Characterization of a Bio-Composite Material (Natural Hydraulic Lime/Date Palm Leaflet) for Architectural Restoration

Mohamed Aymen Kethiri[1,2*], and *Cristina* Tedeschi[2]

[1]LGEM, University Mohamed Khider of Biskra, Biskra, Algeria.
[2]DICA, Portugal Politecnico di Milano, Leonardo da Vinci campus, Milan, Italy.

Abstract. This scientific investigation aims to characterize the physical and mechanical properties of a new biomaterial designed for architectural restoration. The biomaterial studied is a composite of natural hydraulic lime (NHL) and date palm fibre. The study reports the first experimental characterization of these restorative materials. A series of mortar compositions were prepared with different particle size (0.5, 1, and 1.5 mm). The results showed that the mortars containing DPL exhibited significant changes in their properties due to variations in particle size. Increased DPLP led to lower density but whereas mechanical strength. This research provides valuable insights into the use of sustainable and renewable building materials, highlighting the benefits of exploiting agricultural waste in the constructional sector. The findings lay the groundwork for future research and innovation in environmentally friendly construction technologies.

1 Introduction

Drawing upon an extensive review of existing literature, this study stands as a groundbreaking exploration into the bio-composite material made of Natural Hydraulic Lime (NHL) and Date Palm Fiber (DPF), specifically developed for construction applications. This research marks the first experimental characterisation of this novel bio-composite. Date palm is an abundant solid waste in the agricultural sector, particularly in the Middle East and North Africa (MENA) region. DPF are a promising sustainable material for construction applications. DPF have been studied for their potential use in construction materials [1].

Several studies have investigated the use of NHL and other additives in composites for the restoration and preservation of historical and architectural heritage. Maravelaki-Kalaitzaki et al. [2] evaluated the performance of NHL-based mortars and plasters prepared with siliceous sand and crushed brick aggregates. Barbero-Barrera and Flores Medina [3] studied the effect of polypropylene fibers on graphite-NHL pastes, finding that they improved the ductility and toughness of the composite. Vailati et al. [4] defined the mechanical behaviour of a new NHL-based composite material for the preservation and enhancement of

* Corresponding author: aymen.kethiri@univ-biskra.dz / mohamedaymen.kethiri@polimi.it

These proceedings are published with the support of EuLA.

historical and architectural heritage. Gunes et al. [5] studied the durability of NHL-based textile reinforced mortar (TRM) composites through hot water immersion and proposed a rapid and decisive procedure for the design of TRM composites. Angiolilli et al. [6] highlighted the wide use of fibre reinforced mortar (FRM) for the consolidation and rehabilitation of masonry structures due to its reversibility and applicability. Al-Lami et al. [7] studied the effect of wet-dry cycles on the bond behaviour of fibre-reinforced inorganic-matrix systems bonded to masonry substrates. Dimou et al. [8] examined five different cases of binary lime-based pastes composed of a specific type of NHL (NHL5) and metakaolin as pozzolanic addition, reinforced with carbon nanostructures, namely graphene and carbon nanotubes. Demircan et al. [9] studied a high temperature resistant restoration mortar with fly ash and ground granulated blast furnace slag (GGBS), replacing NHL as a binder in mortars with 15, 30, and 60% fly ash and GGBS. The characterization of NHL reinforced by DPF is important for several reasons. Firstly, DPF is an easily processed, low-cost, and accessible natural fibre that has been used in composites for non-structural applications. However, when DPF is used in cementitious composites for structural applications, it Adamu et al. [10] can have a harmful effect on compressive strength and increase porosity [11], [12]. Therefore, studying the characterization of NHL reinforced by DPF can help in devising ways to reduce these negative effects and improve the mechanical properties of the composite [12], [13].

In this work, an experimental study was conducted to assess the impact of the addition of date palm leaflet (DPL) on the physical and mechanical properties of NHL. A series of mortar compositions were prepared with different particle size (0.5, 1, and 1.5 mm). The aim of this study was to exploit and valorise date palm waste as a renewable, biodegradable material available in the MENA region. Furthermore, it highlights an innovative approach on the application of additives derived from recycled plant waste to produce lightweight composite materials. By developing lighter construction materials with improved properties, the environmental burden of organic waste will be reduced, as well as the demand of raw materials for construction and restauration purposes.

2 Materials and Methods

2.1 Raw materials

2.1.1 Date palm leaflet

The date palm component investigated in this study was obtained from leaves, particularly leaflets. The raw material utilized in this study will be processed in accordance with the procedure employed by Kethiri et al. [14]. DPLs were firstly immersed in a tank of water to be cleaned and were afterwards subjected to drying at a temperature of 40 °C for 24 h in an oven to be sure that the powder used for test and analysis is totally sec. This treatment ensures that the material is as dry and free of impurities as possible, as they can affect the results.

