is one option or you can reduce the temperature in the concrete itself, how do you get that? Low heat cement is to reduce the heat of hydration over a long term.

And to reduce initial temperature, use ice, instead of water, we use chilled water or ice to ensure that we down in the temperature range. Now, of course you also have to worry about how this concrete will develop heat as a cement hydrates, at what rate does the heat develops? So, you need to also do apart from temperature measurements in the early stages, you also need to do the calorimetric measurements in the fresh concrete.

So that is the another study that you may want to do in the fresh concrete, so already we have talked about workability, temperature, we talked about setting and then calorimetric studies to understand the rate of heat evolution from the fresh concrete. In a mass concrete structure typically, you will be; if you are contractor doing a mass concrete structure, you will be asked to put up a mock up structure of at least 1 cubic meter, where you place the same concrete.

And show that the core temperature is not exceeding the limits specified or the differential between the core and the surface temperature is not more than 20 degree because that is crucial from the point of view of thermal cracking, so if you can maintain the differential between core and the exterior to less than 20 degrees, then you achieved a good quality concrete which will be having less potential to crack.

So, all these aspects are important as far as fresh concrete is concerned, of course this is something that is more practice oriented, what we will discuss in this chapter here are some topics which are aside from that, we will talk about how best we can understand the flowability of concrete from a scientific perspective primarily by studying the rheology of the concrete and how we can use that to do an appropriate mix design for special concretes likes self-compacting concrete.

So, of course the sections in the textbook are given here from which you can study about fresh concrete, there are basic issues which you already should know about different types of workability test, the setting time determination and so on and so forth, so workability you all know is the ease of mixing, placing, compaction and finishing of the concrete. So, of course by the very definition it seems to be intending to solve a whole lot of issues by just measurement of one parameter.

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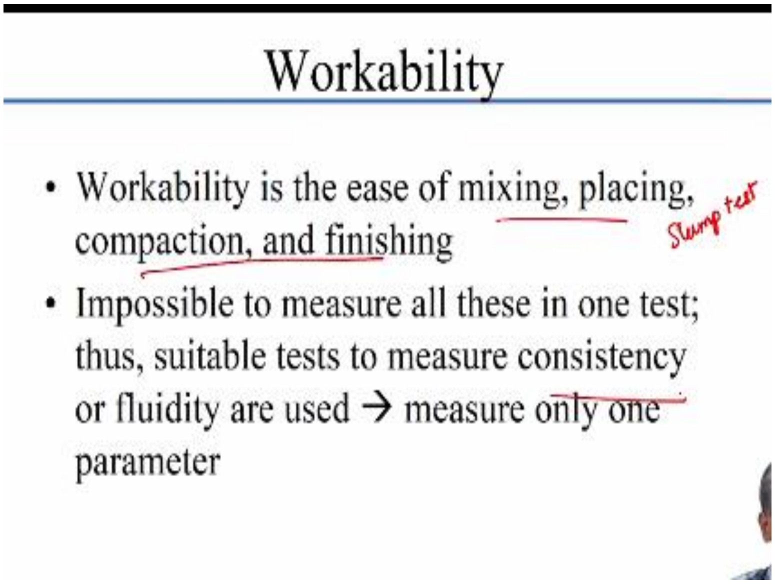

Unfortunately, it is not as easy as that how do you measure workability, what are the tests to measure workability? The commonly used test is the slump test, we also have other test called the flow table test or compaction factor test and so on, VB test and so on. Unfortunately, none of them are as friendly or as site friendly as a slump test, slump test is probably the best suited for site, all you need is a slump cone, you need a flat base and you need a tamping rod and a scoop to put the concrete that is the easiest test to do.

And it is done probably at all the jobsites today, there is no other workability test which is job site friendly of course, people have also develop other methods which can be applied directly to the concrete which is placed inside the form rather than testing on a sample of the concrete but then those are not really as reliable as directly testing the slump of the concrete. Now, the slump test is a measure of the workability but then it is definitely not going to indicate all these things.

Mixing, placing, compaction, finishing all these things cannot be measured in just one test, what the slump test is essentially gives you is a measure of consistency because it is only measuring one parameter that is overall slump of the concrete. Now, if you choose 2 different mixes with the same water content but maybe a different aggregate proportion; coarse to sand, the coarse aggregate to sand proportion, you will find that the slump may not be different by much.

But the characteristics of the mix with respect to placing and compaction will be quite different in these cases especially, when you are trying to pump the mixes, what kind of concrete do you expect will be easier to pump, one has more coarse aggregate or more fine aggregate; when you have more fine aggregate, it is easier to pump because it is more cohesive, it retains the moisture quite well and able to get pumped.

If you have too much coarse aggregate, less fine aggregate, the water will start bleeding out when you pressurise it to pump it. Although, in fresh characteristics, the slump paste will be the same because slump is mostly dependent on the amount of water you have in your mix, so with workability you are not able to resolve that issue of how the other aspects other than consistency can be sorted out with just the measurement of this one parameter.

