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Pavement Materials

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Lecture 45

Cold Bituminous Mixtures

Hello friends. In the last presentation we have discussed about the mixed design concepts related to hot recycled mixtures which was also termed as reclaimed asphalt pavement. Today we will start discussing about cold bituminous mixtures.

Before I start this presentation, I would like to thank Dr. Bhupendra Singh from who is a faculty at IIT Jodhpur and Dr. Kranthi Kuna who is also a faculty at IIT Kharagpur for giving their valuable contents discussions with them for preparation of this particular presentation.

Well, when we talk about asphalt mixtures then depending on the production temperature, when I say production temperature I am indicating about the temperature at which the bitumen and the aggregates are mixed at the hot mix plant to finally have the or to prepare the bituminous mixture which is further compacted in the field.

So, depending on this particular temperature at which bitumen and aggregates are mixed together asphalt mixture in generally categorized into the following types. We have hot mix asphalt about which we have already discussed in detail so which is also denoted as HMA. We have warm mix asphalt which is denoted as WMA and warm mix asphalt is typically prepared at a production temperature of about 10 to 40 degree Celsius lower than the hot mix asphalt. Talking about hot mix asphalt, the approximate mixing temperature in the plant is about 160 to 170 degrees Celsius.

Then we have half warm mix asphalt which is not very popular but are mixtures which can be produced at temperatures lower than 100 degrees Celsius typically. So, they are denoted as HWMA. And finally, we have cold mix asphalt or CMA which will be our topic of discussion today. And cold mix asphalt can be prepared at temperatures somewhere between 0 to 40 degree or 30 degrees Celsius.

This image, it shows the variation of production temperature corresponding to different asphalt mixture technologies and well, if you talk about the ranges of temperature, several literatures have given almost similar ranges but there can be some difference of approximately 5 to 10 degree Celsius if we compare the values of the temperature range from different literatures but approximately on an average, this is the range which you see in this particular image.

One more advantage which we see here is the consumption of energy corresponding to different technologies for preparing asphalt mixtures. You can see and which is very obvious, you see that when we go from CMA to HMA the energy consumption gradually increases and similarly, the GHG emissions which is proportional to the amount of fuel we burned for heating these materials will also increase.

So definitely cold mix asphalt is a technology which is environmental-friendly which leads to lower energy consumption and also lower emission of GHG gases. And since we are burning less fuel, therefore the cost is also less for production of coal mix asphalt.

But some of the disadvantages of cold mix asphalt and this is the reason why cold mix asphalt is not adopted generally for facilities which receive high traffic. So, the reason is that cold mix asphalt has much lower strength in comparison to hot mix asphalt and this makes it unsuitable especially for heavy vehicular loading.

Also, cold mix asphalt has high moisture susceptibility in comparison to hot mix asphalt and the curing period is also very high which means once we lay a layer of mixture prepared a cold mix asphalt mixture, the curing or the evaporation of water or the removal of water from the mixture system it takes some time and this curing period can varies a lot and can sometimes be very large which sometimes makes this technology impractical to adopt in the field condition especially when there is a requirement to open the pavement to the traffic in a short period of time.

Well if you talk about the components of cold mix asphalt then the components include emulsion. So, we have already discussed in detail about an emulsion is a two to three phase system you can say which comprises of water, bitumen globules and then emulsifiers and the emulsion typically has approximately 40 to 75 percent bitumen, about 0.1 to 2.5 percent of emulsifier and approximately 25 to 60 percent of water in it depending on the type of emulsion, the grade of emulsion and so on.

The other component of the cold mix asphalt just like any other asphalt mixture are the aggregates. Now when you talk about the aggregates we also have to talk about the gradation of aggregates. So, the gradation of aggregates in cold mix asphalt can be similar to what we use in hot mix asphalt but various specifications have given their own gradation specifically to be used when a cold mix asphalt is to be prepared. So, gradation may depend on the specification we are looking at.

The cold mix asphalt also contains water, now water is also present in emulsion but in addition to that also some additional water is required for lubricating the aggregates and for improving the workability of the mix and this water also facilitates proper coating of the emulsion over the aggregate particles.

One thing which probably I missed is that cold mix asphalt can also be prepared using a cut back bitumen but we will not be discussing cut back bitumen in this particular lecture considering that the use of cut back bitumen has reduced a lot and for preparation of cold mix asphalt mostly emulsion is being used presently and cut back bitumen because of its inherent disadvantages are not used for production of cold mix asphalt.

