Advanced Topics in Science and Technology of Concrete
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Week - 01
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An overview of recycled concrete aggregates (RCA): sources and types- Part 2

So, let us now look at a conventional crashing process. Again, this is probably going to be a repeat given that this content is already covered to some extent in the other lectures. Give you some examples of how these wastes are getting generated, what streams are we going to be utilising in concrete. So, first, of course, is the weighing, unloading, and storage of the waste that is collected from the sites. Segregation, because you want to ensure that your tree stumps, the wooden waste, the ceramic waste, the sanitary ware, the glass waste—all of that is properly segregated. Now, this is again a big challenge.

This is something that we really need to move forward with, and trying to find solutions to do that more efficiently. Size reduction, then you have primary crushing, which is typically done in a jaw crusher. Then you have a magnetic separator that ensures that all the iron and steel get taken away. Vibrating screens to separate the sizes that have been crushed properly and sizes that are too large that need to be crushed again.

So they are sent back to the jaw crusher. So, if the particles are coarser than the sizes that you really want for the secondary crushing, they are sent back to the jaw crusher to recrush. And then you have secondary crushing, which is typically done by either a cone crusher, or impact crusher, or a combination of the two. And the dust that is generated in this process needs to be either washed or separated by a dry process. And the dust which has been retrieved from the process, the silt, and fines can be disposed of as sludge, or if you really want to be a complete recycler, you want to probably still conserve that part that has been removed as the dust and as the fines and find some other utilisation of that in new construction.

So, again, you can have advanced treatments that leads you to three different categories of materials that you collect from your overall recycling process. You have the coarse aggregate, you have the fine recycle aggregate, and then you have the powder that is extremely fine that needs to be treated specifically for utilisation in new construction. Again, that will be something that we will talk about in one of the future lectures. So, different types of crushers are demonstrated here. Once again, this information will also be taken care of in other lectures, but I just wanted to run you through this because very often the type of crusher dictates the properties of the aggregate that you actually end up getting from it.

So, you have a jaw crusher, which is basically the first stage of crushing. And then you have a cone crusher, which is the second stage of crushing. You can see that the mechanism of how the crushing actually happens differs in these crushers. And then you have the more sophisticated vertical and horizontal shaft impact crushers. So, here, the kind of crushing or the kind of breakage of the particles leads the particles to get an equidimensional shape. That means they are not flaky or elongated, but they are more or less with an equal cuboidal dimension after the crushing process.

So, all of these are staged in a particular recycling plant, typically starting off with a jaw crusher, following with a cone crusher, and sometimes in the third stage, the impact crusher, or if you have a two-stage plant, typically it will be a jaw crusher followed by an impact crusher. So, of course, recycling plants could be of two types: stationary plants or a mobile plants. As you can see in the top, the stationary plant is shown. As the name implies, the instruments and the equipment is installed in location, and it continue to work in the same location. On the other hand, mobile crusher can go from one place to another and execute the same process. Of course, the capacities are going to be much limited in the case of a mobile crusher, as you can readily imagine, as compared to a stationary crushing plant.

Now, the aggregate that is getting obtained from the construction and demolition waste crushing or processing could have very different physical characteristics. Because we know that when it is concrete aggregate, there will be coarse aggregate that is covered by a layer of paste or adhered mortar. So, paste or adhered mortar on the surface of the aggregate is going to cause some change in the characteristics of the aggregate as compared to the stone itself. Now, when this paste or adhered mortar is present, it is going to affect obviously affect density and water absorption. So, based upon the combination of amintrite density and water absorption, silver has done this sort of a classification, where class A of aggregate basically has densities which are more commonly observed with most aggregate and water absorptions that are fairly low.

The Los Angeles abrasion mass loss is restricted to about 40 percent. More, for instance, when we go to aggregate class B, we are having a reduced density, greater water absorption, and more mass loss. That means the aggregates are of a poorer quality, and so on. When you are going to type C, you have even lower density; you have basically much higher water absorption and greater mass loss in the Los Angeles abrasion test. So, when you start collecting aggregate from recycling plants, you can then sort them in terms what kind of properties are exhibited by the aggregates.

