Proceedings of the Pakistan Academy of Sciences:
A: Physical and Computational Sciences 57 (4): 33–46 (2020)

ISSN: 2518-4245 (print), 2518-4253 (online)

Pakistan Academy of Sciences

Research Article

Effect of Pine Needle Fibers on Properties of Cementitious Mortars

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Abstract: The search for renewable and ecological resources of raw materials is beneficial for the progress of any technology including cementitious composites. With that intent, present work is aimed to evaluate the feasibility of pine needles (PN) in Himalayan range of Kashmir as natural fibers in conventional cementitious mortars. Three different lengths of PN, i.e. 13, 25 and 50 mm were chosen as case study. Doses were fixed as 1, 2, 3, 4, and 5% by mass of cement. The results were compared with those of control specimens. Specimens were evaluated in terms of flow-ability, surface saturated dry density (SSD), water absorption, compressive and flexural strengths and ultrasonic pulse velocity. The results show that cementitious mortars reinforced with 1% content and 13 mm length of pine needles offer the highest flow-ability and the lowest density. However, the highest strength and UPV and the lowest water absorption are achieved with 50 mm length of pine needles at 1% dosage. Based on the results, the optimum value of 1% pine needles fibers in cementitious mortars is recommended.

Keywords: Pine needles, Cementitious Mortars, Flow-Ability, Density, Strength of FRCs, Ultrasonic Pulse Velocity, Optimum Fibre Content.

1. INTRODUCTION

Cement composites can be reinforced by using natural fibers, recycled fibers and synthetic fibers. Fibers can be also utilized for aesthetic and decorative purposes e.g. use of straw or bamboo as wallpapers. Fibers can also be used for strength and insulation purposes. When fibers are incorporated in any composite, they act as a medium to arrest the cracks and enhance durability properties. Fibers also create air voids that provide better insulation due to low thermal conductivity [1].

A wide variety of natural fibers are available, like wheat straw, barely straw, coconut fibers and many more [2]. Natural fibers have low density, better mechanical properties, minimum energy consumption, and are environmental friendly, widely available, non-toxic, easily recyclable, biodegradable, and nonabrasive [3, 4].

The genus Pines [kingdom Plantea, division Pinophyta, class Pinosida, order Pinales, family Pinaceae, species Roxburghii] is one of the most broadly dispersed class of trees in the world, encircling 90 plus classes with almost 24 classes original to Asia [5, 6]. Pine trees are commercially vital and have needle-shaped greeneries and wooded seed bearing cones. Leaves are arranged in clusters consisting of two to five needles that provide food by a process named photosynthesis. These needles stay for a period of two years: Afterwards turn brown and fall on forest floor. The falling period of pine needles mostly start from middle of march and end up in July [7].

Pine needles are organic waste and do not decompose for three years. Dry pine needles are flammable. Natural fires are frequent and burning of needles results in harmful emission of gases, and is considered as potentially carcinogenic [8]. It has also been reported that the pine needles once part of the soil might affect the biological properties of the soil [9]: Therefore, its dumping in ground also seems a problem.

Pine needles have been extensively used for many decades in mud-houses of the earthquake

Received: April 2020; Accepted: December 2020
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prone Kashmir region of Pakistan. According to Hayat et al., the poor performance of the houses, appearance of large cracks and the evolution of new building materials are the main reasons, its use as reinforcement material in mud has vanished [10].

The major structural problem with cement composites is their low ductility, lesser flexural and tensile strengths and cracking [11]. Moreover, ordinary cementitious materials do not fall in the category of efficiently sustainable materials [12]. Pine needles have been used as reinforcement material by several researchers in different composites, other than cementitious ones: The following paragraph highlights some of the previous essential works.

Dong et al. studied the feasibility of using pine needles as reinforcement in polymer composites: They concluded that the needles could be incorporated in polymer composites, subjected to non-load bearing applications, and acquired thermal and acoustic insulation [13]. Mengual et al. studied the pine needles reinforced thermos-compression plates: They have reported increased impact energy and bending strength [14]. Singha et al. studied the reinforcement of pine needle powder (~200μm) using phenol-formaldehyde in manufacture of polymer composites: They have reported an increase in compressive, tensile, flexural strength and wear resistance up to 30% loading [15]. Sinha et al. studied the potential of pine needles fibers for PolyLactic Acid (PLA) based composites: Their study revealed that the tensile and flexural resistance increased up to 1.7 and 3.5 times respectively, that of the virgin composites on addition of 8.77% fibers [16]. Gairola et al. studied the impact resistance of epoxy composites reinforced with pine needle fiber and pistachio shell filler [17]. They have reported an increase in impact resistance as compared to the control specimens: The hybrid composite gained the impact strength as high as 23.33 KJ/m2. Jové-Sandoval et al. compared the effect of pine needles fiber and wheat straw on compressive strength of adobe: They have reported that the compressive strength provided by pine needle reinforcement is better than that by the wheat straw. They have further elaborated that the strength is an inverse function of the cross section of the fiber [18]. Yu et al. conducted experimental studies on protein typed soy films, amalgamated with pine needles extract (PNE-2.5 %, 5 %, 10 %) and cellulose Nanocrystals (CNCs-15 %) by dry weight of soy protein isolates powder (SPI) for packing applications: They have reported that the incorporation of PNE and CNCs in bio composite films improved mechanical strength, water barrier capacity, and antioxidant ability [19].