Modification of strength of cold mix as fault which means in addition to these components using which a cold mix asphalt can be produced, we can alter the strength of the cold mix asphalt using additional additives and these includes cement. So, cement is most of the time used for the preparation of cold mix asphalt to increase its strength. The reason being we have water in it.

So, when cement come in contact with the water there is hydration products which are generated which leads to improvement in strength but the amount is very less because this acts like more like active filler rather than we will put a high amount of emulsion to increase the stiffness of the mix. So, that is not the actual target in the mix design process.

So, cement is used in a low quantity, about 1 to 2 percent. We can also use flyash, about 2 to 6 percent. Lime can also be used typically around 2 percent lime has been used for the production of cold mix asphalt and various researchers have used other supplementary additives also to enhance the strength of cold mix asphalt.

This picture shows just a pictorial difference between what is the appearance of cold mix asphalt in contrast to hot mix asphalt, as is very evident from this particular picture you see on the left hand side we have the cold mix asphalt which appears to be more of light to dark brown in colour in comparison to hot mix asphalt which is more of black in colour.

The same mix which I have shown in the picture is available with me right now and you can see it in my hand and very easy difference can be made between a hot mix asphalt mixture and on my right hand I have the cold asphalt mixture. So, you can see these two mixtures which are visually very different from each other, especially the colour of the mixture.

Now, we jump onto discussing the mixed design steps because as a mixture it is similar to any other asphalt mixture. So, I am not going to discuss more about the components in the mixture because the volumetrics remains the same.

We are more interested to understand that how different is the production steps of cold mix asphalt in comparison to hot mix asphalt, the mixed design of which we have already completed and these mixed design steps have been taken from one of the Good review paper which is Cold mix asphalt and review by Jain S and Singh B. It is Shobhit Jain and Bhupender Singh which is published in a journal of cleaner production.

Well, before I begin, I just want to comment that universally there is no standard mixed design process for cold mix asphalt. In fact, various specifications have given their own methodology and most of the methodology are based on trial and error methods. So, mostly it is empirical. The steps are more or less empirical in nature.

And the steps which I am going to discuss today, it is taken from the steps given in MS 14 which is the handbook of cold asphalt mixtures and the steps and most of the other guidelines have also taken MS 14 as the reference to develop their own mixed design process. So, I thought of discussing MS 14 which is one of the initial guidelines in the direction of mixed design of cold mix asphalt.

So, I will be briefly discussing about different steps involved in the mixed design process. So, the first step is to calculate the initial residual bitumen content and initial emulsion content. So, the initial residual bitumen content, this basically is required so that we have some strength in the mix because it is the presence of bitumen in the emulsion that will bind the aggregate particles. So, that is why we need certain quantity of emulsion so that all the aggregate particles stick together inside the cold asphalt mix or cold mix asphalt.

So therefore, the initial residual bitumen content is very important and it is determined using an empirical formula which is shown here. The empirical formula is 0.05A plus 0.1B plus 0.5C multiplied by whole multiplied by 0.7. Here A basically is the percentage of coarse aggregates which are materials larger than 2.36 mm, B is the percentage of fine aggregates and C is the percentage of filler which are material less than 75 micron, ideally. So, using this empirical formula, first we will determine the initial residual bitumen content.

Now, this initial residual bitumen content is not the final bitumen content or final content of the bitumen which will be present in the emulsion which will be using in the mixed design. This is just to start the mixed design process. Now, this IRBC the initial residual bitumen content from where it is actually coming, it is coming from the emulsion. So, when I say initial residual bitumen content, I can also define the initial emulsion content which has to be used.

Using this formula let us say we get the IRBC which means this IRBC should be equal to the percentage of bitumen present in the emulsion x percent of the emulsion content x percent of emulsion content and this x is the percent of the present in that particular emulsion which we are trying to use. So, just using this relationship, we can find that we can write that IRBC is nothing but x percent of initial emulsion content and therefore initial emulsion content is nothing but IRBC divided by x percent. So, we have the initial emulsion content using this formula and this will be using to start the mixed design process.

Now, what is step two? Step two is determination of pre-wetting water content. Now, this is a very important step because pre-wetting water content is required to provide lubrication to the aggregates. And this pre-wetting water content is added before adding the emulsion in the aggregates.

So, this is the water content at which the mix is neither too sloppy nor too stiff. So, this is a definition, an approximate definition of the pre-wetting water content. So, at the pre-wetting water content, when I prepare the cold asphalt mix using the pre-wetting water content and the emulsion content, then the mix should not be too sloppy nor it should be too stiff.