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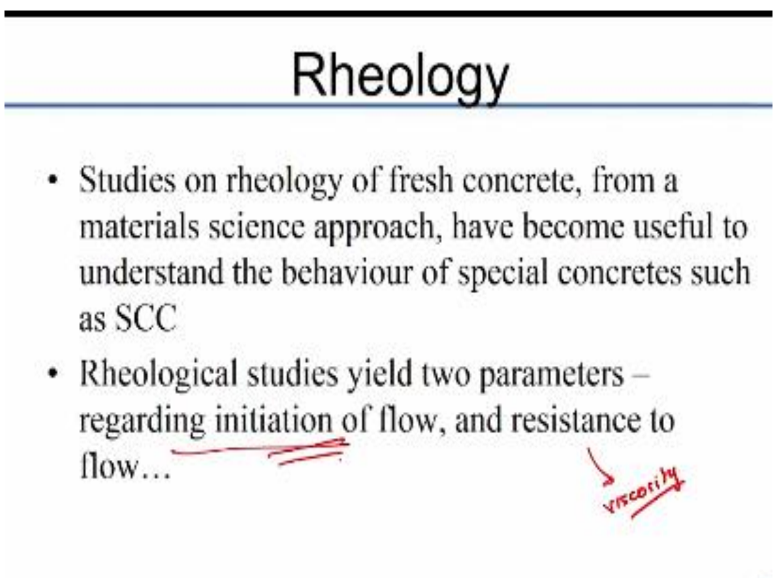

So, especially when we deal with special concrete like self-compacting concrete, we need to move towards a more scientific or fundamental understanding of how flow occurs in these materials by the study of rheology, so essentially rheology or rheological studies yield 2 parameters rather than just 1, one is regarding the initiation of the flow that means what would be the minimum level of resistance that needs to be overcome to make the flow happen.

And then once the flow happens, what is the resistance to this flow? That is something which we already know as viscosity, in most fluids like oil or water, the resistance of flow is governed by the viscosity. So, oils are generally more or less viscous than water, so it depends on the type of oils, most oils are having a higher viscosity than water. Gels have much higher viscosity than water.

Concrete, obviously will have much higher viscosity than water, but one thing that you have not heard off when we talk about liquids is the presence of another factor which controls the initiation of the flow. In the case of water or oil, the moment you apply a shear to it, it will start flowing but in case of semisolid structures or suspensions, you may have to overcome an initial yield or shear stress to make the material start flowing.

So that is basically given by rheology, now how is this relating to real life, now for example, you put a concrete inside a formwork, this concrete does not go anywhere until you start vibrating it, so the vibration creates the initiation of flow and the concrete workability which is your consistency leads to the overall flow after the flow has been initiated, so vibration essentially overcomes this initial build up which is the innate shear stress that needs to be overcome in the material to make it start flowing.

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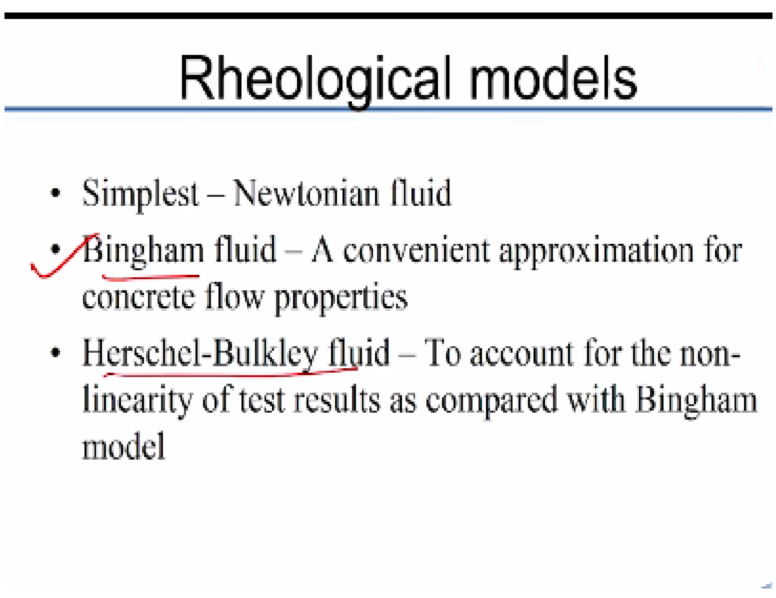

So, there are different rheological model, the simplest one is a Newtonian fluid which you already probably seen when you look at the flow characteristics of liquids like water or oils, but when you start looking at suspensions or something like concrete or probably even cement paste because cement paste is also a suspension of cement particles in water. So, again there also what applies is not really the Newtonian model but more complicated models need to be considered.

Out of these complicated models, the simplest one is that of a Bingham fluid, it is a convenient approximation for the flow properties that are exhibited by cementitious suspensions, but then there are people who do not like simple models who like to complicate their life and use much more complicated models. Among the more complicated models, the easiest one is the Herschel Bulkley fluid.

I will tell you the equation here, you might be wondering why I call it simple but if you look at most of the rheological models, they talk about something much more complex than that and the people who are doing rheology are looking at a whole range of materials, cement paste is just one, they look at bituminous mixtures for instance, then they look at gels, they look at soaps all kinds of polymers can also be used to study their rheology.

Because rheology is the fundamental science, when you study these semisolid or liquid type of materials and understand their early behaviour, for cement paste also rheology is basically, what we study until it starts setting during the period of time when it takes to set, you need to understand the flow characteristics, so rheology has now fascinated several groups of researchers.

And there are people around the world who are looking at different characteristics in terms of rheological flow, but as far as concrete rheology is concernd, the civil engineering community with in the people who are studying rheology like the Bingham model because of its ease of use and the fact that you only have to deal with 2 unknowns rather than a host of unknowns.

