



Evaluation of the Effect of Macro-Synthetic Fibers on Thickness and Cost Index of Jointed Concrete Pavements Considering the Impact of Post-Cracking Flexural Strength

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ABSTRACT: Considering the effect of post-cracking strength and the cost of pavement construction in designing the thickness of jointed concrete pavements lead to more effective and economical pavement design. Therefore, this study evaluates the effect of the addition of macro-synthetic fibers on the thickness and construction cost of jointed concrete pavements, considering the impact of post-cracking flexural strength. The effect of polypropylene macro fibers in the amounts of 0, 1, 2, and 3 kg/m³ on changes of thickness and construction cost index of jointed concrete pavements was studied considering the modulus of rupture and equivalent flexural strength ratio of each mix design in pavement thickness design. It was observed that the addition of macro fibers reduced the thickness of jointed concrete pavement up to 25%. The highest pavement thickness reduction occurred in fiber consumption from 0 to 1 kg/m³. With the addition of more fibers, no more significant decrease in thickness occurred. The addition of fibers increased the cost index of pavement construction up to 57%. Using macro-synthetic fibers up to 1 kg/m³ caused the lowest pavement cost index's growth rate compared to other consumption contents. It was concluded that the optimal amount of macro-synthetic fibers could be determined for economic reduction of the pavement thickness by considering the growth rate of the pavement cost index, which in this study was obtained at the content of 1 kg/m³.

Review History:

Received: 9/24/2020

Revised: 11/27/2020

Accepted: 12/30/2020

Available Online: 1/6/2021

Keywords:

Jointed concrete pavements

Macro-synthetic fibers

Pavement thickness

Construction cost index

Post-cracking flexural strength

1. INTRODUCTION

Jointed plain concrete pavement (JPCP) is one of the most common types of concrete pavements used in roads and airfields surface. The non-use of reinforcing rebars is one of the significant advantages of this pavement over other conventional concrete pavements, such as jointed reinforced concrete pavement (JRCP) and continuously reinforced concrete pavement (CRCP), which reduces construction costs and time. However, the use of transverse joints to reduce cracks due to temperature and humidity change and dowel bars to transfer load efficiently between the slabs increases construction cost in this type of pavement. One practical approach that can make the construction of these pavements more economical is to reduce the concrete pavement thickness. Reducing the thickness of the concrete slab while maintaining the load-bearing capacity and durability of the structure reduces the consumption of various materials and the cost of operations, leading to a reduction in pavement construction's total cost. Pavement thickness depends mainly on the rupture modulus of concrete [1]. As a result, increasing rupture modulus can reduce the thickness of the pavement.

Among the various approaches to increase the flexural strength of concrete, the addition of different fibers can be an

effective approach. Polypropylene synthetic fibers are among the most widely used fibers in concrete pavements due to their low price and wide range of fiber properties, including fiber strength and modulus [2]. The use of synthetic macro fibers is used to increase the strength properties of concrete. The addition of fibers, in addition to improving the strength properties of concrete, also increases its post-cracking strength [3]. However, in conventional pavement design methods, only the effect of resistance before flexural fracture cracking is considered in determining the pavement thickness. To consider the effect of flexural strength after concrete rupture, in designing the thickness of pavement slab, Altubat et al. [4] presented an effective flexural strength method. The results of their work showed the effectiveness of the proposed method in the design of concrete pavement. Thus, considering post-cracking flexural strength may help reduce the thickness and construction cost of jointed concrete pavement.

According to the research background, synthetic macro fibers' effect in different contents on the thickness and cost index of jointed concrete pavement considering post-cracking flexural strength has been less studied. Therefore, the present study investigates macro synthetic fibers' effect on the thickness and cost index of jointed concrete pavements, considering the effect of flexural strength after cracking.

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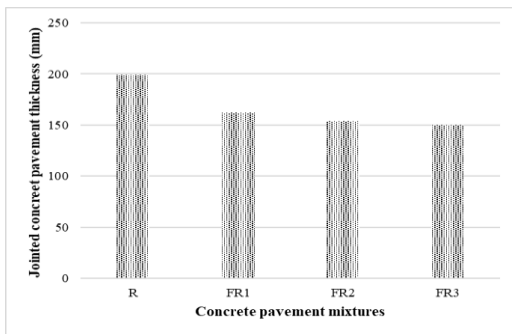


Fig. 1. The thickness of jointed concrete pavement fabricated with reference and fiber-reinforced concrete

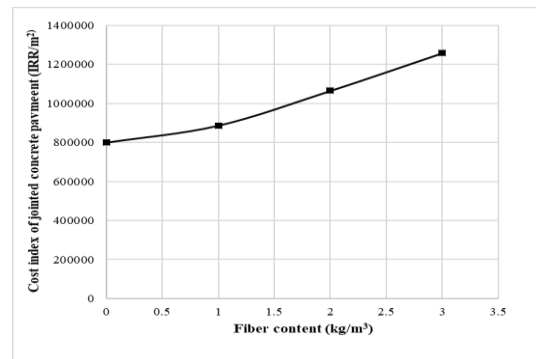


Fig. 2. The cost index of jointed concrete pavement fabricated with reference and fiber-reinforced concrete