Table 1. The proprieties of DPL.

	Bulk density (Kg/m3)	**Absolute density (Kg/m3)**	**Porosity (%)**	**References**
DPL	494.782 ± 9	872,457 ± 21	43 ± 9	[15]

Fig. 1. Date palm leaflet.

2.1.2 Granulometry

A series of tests were conducted to determine the particle size distribution of the leaflets, while the results were an average of fourth measurements. The particle size distribution was determined by the sieving method according to the French standard 18-560 [16], as shown in Figure 2. The particle size distribution ranged from 0.125 mm and 1.5 mm, whereas the proportion of DPL particles of 0.25 mm was less than 40%. On the other hand, the proportion of particles between 0.5 and 1 mm was more between (85 - 90%). The diameters of 0.25, 0.5, and 1 mm represented the dominant part of the date palm powder.

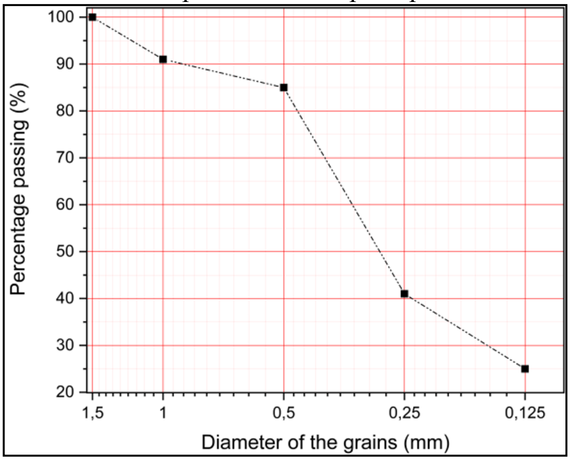

Fig. 2. DPL size distribution.

2.1.3 Natural Hydraulic Lime

Natural Hydraulic Lime (NHL) is a type of lime that is derived from limestone containing natural impurities of clay and other minerals. NHL comes in several different grades. NHL 3,5 is a material compliant with the EN 459-1: 2010 standard [17]. The NHL used in this study is from Chaux Saint-Astier company.

2.1.4 Aggregate

The characteristic of CEN Standard Sand is its specific grain size distribution. The maximum moisture content is 0.2%. The sand is portioned in bags of 1,350 (± 5) g. According to EN 196-1 [18] mortar prisms for compressive strength testing are produced with a mixture of 450 (± 2) g cement, 225 (± 1) g water and one bag of 1,350 (± 5) g CEN Standard Sand.

2.2 Experimental Methodology

2.2.1 Preparation of Specimens

The dimensions of the DPL in the lime varied from 0.25, 0.5, and 1 mm [19], [20]. The DPL proportion was 0.7 (wt.% of NHL) for each particle size fraction; the addition of the DPL is to replace the NHL. Table 2 summarizes the designation used for each composition. The preparation of the mortars followed ASTM C1396/C1396M-17 [21]. Firstly, the NHL and DPL were mixed manually in a container and then the water was added for a total mixing period of 5 min (mixing of 3 min, allowed to rest for 30 sec, and then mixed again for 1–2 min). Afterwards it was poured into the molds (4 × 4 × 16 cm) and compaction was made by using a vibrating table for 20 to 30 s. Specimens were stored under normal climatic conditions: T = 20 ± 2 °C, and RH = 65 ± 5% for 28 days.

Table 2. Mortar compositions and names.

NHL mortar			Date palm fibre		Samples names
Water (g)	Aggregate (g)	NHL (g)	Concentration (%)^{Y}	Size (mm)^{X}	
243	1350	450	-	-	T
		446,85	0.7	0.25	M_DP_0.7_0.25
				0.5	M_DP_0.7_0.5
				1	M_DP_0.7_1

M_DP_Y_X, M: Mortar, DP: Date Palm, Y: concentration (0.7 wt%), X: dimension (0.25, 0.5, 1 mm).

2.2.2 Testing procedure

Density: The density test was conducted on all the specimens, with each one being evaluated three times. The average was then taken in each case during the calculation. The apparent density can be determined by using the following relation, according to ASTM C29/C29M [22]:

$$\rho = m/v \tag{1}$$

Mechanical Characterization: Mechanical strength was tested following ASTM standards. For flexural strength testing (three-point) D790 [23] was applied and for compression C109/C109M-20 [24]. To this direction, a METRO COM traction machine with a capacity of 50 KN and a speed charge of 1 mm/min was employed. Three specimens of each composition were evaluated at the age of 7, 14, and 28 days.

