Advanced Topics in Science and Technology of Concrete
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Recycled Concrete Aggregate (RCA): Availability, Collection, and Processing Methods - Part 2

So, the CND recycling process, that process map that we have just seen is mostly the same globally. The only difference, the only two differences that we can see in different recycling plants are with respect to the number of stages of the crushing that is done and the other thing is the type of the crushers that they usually use. So, normally what happened depending upon the size and the requirement, so we can have a single crushing stage wherein one crusher will be kept and the aggregates will be, the concrete chunks will be crushed. Also, we can have two crushers, so one crusher let us say for reducing the size from 500 mm to 150 mm and the other crusher to reduce the size from 150 mm to coarse aggregate and fine aggregate. And nowadays, tertiary stage crushing is also been seen. So, what happens in the tertiary stage crushing cycles, advanced crushers are kept.

For example, there are vertical shaft impaired crusher and horizontal shaft impaired crusher. These are considered to be advanced crusher which can improve the shape properties of the aggregates. So, these crushers are kept at the end to improve the morphological properties of the aggregates, especially the fine aggregates. The other difference that we can see in different recycling plants is the type of the crusher.

So, normally we have jaw crusher wherein the aggregates are broken by providing the compression. So, normally jaw crushers are used to break the strong aggregates. So, in most of the plant, if you see the first crusher will always be jaw crusher. Then we have vertical shaft impaired crusher, horizontal shaft impaired crusher which applies impact energy to break the aggregates and then apart from that we can have gyratory crushers, we can have cone crushers also as a second crusher or the third crusher in different crushing stages. So, these are the some of the photos which shows how the recycling is done.

So, this is a recycling plant in Chennai. If you see the CND waste material is coming here and then initial segregation is happening and after that it is fed into the system. So, and this is a magnetic separator which is removing the loosened steel bars and thereafter it is the CND waste is transferred from this feeding unit to the crushing unit. So, this is a crusher and then in between people will be standing for initial segregation and after this CND waste is crushed to small sizes. For example, here at least in this particular case the input is input size of the input is around 500 to 600 mm and after the first stage of the crushing it will be reduced to 150 mm to 200 mm and then again it is sent to the second stage of the crushing, wherein the size is further reduced to different sizes and thereafter we are getting the coarse aggregate.

As far as the fine aggregates are concerned in this particular plant they have vertical shaft input crusher which are used to produce good quality fine aggregates. A similar process map can be seen in South Africa, Cape Town South Africa wherein the aggregates are crushed with the help of the geocrusher, but however the second crusher in this particular case was the gyratory crusher in order to get the good shape aggregates. So, two thing happens when the after the aggregates are being crushed, one thing the big size aggregates. So, normally more than 20 mm size aggregate if it is not required then it will again be sent for recrushing. And then also we have seen that a lot of dust will be generated because of the crushing process and then there has been a lot of research which has shown that this dust that is formed or generated during the crushing process can be used as a filler material because of its high surface area.

This dust is nothing but the cementitious system that means the mortar that is attached to the natural aggregate sorry the mortar that is attached to the aggregates. So, this dust is the mortar. So, obviously it will be having lime bearing compounds. So, obviously this can be used as a SCM if properly processed. In fact the recent literature shows that this dust can even be used to replace cement or for the cement regeneration because of its properties and also if it is processed well.

So, this dust is called as concrete fines and then the particles which are less than 300 micrometre could be considered as concrete fines. The issue there are some issues with the you know stationary recycling plant. For example, let us say this is my area and this is the recycling plant. So, if the source is here or the source is here and then trucks are used to transport the CND waste generated at a location to the recycling plant. So, a lot of number of truck trips will be required to transport the waste from the location to the crushing unit and we know there will be lot of CO_2 emissions because of the utilization of the fuel in these trucks.

