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Civil Engineering Journal

Vol. 4, No. 9, September, 2018

Influence of Fibre Length on the Behaviour of Polypropylene Fibre Reinforced Cement Concrete

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Received 22 July 2018; Accepted 18 September 2018

Abstract

Concrete being a mixture of cement, aggregates (fine and coarse) and water, can be used in vast range of applications. It has excellent durability and availability which are its main advantages. Though, concrete is strong in compression it is comparatively weak in tensile loading. Over the years various materials have been used to reinforce concrete to withstand the tensile stresses. Polypropylene fibre is one such fibre which comes in varied sizes, is nowadays being utilized to reinforce concrete. In this study, three PP fibres were used at 0.20%, 0.25% and 0.30% content by weight. The flexural and compressive strengths were determined. Based on the results, it was observed with increase in size of fibre the compressive strength decreased significantly though it was still higher than the controlled sample. The length of PP fibres had significant effect on the compressive strength and flexural strength of concrete. Short PP fibres showed relatively higher compressive strength but lower flexural strength when higher fibre content is used, while long PP fibres achieved lower compressive strength but higher flexural strength than shorter PP fibres. The optimum dosage for both PP fibre sizes was 0.25% at which it achieved increased strength as compared to control sample.

Keywords: Polypropylene (PP) Fibres; Compressive Strength; Flexural Strength; Fibres Reinforced Concrete (FRC).

1. Introduction

Through the last hundred years, Concrete has established itself as one of the major construction and building materials. This has been mainly due to its excellent durability and availability and ease of moulding concrete into any desired shape. Though concrete has various advantages, it is known to strong under compression but relatively weak under tensile stresses. Concrete possesses limited ductility while offering little resistance to abrasion and cracking [1]. Therefore, over the years, researchers have used various materials to reinforce the concrete to withstand such tensile stresses. Civil engineering structures such as houses, bridges, storage tanks, dams, etc. utilize Reinforced Concrete (RC) [2].

RC is a type of concrete in which steel bars are used to reinforce the concrete. Steel bars offer concrete to resist the tensile stresses. RC with steel bars has led to reduction in tensile stresses and improvement in behaviour of RC but it also leads to increased self-weight load on the structure due to the use of steel bars to reinforce concrete. Another disadvantage of steel bars in concrete is it can easily be affected by corrosion, causing the steel bars to loss its strength. Composite materials have gained much popularity due to their ductility and strain hardening properties and the

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http://dx.doi.org/10.28991/cej-03091144

disadvantages related to use of steel bars to reinforce concrete. Reinforcement is necessary due to brittle behaviour of concrete; therefore, researchers have turned to the use of fibres, as reinforcement material, which provides ductility to the concrete. The studies conducted on the effect of fibres in concrete has provided an understanding that fibres when used to develop fibre reinforced concrete (FRC) resist the development and propagation of cracks but also improve the tensile strength and enhance the toughness of concrete. Though these are additional benefits, since the fundamental advantage of addition of fibres is to provide crack bridging. In composites materials, fibres are the major reason for the strength, whereas matrices maintain the bonding between the fibres and prevent from external harm [3].

Over the years, many fibres have been developed and utilized in FRC which have been used in the construction of highway pavements and airports, foundations and tunnels [4]. In recent years the polypropylene (PP) fibres have become widely used in various industries [5]. This is due to PP fibres relatively low cost, ease in splitting into finer sizes, are durable in the environment of cement matrix and they are rust-free. Therefore, in this research work, two different fibre lengths at three various dosages were used to study their effect on the strength performance of PP fibre reinforced concrete.

2. Literature Review

It has been observed that concrete exhibits significantly more brittle behaviour than other building materials such as metal and polymers which are being used in the construction, and due to this it exhibits poor tensile strength [6]. Ever since the development of concrete in early 19th century, it was known that concrete is strong in compression but significantly weak under tensile stresses, due to this, many researchers focused their interest on reinforcements to enhance the mechanical properties of concrete specially its low tensile capacity. Since mid-1800's, steel reinforcement has been used to overcome the brittleness of concrete. Steel bars have been used to reinforce concrete, this is because steel is at least 100 times more resistant to crack growth than concrete based upon the fracture toughness value [6]. The utilization of steel bars, though allows the concrete to counteract the tensile stresses, but at the same time has major drawbacks. The steel can be easily affected or corroded by the salt and can be one of the main reasons of failure constructions and structures [7].