Now, you can also classify the aggregates based upon the extent of damage that the aggregate has incurred during the crushing process. So, what happens when you start crushing the aggregate? Cracks and fissures may be actually forming in the aggregate. And depending upon the amount of cracking that is available, as you can see from this table, you can then classify the extent of microcracking in the aggregate as very low, low, moderate, high, or very high. Now, all of this is done with the help of what is called a megascopic evaluation of the aggregate. Now, what is a megascopic evaluation? Basically, megascopic evaluation means that you are visually observing aggregate and trying to classify the characteristics of it.

Several other things can also be done apart from visual classification. You can also look at scratching and other hardness techniques to measure the hardness of the aggregate. You can look at the streak on a porcelain plate, just like what you do with natural stones; the same can be done for the type of aggregate that is being used as well. But of course, natural stones do a lot more, or rather, produce a lot more variable results. When you have moved from one stone to the other, you will not probably get the same kind of differences when you see crushed concrete as aggregate from different sources. But what you will see is that, based on the crushing techniques, there is a significant bit of damage that has been created in the aggregate.

If there is a lot of damage, then obviously you have a very high extent of microcracking, where more than 80 percent aggregates in a sample. So, let us say you take a sample of 100 pieces of aggregate. If more than 80 pieces have more than 5 microcracks, that means we are seeing an aggregate that is getting extremely weathered because of the crushing process. So, we want to ensure that we have an understanding of the extent of weathering that has happened to the aggregate after the crushing process. We do not want to use aggregate that is likely to be extremely weak after this crushing process. Now, of course, IS 383 dictates the properties that you really require from the aggregate; we will take a look at it again, just for completeness, at the end of this lecture.

But there are several different recommendations with respect to the properties of the material that need to be satisfied to conform to the classification given in IS 383. For instance, for the particle size distribution of the coarse aggregate that is and fine aggregates that is crushed from the construction demolition waste, the specific gravity has to be between 2.1 and 3.2. Water absorption is restricted to 5 percent for normal aggregate and 10 percent for recycled concrete aggregate. You are basically getting consideration for a higher water absorption because there is going to be some adhered mortar to the surface of these aggregates when you are obtaining it from recycled concrete.

Now, the thing is, when you are preparing new concrete with it, we will talk about this in our lecture on fresh concrete properties. Also, when you are preparing concrete with recycled concrete aggregate, you have to take cognizance of the fact that the adhered mortar on the surface may be actually absorbing a lot of moisture and that moisture compensation has to be done in the actual calculation of the mixed water. Only then you will be able to actually dictate the properties properly. So, about 10 percent is permitted for recycled concrete aggregate. The impact value, crushing value, and abrasion value are definitely defined based upon the type of surfaces that are there for the application of the concrete. For varying surfaces, typically a smaller value or a smaller limit is given. For concrete for use in other surfaces, not just varying, which do not, which are not necessarily subjected to varying, in such cases, you have a much greater, much larger scale of aggregate performance that is actually allowed.

For deliterate materials in the aggregate, you again have to follow the same table, table 2, of IS 383, which defines the type of impurities that are seen in the aggregate. Now, of course, deleterious materials are more of a concern with natural aggregate because you are extracting the aggregate from natural source where there could be clay, organic materials, and so on and so forth. In the case of recycled concrete aggregate, it is unlikely that you are going to get other materials, of course, other than your other construction demolition waste such as wood, carpeting, rugs, and things like that, if you have not done a proper segregation. The combined flakiness and elongation index, again, it needs to satisfy the same less than 40 percent limit that is described in IS 383. Now, when we use concrete from recycled sources, or, sorry, aggregate from recycled concrete sources, we need to be aware of the problems that we are likely to get.

One is, of course, the management problems. First of all, there are not suitable regulations which make sure that we are able to utilise this material. In Singapore, for instance, the building code clearly says that at least 20 percent of the aggregate used for any construction, any new construction should be from recycled sources. So, this way, they ensure that they are utilising some amount of material as recycled, but we do not have the same regulation in India. Permissible limits are given; mandatory limits are not given.