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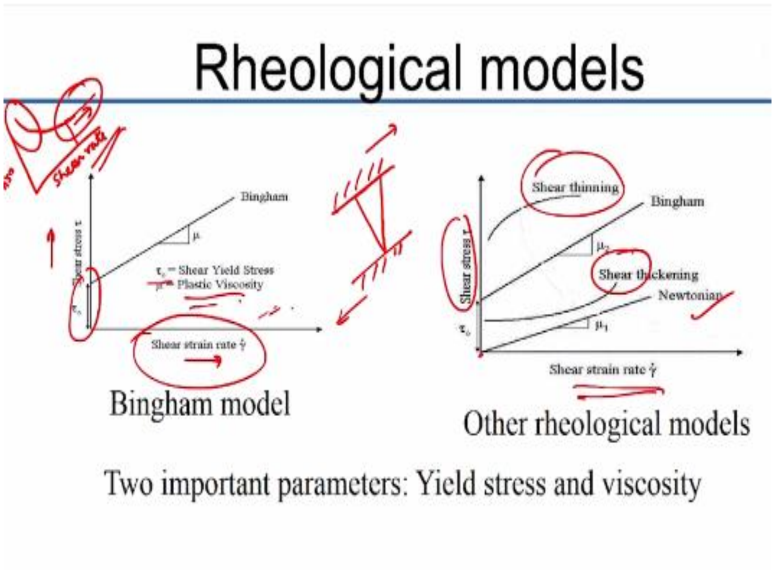

So, this is what it looks like; if you look at the Bingham model, if you plot the shear stress on the y axis and shear strain rate on the x axis of course, this is derived from the classical definition of viscosity, when you have 2 parallel plates; you have 2 parallel plates which are getting sheared and there is a fluid in between, so there is a shear strain, is linearly varying across the height of your fluid.

So, here this is 2 parallel plates which are mowing with the fluid in between, so as soon as it starts shearing, the fluid starts moving, and the rate of shear and the shear stress have a proportionality, so if you look at a Newtonian fluid, the shear stress and the rate of shear that is the shear strain rate have a linear relationship starting from the origin that means as soon as you apply the shear, there is flow that is initiated in the material.

In the case of a Bingham fluid, you need to overcome some minimum shear stress in order to initiate this flow and that shear stress τ_o is called the shear yield stress, but what Bingham fluids approximation tells you is that once the flow is initiated, the flow happens at a constant viscosity and that is called the plastic viscosity. Now, truly speaking that does not happen like that.

Because if you take a concrete in a bucket, you put a stick through it, you try to move the concrete in the beginning your resistance will be high, when you try to move it but when you start mixing at higher and higher speeds, the resistance will keep coming down, so truly speaking if we plot the viscosity versus the speed, viscosity versus shear rate, you will start seeing a drop in the viscosity.

And at particular shear rates and beyond a certain shear rate, it will be almost constant and that constant viscosity is generally called the plastic viscosity which is represented as the slope of the linear part in the Bingham model. So, the true measurement of viscosity will change with respect to shear rate, so obviously when you are doing this experiment to determine the Bingham parameters, your shear rate should be high enough that you are already in that regime which is related to the almost constant viscosity of flow.

If you are in very low shear rates, you have probably going to be somewhere here, so there you will not probably get a linear relationship between the shear stress and a shear strain rate, so this is based on typical parallel plate system but there are other models which can also be representing the kind of behaviour that can be exhibited by cementitious suspensions or sometimes other suspensions also.

For example, you may have a shear thickening behaviour that means at low shear rates, the shear stress is slow but as you increase the shear rate, there is a rapid increase in the shear stress, have you seen this behaviour; you may have seen it in some types of gums for instance, put a stick inside the gum, it is easy to apply but sometimes when you start mixing it too hard, its start stiffening upon.

In other cases, you have the opposite effect, when you put the stick inside this mixture, it is not very easy to mix it up but when you start mixing at a higher speed like what we see in the case of typical concrete, you have what is known as a shear thinning behaviour with increased shear rates, your shear stress; rate of increase of shear stress keeps dropping. So, you can get different types of behaviour from different types of fluids depending upon the nature of the fluid.

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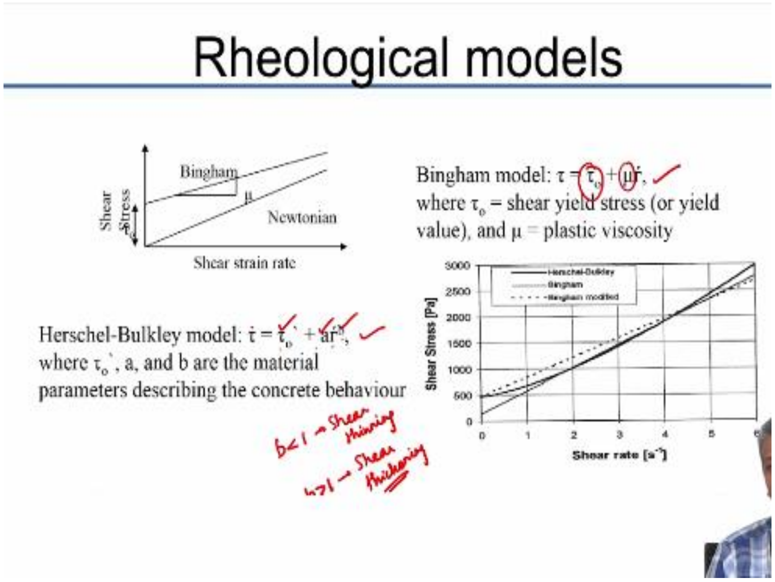

The convenient approximation we are looking at is the Bingham model where 2 unknowns are: shear yield stress and plastic viscosity and you can represent that by a linear equation:

$$\boldsymbol{\tau = \tau_o + \mu \acute{r}}$$

Where, τ = shear stress, τ_o =the shear yield stress, μ = plastic viscosity and $\acute{r}$ = shear strain rate. So here, you can plot the; if you do an experiment you can plot the shear stress against the shear strain rate and obtain the 2 fundamental parameters that define the characteristics of the fluid that is shear yield stress and plastic viscosity.