Another major concern is the cost of the construction when steel is used to reinforce the concrete, not only the initial cost of RCC is very high, but maintenance and repair which is required to increase the life span of the engineering structures also costs. The excess weight of steel reinforce can increase the self-weight load on the structure. Another concern regarding steel reinforcement is the production of steel contributes to the carbon dioxide (CO_2) emission [8]. Therefore, many methods and techniques have been used in the construction industry to minimize the failure of structures and to find suitable material to use to enhance the mechanical properties of concrete. One of the method which has gained importance, is to use reinforce concrete with different types of fibres to counteract cracks, developing FRC. The addition of fibres not only increases the strength and durability but also improves resistance to cracking and deformation characteristics [9].

2.1. Fibre Reinforced Concrete (FRC)

FRC is a type of concrete in which randomly distributed fibres are utilized to reinforce concrete. FRC consists of thousands of small fibres which are randomly dispersed and distributed in the concrete during mixing, which allows the multi-directional improvement in concrete properties, including the post peak ductility performance, pre-crack tensile strength, fatigue strength and impact strength. The main features of fibre reinforcement which make it more attractive than steel reinforcement bars are:

1. The steel reinforcement bars are placed only where they are needed whereas, the fibres are distributed through-out the cross-section.
2. In contrast to steel bars which are continuous and relatively placed with some spacing, the fibres can vary in length but are still relatively short and closely spaced.
3. It is generally not possible to achieve the same area of reinforcement with fibres as with steel bars.
4. The concrete containing fibre as reinforcement is tougher and resistant to impact than ordinary plain concrete.

The main aim of addition of fibres is not only to improve strength of concrete but to control the cracking of concrete and to change the behaviour of the material once the matrix has cracked. This change in behaviour is achieved by bridging across these cracks, so that some post-cracking ductility is provided to the concrete. Reinforcing with such fibres enhances most of the concretes properties such as the post peak ductility performance, pre-crack tensile strength, fracture strength, toughness, impact resistance, flexural Strength resistance and fatigue performance etc. [10]. However, the ability of fibres significantly influences the ductility of FRC. Micro-cracks are developed in concrete during curing and propagate rapidly when applied load is applied, thus causes the concrete to achieve low tensile strength. The main aim of reinforcing concrete with fibres is to control cracks, increase the tensile strength, toughness and to enhance the deformation characteristics of the concrete [11].

The performance of FRC depends on the type of the fibres used. Various types of fibres are produced worldwide, and over the years these fibres which range from synthetically organic fibres such as polypropylene, synthetically inorganic fibres such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos [9]. Concrete mix design is not required to be altered when these fibres are used in concrete. Amongst the fibres used as reinforcement in FRC, PP fibres are hydrophobic which do not absorb water, therefore making it innovative fibre which can improve the tensile and flexural strengths, toughness and resist cracking.

2.2. Polypropylene (PP) Fibres

Polypropylene is a polymerized version of propylene which is a by-product of petroleum refining [12]. PP fibre is a unique thermoplastic polymer and is categorized as synthetically organic fibre. Since one of the main reasons of structural concrete failure is cracking, once cracks are developed, they propagate rapidly when load is applied, thus resulting in loss in concrete strength and negatively affecting its durability. The utilization of PP fibres in concrete overcomes this failure as PP fibres develop a bridge in the matrix of concrete, which enhances the strength of concrete along with toughness and improves the deformation characteristics. Over the years, due to its properties, PP fibres have been added in various types of concrete, ranging from normal conventional concrete to lightweight foamed concrete. With its first use in the construction of US Engineers Crops blast building in 1960's, it has gained popularity and is widely used among polymer fibres.

