

Original article

Enhancement of the Properties of Libyan Concrete through the Incorporation of Natural Additives Derived from Palm Waste or Local Limestone: A Comparative Data-Driven Assessment

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Abstract

The concrete manufactured in Libya is subject to hot-dry weather conditions, variability in the quality of aggregates used, and quality control, whereas the agricultural waste from date palm (*Phoenix dactylifera* L.) and common carbonate rocks can be considered underutilized sources of additives to concrete. This work provides a comparative and evidence-based analysis of natural additives based on palm waste (fibers and ash) and limestone (powder) for improving the characteristics of Libyan concrete. The quantitative data were retrieved from nineteen scientific publications and official sources, harmonized and analyzed by means of relative change and trend analysis. The field data from 20 Libyan projects demonstrated a coefficient of variation in strength of 5.58-25.19%. When used in date palm fiber concrete, increasing the share of fibers from 1% to 3% decreased 28-day compressive strength by 16.6% but increased flexural strength by 11.4%, whereas water absorption increased by 24.5%. Partial substitution of cement (5-10%) by silica fume recovered 4.3-16.7% of the compressive strength lost due to fibers and decreased water absorption by up to 24.8%. As for palm ash and limestone powder as cement substitutes, 10% became the most persistent optimal level: Ashes from date palm seeds at 10% were 31.5 N/mm² compared to 31 N/mm² for the control at 56 days, while Libyan fronds ashes at 10% increased mortar strength at 28 days by 31.3%. Additionally, 10% limestone substitution was competitive, while above this percentage diminished carbonation resistance. Altogether, it can be concluded that waste products from palms should preferably be used in low dosage in the form of fiber or ash, and local limestone as filler at a 10% substitution rate.

Keywords: Libyan Concrete; Date Palm Waste; Date Palm Fibre; Date Palm Ash; Limestone Powder.

Introduction

The primary construction material in Libya is concrete, which is dependent on local resources of cement, aggregates, and water, all of which can be highly variable in nature across the regions of the country. It thus makes sense from an engineering point of view to optimize the quality of such concrete by using cheap and readily available materials. Date palm waste is an extensively available agricultural residue in Libya and in other date palm-producing countries in North Africa and the Arabian Peninsula. The date palm tree (*Phoenix dactylifera* L.) produces fronds, fibers, and seeds which are often burned, disposed of, or simply discarded. Date palm fibers have been extensively studied as reinforcing elements for cement-based composites; in a hot, arid environment, a fiber volume fraction between 2-3%, along with a fiber length of 15-60 mm, increased the flexural strength and toughness of concrete after cracking, but at the same time, reduced its first-crack and compressive strengths [1]. In more recent research, it was shown that an increase in the amount of date palm fibers reduces the compressive strength of the composite, while increasing its flexural and splitting tensile strengths up to 2% content of the fibers [2,3].

Fiber performance is greatly influenced by surface characteristics. A three-hour boiling process, 3% sodium hydroxide, and 1.5% linseed oil coatings all decreased the water absorption rate of individual date palm fibers, while boiling and NaOH increased the flexural and compressive strength of the fiber-cement composite, but linseed oil increased workability and was responsible for the highest porosity of mortar [4]. In repair mortars, 0.75% date palm fibers with either 15% slag or natural pozzolans decreased the capillary absorption by 25-43% and increased the shrinkage by only 3-7%, but decreased the compressive strength from 30 MPa to 20 MPa [5]. However, the baseline itself is not homogeneous; a survey of 20 Libyan construction projects showed that 28-day strengths were normally distributed, but quality control varied, ranging from very good to poor using ACI 214 criteria, with coefficients of variation of 5.58-25.19% [6].

Limestone is the second naturally available additive in the area of study. Limestone rocks are widely exposed in the northern parts of Libya. Also, limestone powder can be used as a partial replacement for Portland cement. In concrete samples made with Portland cement and limestone at different percentages of 0, 5, 10, 15, and 20% limestone at three different w/b ratios of 0.37, 0.45, and 0.55, in which the binder was 350 kg/m³, it was observed that concretes containing up to 10% limestone had competitive performance compared to cement concretes after 28, 90, and 180 days [7]. But in five years, the limestone powder exhibited very low reactivity, higher connected porosity, and late age gain. [8].

Performance of any additive should be measured with respect to the local baseline. Libyan coarse aggregates show some variance: The aggregate from Al-Jufra showed less water absorption (1.3% as opposed to 1.97%), less Los Angeles abrasion (17.8% compared to 20%), and crushing value (17.8% compared to 22.9%), as well as provided better concrete than the aggregate from Sirte [9]. Another cementitious substance studied is the ash of date palm residue. Date palm seed ash that was burnt at 630 °C showed the content of 45.50% SiO₂, 20.75% Al₂O₃ and 7.25% Fe₂O₃, resulting in 56-day compressive strength of 31.5 N/mm² at 10% replacement as opposed to 31 N/mm² in control sample [10]. The ash of date palm fronds

from Libya proved to perform best at 10% replacement in mortar [11], whereas leaching tests proved no environmental hazard for date palm ash at 10% and 100% replacement. [12].

