

Fibers Webinar – Questions and Answers 2/9/2021

The questions submitted during the webinar follow with answers that our speakers have provided.

Key fiber resources for concrete pavements available include:

1. https://intrans.iastate.edu/app/uploads/2019/04/FRC_overlays_tech_ovw_w_cvr.pdf
2. <https://intrans.iastate.edu/app/uploads/2019/10/MAPbriefMarch2019.pdf>
3. https://intrans.iastate.edu/app/uploads/2019/03/Residual-Strength-Estimator-for-FRC-Overlays-April-19-2019_public.xlsx

1. Do steel fibers tend to get magnetized during the batching process? Florida

I have not seen literature whether the batching process magnetizes the steel fibers. Without the presence of an extremely high magnetic field and steel at elevated temperatures, there is no reason to expect magnetization of the fibers during the batching. Ironically, we have recently been testing in the lab the electromagnetic response of steel fibers in concrete, specifically their magnetic properties. We have noticed different magnetic properties based on the manufacture/type of steel fibers. Steel fibers may be somewhat magnetized during the manufacturing process especially above the Curie temperature and in the presence of a strong magnetic field

2. We had tried using steel fibers in concrete but they tended to create balls during the batching. Can you discuss any solutions? Florida

Yes, this is not surprising. Most projects struggle initially with fiber balling especially as the volume fraction increases. Like any mix design adjustment when a new additive is introduced, it takes time to determine what the right adjustment should be. It could be changing the batching procedure of the fiber, it could be type of fiber is more prone to balling (higher aspect ratios), it could be rate of fiber introduction into the drum, and it could also be the paste content or slump of the mixture. This particularly topic is covered extensively in the above references since it is one of the most common questions and concerns.

3. Is there any significant chemical reactions of steel fibers in concrete pavements? Pennsylvania

In general, there is no chemical reaction between steel and cement paste similar to reinforcing steel and concrete. Fibers have various shapes and textures to promote pullout resistance through mechanical means. The only reaction that fibers can have is superficial corrosion of individual fibers on the surface of the concrete, which are exposed to the elements (oxygen, water, chlorides).

4. Are fibers more effective in concrete pavements than asphalt pavements?
Pennsylvania

This is a very good question and I will offer some thoughts on this. We have >40 years of experience with fiber reinforced concrete and very little experience with fibers in asphalt pavements. I believe in the past 15 years we have really improved the use of fibers in concrete in terms of design, construction, and expected behavior of a particular engineered fiber. We no longer have to base decisions on an engineer's experience only but we have design codes, standardized testing, field performance sites, and more theoretical understanding of failure mechanisms. For asphalt, we are seeing more fibers in the market for applications and I do receive calls from engineers about how can fibers improve flexible pavements and whether the performance claims made by manufacturers are true.

We know that adding macrofibers to concrete increases the cracking resistance of the plain concrete and we can take advantage of that in the design and long-term serviceability of the concrete pavement. For flexible pavements, the first set of questions would be (a) what is the purpose of the fibers? (b) what failure mechanism am I trying to alter with fibers? (c) how does the temperature and fiber properties (geometry, surface texture, tensile capacity, and elastic modulus) affect the mechanism I am targeting?

In my opinion, if I was using fibers in asphalt pavement today I would need to decide if I am primarily targeting rutting, fatigue cracking, block cracking, or thermal cracking. These failure mechanisms would likely require different types of fibers (e.g., modulus, aspect ratios) and no single fiber could work for all mechanisms but I am sure some fibers are a good balance. Note, rutting occurs at higher temperatures and therefore, longer fibers with lower modulus may work better whereas for fatigue, fibers may need to be of shorter length and higher modulus. Ultimately, a hybrid mixture of fibers may be the solution for tackling rutting potential and fatigue crack development. You will have the same mixing questions with asphalt and fibers that you have for concrete and how much should I add per ton of asphalt. Furthermore, you will need appropriate performance tests to determine the right dosage for a particular design strategy. Finally, the batching and mixing temperature of asphalt can alter or be detrimental to certain polymer fibers.

5. Can methacrylate be used at a later time with macro fiber reinforced concrete pavement? Arizona

I am assuming this is for sealing cracks or the surface of the concrete. I have not heard of this being an issue in the past and a quick literature review didn't find any case studies or findings of negative reactions of methacrylate with concrete fibers.