So, one of the way to reduce the carbon emissions because of the due to the movement of the CND waste is by directly taking the crusher directly to the site and this is called as onsite recycling. So, the process that will be followed for the onsite recycling will be same as that done for the stationary plant. Only difference is that here the crusher will be coming to the site. So, here you can see initially size reduction is done with the help of the jackhammer and then thereafter the small sizes concrete chunks are directly fed into the crushers and thereby getting the aggregates and then also the latest you know machinist are also having the sorting system. So, we can get different sizes of the aggregates after crushing the CND waste.

So, traditionally there were issues with the onsite recycling. For example, let us say if we have to do the recycling in the residential area, so because of the crushing dust will be generated. So, nowadays water is being sprinkled during the feeding system only so as to reduce the emission of the dust. The other issue is the noise. So, but nowadays advanced crushers are coming which are able to reduce the noise to a considerable level.

So, now coming to the point, so in the initially we discussed that after 40 to 80 years we might not be having the good supply of the natural aggregates. So, that is why we have to use the recycle concrete aggregates. But if you see globally there are different code provisions and wherein although 100 percent replacement of the natural aggregate by the recycle concrete aggregate is allowed, but it is mostly for the non-structural elements, not for the concrete structure system. So, when it has to be used for the plain concrete systems then the replacement level is mostly in is around 30 percent. And then if it is used for the reinforced concrete system the percentage replacement reduces.

So, that means we cannot fully replace the natural aggregate with the help of the recycle concrete aggregates. So, why is it so? There are different reasons, but one of the primary reasons is the added mortar. So, what happens when we recycle the concrete chunks it will have aggregates and then around the aggregates will be having the cement mortar from the parent concrete. So, this cement mortar paste is highly porous in nature and then if you see the coefficient of water absorption, the coefficient of water absorption of the recycle concrete aggregates because of the added mortar could be around 4 to 5 times than that of natural aggregate. Similarly, if we see the density of this recycle aggregates because of the sticking of the added mortar the bulk density of the recycle concrete aggregate also reduces.

So, if we use this recycle concrete aggregate in the new concrete system, so what will happen? Multiple ITGs will be formed. So, what is this ITG? It is interfacial transition zone. So, let us see in a conventional concrete what happens? We have a natural aggregate and then we it is a mortar system around the aggregates. So, there will be only one interfacial transition zone between the aggregate and between the mortar, but in case of the recycle concrete aggregate because of the presence of the added mortar multiple interfacial transition zones will be forming. So, here in this picture you can see one transition will be obviously between the aggregate and the mortar because the mortar will not be totally binding or covering the aggregates.

There will be some patches from which the new mortar can go and then bond with the aggregate. The other interfacial transition will be between the old mortar and the old aggregate and then the third interfacial transition zone could be between the new mortar and the old mortar. So, obviously when the when this system is loaded the crack can propagate from different interfacial transition zone or between different matrices. So, for example, the crack can go through the new mortar, the crack can go through the interfacial transition zone between the new mortar and old mortar, the crack can go through the old mortar or crack can go through the ITG between the old aggregate and old mortar and in fact, the crack can go in case of the aggregate. But mostly for most of the structures what we have seen that the crack will be passing either through the old mortar or through the interfacial transition zone between the old mortar and old aggregate.

So, this shows that the quality of the concrete made with recycled concrete aggregate will mostly be dependent on the concentration of the added mortar and not to the new mortar. So, that means if you keep on increasing the cement contents, so the improvement in the strength might not be significant as compared to natural aggregates. So, that means the added mortar content can be considered as a culprit. So, this added mortar content depends upon numerous parameters. So, let us see what are these parameters.

The first thing is that the added mortar content decreases with the increase on the increase of the increase in the size of the aggregate. So, obviously when we have small size aggregates, it has more surface area and then obviously the added mortar content will also be higher. So, as the added mortar content increases, we see the properties of the aggregates significantly reduces. For example, one of the important properties of the aggregate is coefficient of absorption. So, as the added mortar content increases, the water absorption also increases.

