



Investigation of the Effect of Addition Nano-papyrus Cane on the Mechanical Properties of Concrete

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Abstract

This paper investigates the effect of nano-papyrus cane ash as an additive on concretes' mechanical and physical properties. Three types of concrete mixtures, 1:2:4, 1:1.5:3, and 1:1:2 were prepared for each mixture, nano-papyrus ash was added in five different dosages of 0.75, 1.5, 3, 4.5, and 6% by weight of cement; therefore, eighteen mixes would be studied in this work. Physical properties represented by dry density and slump were also measured for each mix. Moreover, to evaluate the mechanical properties development split tensile strength and compressive strength were obtained at age (7 and 28). Results manifested that the adding of nano ash developed the compressive strength and split tensile strength of concrete and the maximum enhancement recognized in the mixes with a content of 4.5% nano-papyrus in each studied mixture in this work. The slump test results indicated that the workability of concrete increased with adding nano-papyrus ash gradually with increasing nanoparticles' content. As well as, dry density was significant increased with nano-papyrus ratio; greater values were recorded in mixtures with 1.5-4.5% content of nano-papyrus. When comparing the concrete mixes used, it was found that the best results were obtained with 1:1:2 mixtures. This remarkable improvement in concrete properties considers the nano-papyrus is considered a cement economical and useful replacement for traditional construction material.

Keywords: Nano Cement; Papyrus Cane; Workability of Concrete; Sustainable Concrete; Concrete Mixes.

1. Introduction

Civil infrastructures around the world being incomplete condition, and important efforts are required for rendering the deteriorating infrastructures back to working and safe condition, multi-functional and smart composites, such as nanomaterials, are perfect materials to achieve such aims [1]. The nanomaterials used to improve the properties can enhance the cementitious substances' durability, strength, and structural efficiency. The nanomaterials utilization with cement can decrease the emissions of (CO₂) associated with concrete manufacturing [2]. The nanoparticles possess a significant surface-area-to-volume ratio, so it is higher than their atoms at the surface and is therefore too reactive. The behavior of these materials is chiefly affected via the chemical reactions at the interface. In this work, Nano-papyrus ash was added to be one of the concrete constituents, and the main advantages of this vegetable fibers are from the lower cost of procurement it and its features being appropriate for using as pozzolanic materials. An additional

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significant feature of using plants is that they are renewable natural resources, and thus they do not harm the environment.

Carla Regina Ferreira et al. investigated organic fiber's influence from either sugarcane or bamboo upon the concrete mechanical properties. They concluded that the concrete comprising (2% v/w) of bamboo fibers revealed better mechanical strength and static modulus of elasticity than the concrete without any addition and the concrete with the addition of sugar cane fibers [3]. Ribeiro et al. depicted the technical viability of utilizing the sugar cane ash as pozzolanic substantial in the construction, which would substitute appropriate disposal for such waste whereas providing outcomes with the high technical performance [4]. Chi (2012) found reported that the fresh mortar flow spread would reduce with an increment of the sugar cane ash's replacement. Specimens with 10% sugar cane ash possess superior performance upon the compressive strength, the absorption of water, the absorption of initial surface, the penetration of chloride ion, and the drying shrinkage [5]. Eethar et al. (2020) studied the influence of the fixed quantity of the ultrafine wood ash upon mortar properties. They obtained that strength and the new characteristics of mortar being raised via the addition of the wood ash, also indicated that the ashes of wood act as fumed silica or fly ash owing to the particles size and shape beyond burning and grinding them to the ultrafine particles [6]. Jemimah Carmichae et al. investigated the effect of using nano cement for different concrete mixes. They found that the compressive strength of the concrete comprising nanomaterials was higher than the usual cement concrete. The values of permeability were obtained to be reduced with the nano cement addition [7].