3 Results and discussion

3.1 Density

In the constructional sector, the utilization of lightweight materials is highly embraced due to their economic advantages [25], due their potential to uphold stability, stiffness, and

 https://doi.org/10.1051/matecconf/202440307004

durability [26], [27]. The density of the examined M_DP composites was determined utilizing the five-weighing method. The margin of error in the calculations was below 2%. Figure 3 depicts the variations in apparent densities of the M_DP material about varied sizes.

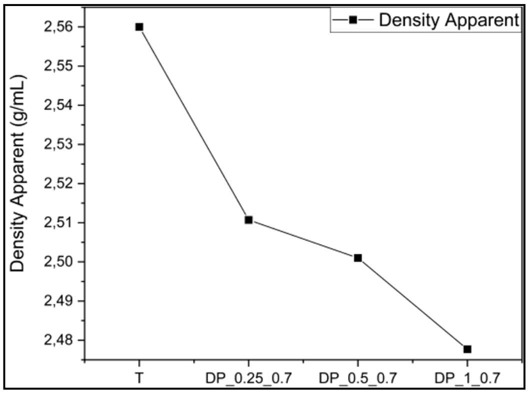

Fig. 2. The density of the specimens.

3.2 Mechanical Proprieties

The addition of DPLP into the compositions significantly impacts its mechanical behaviour, particularly in terms of flexural and compressive.

3.2.1 Flexural Strength

Figure 3 shows the flexural strength of all specimens. The results obtained reveal that the bending strength decreases as the dimensions of the DPL increase [28], [29]. A reduction in flexural strength was observed upon inclusion of M_DP. The latter variation depends on the particle size of DPL (decreases with the increase in dimension).

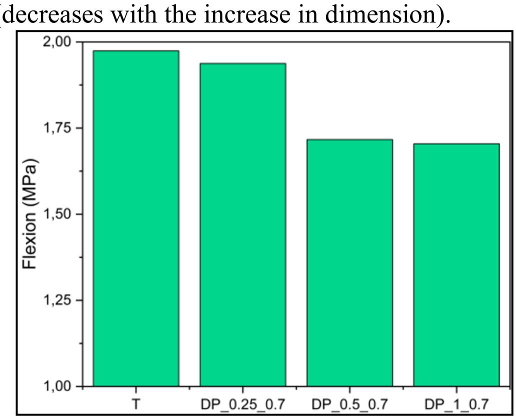

Fig. 3. The density of the specimens.

3.2.2 Compressive Strength

Figure 4 shows the compressive strength for all compositions, which decreased, while the DPL dimension increased [30], [31]. A drop was shown when adding the DPL. The latter variation depends on the particle size of DPL (decreases with the increase in dimension).

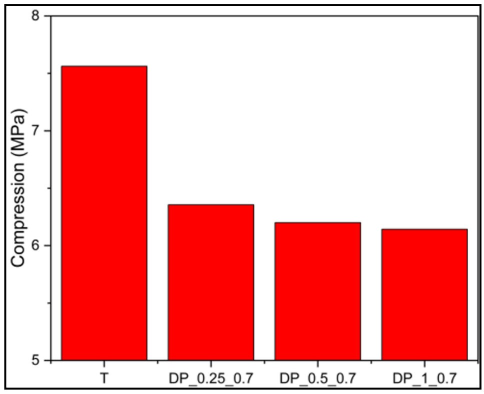

Fig. 4. The density of the specimens.

4 Conclusion

This study focused on characterization of a bio-composite material based on date palm fibre and the naturel hydraulic lime for architectural restoration. The addition of DPL modifies the mortar matrix, creating lightness. The main conclusions deriving from this study are as follows:

The addition of DPL allows the mortar to lose its density which directly implies a lightweight material favoured in the field of restoration.

The addition of DPL allows the mortar to negatively influence the mechanical resistance (flexion and compression); In the field of restoration or restoration materials, mechanical resistance is not an important parameter.

According to the experimental results, porosity was the parameter that mostly influenced the physical, mechanical, and thermal properties of the tested mortars. DPLP addition may modify the porosity of the gypsum mortars, according to its proportion and particle size. An increase in porosity imparts a degree of lightness to the material, favourable for specific applications (i.e., renders and plasters). To this extend, DPLP can be used for producing sustainable mortars with elaborated properties, following the diachronic constructional principles of the MENA region.

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