So, this water content is also a function of the type of mix gradation. If it is a dense graded mix this water content can be different. If it is a gap graded mix this water content can be different approximately this water content ranges from 1 to 2 percent of weight of aggregates typically. This is just an approximate range. Now this range depends on various factors. So, two methods can be used to determine the pre-wetting water content. One is the coating test and the other is maximum dry density test.

So, what do we do here? We will prepare the sample using different percentage of water. So, you will take maybe 0.5 percent water by weight of the aggregate then 1 percent water by weight of the aggregate 1.5 percent water by weight of the aggregate so at an increment of 0.5 percent first I will select this pre-wetting water content different percentages and I will mix it with the aggregates. Then I will add the initial emulsion content and I will start preparing the mixture the loose mixture. Then if I am using the coating test, I will just visually observe the mixture.

So, in the coating test when I observe the mixture the degree of coating should not be less than 50 percent. So, I keep on increasing the water content and the water content at which the degree of coating is greater than 50 percent can be taken as the pre-wetting water content but this test is more or less subjective in nature. It depends on the visual observation. The other method which can be used is the maximum dry density test. So, what I do, I do a probably a proctored density test at different pre-wetting water content and here I will see the maximum dry density of the emulsion or the cold mix asphalt.

So, I am preparing cold mix asphalt using this pre-wetting water content and the initial emulsion content. So, I will see that typically what we see in the soil the graph will be something like this so at the maximum density whatever water content I get will be selected as the let me not call this as pre-wetting. I will just call this as water content so this is called as pre-wetting water content. So, based on the maximum dry density I can choose the pre-wetting water content. So, now I have the pre-wetting water content and the emulsion content with me after this step.

In step 3 I have to determine the optimum total liquid content at compaction. What is total liquid content? Total liquid content is the pre-wetting water content which I have obtained using the maximum dry density and then we have some liquid or presence of some liquid content in the emulsion also. So, this is the total liquid content which I have but I have yet not determined the optimum liquid content. I have the total liquid content which is the pre-water content plus the liquid content in the initial emulsion.

So, how to determine the optimum liquid content? I will prepare Marshall samples. So I have to do a Marshall compaction here, using 50 blows of compaction on both the site using pre-wetting water content and initial emulsion content. So, in this step, what I am doing, the initial emulsion content, I will fix it, and I will increase the water content that is the pre-wetting water content by increment of 1 percent for preparation of Marshall samples.

Once I have the samples ready with me, I will condition the samples. How do I condition the sample? I will keep the sample in the mold for 24 hours, then in the oven at 40 degrees Celsius for 24 hours, then at the room temperature for 24 hours. So, this is the conditioning process which I will follow and then I will take the samples and I will perform the Marshall stability test at the room temperature. So, optimum total liquid content is the water content at which the stability is maximum. So, I will note down at what water content the stability becomes the maximum.

So, I hope this step is clear to you that we have the total liquid content that is pre-water content and the liquid content in the initial emulsion. I will prepare Marshall samples by keeping the initial emulsion content fixed but by increasing the water content by 1 percent every time.

And then I will compact the samples using Marshall compaction giving 50 blows on both the sides and then after proper conditioning of the sample, I will measure the Marshall stability. And I will note down that at what liquid content I am getting the maximum stability and that liquid content is termed as the optimum total liquid content. So, using step 3, I have the optimum total liquid content with me.

Then what I do, we will prepare sample at different residual bitumen content. Now I am just going on the other direction. Till now, I was evaluating what should be the optimum total liquid content or water content in the mixture. And now, once I have determined that I am now interested to find out what should be the optimum residual bitumen content. The residual bitumen content we determined only in the first step which was termed as initial residual bitumen content. And in this step, I am going to determine the optimum residual bitumen content, I mean, using this particular step.

So, what I do here? I will vary the initial emulsion content. Once I start varying the initial emulsion content indirectly, I am also wearing the residual bitumen content because this bitumen is present in the emulsion. So, residual bitumen content is varied by changing the emulsion content.

But when you change the emulsion content, you also have to change the pre-wetting water content so that the total liquid is maintained at the optimum liquid content which we have determined in step three. I will just repeat this step, I am varying the emulsion content here. So, once I start wearing the initial emulsion content, I also have to change the pre-wetting water content such that the total liquid content remains similar to the optimum total liquid content which I have determined in the previous step.

So, specimens are prepared at varying RBC and they are subjected to similar conditioning and testing which was discussed previously in step 3. Here also, I am doing the same thing, preparing martial samples, using 50 blows on both the sides, doing the same conditioning, and then going for Marshall stability test.

