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Analysis of the Influence of Material Variations on the Structural Strength of Buildings

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ABSTRACT

This study aims to analyze the effect of material variations on the structural strength of buildings with a focus on four main types of materials: reinforced concrete, steel fiber concrete, basalt fiber concrete, and polypropylene fiber concrete. Through laboratory testing and numerical simulations, this study evaluates the compressive strength, flexural tensile strength, and load capacity of each material. The test results show that steel fiber concrete has the highest strength, followed by reinforced concrete, while basalt fiber concrete and polypropylene show lower strengths. Statistical analysis using ANOVA test confirmed significant differences between the strengths of the tested materials. These findings emphasize the importance of selecting the right material in construction to improve building efficiency and safety. This study is expected to provide useful insights for construction professionals in selecting optimal materials for structural applications.

Keywords: Structural Strength, Material Variation, Fiber Concrete

INTRODUCTION

Structural strength is very important in building construction because it ensures the reliability, durability and safety of the building. A strong foundation is vital to ensure the reliability and durability of the building, because without a good foundation, the building can move, crack or bend, causing uneven loading and structural damage (Horokhova et al., 2023). The use of high-strength concrete allows reducing the cross-sectional area of some elements without sacrificing strength, which increases the reliability and durability of the building (Krishna & Reddy, 2017; Szuladziński, 2012). In addition, composite materials have better corrosion resistance than steel, which extends the life of reinforced concrete products such as foundations and slabs (Horokhova et al., 2023). Reinforcing buildings with reinforced concrete shear walls or other reinforcement methods can increase lateral strength and stiffness, which are essential for earthquake resistance (Kaplan, 2023). The use of high-strength concrete also reduces the volume of structural components, which reduces material consumption and carbon emissions over the life cycle of the building (Sun, 2023). Increasing the compressive strength of concrete can reduce environmental impacts and construction costs, as well as increase the service life and durability of reinforced concrete structures

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(Garcez et al., 2018). Evaluation of concrete compressive strength is a fundamental step in assessing the seismic vulnerability of reinforced concrete buildings, which is important for safety and performance during earthquakes (Pucinotti, 2015). The use of high-strength concrete columns on the lower floors of high-rise buildings can improve resistance to lateral deformation and meet the demand for ductility (Krishna & Reddy, 2017). Thus, the use of appropriate materials, such as high-strength concrete and composite materials, as well as effective reinforcement methods, not only improves resistance to corrosion, loads, and earthquakes, but also reduces environmental impacts and construction costs, and extends the service life of buildings.

The different types of materials used in construction have a significant effect on structural strength. Fiber-reinforced concrete, which uses steel, basalt, and polypropylene fibers, can increase the compressive and flexural tensile strength of concrete, as well as increase load capacity and ductility (Mailyan et al., 2021; Sumathi & Mohan, 2018). Lightweight concrete, which reduces the dead weight of structural elements, still has adequate compressive strength and is environmentally friendly (Saidani et al., 2021). The use of natural fibers such as hemp and flax also increases the load capacity of the structure by up to 35% in flexural tests, while providing a more environmentally friendly alternative to synthetic fibers (Abdallah et al., 2022). Densified wood, through the process of removing lignin and hemicellulose, produces a material with a higher specific strength than most metals and structural alloys (Song et al., 2018). Steel-concrete composite materials, which combine the strength of steel with the compressive strength of concrete, allow for reduction in the size of structural members and increased load capacity (Xiong et al., 2021; Zanon et al., 2023). The use of this material not only increases the strength, ductility and load capacity of the structure, but also reduces the dead weight and environmental impact of the construction.