There have been research initiatives on documenting local concrete practices and waste valorisation. The grades C25, C30, and C35 concrete mixes made of regional material in Benghazi city have satisfied or surpassed the requirements for compressive strength over seven months [13], and Libyan iron slag increased the compressive strength of self-compacting concrete when 60% of coarse aggregate was replaced [14]. In the larger context, the use of 45% Portland cement along with 30% basaltic ash and 15% limestone powder achieved a strength of 39 MPa at 28 days and 57 MPa after a year, with a clinker factor of 0.52 compared to 0.95 for normal Portland cement [15]. There is a clear environmental benefit too: cement used in Libya has an estimated emission factor of 1,083.60 kg CO₂ per tonne, which is more than the global average of 0.798 t CO₂ per tonne [16], and the national production (3.1 Mt in 2020, against the capacity of 9.3 Mt/year) has much room left for low-clinker binders [17]. The raw materials are available locally. Furthermore, the Benghazi Formation, which is an impure dolomitic limestone, is suitable as aggregate [18]; whereas date palm mesh fibres with 34-45.1 % cellulose, 16.9-18.2 % lignin and tensile strengths of 170-290 MPa have been reported depending upon their length [19]. Nevertheless, there is no literature that compares the two kinds of waste materials for Libya. This research therefore aims to address the existing gap in knowledge through a comprehensive synthesis of the available literature. The study first seeks to establish a baseline for concrete production in Libya by assessing the quality of concrete commonly produced in practice and examining the properties of locally available aggregates. It then investigates the influence of date palm fibres, both independently and in combination with silica fume, on key concrete properties, including fresh-state behaviour, mechanical performance, and durability-related characteristics. Furthermore, the study compares the effectiveness of palm ash and limestone powder as partial cement replacements at their optimum replacement levels. The findings are expected to provide a scientific basis for subsequent mix-design trials in Libya, particularly through the utilisation of locally available palm-derived waste materials and limestone as sustainable alternatives in concrete production.

Material and Methodology

Data Sources and Selection Criteria

This research is an empirical comparison study that relies only on the results of experiments already published in journals. These publications were found in September 2026 via targeted searches of publishing sites and journals using different combinations of the keywords date palm fibre, date palm ash, limestone powder, cement replacement, concrete, mortar and Libya. The papers were included in the study if they provided numerical information regarding the strength, workability, absorption or durability of concrete or mortar samples containing date palm fibre or ash, limestone powder or if they described the characteristics of concrete in Libya or its aggregates. Nineteen papers published in the years 2005 to 2025 satisfied these conditions and are referred to as [1] to [19], respectively.

Dosage bases and mixing ratios vary between different references and have been taken from original works. Fibre contents are described in terms of percentages by weight of binder (cement + silica fume) for 20-30 mm fibres, where silica fume substitutes cement by volume [2]; percentages by weight of cement for 20-30 mm fibres [3]; volume fraction of concrete for 15-60 mm fibres [1]; and as 0.75% by volume of mortar for 2-10 mm fibres in conjunction with 15% mineral substitution by weight at the water-to-binder ratio of 0.5 [5]. Ashes replacement takes place by weight of cement in the cases of seed-ash concrete (water-to-cement ratio of 0.53) [10] and frond-ash mortar (water-to-cement ratio of 0.50) [11]. Limestone substitutions were expressed in terms of weight at a constant binder concentration of 350 kg/m³ [7] and water-to-cementitious ratio of 0.35 [15], while the water-to-binder ratio was adjusted to compensate for 28-day compressive strength in [8]. Dosage bases are not specified in [4], [8], and [12] texts available to the author. Thus, comparison between results is based on relative changes and position of optima.

General Data Extraction Protocol

Stage I (Selection and Screening): The candidate studies were selected according to the presence of a palm-waste or limestone additive in a cement-based system and numerical data of any kind. Stage II (Data extraction): The additive name, its concentration, system, curing age, as well as all the properties mentioned by the authors, such as slump, compressive, flexural and splitting tensile strength, water absorption, pore volume, shrinkage and carbonation/chloride resistance, were entered into a structured table for each selected paper. Stage III (Data Harmonization): The value was normalized relative to a reference sample of the same study in order to calculate the percentage change $\Delta = (X_{\text{treated}} - X_{\text{reference}}) / X_{\text{reference}} \times 100$. Reported values in terms of percentages were used as-is, while arithmetic combinations of data across sources never occurred.

Analysis Methods

Linear relationships between a property and fibre contents were obtained using linear regression through least squares. Since each series has only three fibre contents, i.e., 1%, 2% and 3%, both slopes and correlation coefficients are descriptive and do not form part of the test of significance. Qualitative assessments for the performance matrix (Table 5) were done based on the trend described in the references.