Fakhri et al. (2020) evaluated the mortars' strength characteristics with industrial waste materials. The outcomes elucidated that the whole replacements presented the strength development. Such enhancement was less in the premature ages and increased at the advanced ages compared to the control specimens [8]. Joshaghani (2017) study the effect of nano-silica and sugar cane bagasse ash on the mechanical and durability properties of mortar and found that nano-silica improved mechanical and durability properties of mortar. At the same time, SCBA did not have a substantial influence on mortar performance [9]. Stefanidou (2017) study the influence of two nanoparticles (nano-silica and nano-alumina) on pozzolanic binders' properties. Natural pozzolan and metakaolin this study explained that the use of nanoparticles reduced carbonation in all hydrated systems comparing to reference specimens, and this action leads to improve the mechanical and durability properties of concrete [10]. Al-Swaidani (2019) investigates the optimum Nano-Natural Pozzolan (N.N.P.) content in the nano-natural pozzolan based binder concrete. The results revealed that the efficiency factor (k) decreased to some extent, when the nano-natural pozzolan content was more than 4%. The calculated durability indicators showed that the contents of 3-4% had approximately the highest indicators values [11]. Alaa A. (2018) study the structure, mechanical and physical properties of cement mortar incorporated nano fly ash with content ranged (0.25-1) % by the weight of cement, experimental outcome display that generated nano-powder improve the structure and enhance the compressive strength of cement mortar [12].

The present work investigates the influence of utilizing nano-papyrus cane ash as additive materials with pozzolanic properties to concrete with different contents and three concrete mix grades. Accordingly, the themes of this research will concentrate on the application's benefits and the determinants of this additive in the technology of cement and concrete. As well, the optimal amount and mix grade would be known.

2. Experimental Part

2.1. Materials

Commercially obtainable normal Portland cement type (I) was used in the present investigation. Cement chemical analysis indicating its conformity to the Iraqi specifications (I.Q.S.) no. 5/1984 [13]. Natural sand and crushed gravel utilized through the current study are presented used Tables 1 and 2 shows the fine aggregate and coarse aggregate grading according to the Iraqi specification (no. 45/1984) limits [14]. The superplasticizer, Kut Plast SP400, was used, a chloride-free admixture based on the modified sulfonated naphthalene formaldehyde condensate. It is non-flammable and complies with the (ASTM494 – 2004) [15]. Nano-papyrus has been manufactured in the engineering laboratory at the University of Technology, Baghdad, Iraq. It has a 15000 cm²/gm surface area with a chemical composition displayed in Table 3.

Table1. Sieve analysis for fine aggregate

Sieve Size (mm)	Passing %	Limit of I.Q.S. no. 45-1984
4.75	97	90-100
2.36	87	75-100
1.18	62	55-90
0.6	45	35-59
0.3	14	8-30
0.15	4	0-10

Table 2. Sieve analysis for fine aggregate

Sieve Size (mm)	Passing %	Limit of I.Q.S. no. 45-1984
37.5	100	100
20	95	95-100
10	36	30-60
5	3	0-10
0.075	0.09	≤ 3

Table 3. Chemical composition of Nano-Papyrus

Oxide composition	Content (%)
SiO ₂	72.43
Al ₂ O ₃	9.32
Fe ₂ O ₃	0.5
SO ₃	1.34
MgO	4.52
CaO	7.43
Total	95.54
Ignition Loss	4.46

2.2. Mix Proportions

Three types of concrete mixes: 1:2:4, 1:1.5:3, and 1:1:2 were used in this work, each mix with six different nano-papyrus addition (0, 0.75, 1.5, 3, 4.5, and 6%). So, eighteen mixes of concrete were applied in the present work. The fixed parameters for each mix include the cement, the fractions of fine and coarse aggregate, and the superplasticizer's contents. The components of each sample were carefully mixed in the concrete mixer. After that, the mixes were cast in steel molds, specified the compressive strength or split tensile strength requirement, and were vibrated for 20 seconds using a vibration table. The details and symbols of all mixes are revealed in Table 4.