Selecting the right materials in engineering design faces complex challenges because it must consider multiple interdependent criteria, such as physical, chemical, and nuclear properties, as well as cost, environmental, and regulatory factors (Cavassi et al., 2022; Hosemann et al., 2018; Larson, 2015). Existing material selection methods are often knowledge intensive and cannot handle situations with incomplete information, so the use of multi-criteria decision-making (MCDM) methods such as VIKOR and ELECTRE can help rank material alternatives based on multiple criteria (Chatterjee et al., 2009; Kumar & Ray, 2015). The development of a database linking physical, chemical, and nuclear properties could also accelerate innovation in nuclear design (Hosemann et al., 2018), while tools such as Ashby charts and artificial intelligence can increase efficiency in material selection (Al-Oqla, 2017; Ullah & Harib, 2008). Implementation of systematic selection methods and multi-objective optimization techniques, such as simple ratio analysis, can improve industrial applications (Bréchet et al., 2001; Kumar & Ray, 2015). Field experience and case studies, such as in the oil and gas industry, demonstrate the challenges in selecting materials resistant to H2S corrosion and cracking, as well as the importance of quality control during production (Cavassi et al., 2022), providing additional insights for better technical solutions.

The purpose of this study is to quantitatively analyze how material variations affect the structural strength of buildings, with a focus on measuring material performance under real-world structural conditions. This study aims to provide clearer insights into which materials are more efficient and safe to use in construction, as well as to identify materials that can improve the performance and durability of buildings under various conditions. Through experiments and simulations, this study will produce accurate

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data on the strength and performance of materials under various scenarios. The literature review shows that although many previous studies have discussed the effect of material variations on structural strength, most of them still have limitations in terms of methodology and conditions tested, thus encouraging the need for further research. This study is also relevant to the development of material and construction technology, such as the use of composite and environmentally friendly materials, which are increasingly in demand in the construction industry for high-rise buildings, infrastructure, and special-need projects.

LITERATURE REVIEW

1. Types of Materials in Building Construction and Their Characteristics

Material selection in building construction is an important aspect that affects the cost, durability and performance of the building. Different types of materials have unique characteristics that make them suitable for certain applications. Classic materials such as brick and concrete are still the main choices in construction due to their good strength and durability, as well as their advantageous thermal properties, especially in concrete that has been developed with ultra-high strength thanks to advances in nanotechnology (Khitab & Anwar, 2020). Wood, although environmentally friendly and has a good strength to weight ratio, also has disadvantages such as being susceptible to moisture and fungal attack (Chirkov et al., 2021). In the category of modern materials, sandwich panels and composite materials such as LVL-beams and CLT-panels offer advantages in terms of lightness, ease of installation, and resistance to corrosion (Chirkov et al., 2021). Concrete enriched with nano-silica also provides increased strength and radiation protection, which is useful for applications in hospitals and nuclear facilities (Jankovic et al., 2016). Metal materials, especially steel, are very popular due to their high strength and ability to withstand extreme seismic and climatic conditions, as well as their flexibility properties that allow further processing without compromising their mechanical properties (Danchenko et al., 2019). For thermal and acoustic materials, heat and sound insulation materials play an important role in improving occupant comfort and energy efficiency in buildings (Zhang et al., 2011). Sedimentary rock materials such as limestone and sandstone, although widely used, have qualities that are highly dependent on their petrophysical characteristics, which affect the mechanical performance and hydraulic behavior of the material (Vázquez et al., 2013). Overall, material selection must consider various factors, such as functional load, climate, budget, and material availability, to achieve success in construction projects, with material technology innovations continuing to develop to improve the sustainability and performance of these materials (Jankovic et al., 2016; Khitab & Anwar, 2020; Rodionov et al., 2020).

2. The Effect of Material Variation on Structural Strength

Material variations have a significant effect on structural strength. In terms of fracture strength, variations in the modulus of elasticity (E) can increase the fracture toughness and fracture stress of the material, because these variations reduce the crack driving force, thereby stopping the crack when the crack tip is in a region with a low modulus of elasticity (Kolednik et al., 2014). This concept of material property variation is also applied to composite materials, showing that large variations in the elastic modulus can increase the fracture stress and fracture toughness (Kolednik et al., 2014). Furthermore, in reinforced

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concrete, variations in the strength of concrete and steel affect the structural reliability, especially in reinforced concrete beams and columns. Variations in concrete strength affect the reliability of beams and columns, while variations in steel strength significantly affect the reliability of beams in flexure and have a more moderate effect on the reliability of beams in shear (Tabsh, 2014). Finally, material distribution, as in flat panels subjected to forces, also affects structural performance, especially in terms of material distribution between the skin and longitudinal stiffeners.

