REDUCED CRACKING OF SLAB ON GROUND PROJECTS WITH SYNTHETIC FIBER REINFORCED CONCRETE

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Abstract

Cracking of slabs on ground can indicate major problems and compromised durability and detract from the appearance of monolithic construction. There are too many causes of cracking. Some causes of cracking are prioritized and discussed. Some cracking problems are more controllable by proper material selections and construction practices. Projects are discussed that show significant benefits by using synthetic fiber reinforced concrete to control cracking and increase durability.

Keywords: concrete cracking, slab on ground, synthetic fiber reinforced concrete

1. Introduction

Fiber reinforcement is a most effective way of improving the resistance of concrete to cracking, but little is known of the benefits of fiber reinforcement on long-term durability. The role of fiber reinforcement in enhancing durability can be understood from real-life situations and provide a foundation for life-cycle engineering analysis of fiber-reinforced concrete. Insight is needed from practice on this state-of-the-art topic for academia, and the industry, for further real-life applications. Contractors, material suppliers, engineers, researchers, scientists and owners should benefit from this paper.

Cracking of slabs on ground can indicate major problems and detract from the appearance of monolithic construction. Cracking can also indicate compromised durability. There are many causes of cracking and durability problems that are prioritized and discussed. These problems are more controllable by proper material selections and construction practices. [1]

A thesaurus lists synonyms of words for durability as imperishability, durableness, longevity, resilience, strength, sturdiness, toughness, and robustness. The word toughness is very convenient because that is also a mechanical property of fiber reinforced concrete (frc). An antonym or opposite would be fragility, which is also convenient and is another way of describing concrete without fibers as brittle.

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Durable concrete could be described as concrete that lasts longer without cracks and concrete with cracks is not durable and has failed to last as long without cracks and may need to be replaced. [2, 3]

2. Fiber reinforced concrete defined and basic understanding

In theory, FRC contains enough fibers to intercept and resist micro-cracks from becoming macro-cracks. Concrete is understood to be brittle and weak in tension. The purpose of conventional reinforcing is to hold broken macro pieces of concrete together and the purpose of fibers is to do the same reinforcing work with micro pieces of concrete – hold broken pieces of concrete together. Therefore, the significant difference between fibers and conventional reinforcing steel is a matter of scale and continuity.

Fibers do not have the classical development length issues for full material strength without pull out. Therefore, reinforced is not a material but whatever holds broken concrete together and how well it holds it together is a matter of efficiency of the reinforcement and a different discussion than answering this question, are fibers really reinforcement?

FRC works because of an understanding of two theories, strength of materials and fracture mechanics. [4]

Tab. 1: Aspects and two theories of FRC theoretical mechanics

FRC Theoretical Mechanics		
Aspects	Theory 1	Theory 2
Basic Conceptions	Reinforcement	Fracture toughening
Background	Strength of Materials	Fracture Mechanics
Emphasis	Bond and anchorage	Energy absorption
Requirement	Strong stiff fibers	Adequate numbers of fibers
Fiber Functions	Spans over cracks	Matter states and ages
Resultant Objective	Significant matrix damage	Matrix integrity
Force Conductors	FIBERS	MATRIX

Strength of materials has an emphasis on bond and anchorage of the reinforcement material and requires strong stiff fibers (such as deformed steel re-bar and remember scale issues). The reinforcing material must span across the cracks, there is matrix (concrete) damage, and the reinforcement carries the load.

Strength of materials is mathematically determinate, has factors of safety, load factors, tables and codes, and might historically be described and understood as strength.

Fracture mechanics has an emphasis on energy absorption through fracture toughening of the matrix (how the concrete cracks). The numbers of fibers are statistically important along with the matrix material matter state as concrete transitions from liquid to solid and other age appropriate descriptions and behaviour. The reinforcing material must work during this matter transition, there is matrix (concrete) integrity, and the matrix, not the reinforcement, carries the load.

Fracture mechanics is mathematically indeterminate and can best be described statistically because of too many unknowns, including concentrators of energy. Fracture mechanics might be office practice because of an unexplained incident that does not want to be repeated and is not covered by the codes. Fracture mechanics might be described as based on experience, looks to the future of what might happen not what has happened with a table and code and could be understood as stress rather than strength.

3. Some discussion of concrete cracking for slabs on ground

The cause of all cracking in slabs on ground is completely unknown but there are some primary reasons that can be discussed and addressed in design.

The cause of cracking can be from applied loading external or internal to the slab as a structural or material issue with the six degrees of freedom and this can only cause two responses, rotation bending moment (force through a distance) or direct tension force through no distance.