Although, the use of pine needles as powder or fibers in cementitious composites is rare, the concept of employing agricultural and industrial fibers for enhancing their performance is not new [20, 21]. Mansur et al. experimentally investigated the impact, flexural and tensile strengths of cement mortar reinforced with woven bamboo fibers [treated and untreated strips of 5.5 mm width and 0.88 mm average thickness]: Their results demonstrate that the reinforcement enhances toughness, ductility, tensile, flexural and impact strengths [22]. Araya-Letelier et al. used pig hair in cement mortars: They have reported an improvement in plastic shrinkage, impact strength, age of cracking and abrasion resistance with increase in fiber volume [23]. Lertwattanaruk et al. studied the physical, mechanical and thermal properties of cement-based composites reinforced with natural cellulose fibers (coir and oil palm fibers of length 5-10 mm): Their study reveals that the fibers incorporated cement mortar specimens have low compressive and flexural strength but enhanced thermal insulation as compared to control specimens [24]. Asasutjarit et al. conducted study to determine the thermal, mechanical and physical properties of coir fiber incorporated light weight cement boards: Their results revealed that 5 cm long, pretreated and boiled coir fibers incorporated samples had better mechanical properties and lesser thermal conductivity as related to other tested samples [25]. Ali et al. studied the impact of the incorporation of coconut fibers on properties of concrete: The fibers were added @ 1 %, 2 %, 3 % and 5 % by mass of cement with variable fiber lengths of 2.5 cm, 5 cm and 7.5 cm. Their study indicates the optimum fiber length and fiber content as 5 cm and 5 % respectively [26].

The aim of current research is to utilize the pine needle fibers in cementitious mortar for improving its physical and mechanical properties. Pine needles are environmental waste and their burning in air adds to greenhouse gas emissions. The recycling of pine needles in building materials will minimize the air pollution. The incorporation of these fibers in hardened mortar may act as a medium to arrest the crack propagation due to tensile stresses and hence improve the strain carrying and the load-carrying capacity of specimens. The utilization of natural fibers in cementitious mortar is a sustainable solution to conserve the fertile land, protect the human and wildlife from land pollution and global warming due to dumping and the burning of these fibrous waste respectively.

2. MATERIALS AND METHODS

The materials used for this study are presented in Table 1. The chemical composition of OPC is shown in Table 2. Physical properties of cement and sand were determined as per standard ASTM methods and the results are presented in Table 3 and Table 4 respectively. Material composition is shown in Table 5. The designation and specification of the specimens are shown in Table 6. Mortars, containing pine needles were designated as PN. Three different lengths of pine needles, 13, 25 and 50 mm, were used.

2.1 Mixing and Sample Casting

The mixing of materials were done in Hobart mixer of 5L capacity to prepare the specimens in accordance with ASTM C305-14 standard method [27]. First of all, cement and sand were dry mixed for 60 sec. Then, 50% water was added with the continued mixing for another 30 sec. After that, remaining water was added while continuously mixing for next 30 sec. Later on, the fibers were gradually dispersed in the mix and mixing continued for another three minutes until a uniform consistent mix was achieved. The mixer agitator was rotated at normal as well as high speeds for uniform distribution of fibers in the mix. The whole mixing procedure took 6-8 min for each mix. The flow-ability of the mix was checked through ASTM C230 standard method [28]. After casting, the specimens were kept in molds for 24 hours. The specimens were covered with transparent polythene sheet after casting. After 24 hours, the specimens were de-moulded and kept in a curing chamber containing clean potable water for 28 days at 20°C.

2.2 Test Program

2.2.1 Compressive Strength

The compressive strength test was performed on broken pieces of prism specimens in flexural strength test after 28 days per ASTM C349 [29]. The length of the specimen was not less than 65 mm and they were free from defects, cracks and chipped surfaces. Load was applied gradually at a rate of 2400 ± 200 N/sec till failure.

2.2.2 Flexural Strength

Flexural strength test was performed on hardened specimens of control and fiber incorporated cement mortar composites after 28 days as per ASTM C348 [30]. The specimens were marked properly and load was applied at exact center point at the rate of 50 ± 10 N/sec till rupture.

2.2.3 Ultrasonic Pulse Velocity Test

It is a non-destructive test method that was performed on control and fiber incorporated cement mortar specimens to determine the quality and homogeneity as per ASTM C597-16 method [31].