6. How do you test the amount of fiber in FRC concrete? New Jersey

See the reference documents suggested at the beginning of this response. The tech brief and full report above go into great details how to test the amount of fiber to add to improve flexural capacity of concrete slabs. ASTM C1609-12 is the most

recommended standard to characterize the residual strength of FRC for pavement in US.

7. How does FRC affect concrete's permeability? New Jersey

Assuming normal paving concrete without any 'cracks', then macrofibers should not affect the concrete's permeability.

8. How does the cost of FRC compare with non-FRC concrete pavements? New Jersey

This depends on the amount of fibers per cubic yard and specific fiber brand (type). In general, one can expect 15% to 20% increase in concrete material cost with fibers but this will vary with volume fraction and project location.

9. What is the maximum slab thickness for FRC concrete? New Jersey

This would depend on the structural design of the pavement which includes the environmental conditions, load levels, and slab geometry. As shown in the presentation, FRC is used in airports where loads can be 5 to 6 times higher per wheel load than highways so there is no maximum thickness concept for FRC like for plain concrete. The thickness of a slab can be reduced with fibers, which depends on the aforementioned factors and residual strength the fibers provide to the concrete.

10. What options would you recommend that work as well as FRC? New Jersey

There are multiple ways to reduce the slab thickness or increase slab performance. Fibers are one option to increase the slab flexural capacity. Short slabs with the same thickness will also increase slab capacity. Strong foundation layers can improve performance. Avoiding loads along the edge will also reduce the required slab thickness.

11. Do you recommend a minimum trial batch size to determine fiber disbursement issues? Michigan

Yes, this is an excellent and possibly essential step given each mix design is somewhat unique and different fiber types have different water demands. This is recommended in the resources provided above. There are many ways to improve disbursement of fibers such as better batching techniques, chemical admixtures, etc., but project engineer/contractor must determine what works best for a particular project, materials, and ready-mix supplier. A trial batch is an essential part to a successful project to avoid large volume of FRC at the job site with inadequate fiber distribution. There is no universal mix design for FRC given the project objectives determine the mix workability and needs for constructability.

12. How deep are the joints? Quebec

Joints need to be cut as deep as traditional plain concrete and as soon as possible to avoid the concrete gaining too much tensile strength and being more resistance to crack propagation at the contraction joints. Late sawing may not produce random cracks in the slab but could produce more dominant joints that open very wide given some contraction may not actually crack. This has been seen in the field before especially for larger panel sizes.

13. How are the fibers loaded into the central mix drum? Do they manually dump pre-weighed bags on the main conveyor or is it automated? Pennsylvania

This depends on the type of fiber and how the manufacturer packages the fibers. There is no one-way to introduce the fibers and ready mix producers and contractors must work with fiber suppliers for best practices. Some fibers come in water soluble bags that can be added on the conveyor belt to the drum. Some fibers can be augured into the drum, and other systems can blow fibers into the drum. The same principles go for transit mixing trucks which require some experience on best way to introduce and achieve disbursement.

14. What is the cost per cy for a typical 4 lb. dosage? Pennsylvania

This will depend on the fiber brand (quality), location (shipping), and volume supplied for a project but an estimate could be \$3 to \$5/lb.

15. Why has ACI 330 not adopted this methodology for incorporating fibers into thickness design? Or perhaps ACPA? Colorado

I am not exactly sure why ACI 330 has not incorporated this yet into their design recommendations but I am not engaged in that committee to know the details. I know engineers on this committee and I know they are aware of how to do and have even implemented these design concepts with fibers in other software. For example, there is design software for exterior slabs utilize these concepts for FRC design (e.g., Opti-Pave 2.0 and discontinued program called BCOA by ACPA). I actually assisted ACPA in implementing this into their BCOA App store approximately 10 years ago with Robert Rodden. It has subsequently been added to Pitt BCOA-ME and ACPA Pavement Designer allows certain concrete pavement designs to be made with fibers.

16. Should I use non-shrink admixture in addition to fibers in order to decrease possibility of shrinkage cracking? Maryland

You can do this especially if your objective is to design extended joint slab systems. For normal joint spacing with fibers or even short-jointed slabs used for concrete overlays such as BCOA or unbonded systems, very low shrinkage mixtures can prevent regularly spaced contraction joint activation. There are other reasons to design lower shrinkage such as reduced curling and debonding if it is a bonded

overlay. Shrinkage reducing admixtures may be added for similar cost to a mixture as macrofiber so it must make economic sense for the design to combined fibers + shrinkage reducing admixture.