Libyan Reference Materials

The properties of the aggregates from Libya, which were chosen for use in determining the reference properties, have been described in [9]. Aggregates from Sirte and Al-Jufra (coarse aggregates), and Sabha, Waddan and Zalah (fine aggregates) were characterised by their absorption, specific gravity and mechanical properties as presented in Table 1.

Table 1. Properties of Libyan Coarse and Fine Aggregates Used as the Baseline (Data from [9]).

Aggregate	Absorption/moisture (%)	Specific gravity	Mechanical indicators (%)
Sirte coarse	1.97 (absorption)	2.50	LA abrasion 20; crushing 22.9; impact 35
Al-Jufra coarse	1.30 (absorption)	2.69	LA abrasion 17.8; crushing 17.8; impact 27
Sabha sand	0.08 (moisture)	2.72	—
Waddan sand	0.17 (moisture)	2.65	—
Zalah sand	0.63 (moisture)	2.63	—

Results

Libyan Baseline: Field Concrete Quality and Aggregate Properties

The field data of concrete properties in Libya is provided in Table 2. The 28-day strength of concrete samples collected from 20 different projects followed a normal distribution pattern, although the ratio of the minimum to the designed strength varied from 0.364 to 1.14, which indicates that certain projects did not produce concrete that satisfied the specifications [6]. The average strength was greater than the designed strength by 32%. In Benghazi, grades C25, C30 and C35 recorded over seven months had a normal distribution and satisfied the strength requirement, with Sikament R 2002 additive [13]. The combined baseline is presented in Table 1 and Figure 1. Al-Jufra coarse aggregate showed water absorption reduced by 34.0%, a Los Angeles abrasion value reduced by 11.0%, crushing value reduced by 22.3%, impact value reduced by 22.9% and an increased specific gravity (2.69 and 2.50) when compared to Sirte aggregate [9]. The slump values for the reference concretes prepared from the two aggregates were 95, 90, and 88 mm (Sirte) and 100, 90, and 95 mm (Al-Jufra), while those for the concretes prepared using the three fine aggregates were 60 mm (Zalah), 65 mm (Sabha) and 70 mm (Waddan) [9].

Table 2. Reported Indicators of Concrete Quality and Workability in Libya.

Source	Scope	Reported indicators
Alazhari and Al Shebani [6]	20 projects; 150 mm cubes; 28 days	COV 5.58–25.19%; bias factor 0.693–2.078; f_{min}/f_{cu} 0.364–1.14; mean strength $\approx$ 32% above design
Eldarrat [13]	Grades C25, C30, C35; Benghazi; 7 months	Normal distribution; results consistent with ACI 214R-11 at 95% confidence; requirements met or exceeded
Blash et al. [9]	Sirte and Al-Jufra reference concretes	Slump 88–100 mm
Blash et al. [9]	Sabha, Waddan, Zalah sands	Slump 65, 70 and 60 mm, respectively

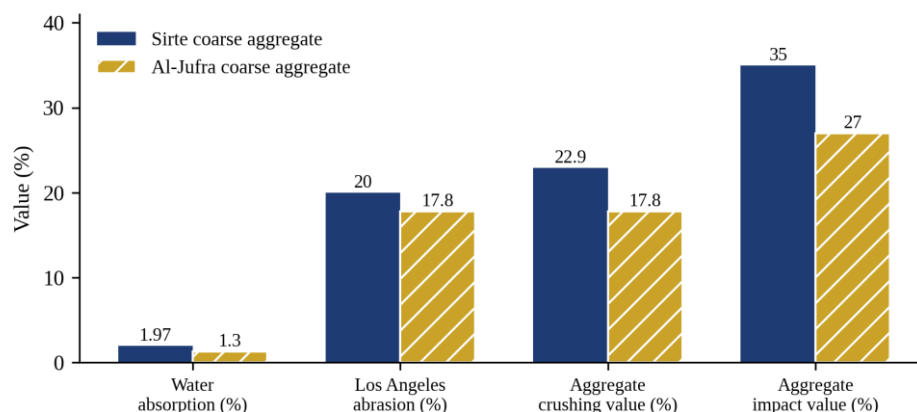


Figure 1. Water absorption and mechanical indicators of Sirte and Al-Jufra coarse aggregates (data from [9]).

Workability and Compressive Strength of Date Palm Fibre Concrete

The property that is the most sensitive to the palm fibres is the compressive strength. The compressive strength of concrete containing 1-3% date palm fibres decreased from 41.6 MPa (for 1% fibre content) to 34.2 MPa (for 2% fibre content) and 34.7 MPa (for 3% fibre content) without silica fume, which resulted in a decrease of 16.6% from 1% to 3% fibre content (Figure 2 and Table 3) [2]. The slope of the fitted straight line is -3.45 MPa per 1% fibre content ($r = -0.83$, $n = 3$). A similar trend was observed on the 7th day. (31.1 MPa).

