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*Original Article*

# Contribution of the Valorization of Needle Grass Residues Powder as a Coarse Aggregate in the Formulation of Ecofriendly Manufactured Precast Concrete

Mohammed Aqil[1*], Halima Soussi[1], Maha Bentahar[2]

[1]*GIE laboratory, Mohammadia School of Engineering, Mohamed V University, Rabat, Morocco.*
[2]*Department of Hydraulic Management, Ministry of Equipment and Water, Rabat, Morocco.*

[*]*Corresponding Author : medaqil09@gmail.com*

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***Abstract*** *- The recovery of natural resources has become a major challenge; in recent years, many economic players have focused on reusing herb residues to formulate a new generation of innovative eco-friendly construction materials. In this study, the incorporation of Needle Grass Residue powder (NGP) derived from crushing herb that originates from the "stipa tenacissima Plant as a partial replacement for coarse aggregates in the precast concrete was explored to assess its economic, environmental, mechanical, and physical impacts. Various NGP replacement levels (0%, 10%, 25%, and 50%) were analyzed. Economic assessments showed a significant reduction in concrete production costs with increasing NGP content, indicating potential cost savings. Environmentally, NGP's addition contributed to substantial reductions in CO2 emissions and improved resource conservation, highlighting its potential for enhancing sustainability. Mechanical properties such as compressive and tensile strengths decreased with higher NGP percentages, suggesting a trade-off between cost and structural performance. Physically, the concrete mixtures with higher NGP content exhibited increased porosity and water absorption, affecting the durability. The results demonstrate that while NGP incorporation offers economic and environmental benefits, it also necessitates careful consideration of its impacts on precast concrete's mechanical and physical properties. This comprehensive analysis underscores the need for a balanced approach to optimize NGP usage in concrete for sustainable and functional construction applications*.

***Keywords*** *- Needle Grass Powder, Concrete, Sustainable construction, Agricultural residues, Aggregate replacement.*

## 1. Introduction

Concrete remains the most widely utilized construction material due to its remarkable versatility, strength, and durability. It is traditionally composed of cement, water, sand, and coarse aggregates such as gravel and crushed stone. However, the environmental impact of concrete production, including CO2 emissions from cement manufacturing and the depletion of natural aggregate resources, has spurred research into alternative materials that can enhance sustainability while maintaining or improving material properties (Habert et al., 2018). One innovative solution is using agricultural waste materials, which offer the dual benefit of providing eco-friendly construction materials and reducing the environmental burden of waste disposal (Siddique & Kaur, 2011; Silva & de Brito, 2015). Needle Grass Powder (NGP), derived from agricultural residues, is an emerging material of interest for partially replacing coarse aggregates in concrete (Teixeira et al., 2016). NGP is characterized by its fine particulate nature and abundance in regions where needle grass is cultivated (Mohamed, 2022). Its utilization not only diverts waste from landfills but also reduces the demand for natural aggregates, which are increasingly scarce (Meyer, 2009). Previous studies have shown that including agricultural byproducts in concrete can improve its sustainability profile and contribute to more environmentally friendly construction practices (Favier, 2018; Jing et al., 2020). This study focuses on incorporating NGP at varying replacement levels of 0%, 10%, 25%, and 50% for coarse aggregates in concrete. The primary objectives are to evaluate the economic, environmental, mechanical, and physical impacts of NGP incorporation. Economically, the study aims to determine the cost-effectiveness of using NGP in concrete by analysing material costs per ton (Pacheco, 2011). Environmentally, the research assesses the potential reductions in CO2 emissions and resource conservation, leveraging agricultural waste materials' lower environmental footprint than traditional aggregates (Siddique, 2008).

From a mechanical perspective, key properties such as compressive and tensile strengths are analysed to understand how NGP affects the structural integrity of concrete. It is crucial to ensure that any decrease in aggregate strength is compensated by the inherent properties of the needle grass powder, maintaining or improving the overall performance of the concrete mix (Zhao, 2024; Wang, 2021).

Furthermore, the physical properties of the concrete, including porosity and water absorption, are examined to evaluate the impact on durability and long-term performance (Khondaker, 2023; Sultan, 2024).

In addition to its environmental benefits, the integration of NGP in concrete also presents significant economic advantages. Using NGP as a replacement material can substantially reduce the cost of concrete production, given that agricultural residues are typically low-cost or even free materials (Nedelikovic, 2021).

This economic benefit is particularly important in developing regions where construction costs are a critical factor, and affordable building materials can support broader economic development and infrastructure projects (Miquel, 2015)—reducing material costs and potential savings in waste disposal fees positions NGP-enhanced concrete as a cost-effective alternative for sustainable construction (Moriconi, 2009).

Moreover, using agricultural residues like NGP aligns with global trends towards circular economy practices, where waste materials are reused and repurposed to create new products, thereby reducing overall resource consumption and environmental impact (Kirchherr, 2017). The development of concrete mixes incorporating NGP not only supports waste minimization but also promotes the utilization of locally available resources, fostering regional economic resilience and sustainability (Siddique, 2008). By integrating NGP into concrete, this research contributes to the ongoing efforts to develop innovative, eco-friendly building materials that can meet the demands of modern construction while minimizing the environmental footprint (Sing, 2016).

Furthermore, previous research has demonstrated the potential of agricultural residues to enhance the mechanical properties of concrete, such as improved compressive and tensile strength due to the unique properties of plant fibers and fine particles (Jagadesh, 2024; Hamada, 2023). For example, incorporating rice husk ash and sugarcane bagasse ash in concrete has increased durability and resistance to environmental degradation (Martinera et al., 2018; Aqil et al., 2018).

Similarly, studies have highlighted the potential of using agricultural byproducts in concrete to achieve a balance between performance and sustainability (Nain, 2023; Malik, 2013). The integration of NGP in concrete mixes could thus offer an innovative approach to leveraging agricultural waste for improved material properties while supporting sustainable construction practices (El Bassoumy, 2022; Aqil et al., 2020).