Table 4. Mixes symbols and quantities

Mix	Mix Sample	Cement (kg/m ³)	Sand (kg/m ³)	Gravel (kg/m ³)	N.P. (%)	S.P. (%)	W/C (%)
Mix 1 1:2:4	M1R.F	298.5	597	1194	-	-	55
	M1NP1	298.5	597	1194	0.75	2	38
	M1NP2	298.5	597	1194	1.5	2	36
	M1NP3	298.5	597	1194	3	2	35
	M1NP4	298.5	597	1194	4.5	2	33
	M1NP5	298.5	597	1194	6	2	36
Mix 2 1:1.5:3	M2R.F	380	570	1140	-	-	55
	M2NP1	380	570	1140	0.75	2	36
	M2NP2	380	570	1140	1.5	2	34
	M2NP3	380	570	1140	3	2	31
	M2NP4	380	570	1140	4.5	2	33
	M2NP5	380	570	1140	6	2	35
Mix 3 1:1:2	M3R.F	522	522	1044	-	-	55
	M3NP1	522	522	1044	0.75	2	34
	M3NP2	522	522	1044	1.5	2	31
	M3NP3	522	522	1044	3	2	32.5
	M3NP4	522	522	1044	4.5	2	34
	M3NP5	522	522	1044	6	2	36

2.3. Specimens

The kinds and sizes of the specimens utilized for the compressive strength test were cubic having (100×100×100 mm) dimension according to the (BS1881- Part 101) [16], and the concrete specimens for the split tensile strength test

were cylindrical having (100 × 200 mm) dimension depending on the (ASTM C31/C31M) [17]. After 24 hours of casting inside the molds, all specimens were fully de-molded and cured by tap water in two groups (1st group for 7 days, and the 2nd group for 28 days). Figure 1 showed the specimens of compressive and split tensile strength tests.

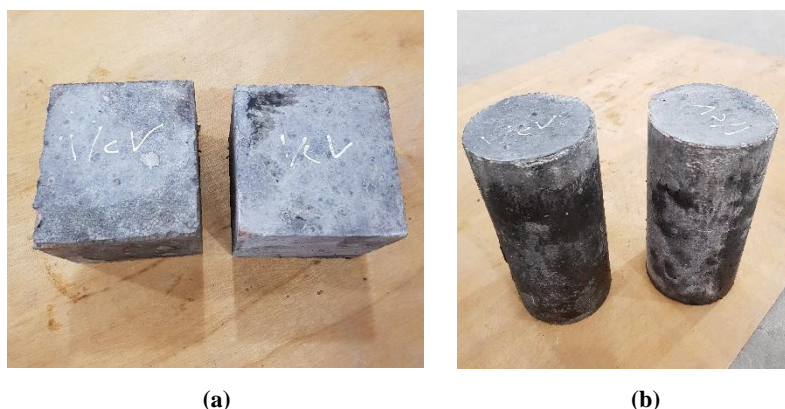


Figure 1. Specimens of (a) Compressive strength test (b) Split tensile strength test

2.4. Tests

According to the BS1881 - Part 101 [16] and the (ASTM C 496 /C 496M - 04) [18], compressive strength and split tensile strength were carried out, respectively. Strength tests were found using a hydraulic compression machine E.L.E. digital of 200 kN/sec; the tests were carried at a uniform rate of 14 N/mm².min after specimens had been centered in a testing machine. The studied ages are 7 and 28 days. Three cubes were produced for every mix at the defined age. The workability of fresh concrete was evaluated using lump tests were achieved depending on the (ASTM 143) [19]; the truncated cone was filled with fresh mortar in three layers, each tamped 20 times with a tamping rod. Next, the mold was lifted away, and the slump value was recorded. According to the (ASTM C642 – 06) [20]. The specimen was dried in an oven at (100-110 °C) for 24 hours then weighed. After that, the specimen was immersed in water for 24 hours, then the submerged weight of the specimen was obtained. This test was conducted at the ages of 28 days. The dry density can be calculated from the Equation 1.

$$\text{Dry density} = \frac{W_1}{W_1 - W_2} \times \rho_w \quad (1)$$

Where: W_1 : the dry weight of the sample (g), W_2 : submerge weight of the sample (g), ρ_w : the density of water is equivalent to 1 (g/cm³) [20].