So, here I do two types of Marshall stability test. First, I do a dry stability test which means after conditioning the sample, I am doing the Marshall stability test that is denoted as the dry Marshall stability test. Then I will prepare multiple replicates of the sample. And then one part of the sample will be subjected to dry Marshall stability. The other part will be subjected to soaking.

So how do I soak the sample? I cannot use the conventional soaking, as we have seen in the hot mix asphalt which was soaking the sample at 60 degree Celsius for 30 to 40 minutes because cold mix asphalt can break at such high curing temperature. So, that is why what we do, we cure it or we soak it at room temperature, basically not at 60 degree Celsius in two steps.

So, I will first take the beaker filled with water to a level such that half of the cylindrical specimen can be submerged in it. So, first I will condition the half part of the sample in 24 hours. Then what I will do, I will reverse this sample and then I will condition again the other half for 24 hours. So, this is this half now.

So, I will condition the other half for 24 hours and after this conditioning is done, I will just take out the sample, dry it using a towel and then perform a Marshall stability test on it. And this result will be denoted or termed as soaked Marshall stability. So, I have dry Marshall stability and I have soaked Marshall stability after this particular step. And I have this soaked in Marshall stability for different cold mix asphalt prepared at different residual bitumen content. So, this is something which you have to remember.

Now, using this result, I will determine the optimum residual bitumen content. So, results of the sample prepared using different RBC are analyzed and optimum residual bitumen content is estimated by optimizing different parameters. These parameters may include soak stability, dry density, air voids, the flow value while doing the Marshall stability test and so on. So again, these parameters are specification dependent. So, I have to select the optimum residual bitumen content such that the ranges of the criteria which is given by the agency is satisfied.

In case we get insufficient stability or air void in the mixture, then an alternate way to go is to increase the level of compaction because we were only making the mix at 50 blows. So, if the air void remains very high, then we can increase the level of compaction to probably 75 blows. And again, the samples are retested using similar procedure which we have discussed.

So, this is a table which is taken from Ministry of Road Transport and Highways which give specifications related to cold mix asphalt. So, you see that the minimum flow value which is desirable is 2 mm at 22 degree Celsius. Now again, this temperature changes from specification to specification. Even in India we have specification on one hand given by Ministry of Road Transport and Highways and on the other hand we have the IRC Manual, which is IRC SP 100 which is again on cold mix asphalt. If you try to compare the specification in both these guidelines, you will see that they differ from each other.

For example, in IRC SP 100, the temperature which is given is 25 degree Celsius. On the other hand, in the Ministry of Road Transport and Highways it is 22.2 degree Celsius. There are a few other differences I will talk about it. Marshall stability minimum 2.2 kilo Newton, again at 22.2 degree Celsius. Retain stability, It is the Marshall stability of the soaked sample divided by Marshall stability of dry specimen. It should be at least 50 percent minimum. This is again a requirement.

The emulsion content is typically varied from 7 to 10 percent while preparing the mixes, the level of compaction is 50 blows. This I have already discussed. The minimum VMA, it depends on the nominal maximum aggregate size.

Now again talking about the nominal maximum aggregate size, the Ministry of Road Transport and Highways have given some specific aggregate gradations to be followed. Researchers have also used conventional gradations like BC and DBM for preparation of cold mix asphalt. IRC SP 100 which is again a specification or guideline on cold mix asphalt. They have given gradations related to semi dense bituminous concrete and also dense bituminous and also bituminous macadam.

So, as I said, the gradation also depends on the specification and VMA is a function of the nominal maximum aggregate size. So, Ministry has already given a table depending on the nominal maximum aggregate size. The minimum VMA ranges from typically 12 to 16 percent.

Now, as per Ministry of Road Transport and Highways, the air void required in the cold mix asphalt should range from 3 to 5 percent. Now, this criteria is seldom met because typically in cold mix asphalt the range is somewhere around 8 to 14 percent and for design purpose mostly it is taken as 7 to 10 percent.

Again, this is one difference between IRC SP 100 and the table given in Ministry of Road Transport and Highways handbook that IRC SP 100 states that for cold mix asphalt, the air void can be in the range of around 7 to 10 percent. So, this is again one of the difference between the existing guidelines.

Everything which we have discussed can be summarized using this flow chart which is again taken from the review paper. I will just do a very quick recap. The first step is to determine the initial residual bitumen content using this empirical formula. And once we have the IRBC we can know the initial emulsion content because IRBC has to come from the emulsion. So, I can determine the initial emulsion content using this formula.

