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Evaluation of the influence of polypropylene fiber on the flexural strength of rigid pavements

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***Abstract*– The low resistance of concrete and its exposure to vehicular overload generates the premature propagation of different types of failures in pavements, such as fissures and cracks that allow water to enter the lower layers, decreasing their resistance and damaging its structure. In this article, the evaluation of the resistance of concrete reinforced with polypropylene microfiber in the presence of bending stress was carried out.**

To improve the performance of concrete, various studies related to how to increase the mechanical properties of concrete recommend the incorporation of materials such as polypropylene fiber. In this study it was evaluated for the percentages of 0.75%, 1% and 1.5% by volume of concrete. The incorporation of fiber to the concrete generated improvements in resistance compared to unreinforced concrete. The laboratory results showed that with the addition of 1% fiber the flexural strength improves by 38% even after reaching its maximum strength compared to the conventional mix. Likewise, through numerical analysis in the ANSYS software, the mechanical properties of the concrete were evaluated, and the appropriate percentage of polypropylene was determined based on the least deformation.

Keywords*– Rigid pavement, micropolypropylene fiber, PCI, concrete, flexural strength, compressive strength.

I. Introduction

At the present time, rigid pavements have become very popular throughout the world due to their high resistance and durability compared to flexible pavements. For this reason, this type of pavement has begun to be used in infrastructure projects such as highways, airports and railways. Rigid pavements have a higher initial cost when used for such projects, as their ability to withstand higher traffic and situated loads is configured.

On the other hand, concrete has good resistance to compressive stress, but is weak to flexural stress. For this reason, fibers are being widely incorporated into the concrete mix to improve its performance under adverse load conditions [1]. Polypropylene microfiber can absorb more energy and decreases the formation and propagation of microcracks even after reaching its maximum resistance. In addition to improving the mechanical properties, it also improves the durability of the concrete.

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On account of the great advantages that rigid pavement has compared to flexible pavement, important studies have been generated in different situations. In one study, steel, glass and polypropylene fibers were added in an amount corresponding to 1% of the total volume of the mixture, with the aim of improving the concrete properties. The result obtained was that the steel fibers had better resistance to bending. However, polypropylene fiber reinforced concrete improves design lifetime and load conditions considerably. At the same time, in the cost benefit analysis, steel fiber is not affordable compared to fiberglass and polypropylene [2]. Also, an investigation shows that the incorporation of polypropylene fiber can control and reduce the cracks generated by shrinkage in rigid pavements. It is also proven that by increasing the amount of fiber in the concrete, the size of the cracks decreases due to shrinkage, and it is evident that the flexural property increases by 13% [3]. Furthermore, the behavior of shrinkage cracking in rigid pavements was investigated, varying the factors of the concrete composition incorporating synthetic fibers. Having as an effect that the flexural resistance of the concrete increases considerably, allowing the achievement of a concrete with greater resistance and better durability [4]. Besides that, a study was carried out using four variables (cement, silica fume, steel fiber and polypropylene fiber), to investigate the behavior of shrinkage cracking in rigid pavements. It was determined that the polypropylene fiber causes the width of the crack to decrease considerably, making its width go beyond the acceptable limit [5].

Apart from that, there are studies in which the incorporation of fiber helps to control the propagation of cracks and improves the behavior in the face of fatigue. Because the fibers control the opening and propagation of cracks even after maximum loading, thus dissipating energy through gradual detachment of the fibers [6]. Having therefore a maximization of the useful life of rigid pavements and a lower energy dissipation per cycle [7]. In the same way, in another article a special concrete was made (considering durability as an important criterion), observing that as the fiber dose increased, the settlement value decreased. In addition, the incorporation of the fiber helps to improve the hardness of the surface, providing it with more resistance [8]. Moreover, in another study, the effect and mechanism that can generate the incorporation of fiber was investigated. Given this, a concrete mixture with better resistance to cracking and tenacity was obtained, making the roughness of the mixture increase and have a non-slip performance [9].