3. Results and Discussion

The experimental work results are demonstrated in Table 5, including the results of mechanical tests, such as compressive strength, splitting tensile strength, physical property (dry density), and slump. The influences of various nano-papyrus contents upon the mechanical and physical properties of the developed concrete were evaluated. The first series is the 1:2:4 mix. The effects of the 1:1.5:3 mix were assessed in the 2nd series. The influences of various contents of nano-papyrus for 1:1:2 mix were investigated in the 3rd series.

Table 5. Results of the experimental work

Mix type	Symbol	Compressive strength (MPa)		Split tensile strength (MPa)	Density Kg/m ³	Slump cm
		7 day	28 day			
Mix. 1 1:2:4	M1R.F	21	31	5.2	2310	30
	M1NP1	28	39	6.4	2328	30
	M1NP2	31.8	43	6.55	2334	31
	M1NP3	33.8	44	6.7	2340	32
	M1NP4	36.4	46	6.85	2348	33
	M1NP5	33	43.5	6.65	2338	36
Mix 2 1:1.5:3	M2R.F	24.8	36	6.3	2385	42
	M2NP1	32.8	45	7.55	2405	41
	M2NP2	36.7	49	7.85	2415	43
	M2NP3	41.4	53	8.15	2435	45
	M2NP4	38.7	51	7.9	2428	45
	M2NP5	34.4	47	7.65	2420	46

Mix 3 1:1:2	M3R.F	32.6	46	6.7	2450	52
	M3NP1	40.5	55.5	7.9	2465	48
	M3NP2	43.3	57	8.3	2485	50
	M3NP3	41.4	56	8.2	2476	51
	M3NP4	39.3	54.4	8.05	2468	53
	M3NP5	37.2	53.2	7.85	2462	55

3.1. Results of Slump Test

The nano-papyrus content influence upon the concrete workability was assessed utilizing the slump test depending on the (ASTM C143) [19]. One can notice from Figure 2 that the concrete comprising nanoparticles manifested somewhat lower workability than the control mix of concrete, and the values of flow at first reduce with the addition of the nanoparticles contents until reaching a 1.5% content. Similar behavior was noted in the three mixes of concrete except the 1:1:2 mix. The reduction continues until the nanoparticles' content reaches 3%; this reduction can be clarified due to the nano-papyrus's high specific surface area. Such a phenomenon is due to the nanomaterials' fine particle size, which possesses much greater surface areas absorbing the water, leaving a lesser amount of free water to contribute to flowability. Erhan (2016) documented that the nano-silica addition to the mix reduces the spreading upon the flow table due to the cohesion increment in a mortar [21]. Similar outcomes were verified via the research Erhan (2005) [22], which showed that owing to its surface influence, the smaller sizes of particle and the higher energy of the surface, and (O^{H-}) and (Ca²⁺) made via the hydration of cement can be adsorbed in the nanoparticles surface more simply, and the reduction of (O^{H-}) and (Ca²⁺) in the paste solution of cement led to speed up the cement hydration reaction [22]. Another note fixed from the same figure was the increase in slump value when nano-papyrus content exceeds 1.5-3%. The increment can cause this behavior to occur in fine materials quantity in the mixture.

Among three mixes, the 1:1:2 mix showed a higher slump value compared to 1:1.5:3 and 1:2:4 mixes, respectively, due to the high amount of fine cement in the mix and reducing the content of aggregate, this works as a lubricant and reduces the internal friction among the particles or aggregates, and consequently, the factor of compacting and the workability raise [23]. Komal's close results reported that the concrete is richer for the lower ratio of aggregate/cement. More paste is obtainable in rich concrete for making the mixture cohesive and fatty to provide better workability [24].