To study the effect of PP fibres on M25 grade concrete, Singh [13] conducted an experimental investigation in which PP fibres were varied from 0% to 0.35%. The strength performance of concrete was studied in terms of compressive and flexural strength. It was found that the concrete samples containing PP fibres exhibited better performance than plain concrete. Improvement in the compressive and flexural strengths were observed. 0.25% PP fibres was determined to be optimum. The performance of PP fibre reinforced concrete was studied [14]. PP fibres varying from 0% to 2% with an increment of 0.5% were added into M30 and M40 grade concrete. It was found that not only the addition of PP fibres reduced the early age shrinkage and moisture loss of the concrete mix, it also decreased the workability of the fresh concrete. Increasing the PP fibres content significantly decreased the workability. The optimum PP fibres content was determined to be 0.5% at which compressive, tensile and flexural strengths were relatively higher than the control sample with no PP fibres.

Jhatial et al., [12] studied the effect of PP fibres on the compressive strength and thermal conductivity of 1600 kg/m^3 density lightweight foamed concrete. Three percentages of PP fibres, i.e., 0.20%, 0.25% and 0.30% were added into the foamed concrete and compared with control sample. It was observed from the results that 0.20% PP fibres gave higher compressive strength while it was noted that with the increase in PP fibre content the thermal conductivity reduced. Jhatial et al., [15] studied that influence of PP fibres on the tensile strength and thermal conductivity of various densities of foamed concrete. Three densities, 1400, 1600 and 1800 kg/m^3 of foamed concrete were added with 0.8% PP fibres. Based upon the results it was observed that the lower densities, i.e., 1400 and 1600 kg/m^3 showed significant increase in tensile strength and reduced thermal conductivity value, compared to their respective control sample with no PP fibres. But for 1800 kg/m^3 density foamed concrete the tensile strength decreased while thermal conductivity increased upon the addition of 0.8% PP fibres.

Ibrahm and Abbas [16] studied the mechanical behaviour of recycled self-compacting concrete (RSCC) when reinforced with PP fibres. The PP fibres fraction ranged from 0% to 0.15%, while the recycled coarse aggregates (RCA) ranged from 0% to 100% replacement of coarse aggregates. It was found that reinforcing RSCC with PP fibres had adverse effect on the rheology properties of fresh mix, as it reduced the workability while increase both consistency and viscosity. It was further noticed that increase in RCA content decreased the compressive strength but when PP fibres were used, the compressive, tensile and flexural strengths increased compared to control sample with no RCA or PP fibres. From the experimental results it was concluded that with 0.1% PP fibres, 25% RCA can be utilized to replace coarse aggregates, while achieving significantly higher strength.

Foamed concrete is a lightweight concrete since no coarse aggregates are utilized and with the reduced density, foamed concrete achieves lower compressive and tensile strengths while developing micro-cracks. Therefore, Jhatial et al. [17] conducted a study on the mechanical properties of foamed concrete reinforced with polypropylene fibres. Two dry densities of foamed concrete (1600 and 1800 kg/m^3) were targeted and reinforced with 0.05%, 0.10% and 0.15%. Based upon the results, it was observed that the PP fibre reinforcement had significant effect on the compressive and tensile strengths as well as modulus of elasticity of foamed concrete. The PP fibre reinforced foamed concrete achieved higher strength enabling it to increase its modulus of elasticity. It was observed that the utilization of 0.15% PP fibres yielded the maximum increase in mechanical properties.

Bagherzadeh et al., [18] studied the influence of various PP fibers content and different PP fibre length on the performance characteristics of the lightweight cement composites. PP fibres were chopped into two different lengths (6 and 12 mm) while the fibre content was 0.15% and 0.35% by cement weight. It was observed that all specimens reinforced with PP fibres displayed improvement in their mechanical strength. However, only the 0.35% PP fibre of 12 mm length performed better in all respects compared to the physical and mechanical properties of reinforced lightweight concrete.

3. Materials and Methods

3.1. Constituent Materials

In this study, Ordinary Portland Cement (OPC), sand, coarse aggregates, water and polypropylene fibres were used. Cement plays important role in the strength parameter of concrete. OPC (EN 197-1:2011, CEM I, Class 42.5N) manufactured by Attock Cement, falcon brand, was used. Well graded, good quality sand (fine aggregates) from Bolhari, while coarse aggregates from Petaro crushing plant were used. Table 1 shows the physical properties of aggregates. Ordinary tap water was used in this study. The water-cement ratio was taken as 0.5.