And use that to define the different types of concretes rather than just using a slump approach, you now have 2 parameters; the shear yield stress and plastic viscosity which are describing the flow characteristics of the concrete. Now, I was talking about other complicated models, this Herschel Bulkley model is a little bit more complicated than the Bingham model but the advantage of using the Herschel Bulkley model is that by the use of these 3 parameters for something which is similar to the shear yield stress.

$$\boldsymbol{\tau = \tau_o` + a\acute{r}^{b}}$$

So, this; then there are 2 parameters a and b, now the parameter b you can see is a power expression of the shear strain rate or it is an exponent of the shear strain rate, so when you have b values which are <1 or >1, you are indicating either a shear thinning or a shear thickening behaviour. When you have less than 1, it is a shear thinning behaviour, when you have greater than 1, it is a shear thickening behaviour.

So, $b < 1$, shear thinning and $b > 1$ is shear thickening, for the most part when you try to apply this relationship to concrete, you may end up getting a shear thinning kind of characteristic, unless you use some special type of gums inside concrete which can introduce shear thickening also. So, Herschel Bulkley model again relates the shear stress to the shear strain rate via 3 parameters; τ_o', a and b, so τ_o prime.

Because it is not exactly the same τ_o as you get from the Bingham model, so this is something which the concrete technologies use as a means of pleasing the rheological scientists because otherwise, if you tell them about using linear models, they will not be very happy, for concrete technologies we like things that are linear, if you can have less number of parameters already we have large number of variables inside concrete.

We have the stone which is a variable, sand are variable, cement even if it is coming from same cement plant, it becomes variable because our production is not always matching the best of the standards and not really because of the production more because of the standard itself because our standards give a room for a large variation in material properties and then we have people; several people who applying this concrete, who again make a big variable.

And when we have so many different variables, our life becomes easier if you have to deal with one less variable, so a linear approximation probably is a good enough one for concrete, as you will see in many examples, it seems to work quite well in most concrete mixes.

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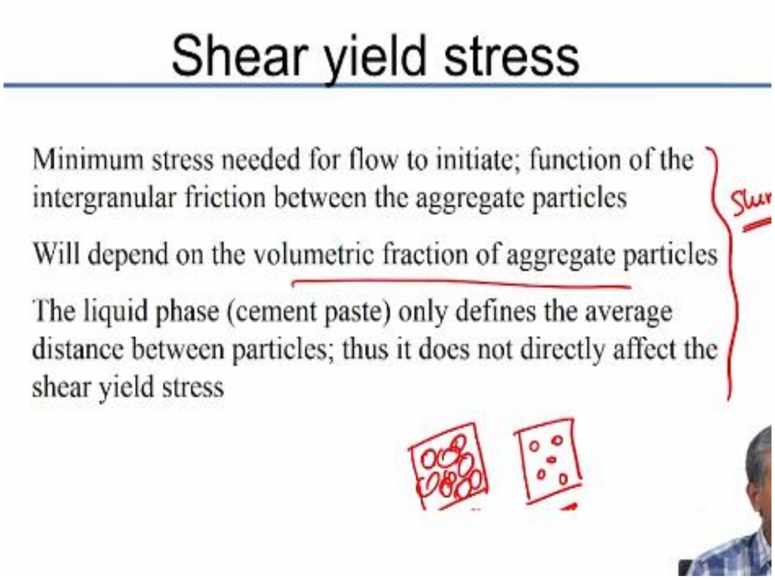

So, what is the shear yield stress mean from the perspective of a suspension of aggregates and cement paste, so you can think about it as the minimum stress that needs; that is needed for the flow to initiate which is dependent on the inter-granular friction between the aggregate particles. Now, if you imagine if you have a volume, which is full of aggregate, if you want to make this volume start flowing, the amount of friction between the aggregates because they are lying next to each other is going to be so substantial that you need an extraordinarily high level of stress to be overcome to make this material start flowing.

Now, the same concept if you apply to a system which has very less aggregate, you have mostly the fluid paste that is surrounding the aggregate, the amount of yield stress that needs to be overcome to make this material flow is much lesser. So, when we deal with systems that have more water, we essentially get this sort of a response, when we increase the water content, we are increasing the space between the aggregate.

So, we are causing it to flow much easier, so we are overcoming the inter granular friction quite easily, alternatively you can also have the same system and still make it flow a lot more by using super plasticiser. When we use a super plasticiser, we are not altering the space between the aggregate but what we are essentially doing is increasing the flowability of the paste and the paste itself is now able to carry more aggregate along with it.

So that is a little bit different as compared to increasing the water content, so generally this shear yield stress seems to be a major dependent on the volume fraction of the aggregate particles. The more volume fraction of aggregates that you have, the greater will be the initial resistance to flow, the lesser amount of aggregate the easier the initial flow will have. The liquid phase that is the paste phase that are surrounding the aggregate defines the average dstance between the particles and may not directly affect the shear yield stress.

But if you are making the liquid very different by incorporating the super plasticiser, you are going to be affecting shear yield stress. Now, in terms of the concrete characteristics or workability characteristics, shear yield stress is essentially defining the slump of your concrete, the slump of the concrete is essentially conveying some idea about its shear yield stress. What is the innate energy or minimum stress required for flow to get initiated?