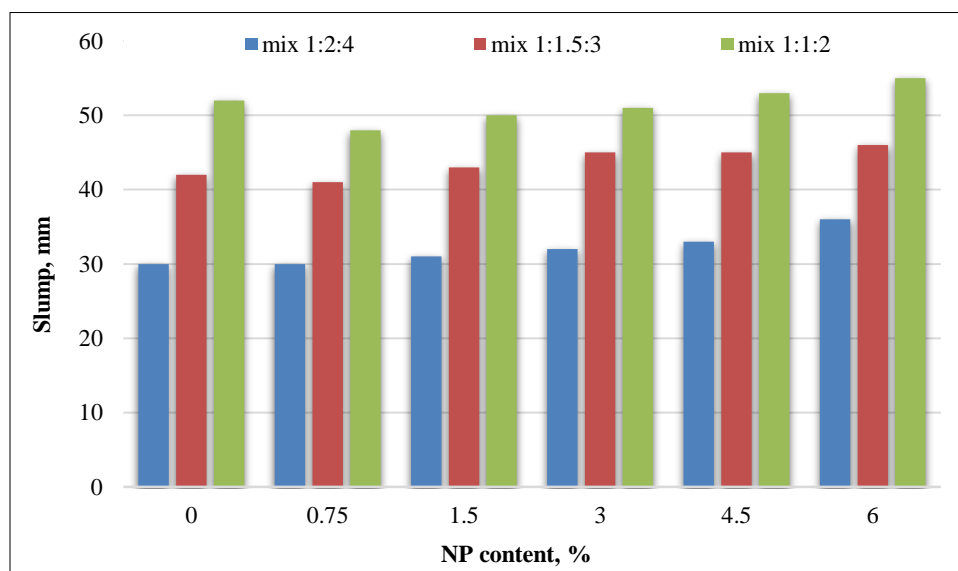


Figure 2. Slump value for all concrete mixes

3.2. Results of Dry Density test

The densities of prepared concrete specimens with nano-papyrus compared with the control specimen are shown in Figure 3. The addition of nano-papyrus to the concrete mixture increases the concrete prepared density compared with the control mix. The density increased with nano-papyrus content until 4.5% and then decreased but still greater than the density of control mix for all mix types with different nano ash contents. So that the density may be increased because of the lower pore (void) amount in the concrete matrix than that in the control mix, or this is caused by a higher degree of structure tightness by introducing a very fine material which fills the pores and gives more dense structure compared with the concrete mixture without nanoparticles. These results are in agreement with those

obtained by Pizoń et al. (2020) [25] and Mendes and Repette (2019) [26]. Mix 1:1:2 also showed higher density values compared to 1:1.5:3 and 1:2:4, respectively, due to the formation of more cement paste in mixes with a higher cement/aggregate ratio, which gives the dense concrete structure.