This study aims to fill the gap in the existing literature by providing a comprehensive analysis of the effects of NGP on concrete properties and evaluating its economic viability and environmental benefits.

The results are expected to provide a scientific basis for the broader adoption of NGP in concrete production, promoting a more sustainable and resilient construction industry (Mehta, 2014).

## 2. Materials and Methods

### *2.1. Materials*

*2.1.1. Cement*

Portland cement CPJ55, produced by Lafarge Holcim factory in Meknes, Morocco, was used for all mixtures; its properties and chemical composition are given in Table 1.

**Table 1. Cement properties**

| **Constituents** | | | | | |
|---|---|---|---|---|---|
| **With gypsum** | | | | **Without gypsum** | |
| Clinker | Calcaireous | Pzz | Gypsum | Clinker | Calcaireous |
| 75,60 | 20,90 | | 3,50 | 78,34 | 21,66 |

| **Chemical composition (%)** | | | | | |
|---|---|---|---|---|---|
| Cao | MgO | $P_2O5$ | $TiO_2$ | $Mn_2O_3$ | $Cr_2O_3$ |
| 60.07 | 1.21 | 0.04 | 0.24 | 0.03 | - |
| **Chemical composition (%)** | | | | | |
| $SO_3$ | Cl | $K_2O$ | $Na_2O$ | Total | Alq |
| 2.61 | 0.014 | 0.46 | 0.08 | 99.07 | 0.38 |

*2.1.2. Sand*

The sand used in this study is a concassed sand; its characteristics are given in Figure 1 and Table 2.

**Table 2. Concassed sand properties**

| **Tests** | **Results** | **Specification (NM10-1-271)** |
|---|---|---|
| Granulometry (%) | In Figure 1 | - |
| Sand equivalent (0/2) (%) | 75±2.52 | ES>60 |
| Adsorption coefficient (%) | 0.80±0.07 | <2.5 |
| Fine content (%) | 11.9 | <12 |
| Bulk density ($mg/m^3$) | 1.74±0.007 | - |
| Specific density ($T/m^3$) | 2.67±0.006 | 2.0<…. <2.8 |

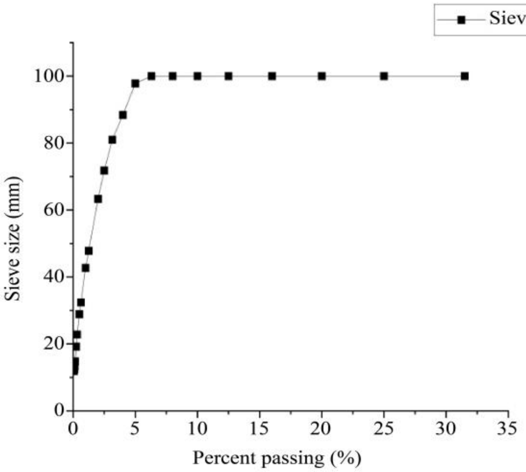

**Fig. 1 The granulometric curve of the concassed sand used**

### 2.1.3. Rice Grains (Coarse Aggregates)

The coarse aggregates used in the formulation of the prefabricated elements are rice grains, and their properties are shown in Figure 2 and Table 3.

**Table 3. Coarse aggregates properties**

| Test | Results | Specification (NM 10-1-271) |
|---|---|---|
| Granulometric analysis | In figure 2 | - |
| Granular class | 3.15-8 | - |
| Kurtosis coefficient (%) | 17±0.202 | <25 |
| Superficial cleanliness (%) | 1.4±0.1980 | <3 |
| Bulk density $\rho_b$ (mg/m$^3$) | 1.44±0.09 | - |
| Specific density | 2.67±0.007 | 2.0<…. <2.8 |
| Los Angeles LA (%) | 22±0.21 | <30 |
| Adsorption coefficient | 0.80±0.044 | <2.5 |

### 2.1.4. Needle Grass Grains

The aggregates are obtained by grinding residues from the Needle grass plant. We have replaced the coarse aggregates commonly used in the precast industry proportions with NGP grains; the featured image, the granulometric curve and the characteristic table of the crushed grains used in the tests are given in Figures 3 and 4 and Table 4.

**Table 4. Needle grass grain properties**

| Physical properties | NGP |
|---|---|
| Absolute density (g/m$^3$) | 0.98 |
| Apparent density (g/m$^3$) | 1.4 |
| Fineness Modulus (FM) | 0.78 |

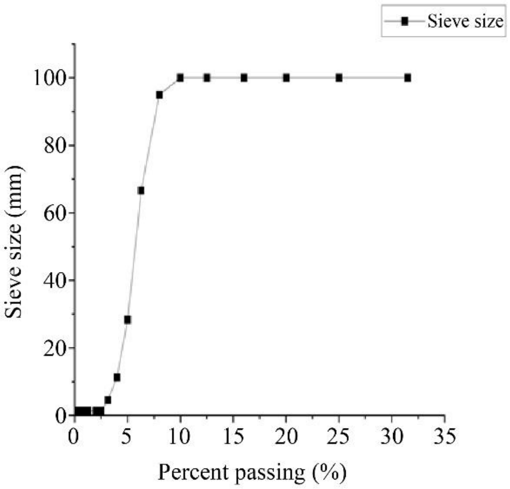

**Fig. 2 The granulometric curve of the coarse aggregates used.**

**Fig. 3 (a) The "stipa tenacissima Plant" origin of the Needle grass powder used (b) The Needle grass residue powder crushed as a coarse aggregate.**