That is defined by the slump, and slump is essentially a measure of your shear yield stress, then we need one more parameter to define how this material is going to be compacted and finished and that is where we have to rely on plastic viscosity.

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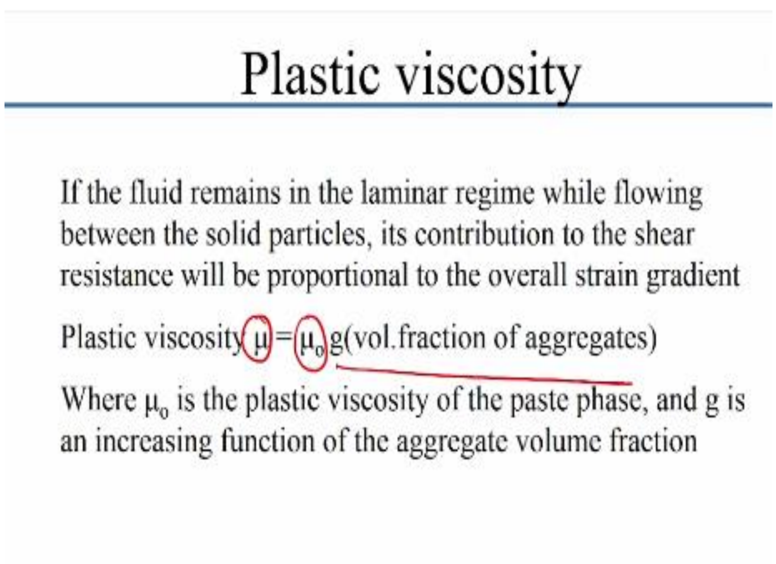

So, once concrete starts flowing if the fluid remains in the laminar regime, the contribution to the shear resistance is proportional to the overall strain gradient, so that is what makes it a linear equation, the contribution of this viscosity is linearly varying with the strain gradient, so that is what defines the linearity in this case, so essentially a plastic viscosity of the concrete μ can be defined as:

$$\mu = \mu_0 g$$

Where, μ_0 = plastic viscosity of the paste and g = volume fraction of aggregate.

Now, why do we say that, why is the volume fraction still important? If there is more aggregate more resistance, why; because the fluid now has to carry more aggregate along with it, so essentially the plastic viscosity of concrete depends not just on the viscosity of the paste but also how much aggregate is there in the system but a shear yield stress as we saw primarily depends more on the extent of aggregate that is there in the system.

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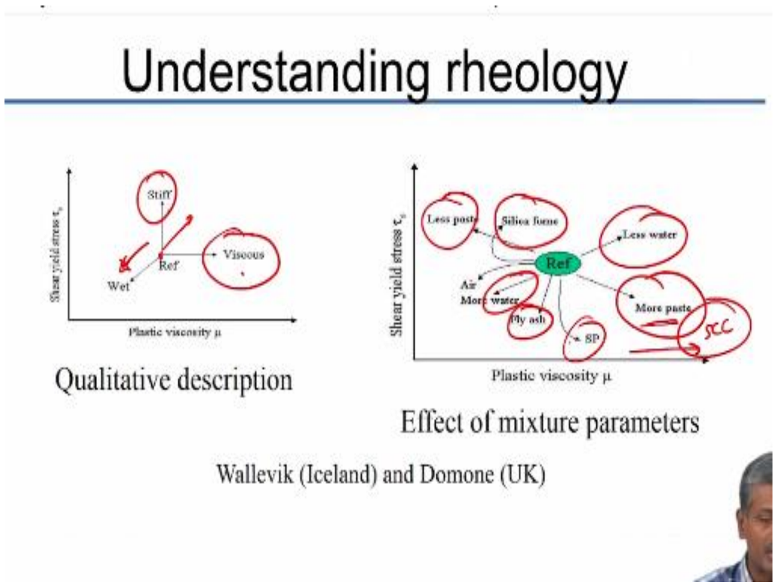

So, here plastic viscosity is depend on both parameters, so how do we understand rheology, we understand it primarily with the use of these 2 parameters; shear yield stress and plastic viscosity, so this is your reference mix for which you are able to determine through rheological experiments the shear yield stress and plastic viscosity, compared to the reference mix if you say that you are making a mix that is wet.

Wet your mix and that you are essentially mowing down in this direction implying you are reducing both the shear yield stress and the plastic viscosity. Why do we say that? When I add more water, we saw that the distance between the particles increases, so the shear yield stress should come down but why should the viscosity come down when I add more water? Again, volumetric fraction of aggregates will be lesser.

Secondly, viscosity of the paste also will come down as more liquid is there in it, so a wetter mix implying when you add more water just like you see on the right side, when you add more water from the reference mix, you are mowing to the bottom left indicating reduction in both shear yield stress and plastic viscosity. Opposite; if you add less water, if you have less water in the mix, you will end up increasing both shear yield stress and plastic viscosity.

Just because of the opposite effects that you see here, now when you increase the shear yield stress alone without affecting the plastic viscosity much, you call it as a stiff mix, so for example instead of 100 millimetre slump, I chose a slump of 50 millimetres but I still have once this concrete gets vibrated, it is still flows the same way as the 100 millimetres slump concrete, so I have not changed the viscosity, I have only increase the yield stress.