Table 1. Aggregates Characteristics

Property	Fine Aggregates	Coarse Aggregates
Specific Gravity	2.63	2.67
Water Absorption	1.6%	1%
Unit Weight	1649.9 kg/m^3	1585.3 kg/m^3

PP fibres with two different fibre lengths, i.e. 12.7 and 25.4 mm were used to reinforce concrete. Three dosages of PP fibres, 0.20%, 0.25% and 0.30% were added. The properties of PP fibres are shown in Table 2.

Table 2. Properties of Polypropylene Fibres

Property	Value	Property	Value
Compressive strength	5500-8000 psi	Thermal conductivity	1.72 W/mK
Flexural strength	6000-8000 psi	Heat & UV stabilization	Long term
Tensile strength at break	4500-6000 psi	Tensile modulus	165 – 225 ksi
Elongation at break	100-600 %	Compressive modulus	150 – 300 ksi
Water absorption	0.01 - 0.03 %	Flexural modulus	170 – 250 ksi
Specific gravity	0.90 - 0.91	Acid resistance	High
Ignition point	593^{0}C	Salt resistance	High
Melting point	160^{0}C - 170^{0}C	Alkali resistance	Alkali proof

3.2. Experimental Procedure

OPC, sand, coarse aggregates and water was mixed together in the concrete mixer and amount of PP fibres with respect to mix proportion was added. All the ingredients are mixed properly in the concrete mixer and the mix was poured into mould as shown in Figure 1 which was kept in open air for 24 hours before being unmoulded and put for 28 days curing in water tank. Cylinder size of 300 × 150 mm and beam of 609.6 × 304.8 mm were cast to determine the effect of addition of different fibre length PP fibres on the compressive and flexural strengths of concrete respectively.

4. Results and Discussion

4.1. Compressive Strength

The compressive strength was conducted according to BS EN 12390-3:2009 [19]. Cylindrical samples of 150 × 300 mm were cast, and water cured for 28 days. The average compressive strength of cylindrical samples with and without PP fibres is tabulated in Table 3 and illustrated in Figure 1.

Table 3. Average compressive strength of concrete reinforced PP Fibres

PP Fibre Length	PP Fibres	Compressive Strength (MPa)	Difference with respect to control sample (%)
	0% (control)	22.45	---
12.25 mm	0.20%	24.21	+ 7.84 %
	0.25%	28.32	+ 26.15 %
	0.30%	24.43	+ 8.82 %
25.4 mm	0.20%	24.91	+ 10.96 %
	0.25%	25.56	+ 13.85 %
	0.30%	23.58	+ 5.03 %

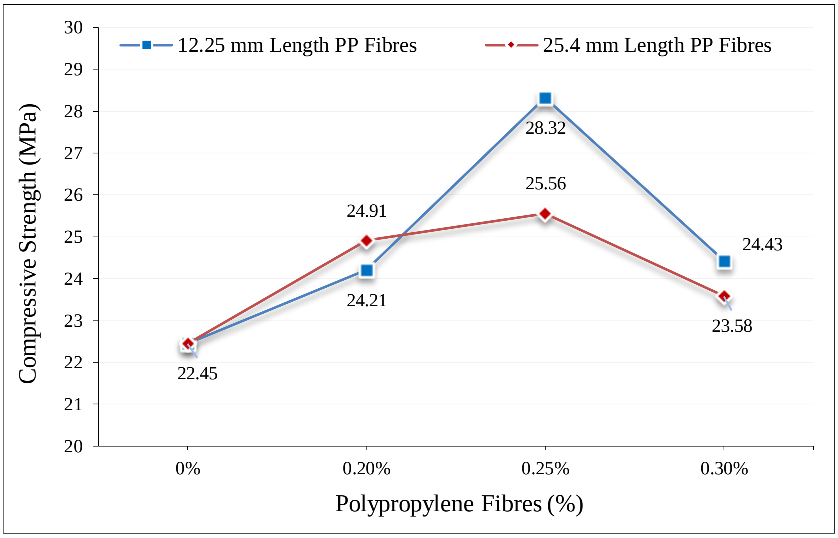

Figure 1. Average compressive strength and PP Fibres content

The average compressive strength of concrete with no addition of PP fibres was determined to be 22.45 MPa, with the addition of 12.7 mm sized PP fibres, the compressive strength significantly increased, such that for 0.20% PP fibres achieved 7.84%, 0.25% PP fibres 26.15% while 0.30% PP fibres 8.82% higher compressive strength than the control sample. The addition of 25.4 mm sized PP fibres gained higher strength than control sample but lower than the shorter sized PP fibres.