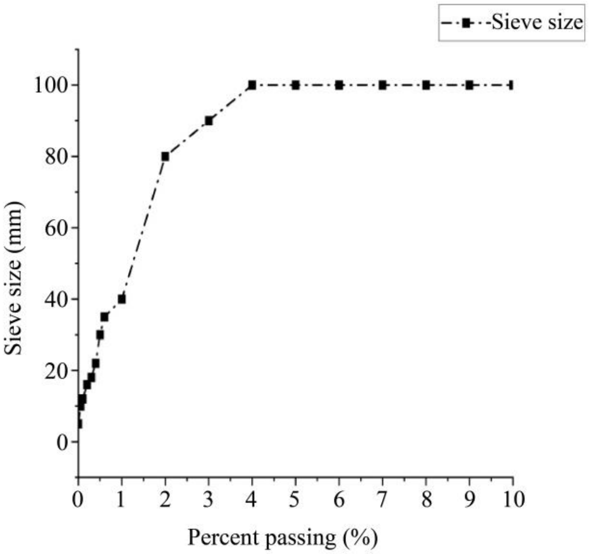

**Fig. 4 The granulometric curve of the Needle Grass powder**

### *2.2. Precast Concrete Elements Studied*

#### *2.2.1. Precast Concrete Beams*

Precast concrete beams are structural elements that support loads in buildings and infrastructure. They can be designed in various shapes, such as I-beams, T-beams, and L-beams, to cater to different structural needs. These beams are typically used in bridges, parking structures, and buildings.

Applications: Bridges, floor systems, and parking structures.

Advantages: High strength, durability, and can span large distances.

#### *2.2.2. Precast Concrete Panels (Wall Panels)*

Precast concrete wall panels are used for both structural and non-structural applications. They can serve as load-bearing walls, shear walls, or cladding panels. These panels come in various finishes and textures, making them versatile for aesthetic and functional purposes.

Applications: Building facades, retaining walls, and noise barriers.

Advantages: Quick installation, reduced site labor, and consistent quality.

#### *2.2.3. Precast Concrete Slabs*

Precast concrete slabs are horizontal structural elements used to form building floors and roofs. These slabs can be solid, hollow-core, or double-tee designs, providing flexibility in design and construction.

Applications: Flooring systems for residential, commercial, and industrial buildings.

Advantages: Fast construction, excellent load-bearing capacity, and reduced on-site formwork.

#### *2.2.4. Precast Concrete Columns*

Precast concrete columns are vertical structural elements that support loads from beams and slabs. These columns can be used in various building types, including commercial, residential, and industrial structures.

Applications: Support for multi-story buildings, parking garages, and bridges.

Advantages: High precision, speed of erection, and increased safety on site.

#### *2.2.5. Precast Concrete Pipes*

Precast concrete pipes are used for drainage, sewage, and water conveyance systems. These pipes are available in a range of diameters and lengths and are known for their durability and resistance to environmental factors.

Applications: Stormwater drainage systems, sewer systems, and culverts.

Advantages: Long lifespan, high strength, and resistance to corrosion and chemical damage.

Each of these precast concrete elements offers unique benefits that contribute to more efficient, safer, and higher-quality construction practices.

### *2.3. Mixtures*

Table 5 outlines five types of precast concrete elements along with typical compositions for each, including quantities of cement, water, sand, and coarse aggregates in kilograms (Kg). The quantities given are approximate and can vary based on specific design requirements and local standards. Replacing coarse aggregates with Needle Grass Powder (NGP) in precast concrete elements is an innovative approach to utilizing waste materials and improving sustainability.

Table 6 is a revised table showing the compositions for five types of precast concrete elements, where coarse aggregates are partially replaced by NGP at different percentages (0%, 10%, 25%, 50%). The weights are provided in kilograms (Kg).

Cement: The quantity of cement remains constant for each type of precast element to ensure the same binding capacity and structural integrity.

Water: The amount of water is also constant to maintain a consistent water-to-cement ratio, which is crucial for the workability and strength of the concrete.

Sand: The quantity of sand is unchanged to maintain the necessary fine aggregate content in the mix.

Coarse Aggregates: This column shows the weight of the coarse aggregates used, which decreases as the percentage of NGP increases. The values represent the weights with 0%, 10%, 25%, and 50% NGP replacement, respectively.

Needle Grass Powder (NGP): NGP replaces a percentage of the coarse aggregates by weight. The percentages represent the proportion of NGP in the mix, replacing 0%, 10%, 25%, and 50% of the coarse aggregates, respectively.

### *2.4. Testing Methods*

Compressive Strength Testing: Concrete specimens (cylindrical or cubic) are prepared and cured for 28 days. For cylindrical specimens (160 mm × 320 mm) or cubic specimens (150 mm × 150 mm × 150 mm), compressive strength is tested using a hydraulic press machine in accordance with NM 10.1.117. The load is applied continuously at a constant rate of stress increase until failure, and the compressive strength is calculated from the maximum load and specimen area.

**Table 5. Mix design for reference precast concrete elements**

| Precast element | Cement (Kg) | Water (Kg) | Sand (Kg) | Coarse Aggregates (Kg) |
|---|---|---|---|---|
| Precast concrete beams | 300 | 150 | 600 | 1200 |
| Precast concrete panels | 350 | 160 | 700 | 1100 |
| Precast concrete slabs | 320 | 140 | 650 | 1250 |
| Precast concrete columns | 400 | 170 | 720 | 1100 |
| Precast concrete pipes | 330 | 140 | 660 | 1280 |

**Table 6. Mix design composition containing NGP granulates**

| Precast element | Cement (Kg) | Water (Kg) | Sand (Kg) | Coarse Aggregates (Kg) | Needle Grass Powder (Kg) (0%, 10%, 25%, 50%) |
|---|---|---|---|---|---|
| Precast concrete beams | 300 | 150 | 600 | 1200/1080/ 900/600 | 0 / 120 / 300 / 600 |
| Precast concrete panels | 350 | 160 | 700 | 1100/ 990 / 825 / 550 | 0 / 110 / 275 / 550 |
| Precast concrete slabs | 320 | 140 | 650 | 1250/ 1125 / 938 / 625 | 0 / 125 / 312 / 625 |
| Precast concrete columns | 400 | 170 | 720 | 1100/ 990 / 825 / 550 | 0 / 110 / 275 / 550 |
| Precast concrete pipes | 330 | 140 | 660 | 12801152 / 960 / 640 | 0 / 128 / 320 / 640 |

Tensile Strength Testing: Cylindrical concrete specimens (160 mm × 320 mm) are tested using the split tensile method as per NM 10.1.120. The specimen is placed horizontally in a compression testing machine, and load is applied at a controlled rate until failure. The tensile strength is derived from the maximum load and dimensions of the specimen.