It is not mandatory for us to use recycled aggregate. There are, of course, no specific code specifications, standards, and guidelines that enable users to understand the properties of concrete with such materials. And this course is one way of actually helping people understand the same thing—to help them understand what happens when you use recycled aggregates instead of normal aggregates. And that is something that I hope, by the end of this course, you will have enough information on to really start looking at maximum utilisation of such material.

There is a lack of experience. Very often in construction, the utilisation of new materials is not permitted because people are not really having experience with the use of these materials. Now, the thing is, it is a chicken and egg situation. You have to first use the material to get experience and then learn from it and derive the best ways of using the material. So, one has to be able to use it, but there are sufficient guidelines given from research, from your codes and standards, which have started accepting the fact that some of aggregates could be recycled, for us to start getting into the field and really practicing this in a much larger way. Now, of course, those problems can be tackled by advocacy, by policy, and so on and so forth.

But technology problems are some things that the engineer has to understand before utilization of such materials. One is, there is cement mortar attached to the aggregate, and that has to be adequately understood. What is the extent of water absorption increase that happens because of this attachment of cement mortar? What is the extent of porosity that is increased when the cement mortar is attached to the surface? Because of this mortar that is attached to the surface, there will be a weak interfacial transition zone that will lead to, that will lead to planes of failure that happen within the concrete and cracks within the recycled aggregate because of the crushing process, that can also lead to much faster failures. And aggregates collected from different sources and sometimes even from the same source because of the mixed nature of the material could show a large variation in quality, and that is something that is not really acceptable in most construction sites. They want the quality to be maintained, and for that, one has to be able to engineer these materials when enough to understand the properties.

There could be contaminants in these materials as well; for instance, asphalt, metals, plastic, rubber, soil, wood, and glass, these are all contaminants that could be present from the source from which the concrete, recycled concrete aggregate has been obtained. If you are not careful about segregation, you can get significant quantities of these contaminants, and that will affect the performance of these aggregates in concrete. Now, just to give a comparison of natural aggregate and recycled concrete aggregate, all of this of course is intuitive because you have this attached mortar to the surface of the recycled aggregate, and this mortar is what is going to cause the most differences in performance with respect to natural aggregate. As compared to natural aggregate, we can expect that recycled concrete aggregates will have higher water absorption, sometimes as high as 4 to 5 times that of normal aggregate. Now, of course, that is not really permitted, as you saw from the previous table that I showed you for recycled concrete aggregates. You need to work with the aggregate, process it in such a way that the water absorption is restricted to 10 percent.

But you can expect that the water absorption of recycled concrete aggregate will be higher. You will definitely get lower mechanical strength because, as I said, the interfacial zones will be weak, and the interfaces will also be further weakened because of the crushing process of the aggregate, that leads to a lot more failures and fissures in the aggregate itself. And overall, it will lead to a compressive strength reduction in new concrete up to 30 percent. Now, is that always the case? No. Why is it not always the case? Because you can derive strategies for optimal processing of recycled concrete aggregate so that it actually ends up giving you nearly the same level of performance as conventional aggregate.

And this is something that you will see in the lecture on hardened concrete properties. You will clearly see that recycled concrete aggregates, if the design and development of the concrete are done in a proper manner, these aggregates will produce concrete which is of as good a quality as your concrete with normal aggregates. Just to give you a recap, because this is something that you would have seen earlier and you will actually see again when you talk about hardened concrete, there are different multiple interfacial transition zones present in recycled aggregate concrete. So, here this is a normal concrete where the aggregate and the bulk paste are separated by what is called the transition zone, which is otherwise known as the ITZ, or Interfacial Transition Zone. Now, it turns out that the porosity is higher in such zones; more porosity and more microcracking may also be also there because of the difference in the mechanical characteristics of the paste and the aggregate.