One type of cracking is caused by applied external loads, such as trucks driving over slabs on ground, but this single type of crack is not caused so much by load because of transfer to the supporting ground and is easily addressed by geometric stiffness by making the slab thicker.

Other types of cracks are caused by many things and includes plastic shrinkage as the concrete material transitions from liquid to solid, hardened shrinkage as the concrete completes the cement hydration, and other tensile stresses due to the amount of difference and rate of difference through the slab. This is another way of summarizing the plastic or hardened shrinkage differences between the very top or bottom of the slab, just below the slab surface, and the slab center. When concrete is cast as a slab on ground there is always a small gap around the perimeter between the concrete and formwork due to the shrinkage as the cement initially hydrates. [2]

Curling is a phenomenon that occurs when the slab dries and shrinks faster on top than the bottom of the slab. Curling causes a small gap under the concrete that must be pushed back down or deflected with loading. Curling can cause the classical failure described as a diamond shape occurring at a joint intersection.

The single most common complaint by floor owners is joint deterioration and cracks caused by slab – edge curling. Further, fork truck maintenance can logically be described as directly related to smoothness of the ride on the slab on ground.

Cracking in slabs on ground can be limited to primarily three types, tension due to shrinkage rate and differences, curling due to differences from initial casting of the concrete and shrinkage, and fatigue due to repeated loading from tension and curling. Department of transportation slabs are designed on the basis of fatigue because the endurance limit is 50% of the normal concrete flexural strength. [5]

4. First generation macro synthetic fiber, one project

This project was constructed in the fall of 1995 and the behaviour obtained can be explained and is understandable as historical credibility to the concepts described and not just theory. [6] The pavement has heavy - duty usage during the harvest season when goods are brought to market. The temperature differences due to the location and weather are -45 Celsius winters to 57-Celsius summers. The location is in very poor soil conditions but on a bed of well - compacted and graded crushed rock. There is normal concrete pavement for 5 kilometers, then 400 meters of macro - synthetic FRC and then another 5 kilometers of normal concrete. Normal concrete pavement was 200 millimeters thick with saw cuts (controlled crack locations) at 6.1 meters and the lane widths were 3.7 meters. FRC dosage was 1.7% and 165 millimeters thick and no saw cuts. The concrete was left alone to crack wherever the cracks occurred. Within two weeks, the FRC cracked at an average 27 meters and was immediately routed and sealed by the transportation agency because that is what was always done. During the 2010 inspection, another crack was found that changed the average spacing to 25 meters.

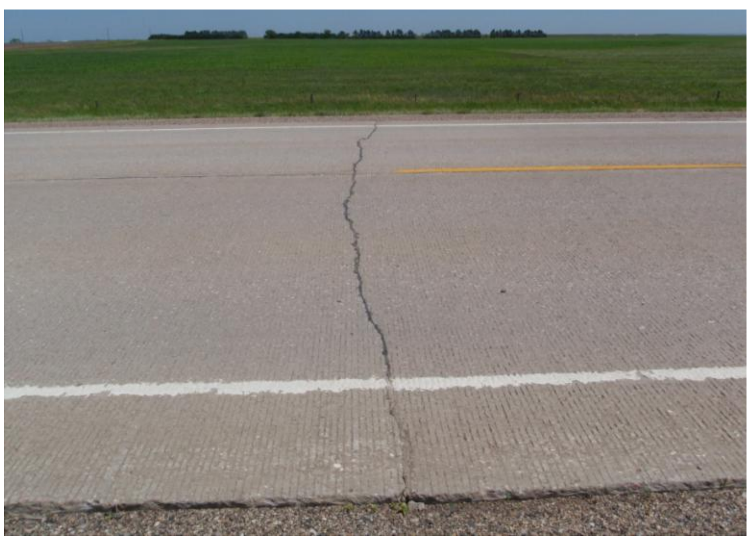

Fig. 1: Full depth FRC pavement crack

5. Second generation macro synthetic fiber, two projects

This one project was constructed in the fall of 2005 with two placements and 2006 with three placements as an overlay of an extremely and badly deteriorated asphalt cement concrete drive with an average slope of 17%. Due to the location of the drive, the work was constructed the opposite way and built from the top down for all 78 meters in length instead of the normal way from the bottom up.