The silica fume mitigated this effect to some degree. As compared to the mixtures without silica fume, the substitution by 5% silica fume resulted in an increase in 28-day compressive strength by 10.1%, 16.7% and 7.5% for 1%, 2% and 3% fibre, respectively, while 10% silica fume substitution increased strength by 5.0%, 11.4% and 4.3% (Table 3) [2]. The 15% substitution proved to be detrimental, as strength change was -1.0%, +4.1% and -7.5% at 1%, 2% and 3% fibre content, respectively; in particular, the mix of 3% fibre and 15% silica fume exhibited the lowest 28-day strength in the whole series (32.1 MPa). In the second hybrid-fibre programme, 0.5% date palm fibre reduced 28-day compressive strength by 14.5%, while 0.5% polypropylene fibre by 5.33%, and the largest decrease, 44.78%, corresponded to 1% date palm and 0.5% polypropylene fibre mixture [3]. Slump decreased from 77 mm to 66 mm (-14%) with 0.5% date palm fibre, while for polypropylene [3].

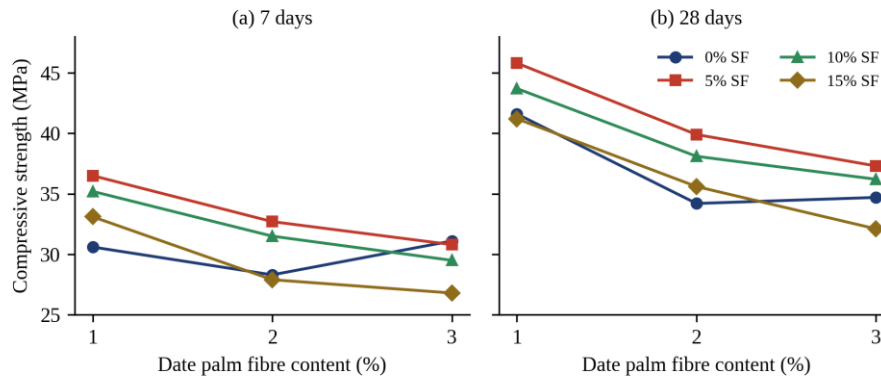


Figure 2. Compressive strength of date palm fibre concrete at (a) 7 days and (b) 28 days as a function of fibre content and silica fume (SF) replacement (data from [2]).

Table 3. Compressive Strength at 28 Days (MPa) of Date Palm Fibre Concrete with Silica Fume; Fibre Content as % by Weight of Binder and Silica Fume as % by Volume of Cement; Values in Parentheses Show the Change Relative to the Mix without Silica Fume at the Same Fibre Content (Data from [2]).

Date palm fibre (%)	0% SF	5% SF	10% SF	15% SF
1	41.6	45.8 (+10.1%)	43.7 (+5.0%)	41.2 (-1.0%)
2	34.2	39.9 (+16.7%)	38.1 (+11.4%)	35.6 (+4.1%)
3	34.7	37.3 (+7.5%)	36.2 (+4.3%)	32.1 (-7.5%)

Flexural and Splitting Tensile Strength

On the other hand, flexural strength was seen to increase with increasing fibre content in all cases in which silica fume was present (Figure 3a). Flexural strength of 28 days without silica fume increased from 5.37 MPa for 1% fibre to 5.98 MPa for 3% fibre (+11.4%; 0.305 MPa per 1% fibre; $r=0.99$), and the maximum flexural strength in the series was recorded for the mixture of 3% fibre and 10% silica fume (6.34 MPa), which was 17.8% higher than the 1% fibre value at the same level of silica fume [2]. In the hybrid test case, date palm fibre at 0.5% improved [3].

The sensitivity of the splitting tensile strength to overdosage is evident in Figure 3b. In the absence of the silica fume, while it increased from 5.97 MPa at 1% fibre to 6.18 MPa at 2% (+3.5%), it dropped to 4.53 MPa at 3% (-24.1% relative to 1%). For the mix containing 10% silica fume, the three-point values were 6.37, 6.42, and 6.12 MPa. Therefore, in the presence of the silica fume, the value of tensile strength at 3% fibre is higher by 35.1% than the corresponding value in its absence [2]. Hence, optimum tensile and flexural properties are achieved for 2% fibre with 10% silica fume, whereas 3% fibre is optimum only for flexure.