Though the addition of both short and long PP fibres increased the compressive strength higher than the control sample containing 0% PP fibres, the long fibres achieved higher compressive strength at 0.20% PP fibre content than the shorter PP fibres at the same content. Further increase in PP fibres content saw significant increase in shorter length PP fibres than the longer fibres. This may be due to longer fibres tend to increase the permeability of concrete.

4.2. Flexural Strength

The flexural strength was conducted according to BS EN 12390-5:2009 [20]. Beam samples of 609.6 × 304.8 mm were cast, and water cured for 28 days. The effect of PP fibres on the flexural strength of concrete is tabulated in Table 4 and shown in Figure 2.

Table 4. Average flexural strength of concrete reinforced PP Fibres

PP Fibre Length	PP Fibres	Compressive Strength (MPa)	Difference with respect to control sample (%)
	0% (Control)	3.83	---
12.25 mm	0.20%	3.49	- 8.88 %
	0.25%	3.65	- 4.70 %
	0.30%	3.56	- 7.05 %
25.4 mm	0.20%	3.75	- 2.09 %
	0.25%	3.81	- 0.52 %
	0.30%	3.63	- 5.22 %

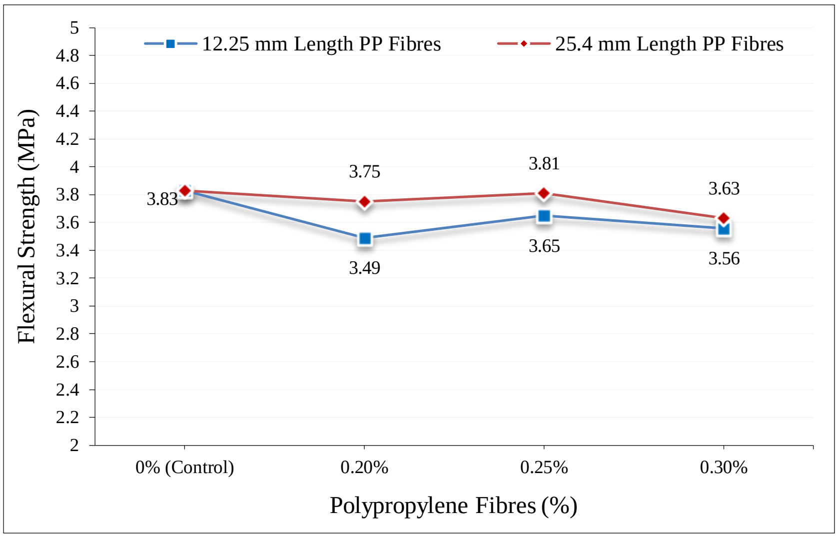

Figure 2. Average flexural strength and PP Fibres content

The cracks are initially formed in the interfacial zone when tension load is applied on the concrete. With the gradual increase in tension load the micro cracks propagate. These micro cracks while propagating, connect to form larger cracks and ultimately causing failure of concrete. The micro cracks can be prevented with short length fibres, as they are very thin and will be large in number when compared with long fibres. This helps in bridging micro cracks more efficiently. The short fibres enable an enormous increase in the tensile strength if the factor of consideration is the formation of micro crack and crack bridging. However, with increase in load, these micro cracks develop into larger macro cracks. In this situation, the long fibres are significantly more effective in bridging the macro cracks, increasing the ductility of concrete and the tensile and flexural strengths. It has been reported that with the addition of PP fibres, micro crack formation is prevented while the scale of micro cracks is reduced due to the PP fibres' crack-arresting, crack thinning and crack-bridging effects [21, 22]. The bridging mechanism of PP fibres allow the tensile and flexural strengths to increase. The effect of short and long fibres is illustrated in Figure 3.

