**Influence of the diameter on the mechanical property of agave fibre and their concentration on the thermomechanical properties of the Gypsum/Agave biocomposite**

**R. Bentahar[1*], N. Belghar[2], L. Aissani[2], S. Derfouf[3], M. Lachi[4], K.Chadi[5], C. Tedeschi[6],**

[1] LGEM laboratory, Mohamed Khider of Biskra University, BP 145 RP, 07000 Biskra, Algeria.

[2] Abbas Laghrour University of Khenchela, Algeria.

[3] University of Batna, Algeria.

[4] University of Reims Champagne-Ardenne Faculty of Exact and Natural Sciences Moulin de la Housse Campus - BP 1039 51687 Reims Cedex 2 – France.

[5] Research Center in Industrial Technologies CRTI, Algiers.

[6] Laboratory for Diagnostic and Investigation on Built Heritage Materials, Dept. Of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 MILANO, Italy.



**Abstract**

A study on agave fibres (AFs) shows a strong correlation between fibre diameter and the mechanical behavior of gypsum/agave biocomposites (GAB). The finest fibres (0.03 mm) demonstrate very high tensile strength (2853.03 MPa) and a significant elastic modulus (225.83 GPa), giving the composite excellent stiffness but also increased brittleness. When mixed into a gypsum matrix, AFs generally improve the material's performance. However, under compression, adding fibres reduces strength (from 7.96 MPa to 1.69 MPa at 3 wt%) due to increased porosity and weak bonding between fibre and matrix. Using a moderate fibre content (1 wt%) enhances ductility and flexural strength (3.35 MPa) while also increasing flexibility (flexural strain of $3.98 \times 10^{-2}$ %) without harming cohesion. On the other hand, fibre contents of 2 wt% or more reduce stiffness (down to 168.48 MPa at 3 wt%) because of weaker adhesion and higher porosity, which leads to structural weakness. Thermal conductivity also varies with fibre content. Adding 1 wt% slightly raises it (0.4445 W/m•K), while 3 wt% significantly lowers it (0.3075 W/m•K), improving insulation through better fibre dispersion and porosity control. Overall, AFs present strong potential for sustainable bio-composites, offering a promising balance between mechanical strength and thermal performance.

**Keywords**: Agave fibres; Gypsum; Bio-composites; Compression; Bending; Thermal conductivity; Thermomechanical properties.

## 1. Introduction

Bio-composites offer a sustainable alternative to traditional materials due to their reduced environmental impact. The use of natural fibres as reinforcement helps decrease dependency on synthetic fibres, such as carbon and glass, which have a substantial ecological footprint. Nonetheless, their industrial use raises health concerns, as machining processes release fine particles that may lead to skin irritation and respiratory illnesses such as pulmonary fibrosis [1].

These materials are valued not only for their mechanical and environmental advantages but also for their biodegradability and recyclability. Biodegradation, facilitated by microorganisms, contributes to reducing plastic waste. However, its effectiveness varies depending on the matrix type and environmental factors. The recyclability of bio-composites involves strategies like mechanical reuse and chemical recovery, but synthetic resins often hinder full biodegradability. For improved sustainability, research is focusing on fully bio-based matrices and optimized recycling methods [2].

Economically, bio-composites promote the valorisation of agricultural residues, enabling local producers to transform plant waste into valuable products. Industrially, plant fibres are increasingly used in the automotive, aerospace, packaging, and textile sectors as alternatives to synthetic materials [3].

In construction, bio-composites are used in insulating panels, ecological bricks, and fibre-reinforced plasters. Typically integrated with lime, plaster, or cement matrices, these materials enhance mechanical performance, reduce weight, and improve thermal and acoustic insulation—thus contributing to energy-efficient, low-carbon buildings [4]. Of particular interest are gypsum-based bio-composites. Gypsum is widely recognized for its mechanical and thermal performance. The inclusion of natural fibres improves its flexibility and resistance to impact. The effectiveness of these composites depends on the interaction between fibres and the mineral matrix. Benzannache et al., for example, used Response Surface Methodology (RSM) to optimize the mechanical properties of Washingtonian gypsum/filifera biocomposites, achieving optimal results with 20% $NaHCO_3$ and 168 hours of treatment [5]. Similarly, Benchouia et al. demonstrated that a hybrid composite of date palm petiole fibres, expanded polystyrene, and gypsum serves effectively as a thermal insulator [6].

This study focuses on Agave americana fibres (see **Error! Reference source not found.**), which are known for their lightweight nature, strength, and durability. Sakuri used AFs in prosthetic socket materials, applying various alkaline and microcrystalline cellulose treatments [7]. Several studies have linked fibre diameter with properties such as tensile strength, elasticity, and elongation at break. Bryan Feigel showed that smaller fibre diameters often correlate with a higher strength but lower strain tolerance due to variations in cross-sectional area [8]. Sasa Sofyan Munawar et al. analyzed various non-woody plant fibres ramie, pineapple, sansevieria, kenaf, abaca, sisal, and coconut finding that, except for coconut, most had non-circular cross-sections [9]. Larger diameters were associated with reduced fibre density and mechanical performance. El Oudiani et al., using Fourier Transform Infrared (FTIR) spectroscopy, found AFs to be rich in cellulose, hemicellulose, and lignin components that grant them high tensile strength [10].

Studies have also assessed AFs in mineral matrices, especially their effect on mechanical and thermal properties when combined with concrete or other fibres. One study on agave-coconut-concrete composites analyzed compressive, tensile, and flexural strengths. Similarly, Benmansour highlighted the potential of date palm mortar/fibre composites for structural elements, showing good thermal conductivity and compressive strength at low fibre contents [11].

Cellulose-fibre-reinforced gypsum has been widely studied for improving the structural and thermal properties of building materials. Adding AFs to plaster reduces cracking, enhances flexibility, and improves resistance to both mechanical stress and environmental conditions. It also boosts the material's ability to regulate humidity, contributing to better indoor hygrothermal comfort. Jan Fort et al. studied plasters modified with SAPs (Superabsorbent Polymers) and cellulose fibres, calculating the moisture buffer value to assess their effectiveness in controlling humidity [12]. Complementary research by Lokmane Saad Azzem showed that wheat straw in construction materials improved reaction time and significantly lowered thermal conductivity, enhancing building energy performance [13].

Collectively, existing studies confirm the value of AFs in biocomposite applications, especially when paired with gypsum matrices. Yet, challenges remain, particularly in optimizing fibre-to-matrix ratios and improving adhesion at the interface. Continued exploration of fibre treatments and pore distribution strategies within the matrix could lead to more efficient, sustainable composites suited for structural and thermal use.

## 2. Materials and methods

Agave leaves used in this study were collected from Mount Sidi Raghis in Oum El Bouaghi Province, eastern Algeria. The fibres were mechanically extracted, a method that enables efficient processing and high fibre yield. After harvesting, the green outer layer of the leaves was manually peeled using a knife, followed by mechanical scraping to eliminate most of the lignin and hemicellulose. The extracted fibres were then soaked in water for 72 hours to reduce residual non-cellulosic components further.

The AF exhibits noticeable variation in diameter along its length, which influences its mechanical behavior. For tensile testing, the isolated elementary fibres were carefully mounted on paper window frames and secured with adhesive at both ends (**Error! Reference source not found.**) to maintain alignment and prevent premature failure during handling. Mechanical characterization was then conducted using an INSTRON 5969 universal testing machine equipped with a 50 kN load cell and a crosshead speed of 2 mm/min, ensuring precise evaluation of the fibres' tensile properties.

FTIR spectroscopy, a non-destructive technique especially in its Attenuated Total Reflectance (ATR) and Near Infrared (NIR) forms was used to analyze the fibre composition and detect structural changes. Using the potassium bromide (KBr) pellet method, 2 mg of dried AF was ground and mixed with 100 mg of KBr. The mixture was pressed into 1 mm-thick tablets under 8 bar pressure. Six scans were conducted per sample using an Avatar 330 spectrometer at a resolution of 4 $cm^{-1}$. The spectra, representing the average of ten scans, were recorded in the range of 4000–400 $cm^{-1}$, focusing on four distinct spectral regions.