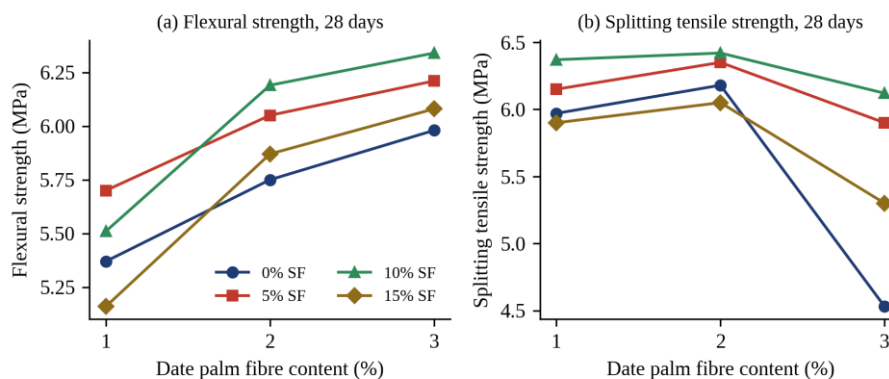


Figure 3. (a) Flexural strength and (b) splitting tensile strength at 28 days of date palm fibre concrete as a function of fibre content and silica fume (SF) replacement (data from [2]).

Water Absorption and Durability-Related Behaviour

Water absorption increased progressively with fiber content (Figure 4). In absence of silica fume, water absorption after 28 days increased from 6.50% at 1% fiber to 7.51% and 8.09% at 2% and 3%, respectively, an increment of 24.5% (0.795 percentage point per 1% fiber, $r = 0.99$) [2]. Ten percent silica fume content decreased the absorption by 24.8%, 16.4% and 5.9% at 1%, 2% and 3% fiber, respectively, to attain the lowest value of the series (4.89%) at 1% fiber, while 15% silica fume increased the absorption higher than the ones without silica fume (6.71%, 8.15% and 8.92%) [2]. In the hybrid method, the pore volume was increased up to 17.5%, especially at higher date palm contents [3].

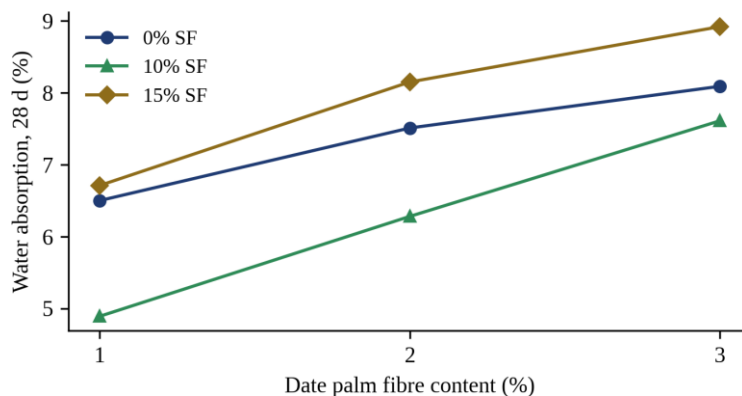


Figure 4. Water absorption at 28 days of date palm fibre concrete as a function of fibre content and silica fume (SF) replacement (data from [2]).

A dosage rate of 0.5% was found to cause a significantly higher reduction in the compressive strength (−14.5% compared with −5.33%) and a higher enhancement in water absorption (11% compared with 5.06%) by the date palm fibres than by polypropylene, but with lower gains in tensile and flexural strengths [3]. On the other hand, the addition of the fibres in combination with slag or pozzolan resulted in the reduction of capillary water absorption by 25–43% [5]; therefore, their influence on transport properties depends on the matrix porosity. The curing conditions play a significant role as well: hot-dry curing increased [1].

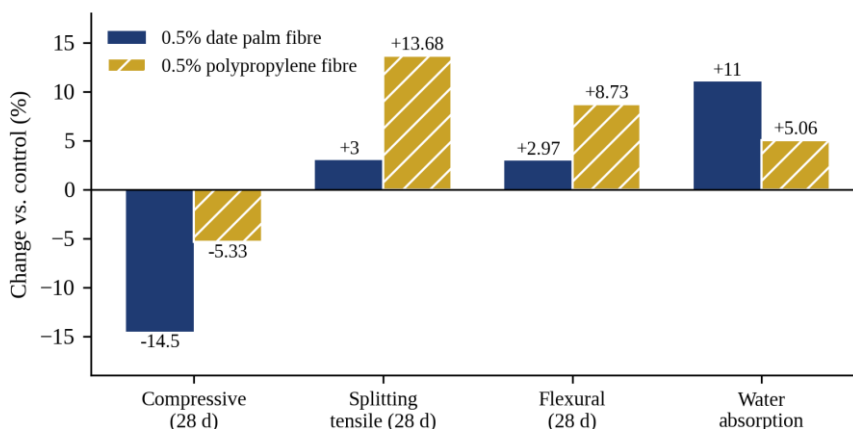


Figure 5. Change in 28-day mechanical properties and water absorption relative to the control for 0.5% date palm fibre and 0.5% polypropylene fibre (data from [3]).