2.2.4 Density Test

The densities of casted specimens were determined after 28 days as per ASTM C373-18 [32]. The specimens were soaked in water at approximately

Table 1. Materials description and specification

Sr. No	Material	Description
1	Ordinary Portland Cement	Fauji Cement (A well-known Pakistani Brand)
2	Sand	Lawrencepur Sand (Well-documented river sand)
3	Pine Needles [PN fibers]	Fallen PN Raw fiber, Collected as waste material from Pine forest in District Bagh, Kashmir, Pakistan

Table 2. Chemical composition of cement

Sr. No.	Ingredients	%
1	Lime (CaO)	62
2	Silica (SiO_2)	22
3	7	Specific Gravity
4	8	Lechatlier's Expansion (mm)
5	Alkalies	1
6	Sulphur	1

Table 3. Physical properties of cement

Sr. No.	Properties	Result
1	Standard Consistency (%)	28
2	Initial Set time (min)	110
3	Final Set time (min)	180
4	Fineness of Cement (%)	7
6	Fineness by Blaine (cm^2/gm)	3120

Table 4. Physical properties of sand

Sr. No.	Properties	Value Obtained
1	Bulk Density Compacted (gm/cm^3)	1.588
2	Bulk Density Loose (gm/cm^3)	1.438
3	SSD Specific Gravity	2.66
4	OD Specific Gravity	2.42
5	Water Absorption (%)	6.24
6	Fineness Modulus	2.54

Table 5. Mortar composition

Cement (g)	Sand (g)	Water (l)	W/C	C/S
600	1200	270	0.45	0.5

Table 6. Material specification and designation

Designation	PN-131	PN-132	PN-133	PN-134	PN-135
13 mm fibers (% by mass of cement)	1	2	3	4	5
Designation	**PN-251**	**PN-252**	**PN-253**	**PN-254**	**PN-255**
25 mm fibers (% by mass of cement)	1	2	3	4	5
Designation	**PN-501**	**PN-502**	**PN-503**	**PN-504**	**PN-555**
50 mm fibers (% by mass of cement)	1	2	3	4	5

21 ± 3 ºC and tested after 48 hours. Compressive strength and density values can also be used to determine the specific strength (defined as ratio of compressive strength to density) at 28 days age.

2.2.5 Water Absorption

The water absorption of casted specimens was determined after 28 days as per ASTM C373-18 [32]. The specimens were soaked in water at approximately 21 ± 3 °C and tested after 48 hours.

3. RESULTS AND DISCUSSIONS

3.1 Workability

The results of the flow-ability are mentioned in Figure 1: The flow index (%) is shown as a function of fiber volumetric fraction (%). From Figure 1, it is evident that the flow-ability decreases with increase in fiber content. The reduction of flowing ability with fiber content is in agreement with the previous studies, using synthetic polypropylene fibers [33–35]. The decrease of flow-ability with increasing fiber length confirms previous studies working with natural basalt-fiber and coconut fiber concrete [36, 37]. Li et al., while working with sisal fiber and its composites, have concluded that longer fibers increase the water absorption: In the case of cementitious composites, this in turn reduces the availability of water for cement lubrication, resulting in decrease of workability [38]. Owing to decreasing workability of mortar with pine needles, a water reducer is always recommended for field applications [35]. According to Hedjazi et al., the fibers reduce the fluidity of the material, thus decreasing the flow-ability [39]. Ezeldin et al. have reported that long fibers at higher volume fractions lead to ball up during mixing [40]: The balling has a detrimental effect on compaction, and leads to reduced workability. Vairagade et al. studied the effect of metallic and PPP fibers on strength of normal concrete [41]: Their study revealed that at the same volume fraction, fibers with longer length reduced workability of concrete to the higher percentage: They have reported that long fibers absorb more cement paste to wrap around and enhance the viscosity of mixture, which ultimately leads to loss of workability. Hence, the reduction of workability with increase in fiber length is quite understandable.

3.2 Density

The SSD results are shown in Figure 2. The average density of the control specimen was found to be 2300.8 kg/m3. The results show that density decreases with the inclusion of fibers; it decreases with an increase in fiber quantity; however, it increases with an increase in fiber length at same dosage. Loh et al. studied the effect of length of kenaf (fiber plant native to east-central Africa) fibers on Kenaf-Polypropylene (K-PP) Composites for automobile inner parts: They have reported that longer fibers absorb more water, resulting in an increase in density [42]. The decrease in density with fiber content is in line with the previous studies involving natural fibers in cementitious composites [43]. The increase in density of cementitious composites with fiber length from 25mm to 50mm is also reported by Ahmad et al. while working with coconut fibers [37]. Other researchers, while working on the effect of fiber length on density on polymer composites have also reported a decrease in density with fiber length [44].

Lighter construction materials are advantageous in terms of lower dead weight of the structure. They are also preferred for insulation purposes, owing to the higher void content in them [45–47].

3.3 Flexural Strength

The flexural strength results are described in Figure 3. Results reveal that the strength decreases with fiber inclusion, as all specimens with fibers reinforcement show lower strength than that of the control specimen.