To prepare the GAB, AFs were used as reinforcement and gypsum as the matrix. Although gypsum has been traditionally used as a water-based paste for coating applications, it has evolved into a versatile material incorporated into prefabricated elements like tiles, slabs, and panels. Gypsum is obtained by the dehydration of a natural rock or industrial by-product, forming calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$).

The gypsum used in this study was Manhargypes, produced by COLPA (Cosider, Lafarge Plâtres Algérie) from the El-Adjiba plant in Bouira, packaged in 40 kg bags for ease of handling. To determine the effect of fibre incorporation, the properties of pure gypsum were first evaluated using a fixed water-to-plaster (W/P) ratio of 0.75. Three fibre content levels were used for the composites: 1 wt.%, 2 wt.%, and 3 wt.%. Fibre weight was calculated using a density range of $\rho_f$ = 1.064–1.335 g/cm³ [14].

The mixing process was carried out at room temperature, with gypsum gradually added to water and stirred for two minutes. Initially, chopped AFs (8–10 mm) were placed to form the first layer inside the mold, after which the remaining gypsum mixture was poured to fill it completely. The mold, specifically designed with two chambers to produce identical prismatic specimens, featured walls at least 10 mm thick and was supported by a rigid casing to maintain its shape. After pouring, the samples were left to set until the gypsum hardened. Following 30 minutes, the specimens were demoulded and allowed to dry under the same conditions for 28 days. The final specimens measured 4 × 4 × 16 cm (see **Error! Reference source not found.**).

Compression and flexural tests were performed to evaluate the mechanical behavior of the biocomposites, particularly stress, strain strain, and elastic modulus. The same equipment and test conditions mentioned during the tensile testing of the AFs were utilized. Each composition was tested in duplicate, and average values were calculated. Tests were conducted at a displacement rate of 0.25 mm/min using parallel piston plates.

Thermal conductivity was measured using the hot-wire method, which monitors the material's response to heat impulses. Heat is generated by electrically heating a resistor embedded in a probe in thermal contact with the sample. Thermal conductivity is then calculated based on the recorded temperature changes. Sample surfaces were polished to ensure optimal thermal contact. The thermal tests were conducted on gypsum–agave biocomposites of dimensions 4 × 4 × 2 cm, containing 1 wt.%, 2 wt.%, or 3 wt.% of AFs.

## 3. Results and discussion

### 3.1. Mechanical behavior of a single fibre

As illustrated in **Error! Reference source not found.**, the results obtained from the tensile experiment for seven AFs elements are presented. The results obtained are stress at rupture, strain strain at rupture, and modulus of elasticity.

Several studies have explored the mechanical behavior of plant fibres, revealing a characteristic three-phase tensile response. This pattern has been observed in hemp and flax fibres, as well as in elementary wood fibres. The stress-strain behavior is typically non-linear, prompting multiple hypotheses to explain this phenomenon under quasi-static tensile loading. For instance, Amroune et al. linked it to cell wall buckling [15], while Placet et al. attributed it to the reorientation of microfibrils and the viscoelastic nature of the cell wall's amorphous regions [16].

AFs display a similar three-phase tensile behavior, as demonstrated by Msahli et al. The initial phase corresponds to linear elastic deformation under minor strains. This is followed by a second phase where large deformations occur with minimal stress increase, indicating a progressive loss of stiffness. The third phase is characterized by plastic deformation and a steep rise in stress, ultimately leading to fibre rupture [17].

As illustrated in **Error! Reference source not found.**, the stress-strain curve of a single AF clearly shows three distinct regions separated by two inflection points. The first marks the onset of modulus reduction, while the second precedes a sharp increase in stiffness. Mechanically, Phase I involves elastic deformation where all fibre components contribute to stiffness. In Phase II, a drop in stiffness and onset of irreversible deformation are observed, likely caused by stick-slip interactions within the fibre's internal structure. Phase III shows a progressive stiffening, explained by amorphous cellulose crystallization induced by shear stress at the matrix–microfibril interface, along with microfibril realignment in the fibre direction.

These observations underscore the complex nature of fibre deformation mechanisms and the significance of microstructural evolution during mechanical loading.

A comprehensive analysis of the experimental data reveals a strong inverse correlation between the diameter of AFs and their mechanical properties (**Error! Reference source not found.**). Three main parameters were evaluated: maximum stress at break (σmax), modulus of elasticity (E), and elongation at break (εmax). The results show that thinner fibres, around 0.03 mm in diameter, demonstrated the highest tensile strength, reaching 2853.03 MPa. In contrast, thicker fibres (0.10–0.12 mm) exhibited significantly lower tensile strengths, ranging from 76.75 MPa to 510.25 MPa. This trend is mainly attributed to the fibre's microstructure—thin fibres tend to have fewer defects and better-aligned cellulose microfibrils, which improve tensile strength. Conversely, thicker fibres often contain voids and impurities that weaken mechanical integrity. These observations are consistent with prior findings on flax fibres [18]. The same inverse relationship applies to stiffness: thin AFs reached up to 225.83 GPa in elastic modulus, while thicker ones recorded much lower values between 12.51 and 12.63 GPa, aligning with conclusions from earlier studies [18]. Interestingly, the elongation at break behaves oppositely. Thicker fibres exhibited higher ductility, with elongation reaching 18.4%, whereas thinner fibres fractured at only 2.6%, reflecting a more brittle nature. Satyanarayana et al. reported results consistent with this known stiffness-ductility trade-off characteristic of natural fibres [19]. Overall, fibre diameter critically influences mechanical behavior: thin fibres are better suited for high-strength, rigid applications, while thicker fibres are preferable for uses requiring flexibility and energy absorption.

### 3.2. Variability and dispersion of mechanical properties

During the investigation of AF, a notable dispersion in mechanical properties was observed (**Error! Reference source not found.**), primarily due to both intrinsic and extrinsic factors. These include variations in biochemical composition, morphological differences, environmental growth conditions, and the presence of dislocation zones on fibre surfaces. The fibre extraction process and testing techniques also significantly influence this variability.

The non-uniform distribution of fibre constituents across layers further contributes to these discrepancies. Placet et al. addressed this by proposing a model that separately homogenizes hemicellulose and lignin and crystalline versus amorphous cellulose to represent each sublayer's mechanical behavior [16]. According to Buroni, the anisotropic behavior of materials is primarily due to the orientation of components like cellulose and hemicellulose [20]. Aslan et al. emphasized that much of the variability arises from the material's intrinsic heterogeneity. Structural irregularities known as "dislocation zones" or "knees" play a significant role in weakening tensile strength and contribute to mechanical result dispersion [21]. Fanti, through optical and SEM imaging, confirmed the presence of these discontinuities and impurities in flax fibres [22]. The extraction method is equally critical; mechanical processes such as decortication can damage fibres, reducing strength and modulus [23]. Additionally, fibre variety, lumen presence, and plant growth conditions affect performance. Furthermore, scutching and combing may introduce defects that compromise the fibrillar structure, diminishing mechanical integrity [24].

### 3.3. Statistical analysis of the mechanical properties of AFs

As shown in **Error! Reference source not found.**, AFs exhibit significant mechanical variability during tensile testing. Young's modulus (**Error! Reference source not found.**-a ) shows an inverse relationship with fibre diameter, expressed by the linear equation $y = -1554x + 178.9(R^2 = 0.575)$, indicating moderate correlation but also suggesting the influence of additional factors like structural defects. Similarly, maximum stress ($\sigma_{max}$) (**Error! Reference source not found.**-b) decreases with increasing diameter, modeled by $y = -1554x + 178.9(R^2 = 0.575)$, highlighting the impact of defects and moisture content. In contrast, maximum strain ($\varepsilon_{max}$) (**Error! Reference source not found.**-c) shows a much weaker correlation, with $y = 75.57x + 3.279(R^2 = 0.211)$, implying that strain behavior is influenced more by internal fibre structure and elongation capacity than by diameter alone. These findings confirm a strong variability in mechanical behavior, with moderate inverse correlations for stiffness and strength, while strain remains poorly explained by diameter alone (see Section 3.1).