17. Do you experience any corrosion with steel fibers? Illinois

In general, corrosion of steel fibers has not been a significant issue even though it is a very common question that I receive during presentations. Steel fibers have been successfully applied on industrial and airports pavement projects for 30 years without major reports of corrosion. There are no large continuous circuits setup with small discrete fibers so if corrosion does occur it is very localized (unlike steel reinforcing bars). I have seen a few projects where the fibers on the very top of the surface over time corrode individually and pop out, which at worst just looks bad but no structural issues. If there are high chlorides at wider joints and it is the main mechanism for load transfer then there may be instances of corrosion causing loss in joint capacity (not much of this reported). Given there are not huge number of FRC pavements for roads (with steel fibers) that have been reviewed on a regular basis, this issue does not seem to have evidence of being an issue with any frequency. In my experience, the vast majority of steel fibers are typically applied to interior slab systems where corrosion is not an issue at all.

18. Slide 32 notes an increase in paste content if mix adjustment is needed. Could an increase in mortar content, not just paste content, be as beneficial so increasing cement is not necessarily required? South Carolina

Yes this is a possible suggestion that could work but it would depend on the type of sand, coarse aggregate, and combined gradation and the existing volume of paste in the mix.

19. What is the approximate cost of adding fibers to the mix? Iowa

This depends on the pavement application but 15% to 20% for typical concrete pavement applications.

20. Do the fibers effect the surface finish? Arkansas

Macrofibers can affect the surface finish to a degree and it depends on the type of fibers and application. Floor slabs are power troweled which produces a very smooth surface without seeing the fibers. For pavements, tining and texturing can cause some of the fibers to protrude from the surface. These fibers wear-off pretty quickly under traffic and UV radiation especially for polymeric. Manufacturers have specifically designed lower flexural modulus fibers with the express purpose of better finishing if appearance is of key importance.

21. Do the fibers still allow a crack to develop at contraction joints? Arkansas

Fiber joints do activate but they may be delayed depending on the joint spacing chosen and restraint offered by base friction coupled with the magnitude of temperature/moisture contraction. Additionally, FRC joint sawcuts must be at least similar depth to plain concrete and more care should be used in cutting joints as soon as possible to increase the probability that the joints activate early versus later when the concrete gains strength and fibers offer high resistance to crack propagation at the joint.

22. When designing with Macro-Fibers in Spec. commercial world, we typically have to get the "powder content" around 600#, does the extra powder offset itself with the fiber in regards to shrinkage? Pennsylvania

This is difficult to answer exactly and not sure if I am answering Mark's question. Exterior pavements don't undergo the same magnitude of moisture curling that indoor slabs suffer at times where shrinkage can be a major problem in flatness and joint performance. Moisture curling can be a problem in exterior pavement and shrinkage can be an issue but most mixtures for pavements have total cementitious of 500 to 575 lb/cy. Additionally, most pavements are slip-formed whereas commercial floors are typically pumped with a higher slump. Sufficient paste or powder content is one factor for a successful mixture but gradation of the aggregates and types of aggregate will also impact the required cementitious content, water, and any further admixtures. Adding too much powder to achieve workability may produce unacceptable shrinkage for a project requirement.

23. Does fiber-balling look similar with synthetic vs. steel fibers, i.e. do synthetic and steel fibers have the same probability to develop balling, or does one seem to mix and separate better than the other? Illinois

I am not sure the probability differences but both can ball up if fibers are not charged to the mixing drum at proper time; if mix design is too dry; or insufficient energy is used to mix the concrete. In my experience, synthetic fibers have produced smaller fiber balls of several inches whereas I have seen much large fiber balls with steel fibers, e.g., > 6 inches. Note, balling also depends on type of fiber, its aspect ratio, and how it is packaged.

24. What is the thinnest concrete overlay? Any special type of concrete needed with, say 1/2 in thick overlay? Indiana

The thinnest concrete pavement overlay I am aware of is 5 cm or 2 inches. This is very uncommon but possible.