Palm Ash and Limestone Powder as Partial Cement Replacement

Palm ash and limestone powder data have been summarized in Table 4 and Figure 6. Date palm seed ash burnt at 630 °C for eight hours and sieved to 75 µm was composed of 45.50% SiO₂, 20.75% Al₂O₃ and 7.25% Fe₂O₃. In the series of replacements of 0, 2.5, 5, 7.5, 10, 15 and 20%, the optimum case was 10%, where the 56-day compressive strength was 31.5 N/mm² compared to 31 N/mm² for the control, and the highest replacement level had 11% lower water absorption than the control [10]. Date palm frond ash from Awjilah in central Libya, as 10, 20 and 30% of cement weight substitution in mortar (water-to-cement ratio 0.50), decreased the flow by 4.5%, 7.7% and 16.6% compared to the control, while decreasing wet density and increasing air content [11]. Its 3-day compressive strengths were 20.0 MPa (control), 24.9, 22.3 and 11.1 MPa; 28-day strengths of 39.0 MPa for the 10% mix which was 31.3%, 28.7% and 93.1% more than the control, 20% and 30% mixes, while at 90 days it reached 43.0 MPa, 20.8%, 3.9% and 138.9% more, respectively. The flexural strength at 28 days was 4.6%, 3.7% and 1.5% less than the control value at 10, 20 and 30% [11], respectively. Leachability studies revealed that no elements exceeded the prescribed limits in the case of 10% and 100% replacement of cement by date palm ash, and the high concentration of aluminium and iron was leachability resistant. [12].

For the limestone group, Portland-limestone cement concretes containing 10% limestone powder were comparable with ordinary cement concretes in terms of compressive strength after 28, 90 and 180 days and poorer performance seemed to prevail for values above that proportion [7]. Concrete mixes with 10, 20 and 30% limestone powder were found to exhibit larger connected porosity, lesser late-age gain for five years and, beyond 10% content, inferior carbonation resistance even though drying shrinkage became reduced [8]. With 30% basaltic ash combined with 15% limestone powder, the values of 28 day and one-year compressive strengths were 39 MPa and 57 MPa, respectively [15]. In the basaltic ash and limestone powder studies, 10% replacement value emerged as the optimum or maximum value for four of the six datasets in Figure 6.

Table 4. Palm Ash and Limestone Powder as Partial Cement Replacement: Levels Tested and Principal Findings.

Additive [source]	Replacement tested	Principal finding
Date palm seed ash [10]	0, 2.5, 5, 7.5, 10, 15, 20%	Optimum 10%: 31.5 vs 31 N/mm ² at 56 d; highest replacement gave 11% less water absorption
Date palm fronds ash, Awjilah, Libya [11]	10, 20, 30% by weight (mortar)	10%: 39.0 MPa at 28 d (+31.3% vs control) and 43.0 MPa at 90 d; flow -4.5% to -16.6%; 28-d flexural -1.5% to -4.6%
Date palm ash [12]	10 and 100% (mortar)	No element above regulatory limits; low leachability of Al and Fe
Portland-limestone cement [7]	0, 5, 10, 15, 20%	Up to 10% competitive with plain cement concrete (28, 90, 180 d)
Limestone powder [8]	10, 20, 30% (equal 28-d strength)	Higher porosity, smaller late-age gains; carbonation resistance falls above 10%; lower drying shrinkage
Limestone powder + basaltic ash [15]	15% limestone + 30% ash	39 MPa (28 d) and 57 MPa (1 year); clinker factor 0.52

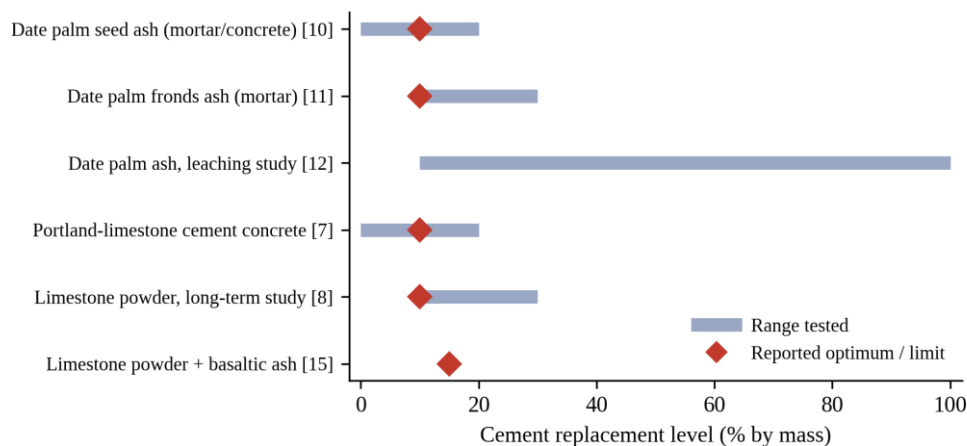


Figure 6. Cement replacement levels tested and the optimum or limiting level reported for palm ash and limestone powder (data from [7], [8], [10]–[12], [15]).