There will be lot more microcracking in the interfacial transition zone. Now, the bulk paste that is away from this ITZ has a much more denser structure, less porosity, and is stronger. So, generally, when normal concrete starts failing or cracking, the cracks are generated typically in this interfacial transition zone. In the case of a recycled concrete aggregate, you have the aggregate, which is collected from the original material, you have the adhered cement mortar that is adhering to the surface of this aggregate. So, because of this, you have the old cement paste and mortar that is attached to this aggregate, and you have an old ITZ, which is between this aggregate and the old cement mortar, and the new ITZ, which is between the aggregate and the new cement paste or cement mortar.

So, in a sense, you have multiple interfacial transition zones or multiple planes of weakness that are present in your recycled concrete aggregate. So, because of this, because of the fact that your ITZ is the weakest link in concrete, and because of the presence of multiple ITZs, you can expect that the overall strength of the concrete is likely to go down if you do not take sufficient precautions to remove as much of this adhered mortar as possible. Again, that is a subject of one of the other lectures, where you learn different techniques in which you can extract this extracted adhered mortar in the most efficient way possible. So, again, as you can readily imagine, failure in recycled concrete or recycled aggregate concrete can happen through multiple modes. One is obviously failure through the new mortar, which is depicted here.

You can have a failure between the interface of the new mortar and the recycled aggregate. You could have failure within the adhered mortar, which is attached to the older aggregate. You could have failure again at the level of the old ITZ. And otherwise, you can have failure right through the aggregate. That means the aggregate itself basically totally splits.

So, it turns out that the common failure modes are the ones which are dictated by the cracks passing through the adhered mortar and the cracks passing through the old ITZ. Again, that is the reason why recycled concrete aggregates typically tend to give lower strengths to your concrete as compared to normal aggregate. Now, just to show you a case study of a stationary C&D waste recycling plant in Chennai, just to give you an idea about what type of waste was getting collected, And so that you have a clear idea about how this type of waste is getting segregated,.

So, this is a process map. You have, of course, the extraction of the construction demolition waste, loading into the hopper, and then you have a primary jaw crusher and a secondary jaw crusher. And then you have vibrating feeder that basically separates the material out based upon the sizes. Now, of course, with these sizes that are collected, you can also send them through into a vertical shaft impact crusher that will create actual create aggregates of a more equidimensional shape. Otherwise, if you just use a jaw crusher, your aggregates will have a lot of flakiness and elongation. Then the dust that is getting generated could be power washed to ensure that you are getting clean aggregate out of it.

This is a typical process map for C&D waste recycling plant, a stationary plant in Chennai. Now, from this plant, we actually did some analysis of the composition of the material in terms of the sizes and terms of the properties that were getting collected. So, here you can see that concrete aggregate nearly 92 percent in the 20-millimetre size range; concrete was nearly 92 percent; brick waste was only about 3 percent; and tiles were about 5 percent. As we went into the other scales, you can see that concrete waste is still the majority of the particles that have been collected in the different particle sizes. So, nearly 85 to 90 percent of the waste that is collected is your concrete waste, and that is where it is very useful to ensure that you can utilise this material again in new construction.

A brick or tile waste is only forms a smaller part of the entire waste. Now, of course, depending about the size that you are collecting, your quantities may be varying and this is only a case study from one particular recycled concrete plant in Chennai. You can have other similar data collected from other units to really try and understand what could be the type of material that is being collected. So, what we also did was study the properties. So, from particle size analysis, as you can see, for the 10 to 20 mm, it is more or less falling within the upper and lower limits that are prescribed in IS-383. 6 to 10 mm, we can see that it is again perfectly within the upper and lower limits that are prescribed by IS-383. So, it is very important for you to see whether your crushing process has produced aggregates that are directly capable of being used or whether you really want to do further processing to really get it to be in the right size and shape. These are the properties that were obtained for the different sizes of aggregate extracted from this plant. You can see the specific gravities are rather low, but they are still within the specified limit of 2.1 to 3.2. Water absorption levels vary depending upon the type of aggregate. You have some increase here, but then again, with 6 to 10 mm, you see a lesser water absorption as compared to the others. The impact value you can see is about 25 to 30 percent. Crushing value again is around 30 percent.