Strength increases from 1 to 2% and then gradually decreases. It can be concluded that the fiber content owing to inducing voids in the medium is responsible for the reduction of flexural strength. The quantity of voids increases with an increase in fiber quantity. According to Selmi, cavities are formed in fiber-reinforced composites (FRCs) during mixing and reinforcing processes and its quantity increases with increase in reinforcement level [48]. Selmi has further elaborated that at lower volume fraction of fibers, the void content does not negatively influence the mechanical properties of the composites: Hence, the increase of flexural strength in the range of 1 to 2% fiber content is in

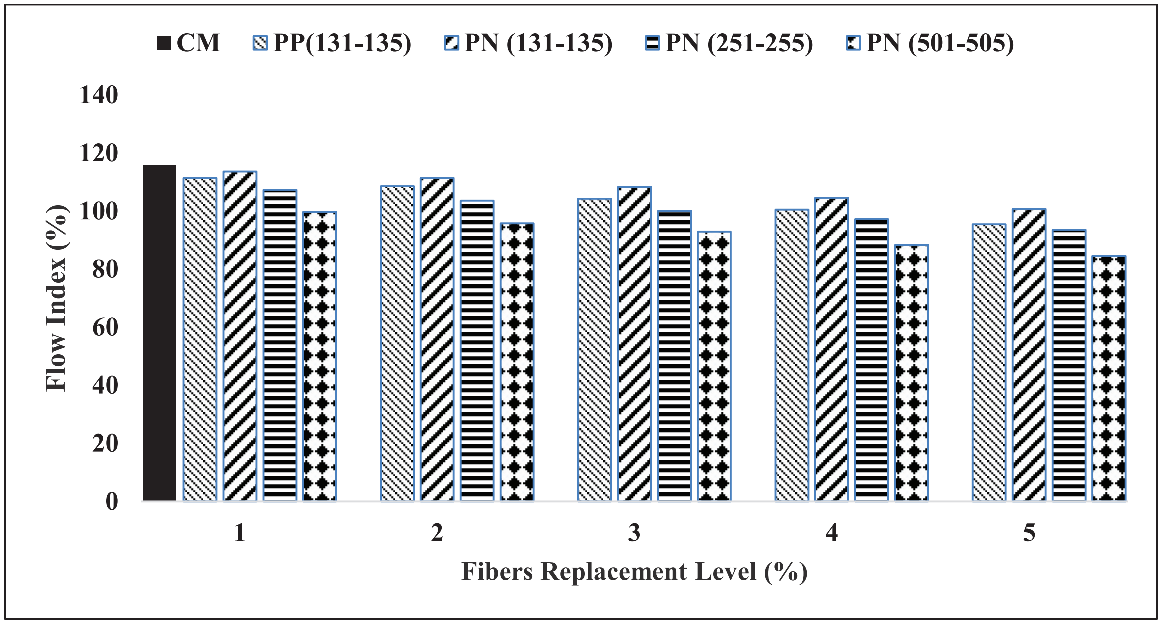

Fig. 1. Variation of flow-ability with fiber content and length

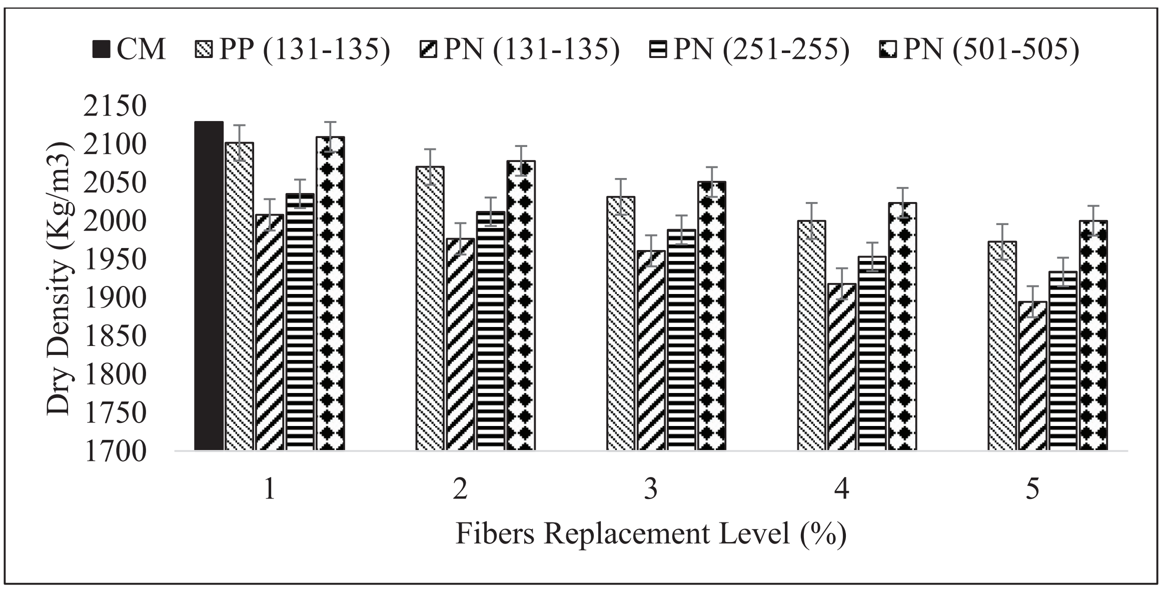

Fig. 2. Variation of density of hardened mortar with fiber content and length

line with the previous studies.