Nevertheless, there are studies where they incorporate fiber for flexible pavement mixtures, reaching excellent results and demonstrating the great versatility it possesses. In a study he investigated the benefits of incorporating fiber into a regenerative pavement. As a main result, a better resistance to cracking was obtained, and the cracking of the mixtures was reduced [10].

The contribution of this study is to evaluate the influence of the micro polypropylene fiber on the resistance to bending and deformation. The flexural strength is determined by testing. Deformation by numerical analysis in Ansys. This makes it possible to determine the proper percentage of polypropylene microfiber.

The proposal for the development of the research was carried out using the AASHTO method where the mixture is designed with polypropylene fiber in different percentages. Laboratory tests are then carried out on standardized beams and cylinders, to be subjected to bending and compression tests. Finally, structural analysis is carried out in the computational model, creating the 4 concrete mixtures in order to analyze the maximum deformation that the concrete beam can withstand.

II. METHODOLOGY

A. *Materials*

- **CEMENT**

  Throughout the study, cement from the Sol type I brand was used.
- **AGGREGATES**

  The coarse aggregate that was used was larger than 12.5mm to obtain a better workability in the mix. On the other hand, the fine aggregate was zone II sand, which was free of dirt, debris and clay.
- **POLYPROPYLENE FIBER**

  The polypropylene microfiber has a length of 9mm and helps to improve resistance in the presence of bending stress in rigid pavement.

B. *Tools*

The tools used were the Ansys software that simulates different structural analyzes such as the deformation that will be obtained by applying a certain load. On the other hand, the universal machine was also used where the bending and compression test of the cylindrical specimens and the standardized beams was carried out.

C. *Method*

As shown in Fig. 1, to determine the state of the road, the first thing that was carried out was the inspection and analysis of the studied pavement. After that, the field data was processed using the PCI method where it was determined that the pavement is faulty. Then the design of the mixture with fiber was carried out using the AASHTO 93 method, where the proportions of cement, water, aggregate and fiber were obtained. The mixture was poured into cylindrical specimens and standardized beams, which were tested under compressive and flexural stresses at 7, 14, 21, and 28 days. The data obtained was analyzed using the Ansys computational model where a trend line can be seen where we could analyze the percentage of fiber that gives the best results for the reinforced mix design.