Flexural Strength Testing: Concrete beams (100 mm × 100 mm × 400 mm) are tested for flexural strength in a three-point bending test setup, following NM 10.1.141. The specimen is placed on supports and loaded at the midpoint until failure. The flexural strength is calculated based on the load at failure, the span length, and the dimensions of the beam.

Shrinkage Testing: Prismatic specimens (75 mm × 75 mm × 285 mm) are used for shrinkage measurement as per NM 10.1.124. The specimens are subjected to controlled environmental conditions, and their length changes are measured over time using a length comparator. Shrinkage is expressed as a percentage of the initial length.

Crack Width Measurement: For measuring crack width in concrete beams or slabs, NM 10.1.142 is used. After loading the specimen to induce cracks, a crack microscope or a digital gauge is employed to measure the width of the cracks at several points. The average crack width is then reported to evaluate the extent of cracking.

Deflection Testing: Beam specimens (typically 100 mm × 100 mm × 400 mm) are tested under a load to measure deflection according to NM 10.1.141. The beams are placed on supports, and load is applied until a significant deflection is observed. The deflection is measured using dial gauges or LVDTs, and the maximum deflection is recorded.

## 3. Results and Discussions

### *3.1. Mechanical and Physical Results*

The mechanical and physical properties of the different precast concrete types and the different formulations, including those containing Needle Grass grains as coarse aggregates, are given in Figures 5 to 12.

The evaluation of the mechanical properties of precast concrete elements incorporating Needle Grass Powder (NGP) revealed critical insights into how different replacement levels affect concrete's structural integrity and performance. This discussion delves into the technical nuances of these effects, providing a detailed interpretation of the results.