So, thereby it will be having a significant effect on the concrete properties made with recycled concrete aggregates. The other parameter on which the added mortar content depends is the grade of the panel concrete. So, let us say we are getting two recycle aggregates, recycle concrete aggregates, one from M90 grade concrete and one from M10 grade concrete. So, the difference will be between these two recycle concrete aggregates is that the bonding between the aggregate and the mortar will be higher, significantly higher in the recycle concrete aggregate that we are using from M90 grade concrete and then the bond strength between the mortar and the aggregate will be significantly lesser in case the recycle concrete aggregates are produced from, are produced from lean concrete mixtures. So, obviously if we crush both these concrete chunks with the same crusher, so because of the lower bond between the mortar and the aggregate, the chances of removal of the added mortar will be higher.

So, the same thing can be seen in the graph wherein the added mortar content is higher in case of the concrete, in case of the, in case of the recycle concrete aggregate that are generated from high strength mixes wherein the added mortar content is lesser in case of the concrete which is made with lesser water by, so highest water by cement ratio or lower strength. The other thing that will be affecting the added mortar concentration is the crushing stress. So, if we are crushing, let us say this is the same concrete chunks and if we are crushing it, re-crushing it again and again will be able to remove the added mortar significantly as shown by these figures. So, in nutshell what we have seen as the added mortar content increases, the strength of the concrete made with recycle concrete aggregate will also be reducing. So, that means we have to address these, this added mortar content.

So, there are different techniques available to address the properties of the recycle concrete aggregates and this can be put in two buckets. One thing is surface modification, the other thing is the total removal of the added mortar. There are other techniques also, very, very simple techniques. For example, changing the mixing approach. So, normally what happens, we place the coarse aggregate, fine aggregate, everything together and then we will feed the water and then the concrete will be produced.

But we can, since these recycle concrete aggregates are highly porous and we know the total absorption by the recycle concrete aggregate, it will be taking some time. So, what we can do, we can add partial water to the coarse aggregate initially. So, coarse aggregate and fine aggregate can be fed and then partial water that is required can be put along with the aggregate, so that the surface, if let us say this is the aggregate, the surface pores can be filled by this water and then this aggregate will not be able to absorb the water from the mixing water for our concrete system. And this mixing approach is called as two-stage mixing approach. Nowadays, filling the pores, surface pores of the recycle aggregate by the cementitious binder is also getting populated.

So, here in this case what happened, whatever the fine sizes, fine material we are having, for example, cement, silica fumes, fly ash, whatever we have, we can add water along with these materials and then we can put the recycle concrete aggregates, mix them well, so that what happened, these finer portions will be able to address the porosity of the recycle concrete aggregate and that is how we can improve the properties of the concrete. The other best technique which shows promising results is that we can directly soak the water before use, but it will be difficult to soak the finer portions of the recycle concrete aggregates. So, slurry impregnation technique is also getting very much attention nowadays because what happens as we can see in this picture, the recycle concrete aggregates will be having a lot of pores and cracks and poor interfacial transition zone, because of the added mortar. So, this, all these things are there in the added mortar. So, what we can do is that we can place this recycle concrete aggregates in a bucket and this bucket will be having these slurries made with different mineral admixtures.

So, they could be different mineral admixtures ranging from fly ash, silica fume, granulated blast furnace like or in fact, the cement slurry can also be used. So, when these aggregates are submerged in the slurries made with different mineral admixtures, SCMs or cement for different concentrations, so what will happen, the pores are filled, these cracks are addressed. In fact, in some of the cases, the interfacial transition zone between the aggregate and the mortar has been seen to be enhanced. So, how this mechanism works by this mechanism, so there are basically three mechanism by virtue of which the slurry impregnation techniques work.

First thing is the filler effect. So, let us say we, when we are using the cement, some material which is highly finer, so obviously it will go inside the added mortar and then it will be able to fill these pores. So, that is the filler effect. The second thing is the secondary hydration of the calcium hydroxide. As we know, this is a hydrated mortar, so it will be having calcium silicate hydrate, it will also be having calcium hydroxide. So, when we are using certain supplementary cementitious admixtures as a slurry material, obviously it will go, it will react with calcium hydroxide and it can lead to formation of the calcium silicate hydrate, therefore reducing the pores and reducing the cracks.