The flexural strength increases with an increase in fiber length at a particular dosage. Longer fibers increase the density of the medium, leading to higher flexural strength. The results are in close coordination with those reported by Karthik et al. while working with coconut inflorescence fiber reinforced unsaturated polyester resin composites [49]. The results are also in close coordination with the density results, presented in Figure 2. It has been reported that dense medium leads to an increase in mechanical strength and lightweight materials are always accompanied with lower strength [50, 51]. Pereira et al. have also reported that longer natural (sisal) fibers increase the fracture resistance of mortars than the shorter ones [52].

3.4 Compressive Strength

The compressive strength results are described in Figure 4. The results show that the compressive strength decreases with fibers inclusion. Results also reveal that the compressive strength decreases

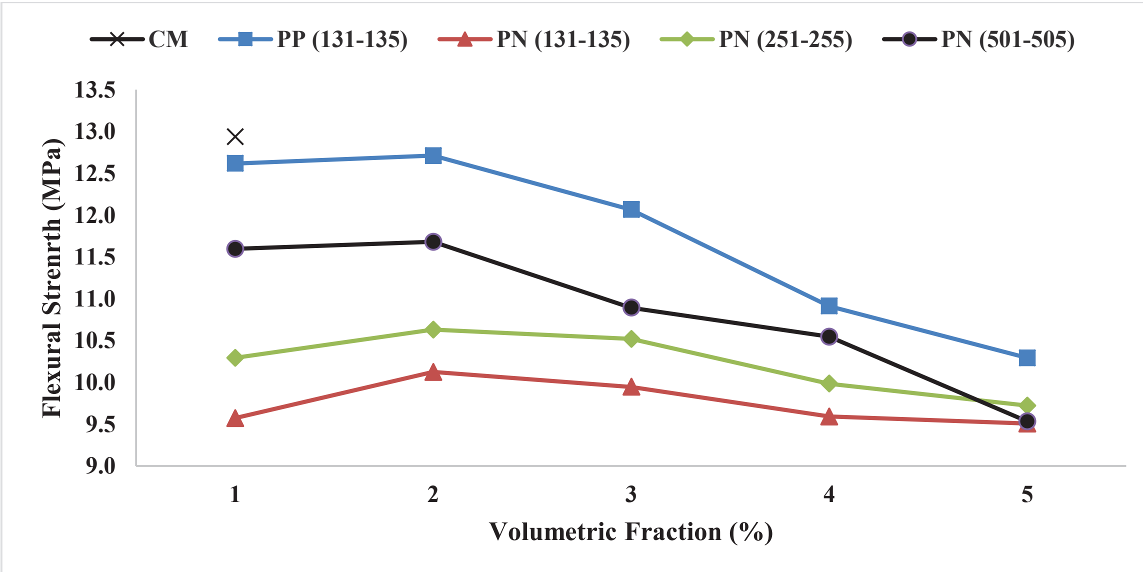

Fig. 3. Variation of flexural strength with fiber content and length

with increase in fiber content. Mashrei et al. studied the effect of PPP fibers on compressive strength of ordinary concrete [53]: Their study revealed that compressive strength increased from 0.1 to 0.2% fiber content and afterwards, it decreased. They have attributed the decrease to agglomeration of fibers and obstruction of hydration of cement at a higher content. Sunil et al. studied the effect of PPP fibers on the compressive strength of hollow concrete blocks [54]. Their study revealed an increase in compressive strength up to 1.5% fiber inclusion; afterwards, a decrease was observed. Singh et al. studied the effect of PPP on ordinary concrete: According to their study, the optimum value of PPP vis-à-vis compressive strength is 0.25%. They have attributed the decrease of compressive strength at higher fiber content to segregation, higher entrapped air and lower unit weight [55]. Siddiqui et al. studied the effect of 9-12 mm long PPP fibers on compressive strength of normal concrete [56]: They have reported that the strength increased up to 0.2% fiber content and a further increase in fiber content reduced the strength. According to Pawade et al., the higher fiber content reduces the workability. Consequently, concrete compaction is highly compromised, resulting in a detrimental effect on compressive strength [57]. Based on the present study results and those reported by the other researchers, fiber content of less than 1% is suggested for strength purposes.

Figure 4 shows that compressive strength increases with an increase in fiber length at the same dose. Najmi et al. studied the effect of length of PPP fibers on compressive strength of ordinary concrete [58]: They used three fibers lengths of 6mm, 13mm and 19mm and observed maximum compressive strength with the longest fibers. Kim et al. used two lengths of PPP fibers [59]: They have reported that longer fibers showed increased residual strength with age than the short one. Hence, the increase of compressive strength with fiber length is in line with various previous studies.