And that is when I call my mix as a stiffer mix, mostly what you will have is, when cement is replaced with silica fume, you might see that your mix starts losing slump but once you vibrate this mix, it is able to flow as easily as your regular cementitious mix, so stiffer mix is typically mean lesser amount of; not lesser amount of paste more greater yield stress and similar plastic viscosity.

Now, a viscous mix is when you increase the plastic viscosity without really affecting the yield stress, you might have seen from your study of different types of concrete that even if you define them, designed them to have the same slump, some concrete slump immediately, some concrete go down very slowly, so that means the yield stress is not affected because we saw earlier that slump is a measure of the yield stress.

Yield stress is not affected but the rate at which the slump happens is an indicator of the viscosity of the mix, so the viscosity is high but the slump is the same or the yield stress is the same that kind of mix is called a viscous mix, and generally what happens is; if you have more paste in your system, you will end up producing a greater viscosity of course, I am not talking about more water, I am primarily talking about more powder; cementitious materials, that increases the volume of the paste.

So, now I have more paste implying there is more spacing between the aggregate, so you are reducing the yield stress but since you have more paste, the viscosity of the system will go up, so in self-compacting concrete, what do we do? We introduce more cementitious materials, so that the mix remains stable without segregation, so if you want SCC, you want the plastic viscosity to be high to resist aggregation.

But at the same time you want the shear stress to be low, so that flow happens on its own without the need for external vibration, so you want to be in a regime that is in this location for SCC, you want to be having a high plastic viscosity but low shear stress, so you are working with a concrete which has more paste, with less paste, you are going in the opposite direction, your viscosity is not that high but your shear yield stress is getting increased.

Now, with fly ash, which is essentially spherical particles, your viscosity also comes down, because of the sphericity of the particle, secondly because fly ash has a greater volume as opposed to cement, when you replace cement with fly ash, you are increasing again the spacing between the aggregates, so your yield stress also will tend to come down. So, when you have more paste, it will still flow the same extent but it will start flowing very slowly.

Because of the cohesion it does not spread immediately for example, if you consider water, it has got zero yield stress, so you pour water on this surface, it spreads immediately, if you pour more viscous liquid it will spread slowly, it may be having zero yield stress, so that it might end up spending the same amount as water and of course that dependent also in the surface tension characteristics and so on.

But still what I am trying to convey is that; a material with the zero yield stress also can be highly viscous and take some time to flow, so when you put more paste, you are not negatively affecting yield stress, you actually reducing the yield stress because you are increasing the spacing between the aggregate but the mix is still cohesive, which makes it flow slower and slower.

With super plasticizer, the primary effect is that you reduce the yield stress of course, you also will reduce the viscosity but if you have a very high dosage of super plasticizer, you might see some negative effect of that also, in terms of your mix getting a little bit more cohesive and sticky, difficult to operate and this happens at very low water cement ratio, if you increase the super plasticizer dosage beyond certain amount, mix starts getting sticky and you may start getting increases in plastic viscosity.

So, using this rheological approach, you can now relate this quite well to the way that you measure slump and the way that you see the concrete flowing once it is in the formwork or once you vibrate it or once you use a special concrete like a self-compacting concrete, so this approach has helped us understand the characteristics required to produce special concretes like SCC because there we need a very strict control in the parameters.

Because it is highly prone to segregation, it is a highly flowable concrete but it is very prone to segregation. So, what this leads to is; how do we actually measure these rheological characteristics, as with any other measurement it involves sophisticated equipment which is going to be expensive.
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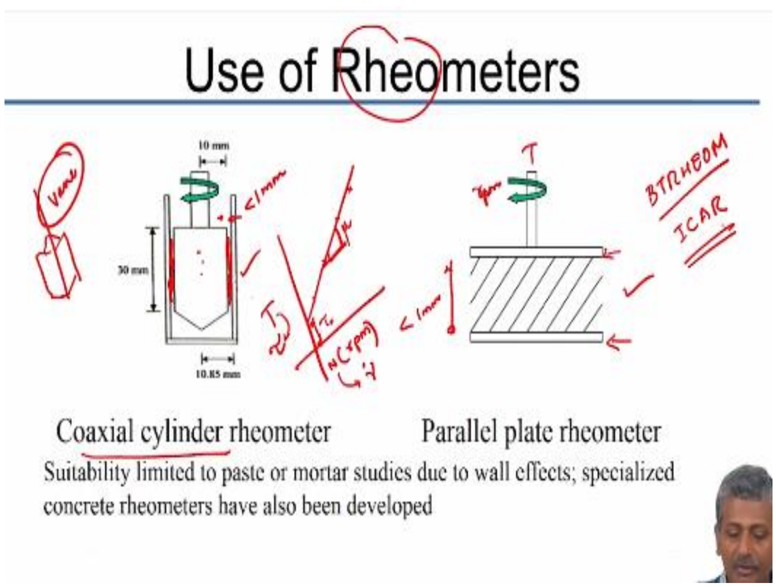

So, in terms of direct measurement of rheology views what are known as the rheometers measurement of rheology is done with rheometers, the 2 conventional geometries of rheometers is coaxial cylinder geometry, where you have one cylinder sitting inside an external cylinder, so one of these internal cylinders made to rotate at different levels of speeds or different speeds or different RPM if you will.

And then the paste is getting sheared between the inner cylinder and the outer cylinder, so the paste is actually filling up the volume between the two cylinders, so the paste is getting sheared between the rotating cylinder and the stationary cylinder and depending upon the torque that is registered in the equipment when you apply a given speed to this inner spindle and rotate it at certain rpm, you register a torque, which is basically related to the resistance of flow of your paste.