It needs to be less than 30. And again, abrasion values again around 30 percent. So, more or less, the properties of the aggregates that have been produced from this plant have been fairly adequate. So, just to show you this IS-383, it is basically the specification for coarse and fine aggregates for concrete. It is a very important standard that all of you should completely read and understand.

Now, similar to this, obviously, there are other standards. For instance, in South Africa, most of the standards are rephrased from the EN standards. So, you will obviously be able to follow the EN standards directly in South Africa and also estimate the kind of specifications that have been put in place for coarse and fine aggregates. So, here I will just, I would like to go through some basics. I would like to again show you the properties that have been mentioned in the lecture and the kinds of properties that your recycled concrete needs to have. For instance, the extent of utilisation is something that has already been covered in the other lecture. But just to show you that you have special types of aggregate that could be used.

You can see the quantities that have been permitted to be used in plain concrete, in reinforced concrete, and lean concrete. The properties are described in the other tables. For instance, the limits of deleterious materials are as per Table 2. And you can see that different types of deleterious materials are listed here, and what all you are allowed to use is also mentioned in this table.

Similarly, ASTM has a table which is quite similar. EN also has a table, which is quite similar. Now, in terms of the other properties like flakiness, elongation index, and other mechanical properties, all of those are defined very clearly in these sections. The other important aspect is the alkali-aggregate reaction. Of course, in recycled concrete aggregate, if you know the provenance of the aggregate that was used in the old concrete, you can then be fairly certain that yes, that aggregate will be the one which governs the ASR capability of this aggregate or ASR potential of the aggregate. As long as the original aggregate was okay, you will not have any problems of the use of crushed recycled aggregate in new concrete.

But sometimes this crushing process can do some damage to the aggregate, which may sometimes make it more alkali reactive. So, you have to be careful about ascertaining the properties of the aggregates that you obtain from recycling. So, all of those characteristics, including soundness, need to be properly assessed. And as long as the aggregate meets all of these aspects, it is capable of being used in concrete. So, just to quickly take you to, of course, these are for the manufactured aggregates iron and steel and electric furnace, oxidation slag, copper slag, and so on.

So, all of these are basically giving characteristics that these aggregates need to have. Coarse aggregate particle size gradation is given in this table, table 7. And of course, we all know Indian standards for fine aggregates; we have different grading zones that have been defined. And all you have to also look at, for instance, is that if your individual aggregates are not meeting grading specifications, you can also look at all an aggregate grading when you are actually designing concrete. The mixture proportions are selected by combining the aggregates in a fashion such that the combined aggregate gradation is falling within the right range. So, again, these are the different aspects that are already mentioned in IS 383.

As I said, this is the standard that governs the utilisation of coarse and fine aggregates. As long as the aggregates that you collect from various sources meet the requirements specified in this IS 383, you are fine to use any of these materials as aggregate. So, just to summarise this lecture with this last slide, we all very clearly understand that is major scope for reutilization of construction demolition waste, not just in India, not just South Africa, but all over the world. One has to be efficient in means of sorting the C&D waste.

Now, this is where a lot of new technologies are required. We are, for instance, working in IIT Madras on robotic technology for sorting to ensure that we are able to get the concrete waste aside, because that is what gives us the maximum use in new construction. We also need to be aware of the materials obtained, limitations of the materials obtained, and the extent of processing required to improve the material properties. So, sometimes the aggregates that we obtained from certain sources may not be of the kind that satisfy the requirements of, let us say, IS 383 in India. What do we need to do? What kind of processing do we need to do, which can be minimal with respect to the energy that is given in, which can be minimal with respect to the extent of CO_2 that gets emitted from such processes to produce material that is proper for utilisation in new construction? And finally, of course, there is a need to evaluate the performance of concrete with such aggregate.

And that is something you will see in the later lectures when we talk about fresh concrete properties and hardened concrete properties. So, with that, I close this session. Thank you all. Thank you.