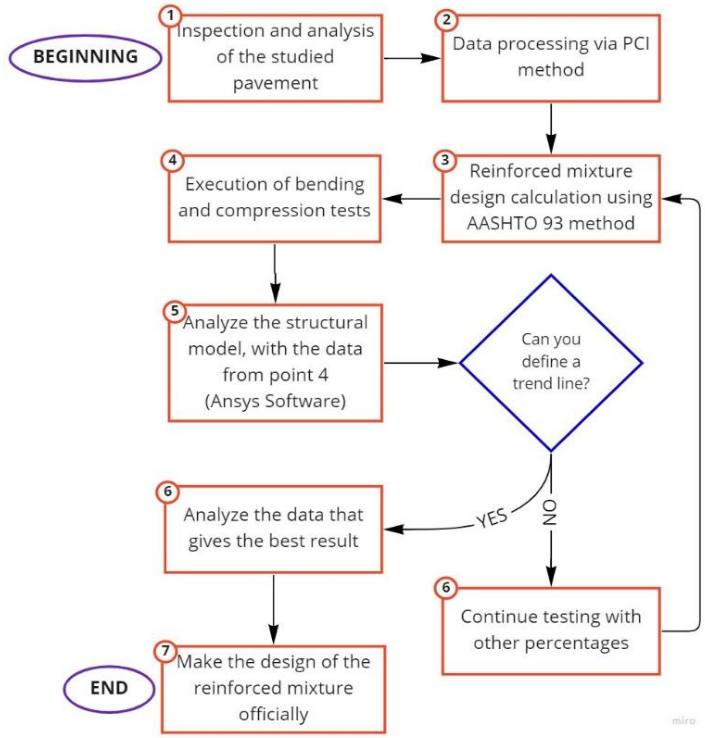


Fig. 1 Flowchart of the methodology

D. *Results*

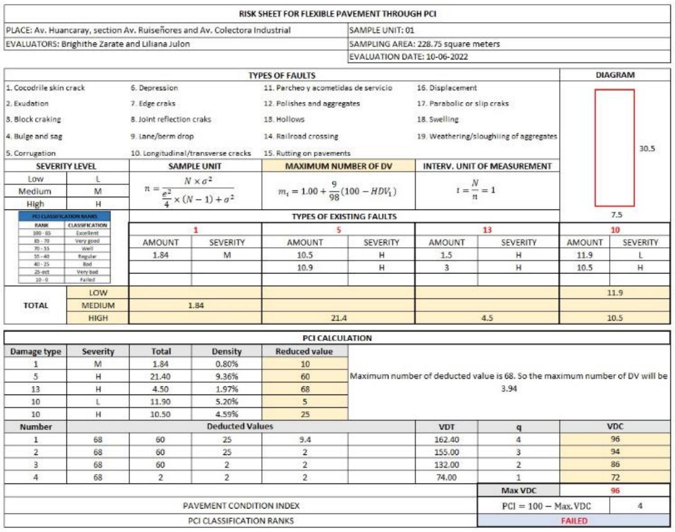
- **PCI METHOD**

  The total number of types of failures found in the analyzed area were 4, as shown in Table 1. The most representative failures were: crocodile skin cracks, longitudinal or transverse cracks, and gap failure. Likewise, there was a corrugation failure with a high severity level. In the investigation by Staub de Melo, J. [11], it is highlighted that pavement failures do not appear from one day to the next nor are they produced by sudden changes, but are the functional and structural accumulation when subjected to dynamic loads that They are subject throughout their useful life, leading to the loss of resistance to stresses such as bending and compression, which propagates the appearance of the aforementioned failures. All this due to the vehicular overload to which the pavement is subjected.

TABLE I
TYPES OF FAILURES IN THE PAVEMENT

FAILURE TYPES			
Crocodile skin crack	Longitudinal crack	Gaps	Corrugation
10	20	10	5

The studied area is almost one kilometer long, for this reason 4 samples were taken to analyze the classification range of the pavement, to subsequently average the results. Fig. 2 shows the calculation of the PCI of the 4 samples.



RISK SHEET FOR FLEXIBLE PAVEMENT THROUGH PCI

PLACE: Av. Huancaray, section Av. Ruiseñores and Av. Colectora Industrial	SAMPLE UNIT: 01
EVALUATORS: Brighithe Zarate and Liliana Julon	SAMPLING AREA: 228.75 square meters
	EVALUATION DATE: 10-06-2022

TYPES OF FAULTS

1. Cocodrile skin crack	6. Depression	11. Parcheo y acometidas de servicio	16. Displacement
2. Exudation	7. Edge craks	12. Polishes and aggregates	17. Parabolic or slip craks
3. Block craking	8. Joint reflection craks	13. Hollows	18. Swelling
4. Bulge and sag	9. Lane/berm drop	14. Railroad crossing	19. Weathering/sloughiing of aggregates
5. Corrugation	10. Longitudinal/transverse cracks	15. Rutting on pavements	

SEVERITY LEVEL		SAMPLE UNIT	MAXIMUM NUMBER OF DV	INTERV. UNIT OF MEASUREMENT
Low	L	$n = \frac{N \times \sigma^2}{\frac{e^2}{4} \times (N-1) + \sigma^2}$	$m_i = 1.00 + \frac{9}{98}(100 - HDV_i)$	$i = \frac{N}{n} = 1$
Medium	M			
High	H			

PCI CLASSIFICATION RANKS

RANK	CLASSIFICATION
100 - 85	Excellent
85 - 70	Very good
70 - 55	Well
55 - 40	Regular
40 - 25	Bad
25-oct	Very bad
10 - 0	Failed

TYPES OF EXISTING FAULTS

		1		5		13		10	
		AMOUNT	SEVERITY	AMOUNT	SEVERITY	AMOUNT	SEVERITY	AMOUNT	SEVERITY
		1.84	M	10.5	H	1.5	H	11.9	L
				10.9	H	3	H	10.5	H
TOTAL	LOW							11.9	
	MEDIUM	1.84							
	HIGH			21.4		4.5		10.5	