You plot the torque against your rpm or the speed and then you will generally get a similar to a straight line relationship for more cementitious suspensions, you plot a best fit line through it and then you can convert the torque using the cylinder geometry that you have to the shear stress and the RPM to the strain rate and based on this, you can calculate your shear yield stress and plastic viscosity.

Taking the slope of this linear expression, you will get the plastic viscosity and where it intersects the y axis is your shear yield stress, this torque needs to be converted to the shear stress and the RPM and the speed of spindle needs to be converted at a strain rate but of course that depends on what kind of geometry you are using, that conversion factors is different for coaxial cylinder or for a parallel plate.

In the case of a parallel plate, you will have a lower plate that is stationary and top plate that is getting rotated, and then you are measuring the resistance to flow by the torque that is again resistance, the same measurement is made; torque versus RPM but the conversion of torque to shear stress and RPM to shear strain rate are different based on the geometry of your system. Now, there are some problems with this, as you can see most coaxial cylinder geometries have less than 1 millimetre spacing between.

So, obviously there is no scope of using aggregate in these systems, now what happens if you have large spacing, if you want to create a large spacing, what will happen? If you want to incorporate aggregates and you want to have a cylinder and inner cylinder that is rotating, what will happen in that case? If you have too much space between the walls, the inner spindle that is rotating may not rotate the paste with it at all.

The paste will not rotate it all, it may stay stable and you may have a sliding of the spindle with the boundary of the paste itself, so in any case in most of these equipment also, the spindle that you have on the inside has to be roughened quite a bit on the surface to ensure that it takes the paste along when it tries to rotate, most of these equipment are not built for cementitious suspensions, they are meant for other fluids which are much more easier to measure.

Cementitious suspensions are not very easily measured in terms of their rheological characteristics, so what is the way forward, how do we actually use this to actually measure characteristics of mortar for instance? In geotechnical engineering, you might have heard of this test called vane shear test. What is done there; you have a vane, which have blades like that, these vane blades can be actually also used for measuring the shear resistance of your cement mortars, I mean cement concrete suspensions.

So, most of the concrete rheometers are built on the vane measurement, again there is a complication there, the geometry that the vane gives you cannot easily relate the torque to the shear stress and the speed of rotation to the shear strain rate because of the geometry, you cannot really define a very clear cut expression that it can do for your cylindrical rheometers; coaxial cylinder rheometers or parallel plate rheometers.

So, again in a parallel plate rheometers, we need to ensure that your gap is typically around 1 millimetre or less, so you can only study cement paste usefully with the conventional rheological techniques, if you want to apply these to concrete systems, you have to rely on the vane but then in the case of a vane getting a theoretical approximation of the shear stress and strain rate is quite difficult.

So, you cannot really get any fundamental parameters coming out of your vane geometry, there have been other developments around the world, I have not really indicated what are the rheometers that available around the world, there are; you can actually search in the net, there are some which you can find quite easily and get some information on, one is called a BTRHEOM, it is the concrete rheometer.

And there is an ICAR rheometer, there are several different types of rheometers, which are sold by very specific manufacturers, there are probably around 7 to 8 total manufacturers of rheometers for concrete around the world, for cement paste, not for cement paste, for fluids there are several manufacturers of rheometers because in most polymeric fluids and for most polymeric suspensions, rheology is a very regular routine practice that they need to measure.

But in cement paste, you do not really measure that all the time, so there are some concrete rheometers available but most of these are extremely expensive piece of equipment and very often they do not give your fundamental parameters like the shear stress and the plastic viscosity, you may at best get the relationship which is linear but then you do not really have a way to move forward from them.

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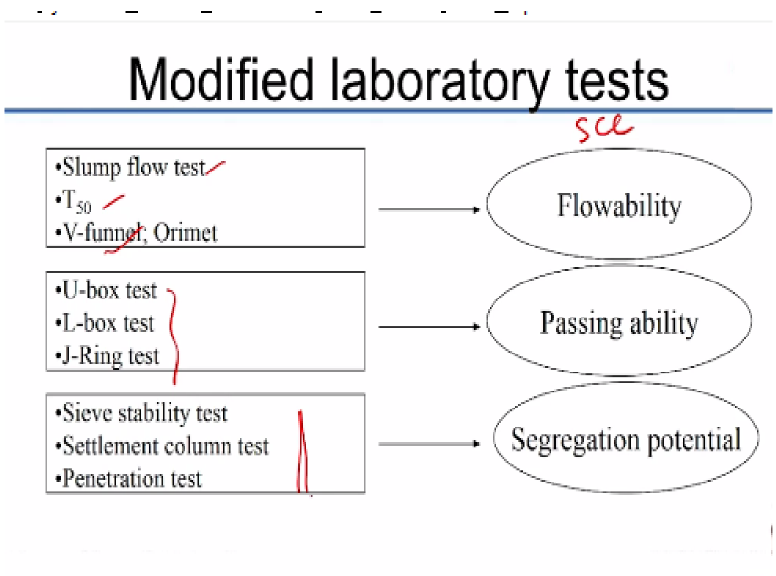

So, what we need to rely on when we deal with self-compacting concrete are empirical test methods which are modified laboratory test, which can actually give a much better picture than the regular conventional slump or workability based tests. So, the flowability for example, if you apply this to SCC, there is 3 primary characteristics that you need to measure for SCC, there is flowability, the passing ability and segregation potential.