The mechanical properties of AFs show marked variability, as illustrated in **Error! Reference source not found.** and **Error! Reference source not found.**. Tensile strength ($\sigma_{max}$) ranges from 76.75 to 2853.03 MPa (*CoV* = 0.82), while the elastic modulus (*E*) varies from 12.51 to 225.3 GPa (*CoV* = 1.05), reflecting the influence of diameter, structure, and processing. Maximum strain strain ($\varepsilon_{max}$) spans 2% to 18.4% (*CoV* = 0.63), highlighting differences in brittleness and flexibility. Such dispersion aligns with prior studies on natural fibres [18], underscoring the need for careful fibre selection and preparation to ensure consistent performance in biocomposite applications.

### 3.4. FTIR spectroscopic analysis

The FTIR spectroscopic analysis of AFs (**Error! Reference source not found.**) reveals functional groups typical of plant biomass components, including cellulose, hemicellulose, and lignin.

According to El Oudiani's study, FTIR analysis yielded satisfactory results confirming the chemical composition of AFs [10]. The broadband between 3600 and 3100 cm⁻¹ corresponds to O-H stretching from hydrogen bonds in cellulose, indicating hydroxyl groups in polysaccharides. Peaks between 2950 and 2854 cm$^{-1}$ relate to the C-H stretching of methyl ($CH_3$) and methylene ($CH_2$) groups in cellulose and hemicellulose. The region from 1740 to 1600 cm$^{-1}$ is attributed to C=O stretching in acetyl groups of hemicellulose. The 1440 cm$^{-1}$ band indicates symmetrical $CH_2$ stretching in polysaccharide chains, while the 1291 cm$^{-1}$ peak corresponds to C-O deformation in acetyl xylan groups, characteristic of lignin. The strong peak at 1022 cm$^{-1}$ is associated with C-O and O-H stretching vibrations from cell wall polysaccharides. The 568 cm$^{-1}$ band, linked to C-OH bond deformation, confirms cellulose presence. These results reinforce the dominance of cellulose in AFs, along with hemicellulose and lignin, all of which influence their mechanical and structural behavior.

### 3.5. GAB compression test analyze

Compression resistance is a key property of building materials. **Error! Reference source not found.** illustrates the variation in the compressive mechanical properties of the GAB based on fibre content. The results of the compression tests, including compression under stress, modulus, and strain strain at the break, are shown in Table 3. The stress compression is determined using the following equation:

$$\sigma_c = E_c.\varepsilon_c \quad (1)$$

Where $\sigma_c$ stress compression ; $E_c$ : elastic module ; $\varepsilon_c$ : strain strain compression

An analysis of the outcomes of the compression test on biocomposites based on AFs underscores the substantial impact of fibre concentration on their mechanical properties (**Error! Reference source not found.**).

It is evident from the findings that compressive strength undergoes a decline with an increase in fibre content. For instance, pure gypsum exhibits stress at a break of 7.96 MPa, which diminishes to 6.13 MPa for 1 wt. % of fibres and further reduces to 2.34 MPa at 2 wt. %. This decline can be attributed to an increase in porosity induced by the incorporation of fibres, resulting in reduced compactness of the matrix and diminished load-bearing capacity [25]. Notwithstanding the decline in compressive strength, an augmentation in the strain at break is observed, ranging from 2.19 10-2 % for pure gypsum to 3.98 10-2 % with 1 wt.% fibre and maintaining a relatively high level of 3.46 10-2 % for 2 wt.%. This evolution reflects a more ductile and less brittle material, which may be advantageous for certain applications requiring better shock absorption. Furthermore, Young's modulus also demonstrates a similar trend: pure gypsum exhibits a high stiffness of 522.60 MPa, which gradually decreases with the addition of fibres (334.61 MPa at 1 wt. % and 146.21 MPa at 2 wt. %), indicating a softening of the material. These outcomes align with the findings of Malmgren L., who observed a decrease in stiffness and an enhancement in ductility with the incorporation of natural fibres within mineral matrices [26]. Consequently, while a low fibre content (1 wt.%) enables the maintenance of adequate mechanical strength whilst enhancing ductility, an excessively high concentration (≥2 wt.%) results in a substantial decline in mechanical performance, rendering the material less conducive to high compressive loads.

### 3.6. GAB three-point bending test

The bending test results of the GAB are clearly summarised and listed in **Error! Reference source not found.**. An analysis of the bending test results for the AF biocomposite reveals that the fibre concentration exerts a significant influence on the material's mechanical properties, including bending stress, strain strain, and Young's modulus ( see **Error! Reference source not found.**). Flexural stress reaches a maximum of 3.36 MPa at 1wt% fibre, exceeding the value for the material without fibre (2.90 MPa), indicating that the addition of a small proportion of fibre improves mechanical flexural strength. However, at 2 wt%, the stress undergoes a sharp decline to 1.08 MPa, indicative of deterioration likely attributable to inadequate fibre dispersion and elevated porosity of the composite, as observed by Kuqo and Mai in their analogous studies of wood fibre-reinforced plaster [25]. Conversely, at 3 wt%, the stress increases to 2.62 MPa, indicative of a partial recovery of mechanical strength, which may be attributed to enhanced fibre distribution and a reduction in internal defects. Additionally, the flexural strain exhibited an increase with the incorporation of fibres, ranging from 9.76 × 10-3 % (0% fibres) to 1.20 × 10-2 % (1% fibres), indicative of enhanced deformability of the material prior to fracture. However, between 2wt% and 3wt%, the deformation remains relatively stable (≈ 1.07 × 10-2 %), suggesting that the effect of fibres on ductility reaches a limit, possibly due to the stiffening of the fibre-matrix network, a phenomenon also reported by Ehsan Ban in their work on the effect of fibre crimping on the elasticity of random fibre networks with and without integration matrices [27]. With regard to the material's stiffness, Young's modulus undergoes a precipitous decline upon the incorporation of fibres, from 451.32 MPa (0% fibres) to 168.49 MPa (2% fibres). This decline is indicative of a loss of stiffness concomitant with an increase in porosity and a diminution in cohesion between the matrix and the fibres. However, at 3% fibres, the modulus rises to 379.36 MPa, which could be attributed to enhanced fibre-matrix adhesion in a manner analogous to the observations made by Valadez Gonzalez on the polyethylene matrix biocomposite reinforced with Agave fourcroydes fibres [28].

The findings of this study suggest that a 1wt% AF content represents an optimal compromise when it comes to enhancing flexural strength and ductility without excessively altering the stiffness of the material. Conversely, an excessive fibre content (≥2%) has been shown to result in a significant decrease in bending stress and Young's modulus.

This emphasizes the importance of optimizing fibre dosage to ensure a balance between flexibility and mechanical strength. The findings underscore the potential of homogeneous fibre dispersion and enhanced adhesion with the gypsum matrix to mitigate these adverse effects, thereby optimizing the performance of the biocomposite.

### 3.7. GAB thermal conductivity test analysis

Thermal conductivity *k (W/m.K)* is an essential physical quantity that characterizes the insulating capacity of a material. The lower the coefficient *k*, the greater the insulating power of the material. **Error! Reference source not found.** groups the values of thermal conductivity and their evolution according to the fibre content of the biocomposite.

An analysis of the results indicates that the thermal conductivity of the biocomposite exhibits a variation according to the concentration of AFs, thereby underscoring the fibres' substantial influence on the material's thermal behavior (see **Error! Reference source not found.**). In the absence of fibres, the thermal conductivity of pure gypsum is 0.25 *W/m.K* [29], thereby confirming its insulating nature. However, the addition of 1wt. % AFs enhanced thermal conductivity to 0.4445 *W/m.K*, likely attributable to the non-homogeneous dispersion of the fibres or the formation of thermal bridges. Conversely, an increase in fibre concentration to 2wt. % and 3wt.% result in a progressive reduction in thermal conductivity to 0.3679 *W/m.K* and 0.3075 *W/m.K*, respectively, indicating enhanced fibre distribution and increased material porosity. The thermal behavior in question can be explained by several phenomena, in particular, the effect of the fibres on the microstructure, which favors the formation of pores filled with air, an excellent thermal insulator. Additionally, an initial rise in conductivity was observed at 1 wt. % can be attributed to poor dispersion of the fibres or the formation of thermal bridges. However, the fibres become more integrated into the matrix at higher concentrations, reducing the overall conductivity. The low thermal conductivity of AFs is primarily attributable to their microporous structure. Furthermore, the homogeneous distribution of these fibres within the reinforced plaster facilitates balanced heat diffusion throughout the material, thereby reducing thermal conductivity. This interaction reduces heat transfer and contributes to the formation of areas of increased resistance, thus improving the insulating properties of the biocomposite. However, it should be noted that the thermal performance of the material is contingent on the rate of incorporation of the fibres. Indeed, several studies [30] have shown that an increase in this rate leads to a decrease in the thermal conductivity of the composite. Moreover, the addition of plant fibres has been demonstrated to impede the propagation of heat, a crucial property for the optimization of thermal regulation in buildings.