Integrated Performance Assessment

Table 5 presents the results obtained by assessing the impact of the different additives in the same way. Date palm fiber is the only additive that can make an improvement in flexural and tensile performance of the concrete mixture, however, with a certain penalty paid in terms of workability, compressive strength and water absorption; while the only other additive known to offset this penalty in the same experiment is silica fume, which is not palm or limestone derived [2]. Both palm ash and limestone powder are used to reduce clinker requirement and, in the case of palm ash, to give value to waste, although above about 10% their contribution becomes marginal due to increased porosity or lack of carbonation resistance or flow [8], [11].

Table 5. Integrated Performance Matrix of Natural Additives for Libyan Concrete, rated from the Direction of the Effects Reported in the Sources.

Additive (dosage)	Workability	Compressive strength	Flexural/tensile	Water absorption	Sustainability role
Date palm fibre (1–2%) [1]–[3]	Lower	Lower	Higher	Higher	Reuses palm waste
Date palm fibre + 10% silica fume [2]	Not reported	Partly recovered	Highest in series	Lower	Offsets fibre penalties
Date palm seed ash (10%) [10]	Not reported	Equal to control	Not reported	Lower at high level	Cement saving; waste reuse
Date palm frond ash, Libyan (10%) [11]	Lower flow (–4.5%)	Higher (+31.3% at 28 d)	Slightly lower (–4.6%)	Not reported	Cement saving; local waste reuse
Limestone powder (≤10%) [7], [8]	Not reported	Competitive	Not reported	Higher porosity at >10%	Lower clinker factor

Discussion

Libyan Baseline and the Importance of Quality Control

The variability in field strengths of Libya (COV 5.58% - 25.19%) is of the same magnitude or greater than the average effectiveness of many additives as listed in Table 3 and Figure 5, so that an additive can be considered effective only when applied in a controlled mix production process [6]. This 32% average over-strength indicates that there is already compensation for this variability through the use of additional cement; thus, a filler competitive up to 10% replacement becomes a method for reducing cement content without reducing the design margin [6], [7]. The reduction in absorption by 34.0% and crushing value by 22.3% of Al-Jufra aggregate in comparison to Sirte aggregate are of similar magnitude to those observed with additives discussed above. Thus, the mix design needs to be adjusted according to the source of aggregates. [9].

The results obtained from Benghazi have proved that local resources can comply with international standards with the use of statistical control [13], while the research on Libyan iron slag has proved that waste-based alternatives could be assessed using fresh, mechanical, and non-destructive tests [14]; similarly, palm waste and limestone could be tested as well.

Mechanisms Controlling Date Palm Fibre Behaviour

Low compressive strength with high flexural and post-cracking properties is seen in different research studies [1]–[3]. The fibres act as crack bridges and increase the toughness but are hydrophilic in nature, absorb water during mixing, and create voids, which is why there was a 14% decrease in the slump for 0.5% fibre and an increase in pore volume by up to 17.5% [3]. So the reduction in the compressive strength can be related to matrix strength and not to the fibre strength; it decreases with increasing dosage, as evident from a 16.6% decrease in the compressive strength between 1% and 3% fibre content [2] and a 44.78% decrease in the hybrid blend of 1% date palm and 0.5% polypropylene fibre [3].

Two solutions are recommended by the literature sources. First of all, it is fiber treatment: a three-hour boiling, soaking in 3% NaOH, and coating with linseed oil decreased the absorption kinetics of the fibers; three-hour boiling and NaOH increased the flexural and compressive strength of the composite, while linseed oil increased its workability but increased porosity [4]. Second, it is matrix densification: 5–10% silica fume enhanced the 28-day compressive strength by 4.3–16.7% and decreased water absorption up to 24.8% in fiber concrete, while 15% was negative, which is caused by a denser matrix and an improved fiber-matrix interface, compensating for the fiber deficiency only in some silica fume ranges [2]. Nevertheless, treatment is not without costs: NaOH-soaked fibers lost 24% of their tensile strength and 35% of their elongation, and fibers may be less durable because of calcium hydroxide released during hydration [19]. The hot-dry curing finding from [1] is especially pertinent to the case of Libya, in that concrete reinforced with fibres, when cured under hot-dry conditions, would have more voids and cracks develop as well as lose their first-crack strength over time, thus necessitating moist curing.

Palm Ash as a Cement Replacement

The evidence indicates that palm ash is a possible but limited replacement for cement. Date palm seed ash comprises of silica, alumina, and iron oxides in the amount of 73.5%, which falls within the limit of a pozzolan material, and its strength at 10% replacement is equivalent to that of the control at 56 days [10]. The study of palm frond ash is the only study among those analyzed that uses Libyan palm residue: the fronds used come from Awjilah, a country that has an estimated number of eight million date palms mostly located in the oases of Awjilah, Jalo and Al Jufrah [11]. However, its increase in strength when used at 10% replacement is higher (+31.3% after 28 days and +20.8% after 90 days compared to control) than that of date palm seed ash [10], even though both studies differ in terms of matrix (mortar versus concrete), type of ash used, and

w/c ratio. From the environmental aspect, all elements are below regulated limits, and aluminum and iron are the least mobile in the cement matrix. [12].