3.5 Ultrasonic Pulse Velocity (UPV)

The UPV results are described in Figure 5. The results reveal that the UPV decreases with fibers inclusion. The results also show that the UPV of the specimens decreases with increase in fiber content at a particular length of the fibers. The UPV of control specimen is 4.36 km/sec, while the maximum velocity achieved is with the longest fibers, and that is 4.2 km/sec at 1% dosage. The minimum UPV achieved is 3.74 km/sec, with 13mm PN fibers at 5% dosage. UPV is an indicator of the quality of the material and is generally linked to the voids present in the material: A high value of UPV indicates a dense and compact medium [60, 61]: As such, it can be concluded that the inclusion of fiber increases the void content in the material.

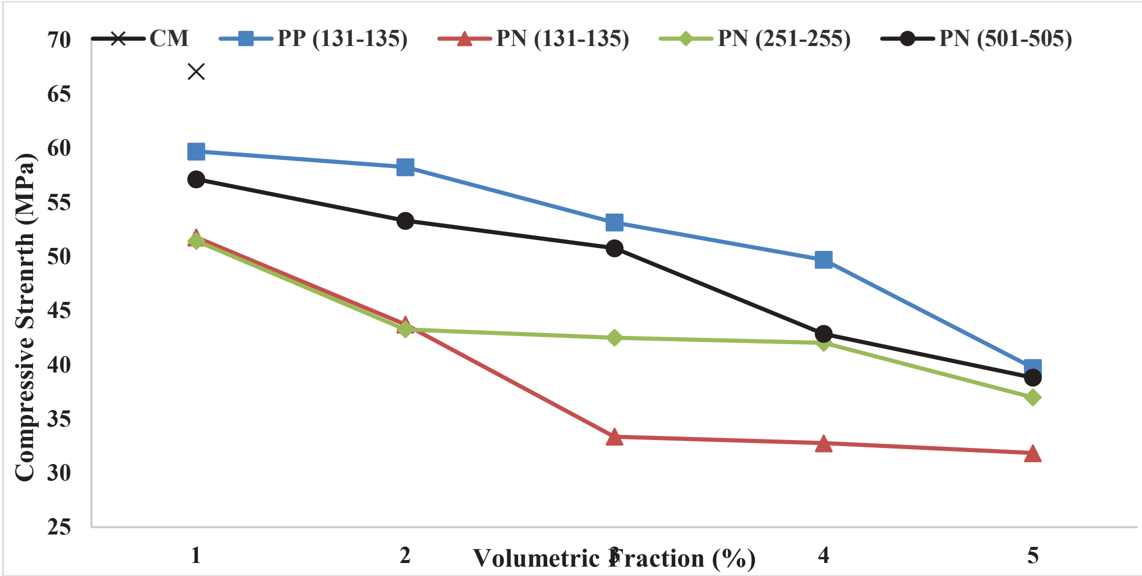

Fig. 4. Variation of compressive strength with fiber content and length

The UPV results are in close agreement with those of hardened density, presented in Figure 2. Hedjazi et al. studied the effect of steel, glass, and nylon fibers on UPV of concrete and have reported a decrease in UPV with an increase in fiber content [39]: They have reported that the development of voids and non-homogeneity of fibers in the medium retards the velocity.

Figure 5 also shows that UPV increases with an increase in fiber length. The results are in agreement with the compressive strength, shown in Figure 4. Yavuz et al. studied the effect of steel and synthetic fibers on UPV of concrete [62]: They used two different lengths 30 and 60 mm for steel fibers and 12 and 22 mm for synthetic fibers. Their study revealed that UPV increases with an increase in fiber length. Rao et al. studied the effect of aspect ratio of fiber in HDPE reinforced concrete [63]: Their study shows that UPV increases with an increase in aspect ratio. Hence, the results not only coincide with those of compressive strength but also with the previous studies.

3.6 Water Absorption

The variation of water absorption of hardened mortar specimens as a function of fiber content and length is presented in Figure 6. The results demonstrate that the control specimens possess the least water absorption and PN fibers of the smallest length impart the highest water absorption.

The water absorption increases with an increase in fiber content. The increase is attributed to the voids induced in the matrix by the fibers. The results are in agreement with the compressive strength and UPV results. According to Parveen et al., plant fibers are prone to high water absorption, which questions their use in composite materials [64]. Alomayri et al. studied the effect of water absorption of cotton fabric-reinforced geo-polymer composites [65]: They have reported that water absorption of the composites increases with an increase in fiber content. Stevulova et al. studied the water absorption behaviour of hemp hurds composites [66]: They have reported that the untreated natural fibers are susceptible to water absorption and their hydrophility can be modified by treating them in NaOH solution.

Figure 6 shows that water absorption of hardened mortar specimens decreases with an increase in fiber length. The results are in close agreement with those of Figure 5 and Figure 2, wherein UPV and density decreased with a decrease in fiber length at a specific dosage.