## Conclusion

The study reveals the significant variability in the mechanical properties of AFs, influenced by fibre diameter. Thinner fibres exhibit higher strength and stiffness, while thicker fibres tend to be more ductile but mechanically weaker due to structural irregularities and internal defects. The variability is further compounded by the non-uniform distribution of components within the fibre layers and the anisotropic nature of natural fibres, which affect their mechanical behavior.

FTIR spectroscopy of AFs confirms the presence of cellulose, hemicellulose, and lignin, providing insights into the chemical composition that influences the mechanical and structural properties of the fibres.

Compression and bending tests reveal that the mechanical properties of AF-reinforced composites are influenced by fibre content. As fibre concentration increases, compressive and flexural strengths decrease due to higher porosity and reduced fibre-matrix cohesion. However, strainstrain at break increases, making the material more ductile and less brittle.

Small amounts of fibre improve flexural strength, but higher concentrations result in a sharp decline in strength, likely due to poor fibre dispersion and increased porosity. The Young's modulus also decreases with higher fibre content, although a slight recovery is observed at higher concentrations, suggesting improved fibre-matrix adhesion.

Thermal conductivity testing shows that fibre content influences the biocomposite's insulating properties. Initially, conductivity increases with low fibre content due to poor dispersion, but as the fibre content increases, conductivity decreases, enhancing thermal insulation.

In conclusion, this study emphasizes the importance of improving the content of thin fibres, achieving homogeneous fibre dispersion, and improving fibre-matrix adhesion to achieve balanced mechanical and thermal properties in agave-based biocomposites. These findings signify the potential for AFs to be utilized in sustainable construction applications, particularly in biocomposites made with building materials such as gypsum and concrete. Future research should focus on improving these parameters and developing specific fibre treatments to enhance fibre-matrix bonding and improve fibre distribution within the matrix.

## References

[1] Inthavong, K., Mouritz, A. P., Dong J., et al, « Inhalation and deposition of carbon and glass composite fibre in the respiratory airway », *Journal of Aerosol Science*, vol. 65, p. 58-68, nov. 2013, https://doi.org/10.1016/j.jaerosci.2013.07.003.

[2] Trivedi, A. K., Gupta, M. K., and Singh, H., « PLA based biocomposites for sustainable products: A review », *Advanced Industrial and Engineering Polymer Research*, vol. 6, nº 4, p. 382-395, oct. 2023, https://doi.org/10.1016/j.aiepr.2023.02.002.

[3] Parameswaranpillai, J., Gopi, J. A., Radoor, and al, « Turning waste plant fibres into advanced plant fibre reinforced polymer composites: A comprehensive review », Composites Part C: Open Access, vol. 10, p. 100333, mars 2023, https://doi.org/10.1016/j.jcomc.2022.100333.

[4] Benallel, A., Tilioua, A., Laaroussi, N., et al,, « Valorization of plant waste for sustainable and ecological insulation in construction: Characterization of thermal and acoustic properties », *Renewable and Sustainable Energy Reviews*, vol. 208, p. 115014, févr. 2025, https://doi.org/10.1016/j.rser.2024.115014.

[5] Benzannache, N., Belaadi, A., Boumaaza, M., et et al, « Improving the mechanical performance of biocomposite plaster/ Washingtonian filifira fibres using the RSM method », *Journal of Building Engineering*, vol. 33, p. 101840, janv. 2021, https://doi.org/10.1016/j.jobe.2020.101840.

[6] Benchouia, H. E., Boussehel, H., Guerira, B., et al, « An experimental evaluation of a hybrid bio-composite based on date palm petiole fibres, expanded polystyrene waste, and gypsum plaster as a sustainable insulating building material », *Construction and Building Materials*, vol. 422, p. 135735, avr. 2024, https://doi.org/10.1016/j.conbuildmat.2024.135735.

[7] Sakuri, S., Surojo, E., Ariawan, D., et al, « Investigation of *Agave cantala*-based composite fibres as prosthetic socket materials accounting for a variety of alkali and microcrystalline cellulose treatments », *Theoretical and Applied Mechanics Letters*, vol. 10, nº 6, p. 405-411, nov. 2020, https://doi.org/10.1016/j.taml.2020.01.052.

[8] Feigel, B., Robles, H., Nelson, J. W., et al, « Assessment of Mechanical Property Variation of As-Processed Bast Fibres », *Sustainability*, vol. 11, nº 9, Art. nº 9, janv. 2019, https://doi.org/10.3390/su11092655.

[9] Munawar, S. S., Umemura, K., et Kawai, S., « Characterization of the morphological, physical, and mechanical properties of seven nonwood plant fibre bundles », *J Wood Sci*, vol. 53, nº 2, p. 108-113, avr. 2007, https://doi.org/10.1007/s10086-006-0836-x.

[10] El Oudiani, A., Msahli, S., et Sakli, F., « In-depth study of agave fibre structure using Fourier transform infrared spectroscopy », *Carbohydrate Polymers*, vol. 164, p. 242-248, Mai 2017, https://doi.org/10.1016/j.carbpol.2017.01.091.

[11] Benmansour, N., Agoudjil, B., Gherabli, A., et al, « Thermal and mechanical performance of natural mortar reinforced with date palm fibres for use as insulating materials in building », *Energy and Buildings*, vol. 81, p. 98-104, oct. 2014, https://doi.org/10.1016/j.enbuild.2014.05.032.

[12] Fořt, J., Šál, J., et Žák, J., « Combined Effect of Superabsorbent Polymers and Cellulose Fibres on Functional Performance of Plasters », *Energies*, vol. 14, nº 12, Art. nº 12, janv. 2021, https://doi.org/10.3390/en14123679.

[13] Saad Azzem, L. and Bellel, N., « Thermal and Physico-Chemical Characteristics of Plaster Reinforced with Wheat Straw for Use as Insulating Materials in Building », *Buildings*, vol. 12, nº 8, Art. nº 8, août 2022, https://doi.org/10.3390/buildings12081119.

[14] Timbangen, S. and Antonius, S. S., « Effect of Mass Addition on Physical Properties and Mechanical Properties of Agave Sisalana Fibre Composites - Epoxy », *Journal of Technomaterial Physics*, vol. 4, nº 1, Art. nº 1, févr. 2022, https://doi.org/10.32734/jotp.v4i1.7082.

[15] Amroune, S., Bezazi, A., Alain, D, et al, « Investigation on Microstructure, Tensile Properties and Fatigue Characterization of Porous Date Palm Fibre », *Journal of Natural Fibres*, vol. 19, nº 17, p. 15751-15764, déc. 2022, https://doi.org/10.1080/15440478.2022.2134255.

[16] Placet, V., Cisse, O., and Boubakar, M. L., « Influence of environmental relative humidity on the tensile and rotational behavior of hemp fibres», *J Mater Sci*, vol. 47, nº 7, p. 3435-3446, avr. 2012, https://doi.org/10.1007/s10853-011-6191-3.

[17] Msahli, S., Chaabouni, Y., Faouzi, S., et al, « Mechanical Behavior of Agave Americana L. Fibres: Correlation Between Fine Structure and Mechanical Properties », *Journal of Applied Sciences*, vol. 7, déc. 2007, https://doi.org/10.3923/jas.2007.3951.3957.

[18] Baley, C., Gomina, M., Breard, J., et al, « Variability of mechanical properties of flax fibres for composite reinforcement. A review », *Industrial Crops and Products*, vol. 145, p. 111984, mars 2020, https://doi.org/10.1016/j.indcrop.2019.111984.

[19] Satyanarayana, K. G., Guimarães, J. L., et Wypych, F., « Studies on lignocellulosic fibres of Brazil. Part I: Source, production, morphology, properties and applications », *Composites Part A: Applied Science and Manufacturing*, vol. 38, nº 7, p. 1694-1709, juill. 2007, https://doi.org/10.1016/j.compositesa.2007.02.006.