Then we will determine the optimum pre-wetting water content and this can be done either using a coating test where we have to ensure at least 50 percent coating or dry density test. So, we will select the pre-wetting water content corresponding to the maximum dry density which will then be termed as the optimum pre-wetting water content. So, just a note here that here we are changing the water content and emulsion we are maintaining at the initial emulsion content.

The next step is to determine the optimum total liquid content. Here what we do, we keep the initial emulsion content constant and we keep changing the pre-wetting water content and we will perform the Marshall stability test. So, the water content corresponding to maximum Marshall stability is basically then combined with the water in the initial immersion content to calculate the optimum total liquid content.

And finally, we will keep the optimum total liquid content constant but we will keep changing the emulsion content. So, in order to do this, once we change the initial emulsion content, we will make parallel changes to the pre-wetting water content such that the optimum total liquid content is maintained.

So, using this step we will make again several mixtures. We will carry out Marshall stability test both in soaked and in dry condition. We will analyze the results and then using that we will determine the optimum residual bitumen content so that the specifications criteria are met.

So, this is the reference for the manual MS 14 which we have discussed in today's lecture. Then we also have specification which I mentioned IRC SP 100. Now in the IRC SP 100 the process of doing the mixed design is almost similar to MS 14 with few minor changes. I would like to discuss the steps given in IRC SP 100. The steps in IRC SP 100 it includes there are some changes. First, they determine the quantity of bitumen emulsion using a similar empirical formula plus 0.5 C.

So, this formula they use to determine here A is basically the percentage of material greater than 2.36 mm, B is the percentage of material less than 2.36 mm and retained on 90 micron sieve and C is the percentage of material less than 90 microns. So, this is what is specified.

So, then what they do, they will keep P constant and vary water content. This is the pre-wetting water content. Now they follow observing the coated mixture and they take the water content, take the pre-wetting water content to obtain maximum coating. This typically ranges from 2 to 3 percent of aggregate weight. So, this is the second step. Then, they will keep the optimum water content fixed of optimum pre-wetting water content fixed and they will prepare martial specimens at varying emulsion content.

This emulsion content can be taken starting from 5 percent. We can go up to 9 to 10 percent by weight of aggregate. The conditioning process includes once you prepare the mixture, you have to do conditioning. So, conditioning will be done for loose mixture. So, 1 to 2 minutes will be taken to mix it then you condition the loose mixture in air 1 to 2 hours using a fan. Then you keep the sample again lose mix following this at 40 degrees Celsius in an oven for 2 hours, then you compact the specimen using 50 blows of Marshall.

Then you extract the sample. Then again, the compacted specimen you have to condition in oven to extract the sample after 24 hours. Then you condition the sample at 40 degrees Celsius in the oven for 72 hours. So, you can see the curing process is different and it is a tedious process here. In fact, in any cold mix asphalt design that you have to subject it to long period of curing and then you have to perform stability test at 25 degree Celsius.

Some specifications also require carrying out indirect tensile strength test on the compacted cold mix asphalt specimen to complete the mixed design process, so this is again a brief overview of what is given in IRC SP 100 and as I said, there is no universal mixed design method. Different specifications have given their own design methodology and mostly all the designs are based on trial and error procedure which consists of different steps for determining the pre-wetting water content and the optimum emulsion or the residual bitumen content.

One more point which I would like to make that we also have another popular specification, that is the TG 2 which also gives guidelines for design of cold mix asphalt mixtures. Another important point here to note is that the mixed design process which we have discussed is mostly for the mixtures to be used in the surface courses of the flexible pavement.

If we have cold asphalt mixtures to be used in the base layer, if we have cold asphalt mixtures prepared using reclaimed asphalt pavement materials, then again the mixed design process will change. So, that mixed design we have not discussed in this particular presentation.

Additionally, one more point that we have not discussed the mixed design of cold mixtures when we are using foam bitumen. The reason being we have not discussed in detail about foaming technology during this particular module and that is why the same is not discussed here.

But we have to understand that ultimately it is an asphalt mixture. So, the ingredients will remain the same, the volumetric concepts will remain the same. Only the steps of mixed design will change. So, it is not very important for us to go through different steps of mixed design because they are well established in the literature but more importantly, we have to understand the fundamentals of the mixture properties that we have already discussed in detail.

So, I would like to conclude this presentation here. And in the next presentation, we will talk about performance based mixed design concepts very briefly. And then finally, in this module, we will discuss about the characterization of bituminous mixtures. Thank you.