And the other thing is that hydration of the unhydrated cement particles. As we know, the complete hydration of the cement will be taking too much of time and when the recycled concrete aggregates are being produced from some recently built structures, in that case, there will be significant quantity of the unhated cement particles and then we are keeping these aggregates into the slurries. So, water will go inside and will be leading to the hydration of the unhated cement particles. But how are these, this technique depends upon numerous parameters, for example, which is the material that we are using. So, literature shows that when micro silica is used, it will be able to reduce the pores by more than 50 percent.

Similarly, it depends upon the concentration of the slurry, how much of the material we are adding, then it depends upon the total soaking duration and obviously the fineness of the slurry. The other technique that can be seen in the literature is the cell feeling of the added mortar. So, there are various techniques of the cell feeling, one of the technique is by using the bacteria. So, normally what happens in this case, some urea will be mixed with the concrete and then this urea will be related in certain bacterias and these bacterias will be responsible for the deposition of the calcium carbonate in the pores and the cracks. But however, there will be issues obviously, because some of the bacterias might not be able to survive in the alkaline environment.

The second thing is that, you know, culturing of these bacteria’s will be difficult and then the working of these bacteria depends mainly on the temperature and the humidity and at this site it will be difficult to maintain the temperature and the humidity. However, the other cell feeling technique is through the carbonation. So, what we can do, we can use the aggregates and we know in this added mortar content calcium hydroxide will be there. So, the carbon dioxide can be feed into the system under pressure and then it can react with calcium hydroxide and form calcium carbonate leading to the improvement in the properties of the added mortar. But mostly, you know, these techniques might not be, you know, adopted into the field.

But we have few incidents wherein the carbon dioxide is directly injected into the fresh concrete and then the results show that injecting the CO2 in the fresh concrete will not compromise with the concrete performance. Now, coming to the techniques wherein we are totally removing the added mortar. So, the added mortar can be effectively removed or not fully, partially at the generation point only. Let us say in the recycling plants, if you are having multiple stages of the crushing, so obviously, it will be able to reduce the added mortar effectively. And also, the study that has been conducted at IIT Madras shows that by changing the crusher type also we can able to effectively reduce the added motor.

For example, in this case, the added motor content for different sizes of the aggregate was found to be higher in case when the concrete chunks are crushed by jaw crushers. And in fact, when the crusher was changed to horizontal shaft temperature crusher, it, so it reduced the added motor effectively. The other important technique to remove the added motor is to submerge the recycled concrete aggregate into the chemical solution. So, various chemicals can be used for, you know, weakening the added mortar. For example, hydrochloric acid can be used, sulfuric acid can be used and phosphoric acid can be used. And then, normally what happens, these acids will be mixed with the waters and then the RCA will be submerged in that. So, it will be leading to the weakening of the added mortar and then by providing some scrubbing, the added mortar can be removed. However, there will be some issues. For example, if the concentration of the acid is more, it may affect the aggregate quality.

Also, this technique might not be sustainable. And then, obviously, we need to consider the associated cost as well. So, the best technique that can be seen in the available literature is thermo-mechanical beneficial technique. As we discussed, the added mortar, you know, the hydrate, it will be hydrated, so it will be contain calcium silicate hydrate, it will be having calcium hydroxide, and in certain cases, it can have calcium carbonate. And we know that the dissolution of the calcium silicate hydrate will be happening at around 230 degrees centigrade. Similarly, between 400 to 500 centigrade, the calcium hydroxide will be dehydrated and for and then when the concrete is heated at a temperature of 700 to 900 degrees centigrade, calcium carbonate can also be, you know, dehydrated.