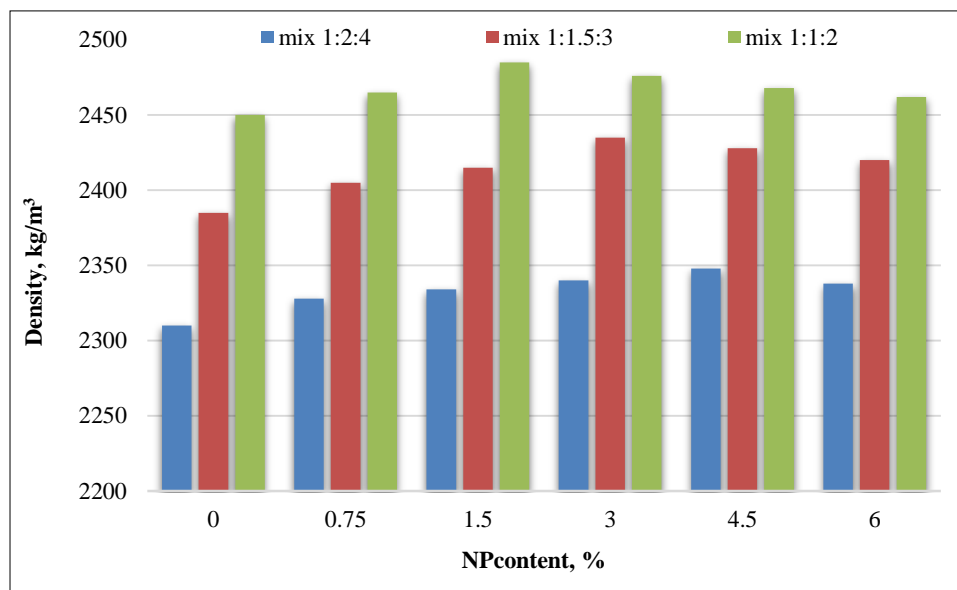


Figure 3. Dry density of concrete mixes with nano-papyrus

3.3. Results of Mechanical Properties

The results compared with the control mixes and the mixes that incorporate nano-papyrus are shown in Figures 4 to 6. Figures 4 and 5 display the compressive strength of the mixes of concrete at the age (7) and (28) days, respectively, for the three mixes groups. One can notice that the compressive strength of the concrete with nano-papyrus enhanced at (7) days, and the nano-papyrus optimal content being 1.5, 3, and 4.5% via the weight of cementitious content for 1:1:2 mix, 1:1.5:3 and 1:2:4 mix, respectively, and the maximum compressive strength (43.3 MPa) was found with 1:1:2 mix and 1.5% of nano-papyrus content. Simultaneously, a greater enhancement (73.3%) was found in mix 1:2:4 with 4.5% N.P. Figure 4 evinces the compressive strength of the mixes of concrete at the age (28) days with the supplemented nano-papyrus N.P. Also, the compressive strength of the concrete with N.P was enhanced at (28) days, and the optimal papyrus content was similar to that obtained at 7 days' age. The maximum compressive strength (57 MPa) was found with a 1:1:2 mix and 1.5% of nano-papyrus content.

In comparison, a greater enhancement of 48.4% was found in mix 1:2:4 with 4.5% N.P. This development in the compressive strength might be due to the nano-papyrus chemical reactivity and its pozzolanic nature, as is evident for its chemical composition in table 3. The more pozzolanic reaction occurs in the mix, the more strength-carrying (C-S-H) being formed, which eventually results in a higher total strength [27]. Such outcomes agree with the works of [28, 29] who stated that the increment could be owing to the truth that the compounds of Calcium Hydroxide present in the lime solution react with the nanoparticles in their surface areas to procedure further (C-S-H) gel, thus raising the compressive strength.

The same trend in the strength development was recognized in the split tensile test results, as shown in figure 6, and the maximum splitting tensile strength recorded was 8.3 MPa for 1:1:2 mix with 1.5% N.P content, while the maximum enhancement ratio was 31.7% for 1:2:4 mix with 4.5% N.P. This improvement resulted from the addition of nano-papyrus cause a decrease in the rate of water segregation concrete, which prevented the moisture from collecting under the aggregate and contributed to the microstructure of the interface transition area between the aggregate and the paste of cement. Simultaneously, the structure of pores in the paste of cement was varied via the pozzolanic reaction. Thus, the concrete strength increased with pozzolan materials having a high quantity of silica [30, 31], which compatible with the results reported by Amudhavalli and Jeena (2012) [32] and Hossain et al. (2015) [31], which stated that up to 10% replacement of cement by silica fume, the split tensile strength showed an increase with the content of silica. This distinction for the papyrus cane ash is ascribed to its higher silica content with the greater pozzolanic influence. This addition for such nanomaterial can be regarded as a feasible additive to concrete, and therefore it is an economical construction substance and eco-friendly to the environment.