There are two limitations: Firstly, the ash was calcined under certain burning parameters (630°C for 8 hours in the seed ash case), so its characteristics are affected by the type of calcination and grain size [10]; and secondly, the flowability of the mortar based on frond ash decreased, thus water reducers could be required in high dosages [11]. This gap is smaller compared to the lack of information about Libya, as there is information about frond ash from Libya but only in mortar with unknown burning temperature [11]; seed ash from Libya and Libyan fibers have not been researched in concrete.

Limestone Powder as a Filler and Partial Replacement

The findings from the study using limestone agree on the fact that the benefit zone is either less than or equal to 10% replacement [7], [8]. In case the percentage of limestone is less than 10%, limestone will serve more as a filler material, while in case the percentage is greater than 10%, dilution of cement and poor reactivity of limestone cause increased connected porosity and low carbonation resistance [8]. The two factors that determine the service life of concrete in a tropical coastal environment are carbonation and chloride resistance.

Limestone mixed with pozzolan is an attractive option because 15% limestone with 30% basaltic ash yielded 57 MPa after one year with a clinker factor of 0.52 [15]; the possibility of palm ash serving as a pozzolan in a ternary blend is only an untested hypothesis. Libyan limestone has been examined as an aggregate for building materials, wherein Benghazi Formation dolomitic limestone (calcite and dolomite) was found to be acceptable [18], but there was no published work reviewed herein involving testing of Libyan limestone powder as a cement substitute. This is the only gap in the literature that has not been filled by existing research data, and will be addressed through the verification programme described in Section 5.5. The Libyan emission factor is 1,083.60 kg CO₂ per tonne of cement [16], thus, each 10% cement substitution with limestone will prevent the emission of up to 108 kg CO₂ per tonne of cement used, without considering the manufacturing of the additive.

Integrated Strategy and Practical Recommendations

It can be observed from the Integrated Performance Matrix (Table 5) that the natural additives are to be employed in two different tracks. Where the control of cracks, toughness, and flexural performance is considered important in structural or non-structural elements like slabs on grade, screeds, pavements, and precast elements, the date palm fibers in an amount of 1-2% should be used, preferably boiled or treated with NaOH along with silica fume or other equivalent pozzolan in the range of 5-10% [1], [2], [4]. While, where compressive strength and durability of the elements are considered important, palm ash or limestone powder in the amount of around 10% replacement of cement would help to save cement and utilize the local materials without compromising on strength [7], [10], [11].

The proposed guidelines are based on published information from different materials and under different conditions than those of Libya, and need to be considered as hypotheses for batching trials rather than design values because the dosages used are different between studies, the fiber series include only three data points, and there are references on mortars. The following step is the development of a mix program including Libyan aggregates, date palm waste material and limestone in the same mixture program under local curing and exposure conditions. The minimum mixture program for the open hole would be casting mixtures with Libyan limestone powder at 0%, 5%, 10% and 15% cement replacement with constant binder content and testing slump, 7-day, 28-day and 90-day compressive strength, water absorption, carbonation depth and chloride penetration based on the design program of [7].

Conclusion

This paper proves that palm waste and limestone, locally available, may be used as natural additives for certain desirable characteristics of Libyan concrete and defines the range of dosages of each additive based on the relevant scientific literature. In the course of a comparison of 19 scientific papers and publications, a correlation was found among additive, dosage, and property, whereby date palm fibers enhanced the flexural resistance but decreased workability, compressive strength, and water absorption, while palm ash and limestone were moderate replacements for cement up to 10% and silica fume helped counter the effect of fibers in the range of 5-10%.

Quantitatively, the most consistent findings included 16.6% reduction in compressive strength and 11.4% increase in flexural strength for increased fibre content from 1% to 3%; 4.3% -16.7% recovery of compressive strength and 24.8% reduction in water absorption with 5%-10% of silica fume; 10% ash substitution with 31.5 N/mm² as compared to 31 N/mm² control at 56 days in concrete, and a 31.3% increment at 28 days in mortar with Libyan frond ash; and considerable reduction in carbonation resistance beyond 10% of limestone replacement. From these findings, the conclusion can be drawn that palm waste and local limestone can serve as sustainable and readily available additive materials within the context of low-carbon construction in Libya. Future work will include: (1) mixes using Libyan aggregates with Libyan palm fibre and ash; (2) Libyan limestone powder with 5%, 10 and 15% replacement, including carbonation and chloride resistance; (3) hot dry curing of fibre concrete mixes; and (4) limestone-palm-ash ternary system.

Conflict of interest. Nil

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