[20] Buroni, F. C., « Piezoresistive modeling of orthotropic 3D-printing composite line extrusions with non-affine reorientation of fibres », *Construction and Building Materials*, vol. 443, p. 137654, sept. 2024, https://doi.org/10.1016/j.conbuildmat.2024.137654.

[21] Aslan, M., Chinga-Carrasco, G., Sørensen, B. F., et al, « Strength variability of single flax fibres», *J Mater Sci*, vol. 46, nº 19, p. 6344-6354, oct. 2011, https://doi.org/10.1007/s10853-011-5581-x.

[22] Fanti, G., « Optical features of flax fibres coming from the Turin Shroud », *SHS Web of Conferences*, vol. 15, p. 00004, 2015, https://doi.org/10.1051/shsconf/20151500004.

[23] Gumarães, C. C., Lima, P. R. L., and Filho, R. D. T., « Properties of banana fibres extracted using equipment from the sisal agro-industry », *Caderno Pedagógico*, vol. 21, nº 9, p. e7665-e7665, sept. 2024, https://doi.org/10.54033/cadpedv21n9-084.

[24] Labidi, K., Cao, Z., Zrida, M., et al, « Alfa fibre/polypropylene composites: Influence of fibre extraction method and chemical treatments », *Journal of Applied Polymer Science*, vol. 136, p. 47392, janv. 2019, https://doi.org/10.1002/app.47392.

[25] Kuqo, A. et Mai, C., « Mechanical properties of lightweight gypsum composites comprised of seagrass *Posidonia oceanica* and pine (*Pinus sylvestris*) wood fibres », *Construction and Building Materials*, vol. 282, p. 122714, Mai 2021, https://doi.org/10.1016/j.conbuildmat.2021.122714.

[26] Malmgren, L., « Strength, ductility and stiffness of fibre-reinforced shotcrete », *Magazine of Concrete Research*, vol. 59, nº 4, p. 287-296, Mai 2007, https://doi.org/10.1680/macr.2007.59.4.287.

[27] Ban, E., Barocas, V. H., Shephard, M. S., et al, « Effect of Fibre Crimp on the Elasticity of Random Fibre Networks With and Without Embedding Matrices », *Journal of Applied Mechanics*, vol. 83, nº 4, p. 041008, avr. 2016, https://doi.org/10.1115/1.4032465.

[28] Valadez-Gonzalez, A., Cervantes-Uc, Olayo, J. M., R., et al, « Effect of fibre surface treatment on the fibre–matrix bond strength of natural fibre reinforced composites », *Composites Part B: Engineering*, vol. 30, nº 3, p. 309-320, avr. 1999, https://doi.org/10.1016/S1359-8368(98)00054-7.

[29] Agossou, O. and Amziane, S., « Analysis of Mechanical and Thermal Performance and Environmental Impact of Flax-Fibre-Reinforced Gypsum Boards », *Buildings*, vol. 13, p. 3098, déc. 2023, https://doi.org/10.3390/buildings13123098.

[30] Charai, M., Mezrhab, A., Karkri, M., et Moga, L., « Thermal performance study of plaster reinforced with Alfa fibres », *AIP Conference Proceedings*, vol. 2429, nº 1, p. 020005, nov. 2021, https://doi.org/10.1063/5.0069628.

## Figures

*Figure 1: Microscopy and Preparation of Agave Fibre for Tensile Testing.* ........ 13
*Figure 2: Main steps of making test specimens: Gypsum/Agave biocomposite (GAB)* ........ 14
*Figure 3: Stress curve for Agave fibre (AF)* ........ 14
Figure 4: Stress curves for Agave American fibre for different thickness ........ 14
*Figure 5: Variation of mechanical properties with Agve Fbres (AFs) diameter; a.Young Modul; b. Stress Maximum; c. Strain Maximum* ........ 15
Figure 6: Fourier transform infrared (FTIR) spectra of agave plants with different thicknesses. ........ 16
Figure 7: Mechanical compression properties for a gypsum/agave biocomposites (GAB): a) rupture compressive stress, b) rupture compressive strain, c) modulus of elasticity. ........ 16
Figure 8: Mechanical bending properties for a gypsum/agave biocomposites (GAB): a) rupture bending stress, b) rupture bending strain strain, c) modulus of elasticity. ........ 17
Figure 9: Variation of the thermal conductivity of the gypsum/agave biocomposites (GAB) as a function of the concentration of fibres. ........ 17

## Tables

Table 1: Results of the Tensile mechanical properties of Agave fibres according to their diameter. ........ **Error! Bookmark not defined.**
Table 2: statistical analysis of the mechanical properties of AF ........ **Error! Bookmark not defined.**
*Table 3: Compressive properties of GAB biocomposite versus FA concentration.* ........ **Error! Bookmark not defined.**
Table 4: Bending properties of GAB biocomposite versus FA concentration. ........ **Error! Bookmark not defined.**
*Table 5 Variation of the thermal conductivity of GAB biocomposites as a function of the concentration of the AF.* ........ **Error! Bookmark not defined.**