The 1:1:2 mix recorded a higher value for both the compressive and splitting tensile strength. Also, the strength of concrete increases with the increase in cement content for each mix because of the extra cement content, the additional formation of the C.S.H. gel with more bonding properties that cause higher concrete strength [33].

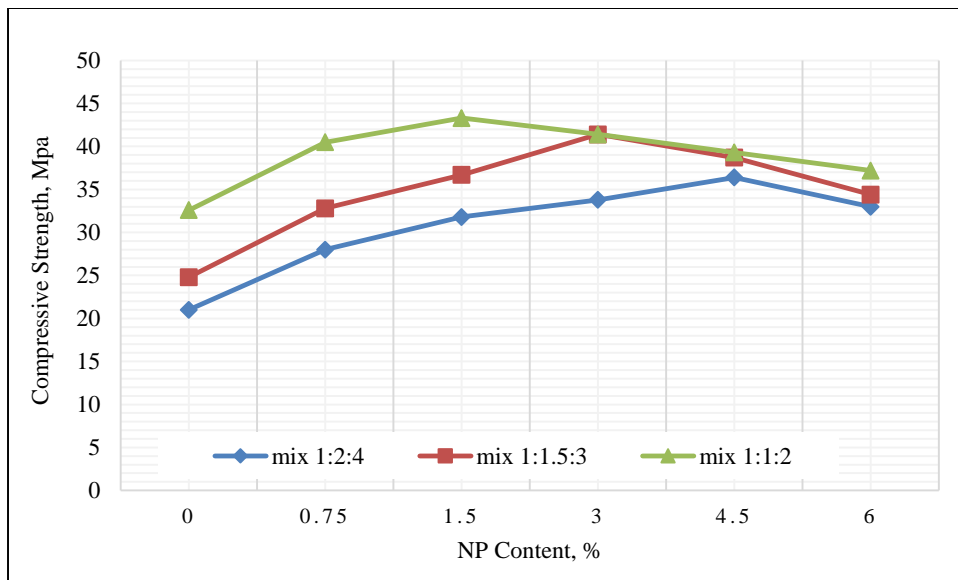


Figure 3. Compressive strength of the concrete mixes with nano-papyrus at (7) days age

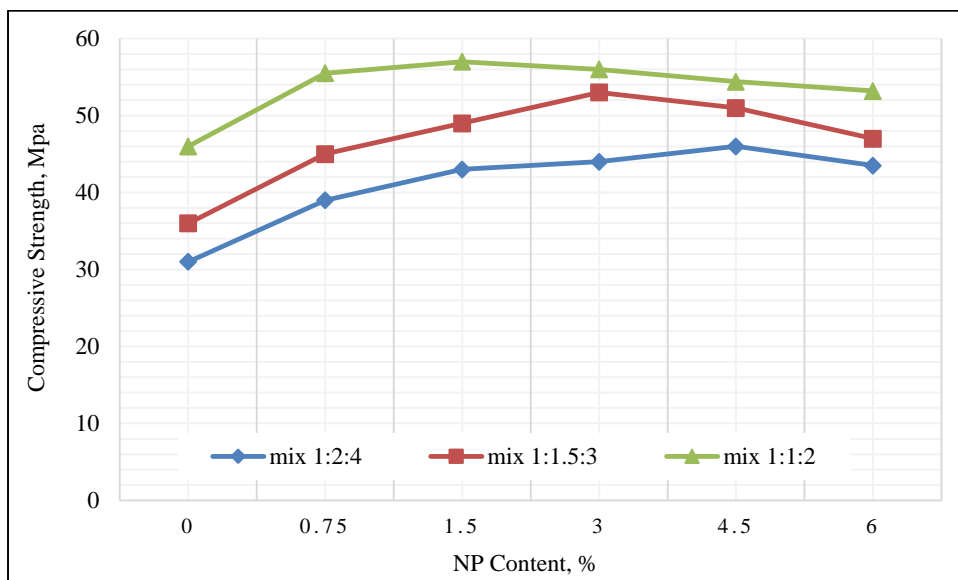


Figure 4. Compressive strength of the concrete mixes with nano-papyrus at (28) days age