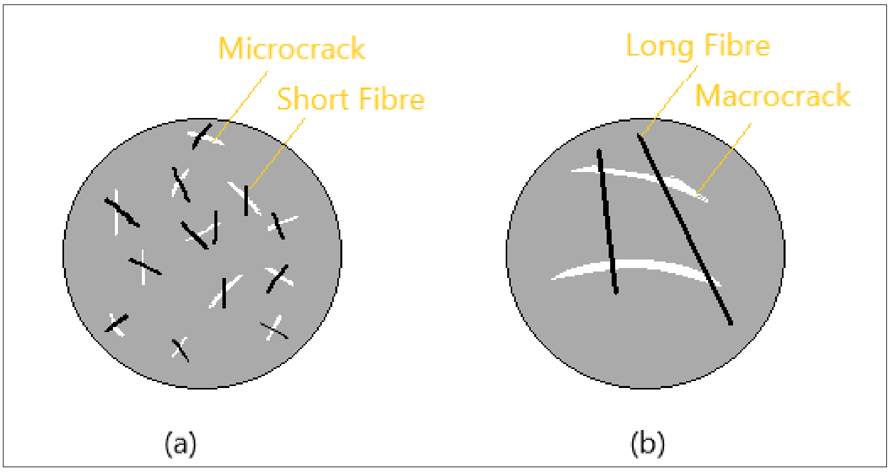

Figure 3. (a) Effect of short fibres on micro-cracking (b) Effect of long fibres on macro-cracking

From Figure 2, it can be observed that the short fibre had adverse effect on the flexural strength, while longer fibres had almost similar flexural strength as the control sample. Though the lower content of short length PP fibres showed significant difference in flexural strength while with further increase in content, the difference is shortened. While the opposite is seen for longer PP fibres. Normal concrete is known to be brittle material which fails without warning. Due to this brittleness it achieves relatively low flexural strength. With the PP fibre reinforcement of concrete, this brittle nature of concrete is converted into ductile as shown in Figure 4. The shorter PP fibres tend to bridge the concrete cracks when used in increased amount, while longer PP fibres can bridge such cracks when smaller amount is added in concrete.

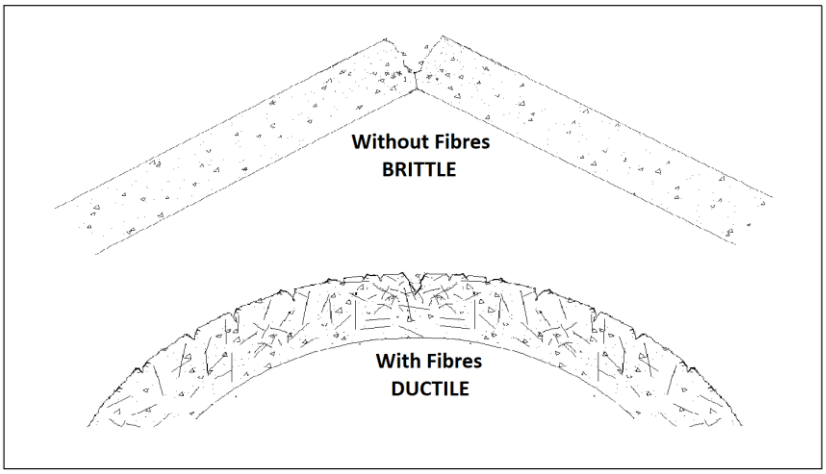

Figure 4. The change from brittle to ductile behaviour of concrete with the reinforcement of fibres [23]

5. Conclusions

The primary objective of this experimental work was to study the influence of PP fibers at different volume fractions and fiber length on the behavior of concrete. Fibres with two different length, 12.7 mm and 25.4 mm were employed for this study. Based on the results obtained, it can be concluded that:

- The length of PP fibres had significant effect on the compressive strength and flexural strength of concrete.
- Short PP fibres (12.7 mm) showed relatively higher compressive strength when higher fibre content is used. While long PP fibres (25.4 mm) achieved lower compressive strength than shorter PP fibres but still the strength achieved was higher than the control sample with no fibre content.
- For flexural strength of concrete, short PP fibres achieved strength while long PP fibres achieved almost similar flexural strength as the control sample.
- The optimum dosage for both PP fibre lengths was 0.25% at which it achieved increased compressive strength as compared to control sample.
- As load is increased micro cracks merge together to form macro cracks, which can be bridged with the utilization of long PP fibres.

6. Acknowledgements

The authors would like to acknowledge and appreciate the support received through the experimental work from department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro.

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