*Figure 1: Microscopy and Preparation of Agave Fibre for Tensile Testing.*

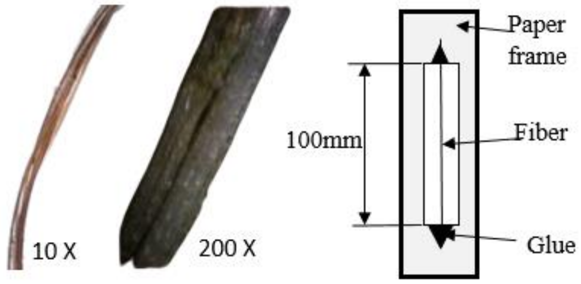



*Figure 2: Main steps of making test specimens: Gypsum/Agave biocomposite (GAB)*

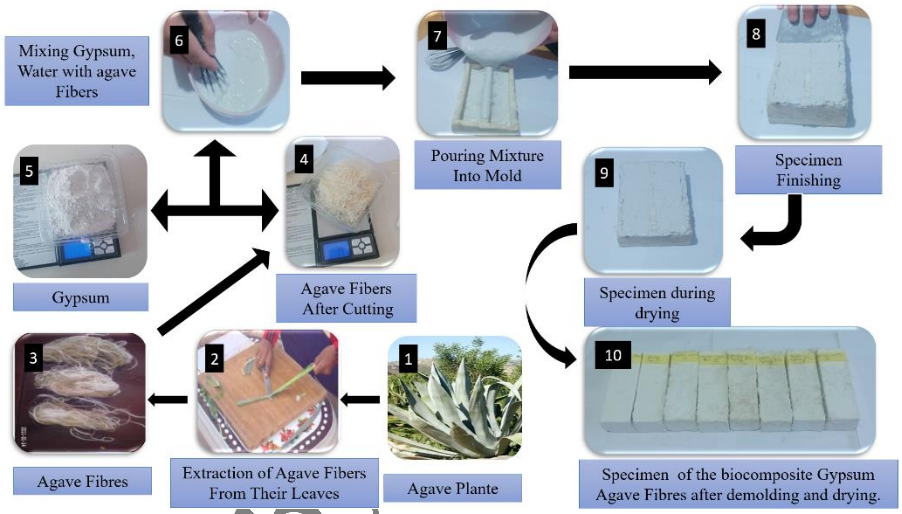



*Figure 3: Stress curve for Agave fibre (AF)*

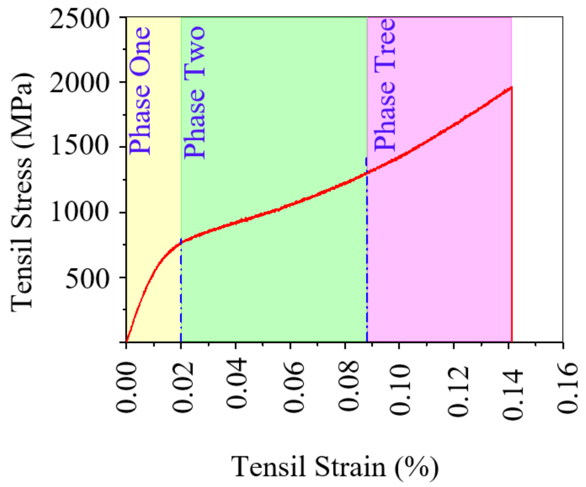



*Figure 4: Stress curves for Agave American fibre for different thickness*

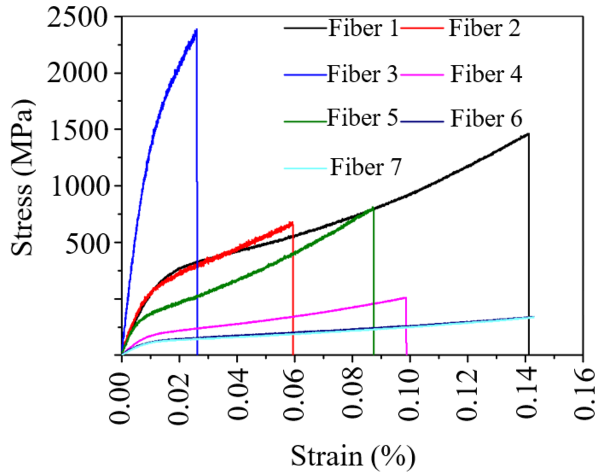



*Figure 5: Variation of mechanical properties with Agve Fbres (AFs) diameter; a.Young Modul; b. Stress Maximum; c. Strain Maximum*

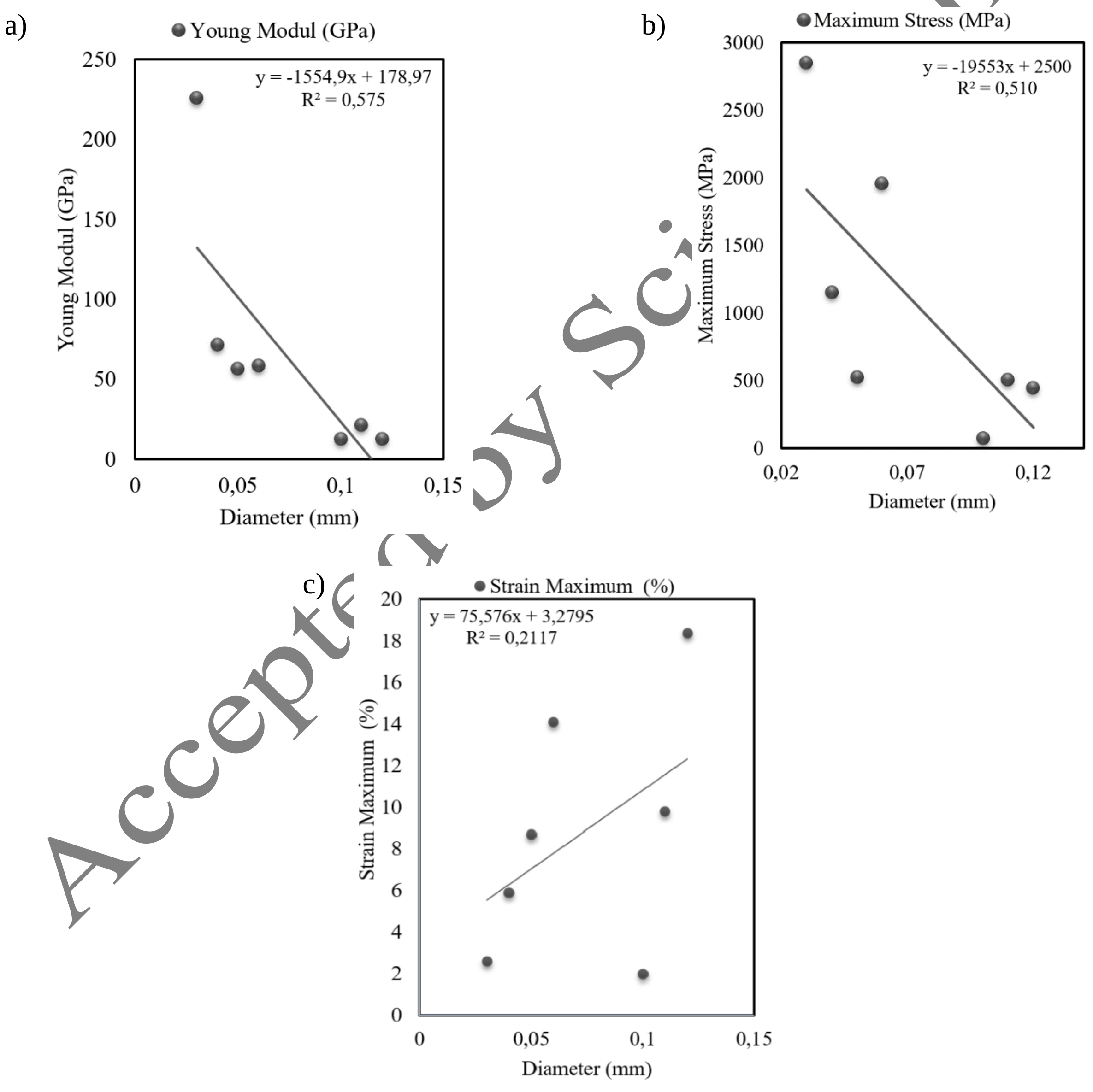


*Figure 6: Fourier transform infrared (FTIR) spectra of agave plants with different thicknesses.*

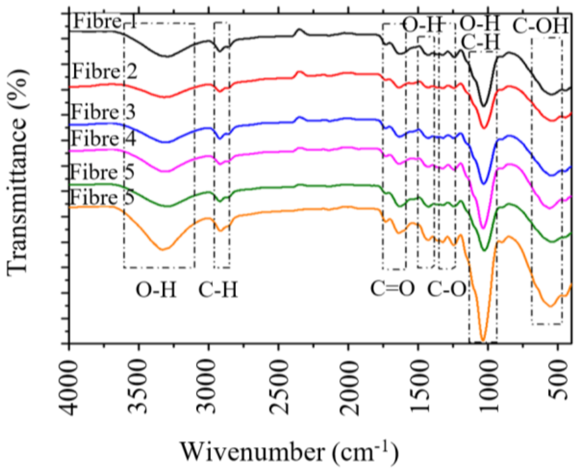
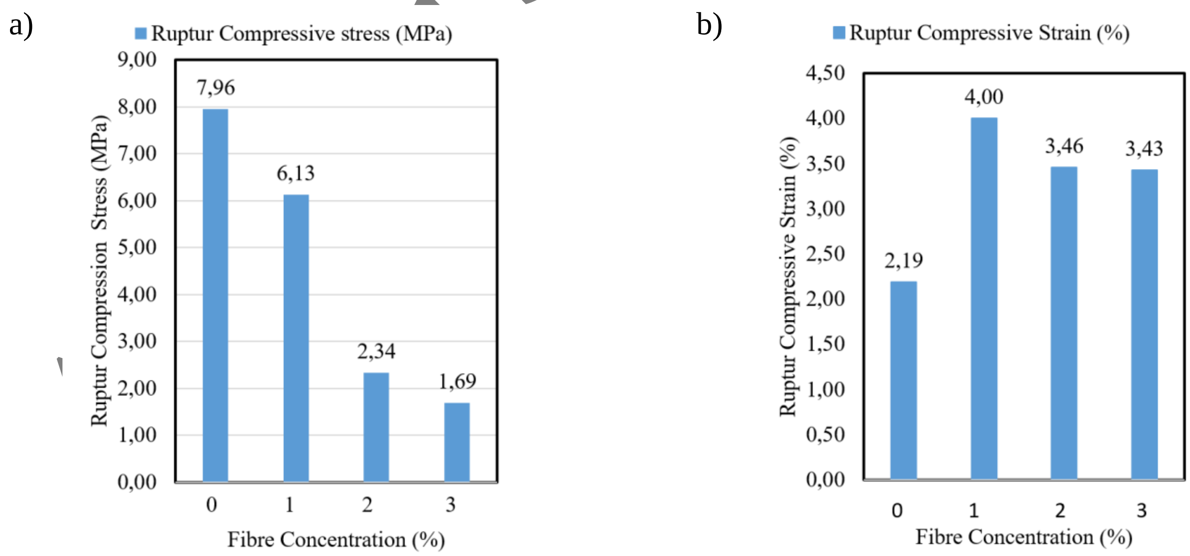