In terms of flowability, you can measure it using slump flow test, in the slump flow test itself, there is another parameter called T50, we will talk about that in just a minute and then you have a flow test through a funnel which is called V funnel test or sometimes there is an alternative test called Orimet test also that is used. Passing ability talks about the ability of SCC to pass between reinforcement and that can be measured using a range of tests again.

And then for segregation potential, you have other test methods, which have been prescribed, so what you need to do is; before applying SCC to the site, you have to make it pass through a number of these tests or a combination of these tests to ensure that it has all these 3 characteristics.

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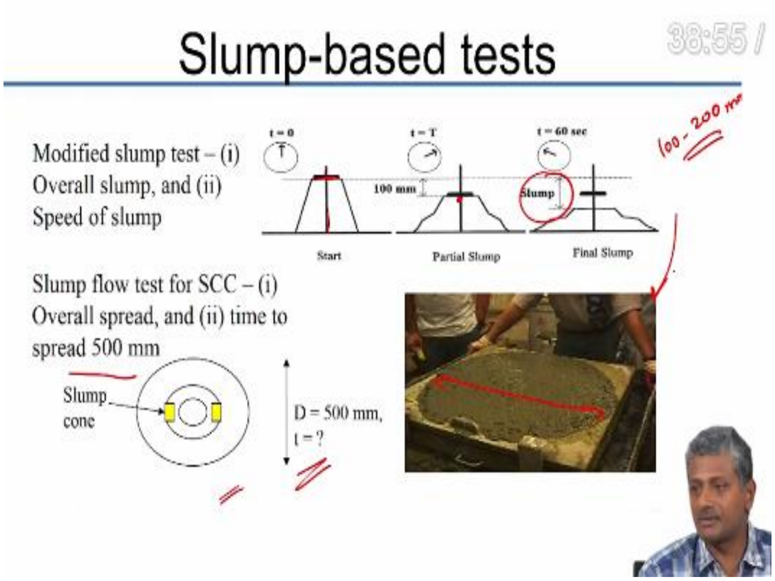

So, let us look at these test briefly, the slump based tests; the primary one which is used by SCC, looks at the slump flow which is basically the concrete which is poured inside the slump cone, you remove the slump cone very fast and allow the concrete to start flowing and you measure the total flow by measuring the diameter of the spread, you can also measure the time taken to spread 500 millimetres.

So, here you are getting 2 parameters; one is the total flow that is related to which fundamental parameter; total spread; total spread is your yield stress, the speed of spread is related to your plastic viscosity, so the time to spread 500 millimetres is related to viscosity. Now, if you were to apply similar concepts to regular concrete which as the slump between 100 to 200 millimetres, you can modify the existing slump apparatus to try and measure the rate at which the slump is happening.

So, just to give a simple arrangement, you have the slump cone here and you have a rod in the centre and at the top of the slump cone level, you are able to keep a very light disc, for example like a CD, like a compact disc, which may have a smaller diameter than the top of the slump cone, so when you remove the slump cone, the concrete start subsiding and the disc also goes down along the rod.

And about 100 millimetres distance, you have some obstacle that will stop the disc, so that will help you measure the time it takes for the disc to subside by 100 millimetres that gives you an indication of the time of flow of the concrete and then of course, you can measure the overall slump at the end of the experiment and that gives you the measure of the shear yield stress, the time to flow and the total flow are 2 indicators from the same test.

Instead of just measuring the only slump, we are also measuring the time taken for the slump to happen, so that is the modified slump flow test, it seems to work quite well for concrete that have slumps between 100 to 200 millimetres, for very dry concrete, it is difficult to do that and for extremely wet concrete, it is much better to do the slump flow test looking at the spread of the concrete rather than looking at the slump.

Now, I hope all of you know how to do the slump test, whenever I visited the site, I found that people are doing it in the wrong way, how many layers do you fill up the slump cone in; 3 layers, and then each layer should be compacted how many times; 25 times, good, then how long should it take to remove the slump cone that is where most people go wrong. If you look at the standards, it is between 5 and 7 seconds that you take to remove the slump cones.

The problem is; if you take it out too fast, you have a tendency of tilting a little bit which may actually make the concrete shear off, if you take it too slow, then your concrete may already start subsiding by the time you are removing your slump cones, you are getting the correct, so it has been standardised to produce a good result, when you take it up in a matter of 5 to 7 seconds.

So, there are many variations that I see on sites, sometimes people start filling up in 4 layers, they do not compact, sometimes they used a trowel to finish the top that is also wrong, you should not use a trowel, you should use a same tamping rod and roll it across the top and strike of the excess material, so all these have to be properly conveyed to the personnel who is doing the test in job site because small variations can make a lot of difference.

Especially, the way that you compact sometimes, you get the shearing off of the concrete, that is not a good test; the good test should be one where the slump properly subsides. Interestingly, lot of companies what they do is; because they need to worry about slump retention, they design for a complete collapse at the ready mix concrete plant, the design slump is about 150 to 180 millimetres.

So that when they reach the job site they at least have a slump of more than 100 to pump the concrete but because they experience such huge slump losses at the RMC plant, they make the concrete completely collapse that means, they make it so with such a high SP dosage and it cannot retain a slump anymore and just collapses, I do not know, if you have seen, notices this practice, it is a very common practice.

So that even if there is a slight extra travel time, we can still maintain a higher slump but there is a danger with that you may actually cause the concrete to segregate in the early stages itself and that something you do not want and in some cases, the specs may be tight enough that they can pull you up for the quality of concrete at the RMC plant also and not just measure it at the job site, so need to be a bit careful when you are trying to make those kind of adjustments.