PCI CALCULATION

Damage type	Severity	Total	Density	Reduced value
1	M	1.84	0.80%	10
5	H	21.40	9.36%	60
13	H	4.50	1.97%	68
10	L	11.90	5.20%	5
10	H	10.50	4.59%	25

Maximum number of deducted value is 68. So the maximum number of DV will be 3.94

Number	Deducted Values					VDT	q	VDC
1	68	60	25	9.4		162.40	4	96
2	68	60	25	2		155.00	3	94
3	68	60	2	2		132.00	2	86
4	68	2	2	2		74.00	1	72

	Max VDC	96
PAVEMENT CONDITION INDEX	PCI = 100 − Max. VDC	4
PCI CLASSIFICATION RANKS	FAILED	

Fig. 2 Calculation of the PCI

- **FLEXURAL STRENGTH**

  Table 2 shows the maximum loads obtained with samples without dosage and with dosages of 0.75, 1 and 1.5% fiber, after being subjected to the bending test that was carried out in the universal machine (Fig. 3) every 7 days. Likewise, Fig. 4 shows 2 test tubes with percentages of 0.75 and 1% fiber after being subjected to the bending test, where it is evident that they reached their maximum modulus of rupture.

TABLE II
FLEXURAL STRENGTH

Name	Booster	Dosage (%)	Age (days)	Maximum load (kgf)	Modulus of Rupture (Mpa)
M1	without reinforce ment	0%	7	1531.68	24.96
M2			14	1815.67	29.59
M3			21	2336.76	38.08
M4			28	2976.98	48.51
M1	with reinforce ment	0.75%	7	1800.78	29.35
M2			14	2200.76	35.86
M3			21	2900.65	47.27
M4			28	3258.86	53.11
M1	with reinforce ment	1.0%	7	2900.53	45.11
M2			14	3200.54	52.16
M3			21	3786.65	60.08
M4			28	4086.65	66.60
M1		1.50%	7	1975.75	34.23
M2	with reinforce ment		14	2186.86	40.75
M3			21	2565.76	52.16
M4			28	2907.76	61.94

Fig. 3 Universal Machine, running bending test on specimen M2

Fig. 4 Specimens M2 and M4, after be subjected to the bending test

- **COMPRESSION STRESS**

  Table 3 shows the maximum loads obtained after carrying out the compression tests, which were carried out weekly. The samples analyzed contain dosages of 0, 0.75, 1 and 1.5% fiber.

TABLE III
COMPRESSION RESISTANCE

Name	Booster	Dosage (%)	Age (days)	Maxim um load (kgf)	Compressive stress (Mpa)
M1	without reinforce ment	0%	7	122.78	42.93
M2			14	139.42	448.75
M3			21	136.74	55.55
M4			28	149.32	63.76
M1	with reinforce ment	0.75%	7	150.13	52.49
M2			14	161.65	56.52
M3			21	172.28	62.76

M4			28	185.83	72.87
M1	with reinforce ment	1.0%	7	242.91	69.64
M2			14	254.47	79.64
M3			21	268.69	87.99
M4			28	275.92	99.65
M1	with reinforce ment	1.50%	7	164.65	57.56
M2			14	175.92	61.51
M3			21	183.51	72.87
M4			28	196.05	83.76

- **COMPUTER ANALYSIS**

With the Ansys software, 3 structural analyzes (total deformation, equivalent stress and deformation) were performed for each sample created (1 sample without fiber and 3 samples with 0.75, 1 and 1.5% fiber). For the sample with 1.5% fiber, after performing the 3 structural analyses, it was obtained that the total deformation was 1.4369×10-8 (Fig. 5), the normal deformation 19540 (Fig. 6) and in the analysis of equivalent stress, a value of 1.093×10-8 was obtained (Fig. 7).