*Figure 7: Mechanical compression properties for a gypsum/agave biocomposites (GAB): a) rupture compressive stress, b) rupture compressive strain, c) modulus of elasticity.*



c)

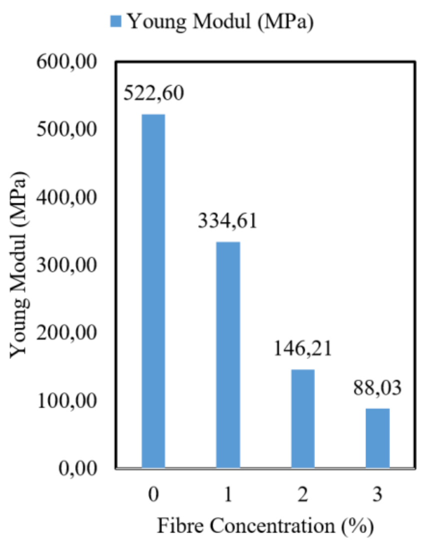



*Figure 8: Mechanical bending properties for a gypsum/agave biocomposites (GAB): a) rupture bending stress, b) rupture bending strain strain, c) modulus of elasticity.*

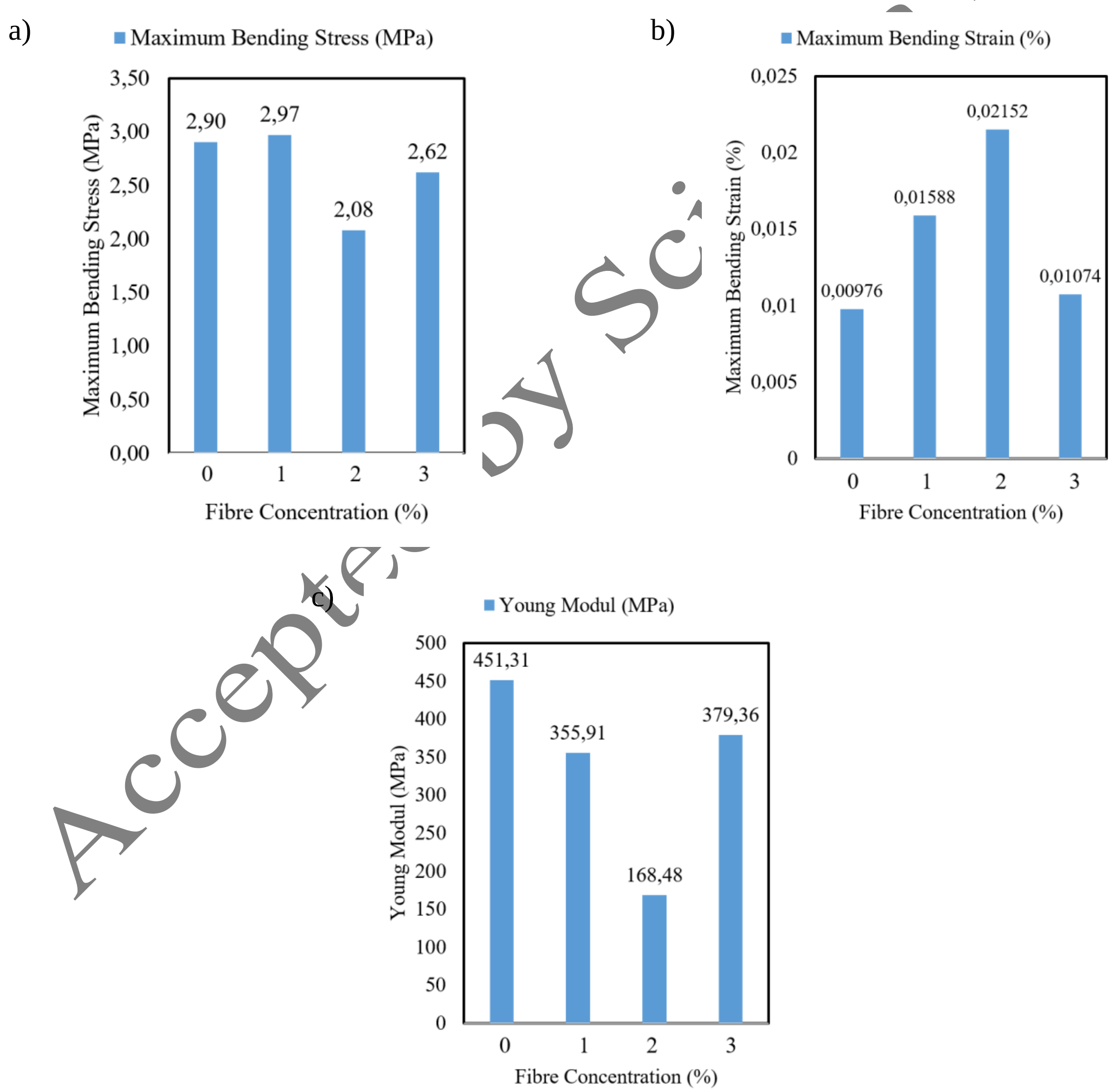



*Figure 9: Variation of the thermal conductivity of the gypsum/agave biocomposites (GAB) as a function of the concentration of fibres.*

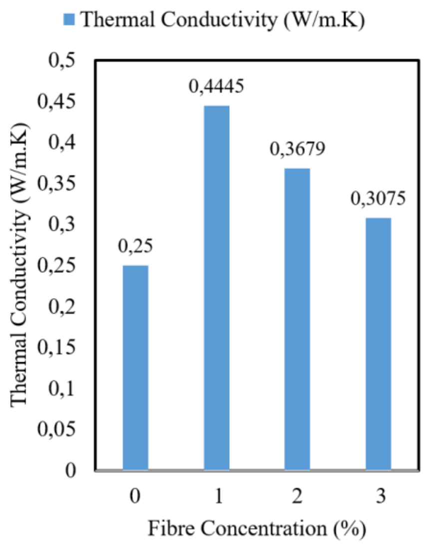



*Table 1: Results of the Tensile mechanical properties of Agave fibres (AF) according to their diameter.*

| | Diameter (mm) | σmax (MPa) | E (GPa) | εmax (%) |
|---|---|---|---|---|
| Fibre 1 | 0.03 | 2853.03 | 225.83 | 2.6 |
| Fibre 2 | 0.04 | 1156.2 | 71.46 | 5.9 |
| Fibre 3 | 0.05 | 529.63 | 56.74 | 8.7 |
| Fibre 4 | 0.06 | 1958.77 | 59.12 | 14.1 |
| Fibre 5 | 0.1 | 76.75 | 12.51 | 2 |
| Fibre 6 | 0.11 | 510.25 | 21.48 | 9.8 |
| Fibre 7 | 0.12 | 449.95 | 12.63 | 18.4 |

*Table 2: statistical analysis of the mechanical properties of Agave fibres (AF)*

| | $\sigma_{max}$ (MPa) | E (GPa) | εmax (%) |
|---|---|---|---|
| Mean | 1076.37 | 65.68 | 8.79 |
| Standard Deviation | 992.15 | 69.51 | 5.53 |
| Min | 76.75 | 12.51 | 2 |
| Max | 2853.03 | 225.3 | 18.4 |
| CoV | 0.82 | 1.05 | 0.63 |

*Table 3: Compressive properties of gypsum/agave biocomposites (GAB) versus Agave Fibre (AF) concentration.*

| Fibre concentration (%) | Rupture Compressive stress (MPa) | Rupture Compressive Strain (%) | Young Module (MPa) |
|---|---|---|---|
| 0 | 7.96 | 2.19 | 522.60 |
| 1 | 6.13 | 3.98 | 334.61 |
| 2 | 2.34 | 3.46 | 146.21 |
| 3 | 1.69 | 3.43 | 88.03 |

*Table 4: Bending properties of gypsum/agave biocomposites GAB versus Agave Fibre (AF) concentration.*

| Agave Fibre concentration (%) | Bending stress (MPa) | Bending strain strain (%) | Young Module (MPa) |
|---|---|---|---|
| 0 | 2.90 | 9.76E-03 | 451.32 |
| 1 | 3.36 | 1.20E-02 | 355.91 |
| 2 | 1.08 | 1.17E-02 | 168.49 |
| 3 | 2.62 | 1.07E-02 | 379.36 |