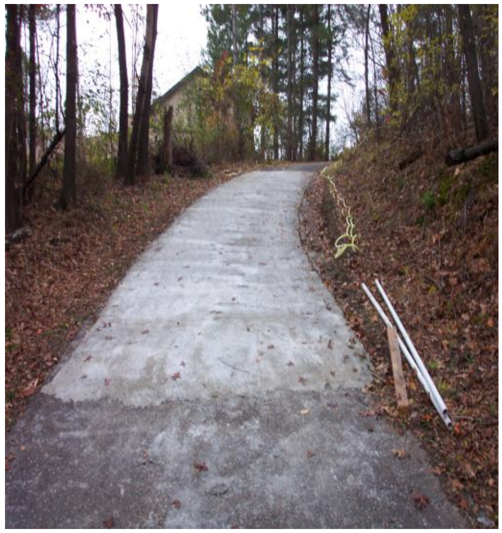

Fig. 2: First of five FRC overlay asphalt placements

The location is near a mighty river and the problem is a soil issue and not a pavement issue. The placement was done on a not prepared surface that was a minimum of 38 - millimeter plus thickness and the fiber dosage was 0.7% due to fiber efficiency improvements. The mixture used small pea sized gravel and 2 parts fly ash to 5 parts cement and air entraining agent because of the freeze thaw issues.

The placements and curing were done the same way both years and the only difference was temperature. The slab with the colder placement time has major crack spacing about 3 meters apart and the warmer placement has major cracks spaced 6 meters apart.

This second project was for an interior warehouse application and part of a two - year study regarding the benefits and affects of fibers and published as a series in a national magazine. The floor was 150 millimeters thickness and the saw cuts and fiber dosage varied. The building had 5,575 square meters total and saw cuts for 16.9 square meters with a fiber dosage of 0.20% and 150 square meters with a fiber dosage of 0.50%.

The 0.20% dosage had a length to thickness ratio of 27 and for the 0.50% dosage the ratio was 80. Normally, the ratio would be between 24 and 30 to minimize mid panel cracking.

The 0.50% dosage slabs had 80% less joints. There was no steel in any of the slabs and no mid – panel cracking. However, the significant difference in the fiber slabs was no curling in the 0.50% dosage slabs. This confirmed behaviour of no curling with this dosage could explain the behaviour observed in the first generation macro – synthetic fibers and project discussed from 1995.

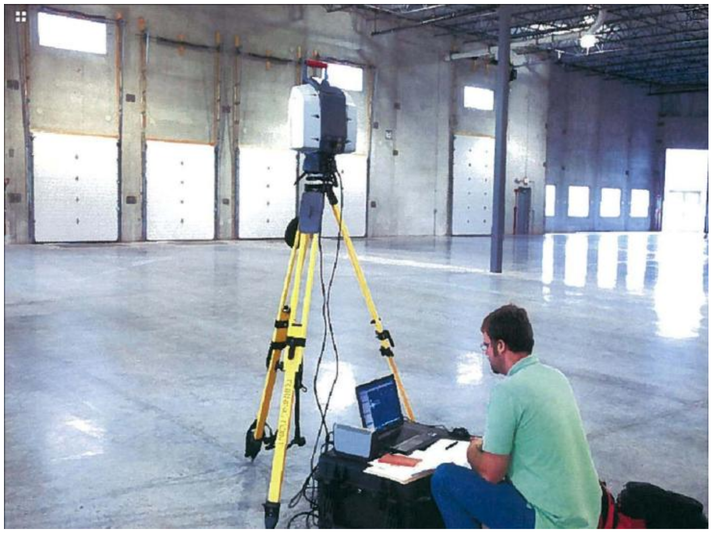

Fig. 3: Precise measurements of floor profile

This is a quote from the editor of the magazine that published the articles on this project "Warehouse maintenance issues start along control joints because forklift traffic causes crumbling and cracking – where curling is the highest and the least support for a panel exists. So high-volume macro fiber slabs offer the possibility of flatter slabs with less maintenance over time." [7, 8, 9, 10] This is specific to the project described but the applicability to other projects should be obvious.

6. Conclusions

There are significant differences in fiber types and dosages to get desired behaviours and mechanical properties of the concrete. Synthetic fibers hold concrete together very well and at sufficient dosage can increase joint spaces and decrease cracks in concrete significantly. The longer length and higher dosage works best for concrete to reduce cracking and increase joint spacing. Fibers can be used in any concrete for many reasons. Durability is improved by any reduction in cracking. Cracking can be caused by fatigue, curling, and tension due to shrinkage. Fibers reduce fatigue and curling and intercept micro - cracks to keep them from becoming macro - cracks.

Fibers can be used with confidence with a "calculated" risk to obtain what will work in a variety of concrete projects to increase durability and reduce cracking in concrete – for whatever reasons concrete cracks. Presently all of the observed behaviors may not be explainable but the scientific method dictates that fibers must be tried because of the repeatable observations of many successful applications.

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