3.7 Surface Texture

Surface textures of the control specimens and those having fibers are shown in Figure 7. Visual studies.

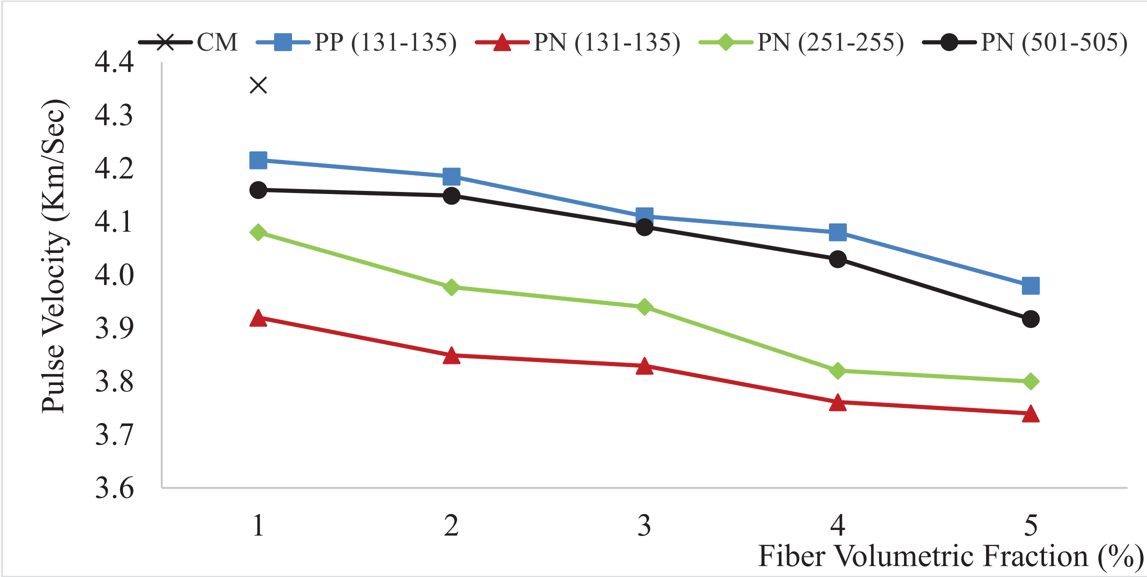

Fig. 5. Variation of Ultrasonic pulse velocity with fiber content and length

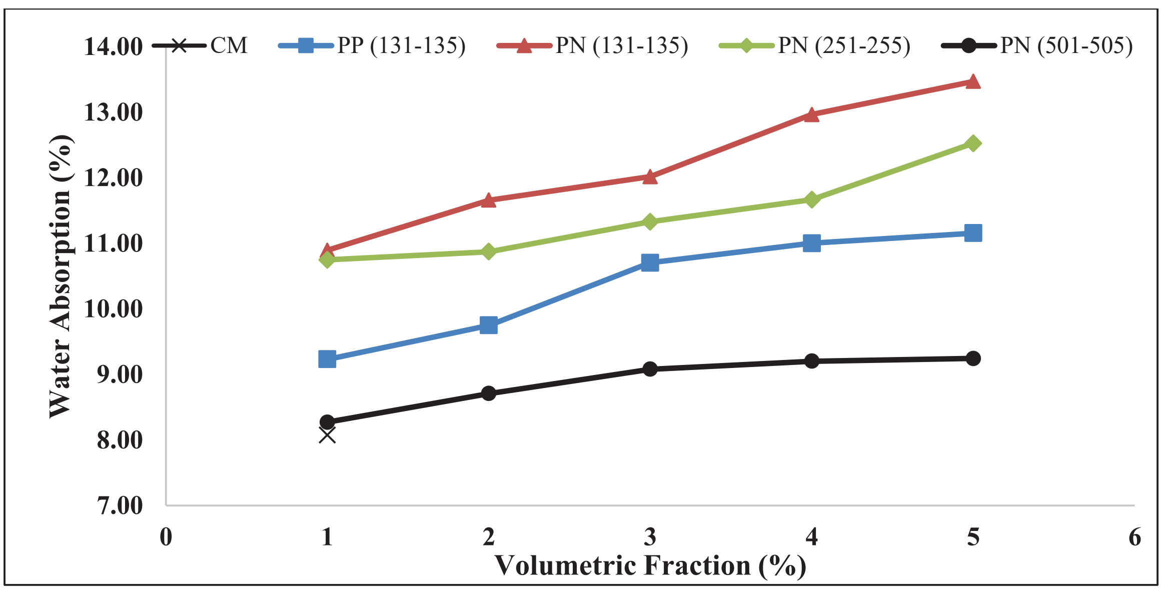

Fig. 6. Variation of water absorption of hardened mortar specimens with fiber content and length

appearance shows that the compaction of the material becomes difficult with increase in fiber content; voids not only increase in number but also in size. Surface appearance of voids is in close agreement with the density data of Figure 2: Density decreases with increase in fiber content. Also, it was observed that at the same dosage, voids were more pronounced in mortars, having PN fibers of smaller length.