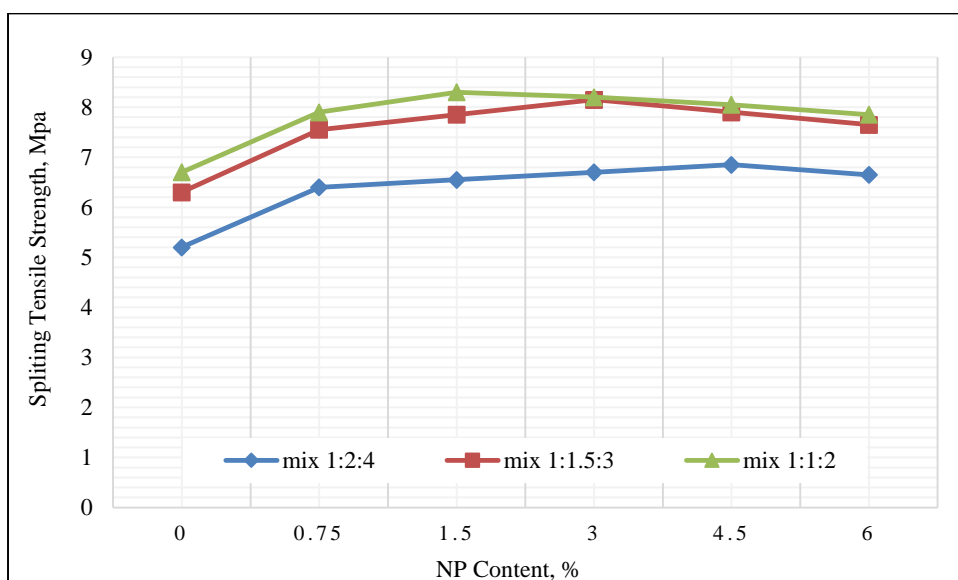


Figure 5. Splitting tensile strength of the concrete mixes with nano-papyrus at (28) days age

4. Conclusions

Based on the obtained results by experimental work, the following conclusions can be drawn:

- For fresh concrete a remarkable improvement in the workability of concrete was recorded by adding nano-papyrus with content more than 1.5% by the weight of cement to the concrete mix. While for mixes with less than this content reduction in slump value was fixed;
- A slight increment in hardened concrete density was recognized after adding nano-papyrus to different concrete mixes with increasing the content of both nano particles and cement content;
- A good enhancement in both the compressive and splitting tensile strength was achieved by adding nano-papyrus ash with different contents, and a maximum strength was recorded with the content of 1.5, 3, and 4.5% 1:1:2 mix, 1:1.5:3 mix, and 1:2:4 mix, respectively;
- Nano papyrus proved its activity as pozzolanic additive and can be as feasible additive to concrete, and therefore it is an economical construction substance and eco-friendly to the environment;
- Mixes 1:1:2 with a high cement/aggregate ratio manifested a greater development in workability, density, and bonding strength than other mixes 1:1.5:3 and 1:2:4.

5. Declarations

5.1. Author Contributions

Conceptualization, F.K. and Z.F.; methodology, Q.J. and Z.F.; software, Z.F. and A.J.; validation, F.K., Z.F. and A.J. formal analysis, F.K.; investigation, F.K., Z.F. and Q.J.; resources, Q.J.; data curation, F.K.; writing—original draft preparation, Z.F.; writing—review and editing, Z.F. and Q.J. ; visualization, Z.F., Q.J. and A.J. ; supervision, F.K.; project administration, F.K. and Z.F.; funding acquisition, A.J.. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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