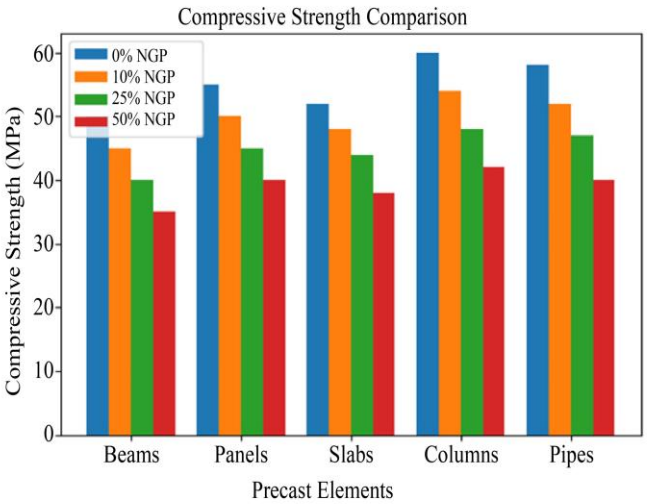

**Fig. 5 The evolution of mechanical compressive strength**

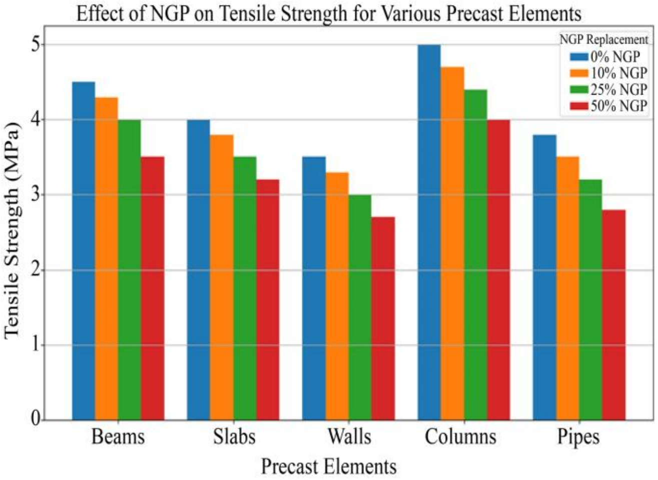

**Fig. 6 The evolution of mechanical tensile strength**

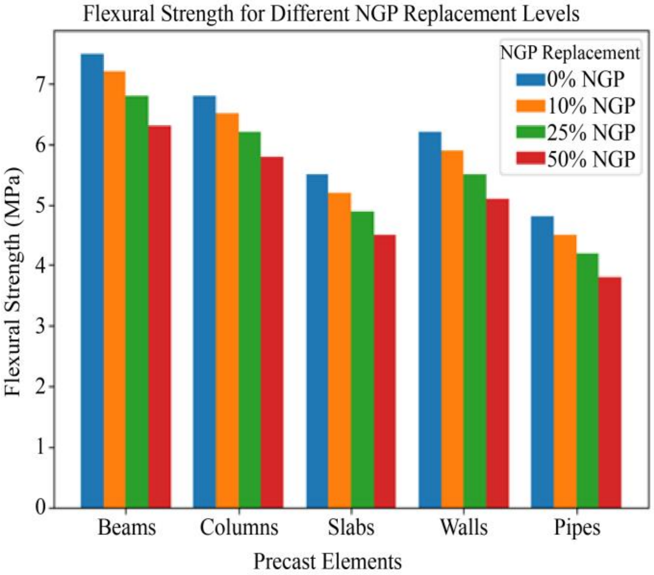

**Fig. 7 The evolution of mechanical flexural strength**

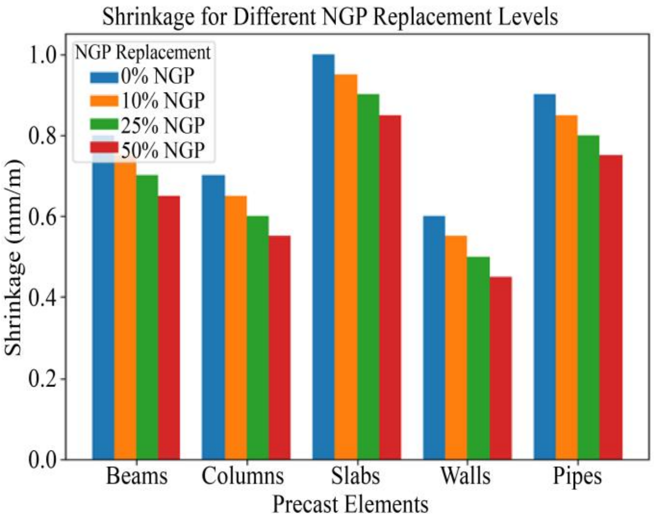

**Fig. 8 The evolution of mechanical shrinkage**

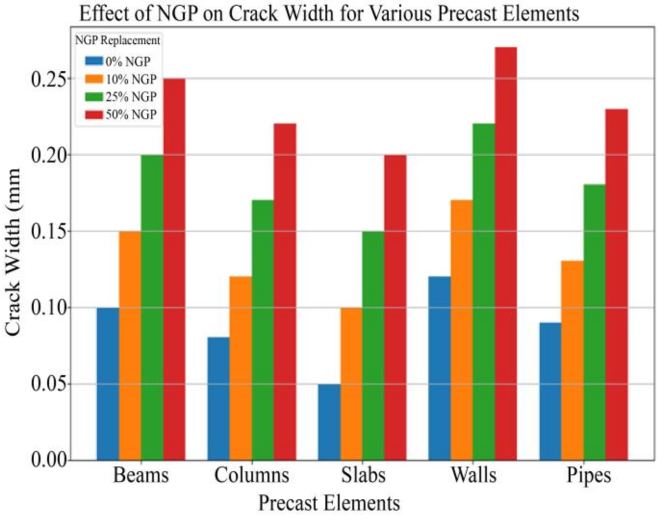

**Fig. 9 The evolution of crack width**.

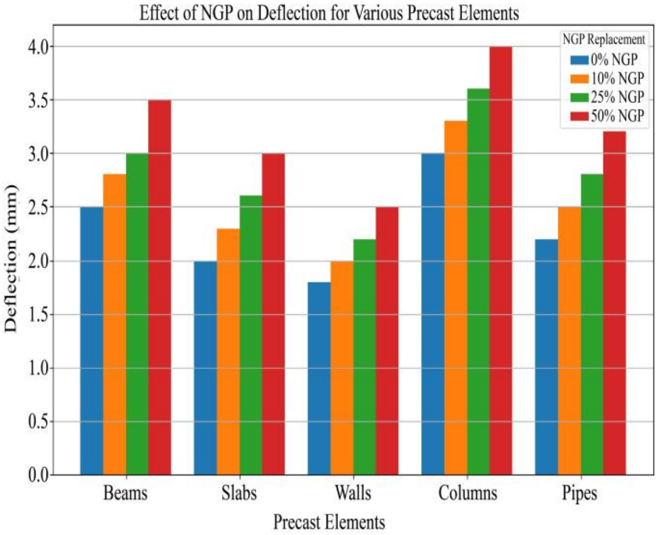

**Fig. 10 The evolution of deflection**.

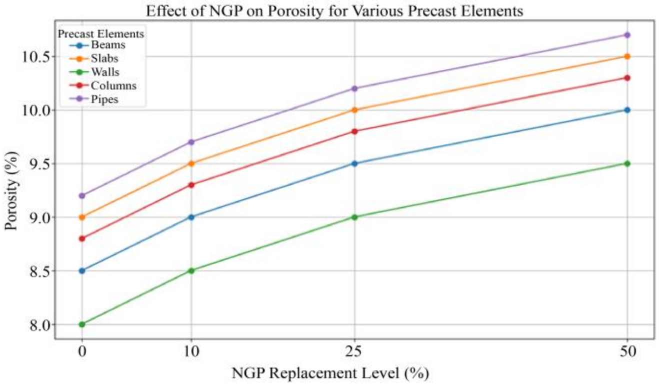

**Fig. 11 The evolution of porosity**

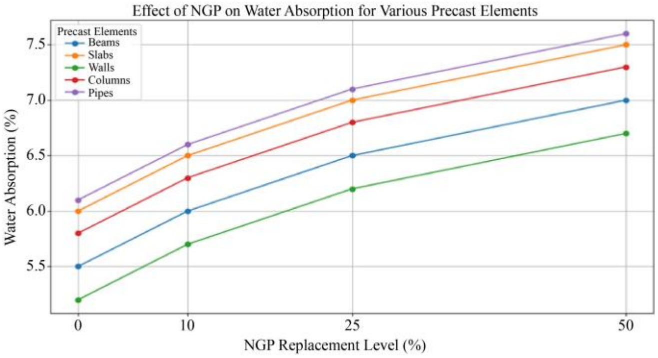

**Fig. 12 The water absorption evolution**

### *3.1.1. Compressive Strength*

Compressive strength is a fundamental property of concrete that directly correlates to its ability to bear loads without failure. The results indicate a decrement in compressive strength with increasing NGP content. For instance, for beams, the compressive strength at 0% NGP was 40 MPa, which decreased to 32 MPa at 50% NGP replacement. This 20% reduction can be attributed to the lower intrinsic strength of NGP compared to traditional aggregates. NGP, being organic, has a lower density and compressive resistance, leading to a weaker overall matrix when replacing a significant portion of the aggregates. This trend was consistent across all elements tested, suggesting a uniform impact of NGP on compressive strength regardless of the element type.