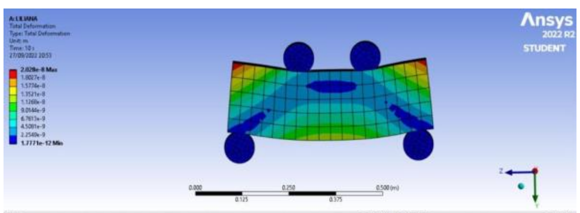


Fig. 5 Total deformation

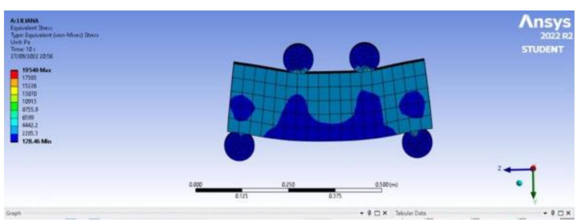


Fig. 6 Normal deformation

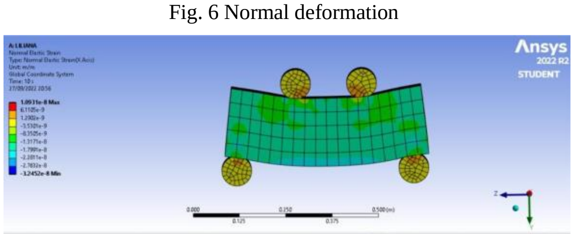


Fig. 7 Equivalent Stress

Table 4 shows the maximum values obtained in the deformation of the samples configured with 0, 0.75, and 1% fiber.

TABLE IV
TOTAL DEFORMATION ANALYSIS

failure types			
Booster	Dosage	Maximum value	Minimum value
without reinforcement	0%	2.8738×10^{-8}	3.8198×10^{-12}
with reinforcement	0.75%	2.299×10^{-8}	3.055×10^{-12}
with reinforcement	1.0%	2028×10^{-8}	1.777×10^{-12}
with reinforcement	1.5%	1.4369×10-8	1.9099×10-12

III. RESULTS

INTERPRETATION

- **Flexural strength**

In Fig. 8 the normalized beam without a fiber dosage is shown. Where it is evident that the failure generated by the flexural stress is in the limits of the central middle third and that the beam broke completely, causing it to come out in two parts.


Fig. 8 M1 test tubes without fiber dosage

However, in Fig. 9 the normalized beam with 1% fiber is shown. Where it is observed that the failure generated by the flexural stress is in the middle of the beam, thus belonging to the central middle third. Also, it is evident that despite the bending stress, the beam maintains its shape and remains in one piece.


Fig. 9 M2 test tube with 1% fiber incorporation

- **Compressive stress**

In Fig. 10, the cylindrical specimen that does not have fiber addition is shown. It is evident that after being subjected to compressive loading there is a Type 2 failure (well-formed cone at one end, vertical cracks running through the bushings, no well-defined cone at the other end).

Fig. 10 M3 specimen without fiber incorporation

On the other hand, Fig. 11 shows the cylindrical specimen with 1% fiber. Where it is observed that the cylindrical specimen does not suffer considerable damage after being subjected to the compression load, thus having a crushing or Type 4 failure (diagonal fracture without cracking).

Fig. 11 M4 test tube with 1% fiber incorporation

RESULT ANALYSIS

A. PCI

After obtaining the four partial results of the 4 samples analyzed, we proceed to average:

$$\mathrm{PCI} = \frac{4 + 64 + 18 + 51}{4} = 34.25 \rightarrow (\mathrm{BAD})$$

Obtaining the value of 34.25, it is evident that the pavement of the studied road is in bad shape, according to the classification ranges of the PCI since it is between 25 and 40.

B. FLEXURAL STRENGTH

Fig. 12 shows the results obtained after carrying out the bending tests with the incorporation of fiber in percentages of 0, 0.75, 1 and 1.5%. Where it is evident that there is an increasing trend line of the flexural resistance when increasing the dosage up to 1%. However, after reaching the maximum value, a noticeable reduction in resistance is evident when a greater amount of fiber is incorporated.