3.8 Ductile Behaviour

The flexural strength image of the specimen PN-132 is shown in Figure 8. A ductile behaviour was observed: The failure started with a hairline crack. It can be observed that pine needles, like other

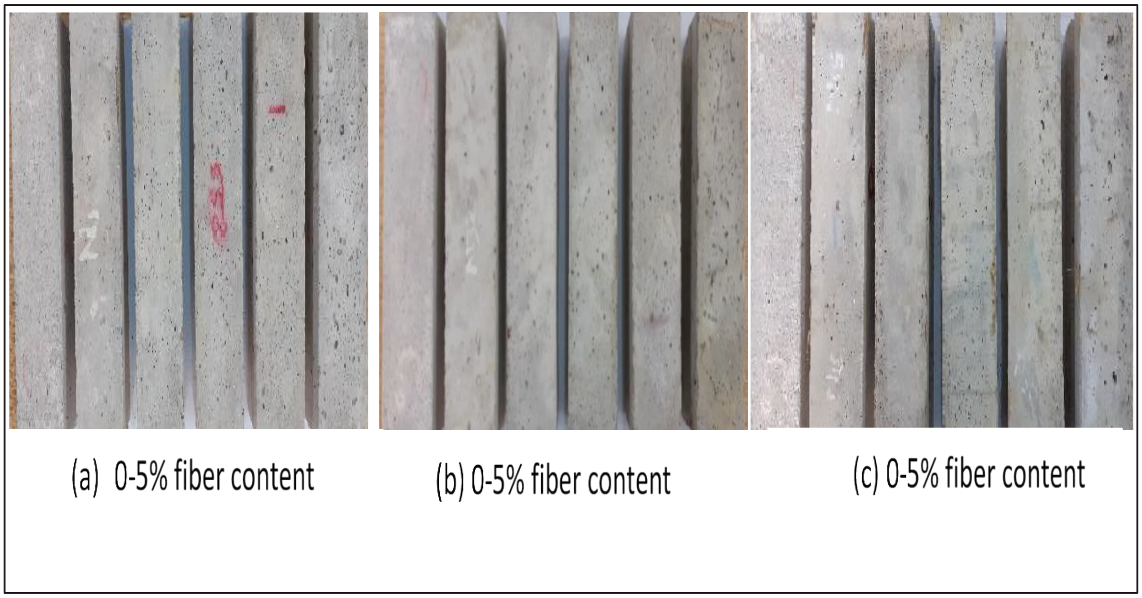

Fig. 7. Surface texture (a) 13 mm PN Fibers (b) 25 mm PN Fibers (c) 50 mm PN Fibers

Fig. 8. Pine needles bridging crack in flexural strength test

natural fibers, possess the tendency of bridging the cracks within cementitious medium.

4. CONCLUSIONS

Based on the experimental results, the following conclusions are withdrawn:

1. Pine needles lower the density of the hardened mortars. With 50 mm long fibers at 5% fiber content by mass of cement, density as low as 2210 Kg/m^3 can be achieved in comparison to 2300 kg/m^3 of control mortar. Lower densities lead to light weight structures.
2. Inclusion of PN fibers, decreases the flow-ability. However, 13 mm fibers at 1% fiber content offer approximately same flow-ability as the control specimens. For compensating the decrease of flow-ability, suitable plasticizers can be included.
3. Flexural strength decreases with an increase of fiber content. Longer fibers (50 mm) at lowest

dose (1%) offer maximum flexural strength, which is 8.4% less than that of the control specimen. The decrease in flexural strength is attributed to the induction of voids.
4. Compressive strength decreases with increase of fiber content. Maximum compressive strength is achieved with 50 mm fibers at 1% dose: The reduction is approximately 10% of that of the control specimens. This happens due to the induction of voids in the fiber-reinforced concrete.
5. UPV test supplements the results of the compressive strength tests. The values indicate reduction of velocities with an increase in fiber content.
6. Fibers also increase the water absorption of the mortar specimens. However, 50mm fibers at 1% dose offer approximately the same water absorption as the control specimens.
7. For non-loading applications, PN fibers of 13 mm at 1% dose are recommended. This optimum dose results in a decrease 3% in density, and approximately same flow-ability.
8. For structural purposes, longer PN needles treated with NaOH with a dosage of less than 1% are recommended.
9. Pine needles are natural fibers; as such they are prone to degradation and need prior treatment for longer life. In the natural environment, they do not decompose for three years.
10. Pine needles like all other fibers may enhance the ductility of the materials.

5. ACKNOWLEDGEMENT

This research was supported by Higher Education Commission (HEC), Government of Pakistan and Office of Research, Innovation and Commercialization (ORIC), Mirpur University of Science and Technology (MUST), Mirpur under the auspices of National Research Program for Universities (NRPU). We thank our colleagues from the Civil Engineering Department, who provided due assistance during the accomplishment of this work.

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