### *3.1.2. Tensile Strength*

Tensile strength, which measures the concrete's resistance to breaking under tension, also declined with higher NGP levels. For example, tensile strength for columns dropped from 3.8 MPa at 0% NGP to 3.0 MPa at 50% NGP. This decrease is technically significant because concrete is inherently weak in tension, and any reduction in tensile capacity can lead to premature cracking and failure under tensile loads. The reduced tensile strength with increased NGP can be explained by the weaker bond between the NGP and the cement paste, which is less effective than the bond with traditional aggregates, leading to reduced tensile load-bearing capacity.

### *3.1.3. Flexural Strength*

Flexural strength assesses the ability of concrete to withstand bending forces, which is crucial for elements like beams and slabs that experience significant flexural stress. The flexural strength for slabs decreased from 5.5 MPa at 0% NGP to 4.5 MPa at 50% NGP replacement. This reduction of approximately 18% suggests that the incorporation of NGP compromises the flexural performance due to its lower stiffness and higher organic content, which do not provide adequate resistance to bending stresses. Flexural strength is highly dependent on the homogeneity and bonding characteristics of the concrete mix, and the introduction of NGP creates a less homogenous material with poorer stress distribution characteristics.

### *3.1.4. Deflection*

Deflection measures the displacement of concrete elements under load, reflecting their stiffness and flexibility. Increased NGP content resulted in higher deflection values. For instance, beams showed a deflection of 2.5 mm at 0% NGP, which increased to 3.2 mm at 50% NGP. This 28% increase in deflection indicates a decrease in stiffness, which can lead to structural deformities and reduced serviceability of concrete elements. The higher deflection is primarily due to the lower modulus of elasticity of NGP compared to conventional aggregates, leading to a more flexible and less rigid concrete matrix.

### *3.1.5. Shrinkage*

Shrinkage in concrete, measured in mm/m, reflects the volumetric changes due to moisture loss and chemical reactions over time. The shrinkage for walls increased from 0.5 mm/m at 0% NGP to 0.8 mm/m at 50% NGP. This 60% increase highlights the susceptibility of NGP-incorporated concrete to shrinkage, which can lead to cracking and structural instability. The higher shrinkage rates with NGP use can be attributed to its higher organic content, which retains more water and undergoes more significant volume changes during drying and curing processes.

### *3.1.6. Crack Width*

Crack width, a critical parameter for assessing the durability and integrity of concrete, also showed adverse effects with higher NGP content. For example, the crack width in pipes increased from 0.3 mm at 0% NGP to 0.6 mm at 50% NGP. The doubling of crack width suggests a significant compromise in durability, leading to greater permeability and susceptibility to environmental degradation. The larger crack widths can be linked to the reduced tensile and flexural strength of NGP concrete, which makes it more prone to cracking under stress.

The observed reduction in mechanical properties with increasing NGP content can be attributed to several factors. Firstly, the intrinsic properties of NGP, such as its lower density and higher organic content, result in a less dense and weaker concrete matrix. Secondly, the bond between NGP and the cement paste is inherently weaker than that between traditional aggregates and cement, reducing overall strength and cohesion. Lastly, the increased porosity and water absorption associated with NGP contribute to higher shrinkage and crack formation, further degrading the mechanical performance of the concrete.

#### *3.1.7. Porosity*

Porosity is a critical property that determines the volume of voids within the concrete matrix, influencing durability and mechanical strength. The results show that the porosity of concrete increases with the addition of NGP. For instance, the porosity of beams rose from 8% at 0% NGP to 12% at 50% NGP. This 50% increase in porosity can be attributed to the finer particle size and irregular shape of NGP compared to conventional coarse aggregates. NGP particles, due to their organic nature, do not pack as efficiently, resulting in more void spaces within the concrete matrix. This increased porosity leads to reduced density and, consequently, lower overall strength and durability of the concrete.

#### *3.1.8. Water Absorption*

Water absorption measures the concrete's capacity to absorb and retain moisture, affecting its durability and susceptibility to damage. The results indicate a significant increase in water absorption with higher NGP content. For columns, water absorption values rose from 5% at 0% NGP to 9% at 50% NGP. This 80% increase in water absorption can be attributed to the higher porosity and organic content of NGP, which have a higher affinity for water compared to traditional aggregates. Increased water absorption can lead to greater vulnerability to freeze-thaw cycles, chemical attack, and overall deterioration, as water can carry harmful substances into the concrete and cause expansion and cracking when it freezes. NGP, being an organic material with a lower density than traditional aggregates, introduces more voids and increases the overall porosity of the concrete. The irregular shape and finer particle size of NGP prevent the formation of a dense, closely packed matrix, leading to higher water absorption due to the increased volume of interconnected pores.

### *3.2. Multicriteria Analysis of Needle Grass Powder (NGP) in Precast Concrete Elements*

Incorporating Needle Grass Powder (NGP) in concrete mixes as a partial replacement for coarse aggregates offers promising potential in terms of sustainability and cost-effectiveness.

To evaluate the viability of this approach, a comprehensive multicriteria analysis was conducted, assessing the economic, mechanical, environmental, and physical impacts of various NGP replacement levels (0%, 10%, 25%, and 50%) across different precast concrete elements, including beams, columns, slabs, walls, and pipes.

The analysis involved multiple steps:

1. Data Collection: Quantitative data on cost, mechanical properties (compressive, tensile, flexural strength, deflection, shrinkage, crack width), and environmental impacts (CO2 emissions, resource conservation) were gathered for each precast element at each NGP replacement level.
2. Normalization and Weighting: Each criterion was normalized and weighted to facilitate a fair comparison across different metrics.
3. Scoring: Each element and replacement level were scored based on the collected data, and the scores were used to create a comprehensive decision matrix.
4. Economic Impact: The cost analysis considered the price per ton of concrete, factoring in the reduced cost of aggregates when NGP was used (Table 7).
5. Environmental Impact: The environmental impact was assessed based on potential reductions in CO2 emissions and natural resource conservation due to the use of NGP, an agricultural byproduct (Table 8).
6. Mechanical and physical Impact: Mechanical properties were evaluated through compressive, tensile, and flexural strength tests, alongside measurements of deflection, shrinkage and crack width (Table 9); furthermore, the physical properties impact (water absorption and porosity) is given in (Table 10).
7. Matrix Decision: The decision matrix aggregates scores from economic, environmental, mechanical, and physical properties for each precast element and NGP replacement level; the results are summarized in (Table 11).