2. MATERIALS & METHODOLOGY

Materials used in this research to make concrete mixture were fine aggregates (0-5 mm), coarse aggregates (5-12 mm) and (12-19 mm), portland cement type 2 with a density of 3130 kg/m³, superplasticizer based on polycarbonate ether and water. The fineness modulus, relative density, and absorption of fine aggregates according to ASTM C33 and ASTM C128 standards were 2.8, 2.6, and 2.9%, respectively. Relative density and absorption of coarse aggregates (5-12 mm) were 2.5 and 2.5%, respectively, and coarse aggregates (12-19 mm) were 2.6 and 2.0%, respectively, according to ASTM C127 standard. The fibers used in this study were macro synthetic fibers based on polypropylene with the commercial name of FORTA™, conforming to ASTM C1116 and ASTM D7508 standards. The fibers' properties are as follows: length: 54 mm, diameter: 0.4 mm, tensile strength of 693 MPa, and elastic modulus of 6.4 GPa. The proportions for concrete pavement mixtures were selected according to Iranian concrete pavement regulations, manual No.731. These criteria included a minimum compressive strength (28-day cylindrical specimens) of 30 MPa, a slump of 10-70 mm, and a maximum water-to-cement ratio of 0.53. Concrete pavement mixtures proportions for the fabrication of 1 m³ concrete in saturated-surface dry conditions were as follows: cement: 350 kg/m³, fine aggregates (0-5 mm): 1057 kg/m³, coarse aggregates (5-12 mm): 564 kg/m³, coarse aggregates (12-19 mm): 141 kg/m³, water: 175 kg/m³. Fibers were added at the content of 1, 2, and 3 kg/m³. The amount of superplasticizer was added to reach a target slump of 60±20 mm in all concrete mixtures. Therefore, one reference (R) and four fiber-reinforced concrete mixtures (FR1, FR2, and FR3) were considered.

Rupture modulus and equivalent flexural strength ratio of each mixture were determined according to ASTM C78 and ASTM C1609 standard test methods, using beam specimens with a dimension of 500*150*150* and the effective length of 450 mm at the age of 28 days. The minimum required thickness of jointed concrete pavement (h_{design}) fabricated with reference and fiber-reinforced concrete mixtures, used in major arterials, were designed according to PCA design method using concrete pavement design program, Streetpave 12. The cost index of each concrete pavement was determined according to equation (1):

$$C = \frac{C_{concrete} * h_{design}}{1000} \quad (1)$$

Where C is cost index (IRR/m²), $C_{concrete}$ is materials cost for 1 m³ of concrete pavement (IRR/m³), and h_{design} is the minimum required thickness (mm).

3. RESULT & DISCUSSION

Fig. 1 shows the thickness of jointed concrete pavements fabricated with reference and fiber-reinforced concrete mixtures. It can be seen that the addition of fibers reduces the thickness of fiber-reinforced concrete pavement compared to reference one. It is due to the increase in rupture modulus and consideration of the effect of post-cracking flexural strength of fiber-reinforced concrete mixtures in the design of pavement. By adding fibers at the content of 1, 2, and 3 kg/m³, the pavement thickness is reduced by 19, 23, and 25%, respectively. These results show that by adding fibers at the content of 1 kg/m³, there is a significant reduction in the thickness of the pavement slab, but after adding fibers at the content of 2 and 3 kg/m³, the reduction in pavement thickness is not more. In other words, by adding more fibers than 1 kg/m³, there is no significant reduction in the thickness of the pavement.

Fig. 2 shows the cost index of jointed concrete pavement fabricated with reference and fiber-reinforced concrete mixtures. It can be seen that the addition of fibers increases the cost of construction of one square meter of fiber-reinforced concrete pavements. Adding fibers at the content of 1, 2, and 3 kg/m³ increases the cost index by 10, 33, and 57%, respectively. It is seen that the positive effect of fibers up to 1 kg/m³ on reducing the pavement thickness can control the growth rate of the cost index. With the addition of more fibers, its positive effect on reducing the thickness of the pavement is reduced. On the other hand, the cost of making 1 m³ of concrete is continuously increasing. As a result, pavement construction's cost index grows by adding fibers more than 1 kg/m³. Therefore, by considering the cost index, which takes into account the effect of reducing the thickness and the cost of pavement construction, it is possible to determine the optimal content of macro synthetic fibers to

reduce the thickness of the pavement, which was obtained at the content of 1 kg/m³ in this study.

4. CONCLUSION

The most important results obtained from this research are as follows:

- Adding fibers to a specific content (1 kg/m³) reduced the concrete pavement thickness significantly. Nevertheless, by adding more fibers, no more significant reduction in pavement thickness was observed.

- The increase in the cost index of fiber-reinforced jointed concrete pavement in the fiber content of 1 kg/m³ occurred at a lower rate than other content. It shows that the positive effect of this content on reducing the pavement thickness can control the increase in the pavement construction cost.

- By considering the effect of adding macro synthetic fibers on changes in cost index, which considers the effect of thickness changes and the cost of pavement construction

simultaneously, the optimal amount of fiber consumption can be determined.

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HOW TO CITE THIS ARTICLE

A. Hassani, S.J. Vaziri Kang Olyaei, M.R. Hajizadeh, *Evaluation of the Effect of Macro-Synthetic Fibers on Thickness and Cost Index of Jointed Concrete Pavements Considering the Impact of Post-Cracking Flexural Strength*, *Amirkabir J. Civil Eng.*, 53(2) (2021) 177-180.

DOI: [10.22060/ceej.2021.19050.7048](https://doi.org/10.22060/ceej.2021.19050.7048)