*Table 5 : Variation of the thermal conductivity of gypsum/agave biocomposites GAB as a function of the concentration of the Agave Fibre (AF).*

| Agave Fibre concentration (%) | Thermal conductivity (*W/m.K*) |
|---|---|
| 0 | 0.25 |
| 1 | 0.4445 |
| 2 | 0.3679 |
| 3 | 0.3075 |



Mr. **Ramadane Bentahar** is currently a **PhD candidate in Mechanical Engineering.** He has actively participated in numerous scientific events and conferences, where he has presented research related to **natural fibers and biocomposites**. He took part in the **1st Euro-Maghreb Conference on Biocomposites** held in Marrakech (March 28–29, 2016), where he delivered an **oral presentation** titled *"Optical Observation and Mechanical Characterization of the Bio-Fiber: Agave Americana"* and a **poster**

**presentation** on the *"Mechanical Behavior of the Luffa Bio-Fiber"*. He also presented an oral communication on the *"Mechanical Behavior of Agave Fiber"* at the **1st Arab Conference on Mechanical Engineering (ARCME'17)** in Biskra, Algeria, and participated in the **1st National Day on Renewable Energy and Advanced Materials (JNERMA)** at the University of Larbi Ben M'hidi (November 13, 2018), where he showcased a poster presentation entitled *"Valorization of Plant Fibers in Algeria: Study of the Effect of Agave and Luffa Fiber Concentration on the Mechanical Properties of Biocomposites."*

**Professor Noureddine Belghar** is a senior academic and researcher currently affiliated with the University of Khenchela, Algeria, where he serves as a professor and project leader (PRFU) at the Energy and Materials Engineering Laboratory (*LGEM*). He holds a Ph.D. in thermal and fluid sciences and has developed extensive expertise in computational fluid dynamics (CFD), renewable energy systems, nanofluids, and sustainable building materials. His teaching and research activities are affiliated with both the University of Khenchela and the University of Biskra, particularly through the LGEM laboratory focused on chemical methods and sustainable development.

Over the years, Professor Belghar has published numerous peer-reviewed scientific articles covering a wide range of topics, including turbulent flow in cyclone separators, thermal optimization in solar air collectors, nanofluid-enhanced heat exchangers, and the characterization of natural fibers for eco-friendly construction. His recent works focus on the valorization of agricultural waste such as date palm leaflets and wastepaper as insulation or reinforcement materials in green composites. He is actively involved in mentoring PhD students, leading experimental and numerical research projects, and advancing energy-efficient technologies for sustainable engineering applications.

Professor Linda AISSANI is an academic affiliated with the Department of Physics at Abbès Laghrour University of Khenchela, Algeria. Her academic foundation lies in materials science and metallurgy, a field in which she holds a professorship and has authored numerous scholarly publications. She has also earned a Habilitation à Diriger des Recherches (HDR) in materials physics and metallurgy, further solidifying her expertise and leadership in the discipline.

Her professional experience spans a wide range of specializations, including tribology, surface engineering, ferromagnetism, and the optical and mechanical properties of materials. She is also highly involved in coating technologies, microstructural analysis, heat treatment, and photocatalysis. Proficient in both advanced characterization techniques and computational materials design, her current research focuses on the development of thin films, condensed matter systems, and advanced composite and polymeric materials, with applications in the energy and biomedical sectors.

**Professor** Semcheddine Derfouf is a senior lecturer and researcher at the University of Batna 2, Algeria, specializing in mechanical engineering with particular focus on viscoelastic-viscoplastic modeling, renewable energy systems, and composite materials. He has delivered undergraduate and graduate courses such as *Basic Technology*, *Hydraulic and Pneumatic Systems*, *Numerical Methods*, and *Probability and*

*Statistics* across various engineering programs, particularly in Civil and Hydraulic Engineering. He is actively involved in academic instruction and supervises practical work and tutorials.

His research contributions span a variety of domains including wind turbine performance optimization, bio-composite materials, and rheological behavior of thermoplastic and composite systems. Dr. Derfouf has authored and co-authored numerous scientific papers published in international journals such as *Sustainability*, *Frattura ed Integrità Strutturale*, *Applied Solar Energy*, and *Larhyss Journal*. Additionally, he has supervised several PhD theses addressing energy recovery systems, structural optimization in irrigation systems, and the mechanical behavior of natural fibers in composites. His academic profile reflects a commitment to interdisciplinary research with practical applications in sustainable engineering

**Professor Mohammed LACHI** is a senior researcher at the University of Reims Champagne-Ardenne (URCA), affiliated with the ITheMM laboratory (Institut de Thermique, Mécanique, Matériaux). His areas of expertise include heat and mass transfer, thermal characterization of materials, building energy efficiency, and coupled hygrothermal phenomena. Over the past decades, he has developed deep insights into the thermal dynamics of both traditional and innovative construction materials. His research focuses strongly on sustainable building technologies, including the use of agro-based materials such as hemp, date palm fibers, and beet pulp to create environmentally friendly composites with enhanced thermal and mechanical properties.

Professor LACHI has published extensively in leading international journals such as *Energy and Buildings*, *Construction and Building Materials*, and the *International Journal of Heat and Mass Transfer*. His work encompasses both experimental and numerical approaches, contributing to the advancement of passive cooling strategies, thermal comfort assessment, and the performance optimization of building components like earth–air heat exchangers and radiant floor systems. Through his interdisciplinary collaborations and commitment to sustainable engineering, Professor LACHI continues to influence the evolution of green building technologies and energy-conscious architectural design.

**Professor Kamel Chadi** is a researcher at the **Research Center in Industrial Technologies (CRTI)** in Algiers, Algeria. His work primarily focuses on **computational fluid dynamics (CFD)** and **heat transfer phenomena** in complex systems, with a strong emphasis on nanofluids, thermal management, and energy efficiency in micro- and mini-channel geometries. He has contributed extensively to the numerical modeling and parametric analysis of fluid flow and heat transfer, particularly in applications related to electronics cooling, sustainable thermal systems, and environmental engineering. One of his notable contributions includes a CFD-based investigation into airflows and pollution distribution in historical neighborhoods of Annaba, highlighting his interdisciplinary approach linking thermal science to environmental concerns.

Dr. Chadi has authored and co-authored numerous peer-reviewed articles published in respected international journals such as *Heat Transfer*, *Numerical Heat Transfer Applications*, *SN Applied Sciences*, and the *Journal of Process Mechanical Engineering*. His research explores a variety of innovative configurations, including the use of hybrid nanofluids, interior rotating cylinders, ribbed micro-channels, and U-shaped obstacles to enhance convective heat transfer. He has collaborated with leading researchers from Algeria and internationally, focusing on optimizing thermal performance through geometric and material parameter variation. His scientific output underlines his expertise in CFD-based thermal analysis, additive manufacturing, and sustainable cooling technologies, making significant contributions to the advancement of energy-efficient engineering solutions.

**Professor Cristina Tedeschi** is a professor and researcher in the Department of Civil and Environmental Engineering at the **Politecnico di Milano**, where she is affiliated with the *Laboratory of Diagnosis and Investigation of Built Heritage Materials*. Her research focuses on the characterization, conservation, and structural behavior of historical construction materials, with particular emphasis on mortars, masonry, and stone. She has significantly contributed to the development of compatible restoration techniques for historic structures, combining experimental analyses with in situ diagnostics to assess mechanical performance and durability.

Professor Tedeschi has participated in several high-profile restoration projects, including the rehabilitation of the Noto Cathedral in Sicily and experimental campaigns on strengthened stone masonry walls. She has published over 100 scientific articles in peer-reviewed international journals and serves as a reference in the field of historical building conservation and non-destructive testing techniques. Her work encompasses the study of natural hydraulic lime mortars (NHL), the behavior of thick bedding mortars in Byzantine architecture, and the integration of sustainable materials such as palm fibers into restoration mortars. She has also been actively involved in international scientific committees, including the **RILEM Technical Committee TC 203-RHM**, which addresses repair mortars for historic masonry.