So, normally in this technique, what happens, obviously, the concentration of CHS and calcium hydroxide is significantly higher than the calcium carbonate. So, the concrete chunks of size around 50 mm are kept in the oven and then heated at a temperature of 500 degrees centigrade for around 1 hour. So, it leads to the dehydration of the hydrated compounds. And also different other mechanisms will also be happening. So, for example, we have the coefficient of thermal expansion of the aggregate is different from the coefficient of thermal expansion of the motor.

So, obviously, because of this difference in the coefficient of expansion, the weakening of the added motor will be done. And so, after keeping this oven, these aggregates, these concrete chunks are kept into the open environment or you can say at the ambient temperature. So, there will be thermal shock and because of the thermal shock, again, the weakening of the added motor will be happening. So, because by virtue of these three mechanisms, the added motor is already weakened and now the only thing required will be to provide some scrubbing. So, these concrete chunks can be kept in the milling machines and then by virtue of the scrubbing, the added motor can be removed.

So, here there is a comparative study that has been done, wherein the thermo-mechanical beneficial RCA is compared with without treatment RCA and also with the industrial produced RCA. Here you can see the properties of the thermo-mechanically beneficial RCA is significantly higher than the other aggregate. In fact, the density was even higher than the, you know, no conventional use granite aggregate that is, that are found in India. So, and the best and the other important, you know, benefit, other important benefit with respect to thermo-mechanical beneficial technique is that it is not only improving the quality of the coarse aggregate. For example, here, these are the coarse aggregate wherein we can see they are completely free from the added motor, but this technique will also be producing high-quality fine recycled concrete aggregate.

For example, here in this figure, you can see the density of the treated RCA is 2.35, which is significantly higher than the untreated version and the industry produced RCA. So, but there will be some issues with technique because we are using electricity to heat the aggregates. So, if we see from the sustainability point of view, this might not, this might not be sustainable. So, one study was conducted at IIT Madras wherein this, the fuel was changed from electricity to solar energy, concentrated solar energy.

So, normally what happens at the solar plants, the solar energy is used to generate the electricity. So, normally they have the parabolic disk, which will be used to, you know, divert the sun rays directly to one receiver. So, normally, if you see these receivers are hollow from inside. So, the concrete chunks can be kept inside these hollow blocks and then that sunlight can be directly fed over this receiver and then it can be heated to a temperature of around 500 degree centigrade, which is, which we have used in thermo-mechanical manufacturing techniques. So, normally, you know, these kinds of plants will be having a lot of parabolic disk for generating the electricity.

So, obviously, they will be having a lot of receivers. So, that means the quantity of treated aggregates can be higher depending upon the number of the system that one factory will be having. So, this is a line diagram, which is showing, you know, what are the various parameters that was followed in this particular study. So, in nutshell, what we can see, there are different beneficiation techniques from, you know, from altering the mixing approach wherein the water can be added into, you know, at different times or the aggregates can be used in, you know, saturated surface dry condition. So, but the improvement in the concrete properties by following the surface modification techniques might not be significant. However, these techniques are very simple and then no extra cost will be required and these kinds of the techniques can be applied directly into the field also.

On the other hand, when we are following the removal of the added motor with the help of the thermo-mechanical manufacturing techniques or the chemical techniques also. So, in that case, the removal of the added motor has been seen to be significant and obviously, the concrete that will be made with the treated recycle concrete aggregate will be much better, but we need to consider other aspects. For example, what will be the cost, whether this kind of techniques can be applied directly into the field, whether they are large-scale applicable or not and then what will be the corresponding energy consumption, these needs to be considered. On the other hand, if we are able to, you know, address the added motor directly by using slurry impregnation technique or any other material, then these techniques might not able to improve the strength of the concrete made with RCA as significant to, as compared to where we are using, where we are totally removing the added motor, but these techniques are considerably better than the other approaches, for example, different mixing approach. And these techniques might be large-scale applicable and obviously, again, because we are using different mineral admixtures, supplementary cementation admixtures, so again, we need to see the cost and the energy consumption. So, thank you, thank you very much.