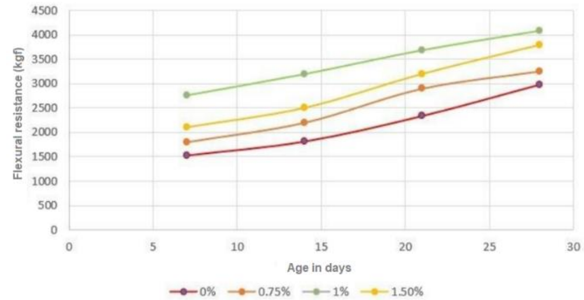


Fig. 12 Line graph of the bending test

C. COMPRESSIVE STRESS

Fig. 13 shows the results obtained after carrying out the compression tests with the incorporation of fiber in percentages of 0, 0.75, 1 and 1.5%. Where it is evident that an increasing trend line of compressive strength is also generated, as in the case of flexion, since by increasing the dosage up to 1% better results are obtained compared to the higher percentage (1.5%). where a noticeable reduction in resistance is evident.

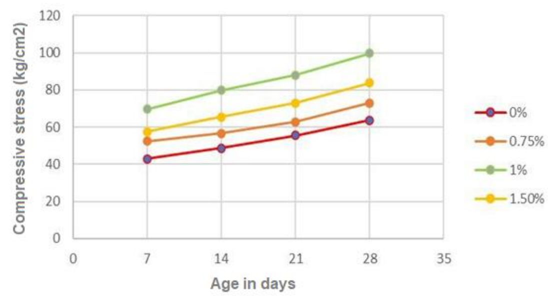


Fig. 13 Compression test line graph

D. COMPUTATIONAL ANALYSIS

In Fig. 14 the trend line is shown after creating the 4 samples configuring their properties, to later perform the structural analysis. Where it is evident that the 1.5% fiber sample obtains a lower deformation (mm) compared to the other samples.

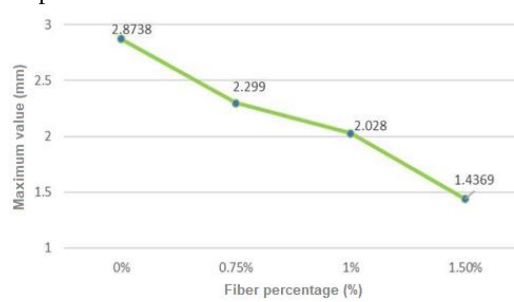


Fig. 14 Trend line of computational analysis

VALIDATION

- **COMPRESSIVE STRENGTH**

  In the study carried out by Abdulaziz, A. [10], where he seeks to improve the flexural strength by introducing polypropylene fiber, because the fibers control the opening and propagation of cracks even after maximum load. It was obtained that with the addition of the conventional mix, its compressive strength increases by 18% over the simple mix. However, in our study, after subjecting the cylindrical specimens to compressive stress, an improvement of 44% was obtained compared to the simple mixture.

- **BENDING EFFORT**

  In the study carried out by Hussein, I. [2], to evaluate the economic advantages and the mechanical performance of the use of fibers in rigid concrete pavements. It was obtained that the flexural resistance increased by 22.6% over the mixture without the addition of fiber. On the other hand, in our study, after carrying out the flexural tests, a resistance greater than approximately 38% was obtained compared to the simple mixture.

IV. CONCLUSIONS

- Using the PCI method, the studied pavement obtains a bad result because it is in the range of 25-40. A total redesign of the pavement is recommended.
- The incorporation of polypropylene microfiber improved the mechanical behavior of the pavement mix. Making the elastic modulus and the flexural resistance of the pavement increase. This influences the increase in crack resistance by 50%.
- By incorporating 1% fiber in the mix, an improvement of 38% in resistance in the presence of bending stress was obtained, being the best result compared to the other percentages.
- The maximum flexural load was obtained with the incorporation of 1% fiber from 7 days of curing, giving a value of 2767.53 kgf and 4086.65 kgf at 28 days.
- The maximum deformation analyzed in Ansys, results in the sample configured with 1.5% polypropylene fiber having a lower deformation being 1.4369×10^{-8}.
- Therefore, the minimum deformation analyzed in Ansys is obtained with the sample configured with 1.5%, which is slightly less than the sample configured with 1%. However, the sample with 1% has better flexural strength.

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