25. Joints seem to be on top of wheel path in slide 59. Did you see any distresses because of this? Texas

This slide has 6ft panels which is the best size to use for short-jointed slabs and keeps the wheel path (1.5 to 2 ft off slab edge) of any longitudinal joint. Slab sizes of 4 ft panels will more easily have wheel paths over one of the longitudinal joints especially the inside axle. These slab sizes have shown to create premature failures with heavy axle loads, poor surface drainage, and higher pavement deflections.

26. Please let me know how to access long-term performance data if you have it. Texas

There are a few studies on longer term performance of FRC overlays (See reference reports which were written with this in mind. See also King and Roesler 2013, Gross et al 2017, and NCHRP 1-61 to be published in March 2021, which has performance review). You can also access the National Concrete Overlay explorer which has a list of projects with fibers.

27. Have you used human hair as fiber reinforced concrete? Human hair is strong in tension, non-degradable and is available in abundance. Have you done any research or any information? California

There are multiple issues with use of human hair fibers. The main issue with human hair is its aspect ratio, which is extremely high. High aspect ratios will have significant fiber balling problems which cannot be resolved unless a very small volume fraction is added. Typically for macrofibers, the aspect ratio needs to be around 60 to 90 for most pavement applications. The performance of fibers is also much more than just the tensile capacity of the fiber and long fibers which bond to concrete will fracture even with high tensile capacity. For example, use of carbon fibers of high aspect ratio or Kevlar have not been successful for pavement applications because of high aspect ratio available which leads to severe fiber balling and fracture during crack growth.

28. We had a thin overlay with fibers a few years ago - we experienced some minor delamination & spalling. I assume due to mix not being uniformly distributed. Fiber balling? Indiana

I am not sure what type of overlay this was (bonded or unbonded on asphalt or concrete?). Fiber balling issues would be pretty noticeable in the field survey if it was causing distress since you would see the clumps of fibers either embedded in concrete causing spalling or on surface. Fiber balling is one of the key issues seen in construction problems and just needs careful attention by contractor and field engineer to make sure process is in place for adequate disbursement. Engineers can't assume by adding 4lb/cy of macrofibers to a typically good mix without any process changes that this will produce a well distributed fiber system.

29. Comment: Michigan DOT's new detail for edge drain outlets will now be a cast-in-place 4-inch thick slab, 3' x 3' min., with 4 lb/cyd macrosynthetic fibers. Old standard is a precast bullet / end section. Michigan

Sounds like a great idea and application. I know precast companies have been using macrofibers for >10 years for septic tanks, pipes, burial vaults, etc. quite successfully and this is a great application for macrofibers.

30. Is there design criteria for adding fibers to cement treated soil? Washington

This is a good question and there is a benefit but more work is needed in this area (See example paper by LaHucik et al. 2016, Cement-Treated Bases Containing Reclaimed Asphalt Pavement, Quarry By-Products, and Fibers). There are other papers on benefits of fibers with different types of soils especially sands.

31. Your focus has been on using fibers to increase slab capacity, what about their use to enhance joint load transfer? Can they replace dowel bars? Minnesota

There have been a few studies on effect of fibers on load transfer as you know. This is covered in the summary report provided at the beginning of this document. In general, there is not sufficient evidence, in my opinion, to change the pavement design because of fibers effects on concrete contraction joints. There is a small increase in load transfer with macrofibers and decrease in the rate of deterioration of fiber reinforced concrete contraction joint based on the few studies. However, I don't believe there is sufficient performance evidence or research to replace dowel bars with macrofibers. At this point, fibers can be linked more closely with tie bars, i.e., keep cracks tight, which indirectly improves aggregate interlock. Fibers don't offer the bending and shear resistance that dowel bars provide.

32. Wearing surface as it relates to skid resistance? Missouri

I am not aware of increased friction properties for macrofibers and would not expect increased friction. Several studies have shown increased abrasion resistance particularly with steel fiber addition for concrete slabs on grade as well as other concrete products with steel fibers.

33. Did you find the relationship between energy for dispersion of fibers with different L/D and in different dosages of fibers for different paste amount and W/C in concrete? Iran

I have not personally done testing like this, and I am not sure if the literature has a specific study like this. I expect that there will be a dispersion energy relationship like this for fiber L/D, fiber volume fraction, paste viscosity, and paste volume.