The multicriteria analysis aimed to evaluate the impacts of incorporating Needle Grass Powder (NGP) to replace coarse aggregates in precast concrete elements like beams, columns, slabs, walls, and pipes. The analysis covered mechanical properties (compressive strength, tensile strength, flexural strength, shrinkage, and crack width), physical properties (porosity and water absorption), environmental impacts ($CO_2$ reduction and resource conservation), and economic implications (cost per ton of concrete). The results demonstrated that increasing NGP content leads to notable cost reductions due to the lower price of NGP compared to traditional aggregates, with the most substantial savings at 50% replacement.

Technically, including NGP in concrete mixes led to a nuanced impact on mechanical properties. Compressive and tensile strengths showed slight declines with higher NGP content, attributed to the reduced interlocking capability and bonding strength between the cement matrix and the finer NGP particles. Flexural strength remained relatively stable, suggesting that NGP contributes adequately to load distribution within the composite. However, the shrinkage values increased with higher NGP percentages, indicating a higher propensity for volumetric changes during drying, which could affect structural integrity over time. Crack width analysis revealed that higher NGP content could lead to slightly wider cracks, potentially compromising the long-term durability of the concrete. Despite these mechanical trade-offs, the cost reduction and environmental sustainability benefits underscore the viability of NGP as an eco-friendly and economical alternative for concrete production.

**Table 7. The economic impact of adding NGP grains**

| Precast element | NGP replacement | Cost (Mad/ton) | Cost reduction |
|---|---|---|---|
| Beams | 0 | 674.98 | 0 |
| | 10 | 620.98 | 8 |
| | 25 | 566.98 | 16 |
| | 50 | 485.99 | 28 |
| Columns | 0 | 701.98 | 0 |
| | 10 | 647.98 | 7.7 |
| | 25 | 593.98 | 15.4 |
| | 50 | 512.98 | 26.9 |
| Slabs | 0 | 647.98 | 0 |
| | 10 | 593.98 | 8.3 |
| | 25 | 539.98 | 16.7 |
| | 50 | 458.99 | 29.2 |
| Pipes | 0 | 688.48 | 0 |
| | 10 | 634.48 | 7.8 |
| | 25 | 580.48 | 15.7 |
| | 50 | 499.49 | 27.5 |
| Walls | 0 | 661.48 | 0 |
| | 10 | 607.48 | 8.2 |
| | 25 | 553.48 | 16.3 |
| | 50 | 472.49 | 28.6 |

**Table 8. The environmental impact of adding NGP grains**

| Precast element | NGP (%) | Compressive strength (MPa) | Tensile strength (MPa) | Flexural strength (MPa) | Shrinkage (mm/m) | Crack width (mm) |
|---|---|---|---|---|---|---|
| Beams | 0 | 35 | 3.45 | 6 | 0.5 | 0.3 |
| | 10 | 32 | 3.17 | 5.7 | 0.55 | 0.4 |
| | 25 | 30 | 2.95 | 5.4 | 0.6 | 0.45 |
| | 50 | 28 | 2.725 | 5 | 0.65 | 0.5 |
| Columns | 0 | 38 | 3.757 | 6.5 | 0.5 | 0.3 |
| | 10 | 35 | 3.45 | 6.2 | 0.55 | 0.4 |
| | 25 | 33 | 3.276 | 5.9 | 0.6 | 0.45 |
| | 50 | 30 | 2.9275 | 5.5 | 0.65 | 0.5 |
| Slabs | 0 | 36 | 3.55 | 6.3 | 0.5 | 0.3 |
| | 10 | 34 | 3.35 | 6 | 0.55 | 0.4 |
| | 25 | 31 | 3.025 | 5.7 | 0.6 | 0.45 |
| | 50 | 29 | 2.875 | 5.3 | 0.65 | 0.5 |
| Walls | 0 | 34 | 3.375 | 6.1 | 0.5 | 0.3 |
| | 10 | 31 | 3.04 | 5.8 | 0.55 | 0.4 |
| | 25 | 28 | 2.75 | 5.4 | 0.6 | 0.45 |
| | 50 | 26 | 2.58 | 5 | 0.65 | 0.5 |
| Pipes | 0 | 35 | 3.48 | 6.2 | 0.5 | 0.3 |
| | 10 | 32 | 3.18 | 5.9 | 0.55 | 0.4 |
| | 25 | 30 | 2.95 | 5.6 | 0.6 | 0.45 |
| | 50 | 28 | 2.8 | 5.2 | 0.65 | 0.5 |

Table 9. The mechanical impact of adding NGP grains

| Precast element | NGP replacement (%) | $CO_2$ reduction (%) | Resource conservation (%) |
|---|---|---|---|
| Beams | 0 | 0 | 0 |
| | 10 | 5 | 10 |
| | 25 | 15 | 25 |
| | 50 | 30 | 50 |
| Columns | 0 | 0 | 0 |
| | 10 | 5 | 10 |
| | 25 | 15 | 25 |
| | 50 | 30 | 50 |
| Slabs | 0 | 0 | 0 |
| | 10 | 5 | 10 |
| | 25 | 15 | 25 |
| | 50 | 30 | 50 |
| Pipes | 0 | 0 | 0 |
| | 10 | 5 | 10 |
| | 25 | 15 | 25 |
| | 50 | 30 | 50 |
| Walls | 0 | 0 | 0 |
| | 10 | 5 | 10 |
| | 25 | 15 | 25 |
| | 50 | 30 | 50 |

Table 10. The physical impact of adding NGP grains

| Precast element | NGP replacement (%) | Water absorption (%) | Porosity (%) |
|---|---|---|---|
| Beams | 0 | 6 | 10 |
| | 10 | 7 | 11 |
| | 25 | 8 | 13 |
| | 50 | 10 | 16 |
| Columns | 0 | 5 | 9 |
| | 10 | 6 | 10 |
| | 25 | 7 | 12 |
| | 50 | 9 | 15 |
| Slabs | 0 | 6 | 12 |
| | 10 | 7 | 13 |
| | 25 | 8 | 15 |
| | 50 | 11 | 18 |
| Pipes | 0 | 5 | 11 |
| | 10 | 6 | 12 |
| | 25 | 7 | 14 |
| | 50 | 9 | 17 |
| Walls | 0 | 7 | 14 |
| | 10 | 8 | 15 |
| | 25 | 9 | 17 |
| | 50 | 12 | 20 |

**Table 11. The Decision matrix for NGP incorporation**

| Precast element | NGP replacement (%) | Economic Impact (Score) | Environmental Impact (Score) | Mechanical Impact (Score) | Physical Impact (Score) | Total (Score) |
|---|---|---|---|---|---|---|
| Beams | 0 | 1 | 1 | 10 | 9 | 21 |
| | 10 | 3 | 3 | 9 | 8 | 23 |
| | 25 | 5 | 5 | 7 | 6 | 23 |
| | 50 | 8 | 8 | 5 | 4 | 25 |
| Columns | 0 | 1 | 1 | 10 | 10 | 22 |
| | 10 | 3 | 3 | 9 | 8 | 23 |
| | 25 | 5 | 5 | 7 | 7 | 24 |
| | 50 | 7 | 8 | 5 | 5 | 25 |
| Slabs | 0 | 1 | 1 | 10 | 8 | 20 |
| | 10 | 3 | 3 | 9 | 7 | 22 |
| | 25 | 5 | 5 | 7 | 5 | 22 |
| | 50 | 8 | 8 | 5 | 4 | 25 |
| Pipes | 0 | 1 | 1 | 10 | 9 | 21 |
| | 10 | 3 | 3 | 9 | 8 | 23 |
| | 25 | 5 | 5 | 7 | 6 | 23 |
| | 50 | 8 | 8 | 5 | 5 | 26 |
| Walls | 0 | 1 | 1 | 10 | 7 | 19 |
| | 10 | 3 | 3 | 9 | 6 | 21 |
| | 25 | 5 | 5 | 7 | 5 | 22 |
| | 50 | 8 | 8 | 5 | 3 | 24 |

## 4. Conclusion

The investigation into using Needle Grass Powder (NGP) as a partial replacement for coarse aggregates in precast concrete elements has yielded promising results, demonstrating the material's potential to contribute significantly to sustainable construction practices. The study comprehensively analyzed the economic, environmental, mechanical, and physical impacts of NGP integration at various replacement levels (0%, 10%, 25%, and 50%) across different precast concrete applications, including beams, columns, slabs, walls, and pipes. Economically, incorporating NGP presents a viable solution to reduce the overall cost of concrete production. The cost analysis revealed a progressive decrease in material costs as the percentage of NGP increased, with the most notable cost reductions observed at the 50% replacement level. This economic benefit is particularly significant in regions where reducing construction costs is critical for economic development and infrastructure expansion. The findings suggest that NGP can serve as a cost-effective alternative to traditional aggregates, making sustainable construction more accessible and affordable.

From an environmental perspective, using NGP aligns with the global push towards greener building materials. The analysis indicated substantial reductions in $CO_2$ emissions and resource conservation benefits, primarily due to the lower environmental footprint of NGP compared to conventional aggregates. By diverting agricultural residues from landfills and repurposing them in concrete, the study highlights the potential of NGP to contribute to a circular economy. This helps minimise environmental pollution and conserves natural resources, promoting more sustainable and eco-friendly construction practices.

Mechanically, the study provided detailed insights into the performance of NGP-enhanced concrete. While a slight reduction in compressive and tensile strength was noted with higher NGP content, the concrete mixes maintained adequate strength for structural applications. The flexural strength remained stable, indicating that NGP could effectively support load distribution within the composite. However, the increased shrinkage and crack width observed at higher NGP levels suggest a need for careful consideration in structural applications where long-term durability and dimensional stability are critical. Despite these mechanical trade-offs, the benefits in terms of cost reduction and environmental sustainability support the use of NGP as a viable aggregate substitute.

Physically, the impact of NGP on concrete properties such as porosity and water absorption was significant. The analysis revealed that higher NGP content led to increased porosity and water absorption, which could affect the long-term durability and performance of concrete structures. These findings underscore the importance of optimizing NGP content to balance mechanical performance with durability requirements. The study suggests that further research and development could focus on enhancing the compatibility of NGP with cementitious matrices to mitigate these effects and improve overall performance.

The comprehensive multicriteria analysis demonstrated the holistic benefits of integrating NGP in concrete production. The scoring matrix, which considered economic, environmental, mechanical, and physical impacts, highlighted the overall advantage of using NGP, particularly at higher replacement levels, despite the need to address specific mechanical and durability concerns. The study advocates for a balanced approach that leverages the economic and environmental benefits of NGP while maintaining an acceptable level of performance in critical mechanical and physical properties. In conclusion, the research provides a strong foundation for the broader adoption of NGP as a sustainable alternative in concrete production. The findings underscore the potential of agricultural residues to transform the construction industry by providing eco-friendly, cost-effective, and sustainable materials. By integrating NGP into concrete, the study supports waste minimization and resource conservation and promotes innovative construction practices that align with global sustainability goals. Future research should focus on optimizing NGP formulations and exploring advanced technologies to enhance the performance and durability of NGP-enhanced concrete, thereby paving the way for more resilient and sustainable construction solutions.

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