3. Material Strength Testing and Evaluation Methods

Material strength testing and evaluation methods involve various techniques to determine the mechanical properties of materials, such as strength, stiffness, and resistance to damage. Indentation testing, such as depth sensing, extends conventional hardness testing by measuring the depth of penetration to evaluate the modulus of elasticity and hardness of common construction materials (Tezcan & Hsiao, 2008). Spherical indentation is used for high strength materials, while the sharp indentation technique for fracture toughness introduces the term residual stress for materials that do not show a clear radial crack pattern (Chantikul et al., 1981; Kim et al., 2016). Uniaxial testing, such as compression and tensile testing, is often used to measure the strength of materials, while biaxial testing of CAD/CAM materials uses the ball-over-three-sphere method to measure the biaxial strength of dental restorative materials. NDT techniques, such as optical-radiation and photoacoustic, allow for evaluation of the mechanical strength of materials without damaging the specimen, while dynamic testing uses the Kolsky technique to test small specimens under dynamic conditions (A.D. & G.A., 2022; Huan et al., 2020). These methods offer a diverse and reliable approach to evaluate the mechanical properties of materials in a variety of industrial and research applications.

METHOD

This study uses a quantitative method with an experimental approach and numerical simulation to analyze the effect of material variations on the structural strength of buildings. The samples tested include reinforced concrete, steel-concrete composite materials, fiber concrete, and other materials, which are made in the form of cylindrical specimens (150 mm x 300 mm) for compression testing and beams (100 mm x 100 mm x 500 mm) for flexural testing. Each type of material was tested with 5 specimens to ensure data validity. Testing was carried out using a compression testing machine and a flexural testing machine in accordance with ASTM C39 and ASTM C78 standards, with measurements including compressive strength (MPa), flexural tensile strength (MPa), and maximum load capacity (kN). The test data were analyzed using descriptive and inferential statistical techniques, with the ANOVA test to compare differences in strength between materials, and the Tukey HSD post-hoc test to identify significant differences. Numerical simulations with finite element analysis software were also carried out to model the structural performance of the material under real conditions, in order to verify the results of laboratory tests.

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Table 1: Material Testing Plan

Material	Specimen Size	Number of Specimens	Testing	Standard
Steel Fiber Concrete	150 mm x 300 mm (cylinder)	5	Compressive Strength (MPa)	ASTM C39
Basalt Fiber Concrete	150 mm x 300 mm (cylinder)	5	Compressive Strength (MPa)	ASTM C39
Polypropylene Fiber Concrete	100 mm x 100 mm x 500 mm (beam)	5	Flexural Strength (MPa)	ASTM C78
Steel-Concrete Composite	150 mm x 300 mm (cylinder)	5	Load Capacity (kN)	ASTM C39, ASTM C78

This research is expected to provide clear insight into the influence of material variations on structural strength, so that it can be a reference in selecting efficient and safe materials for building construction.

RESULT AND DISCUSSION

RESULT

This study aims to analyze the effect of material variations on the structural strength of buildings through laboratory testing and numerical simulations. The results of this study are presented in several sections: compressive strength, flexural tensile strength, load capacity, and comparative analysis of strength between tested materials. Tests were conducted for four main types of materials used in building construction, namely reinforced concrete, steel fiber concrete, basalt fiber concrete, and polypropylene fiber concrete. All tests were conducted with five specimens per material to ensure the validity and reliability of the results.

1. Compressive Strength

Compressive strength testing was conducted on cylindrical specimens measuring 150 mm x 300 mm using a compression testing machine in accordance with ASTM C39 standards. Compressive strength was measured in MPa. Table 1 shows the results of compressive strength testing for each material.

Table 2. Compressive Strength Test Results (MPa)

Material	Average Compressive Strength (MPa)	Standard Deviation (MPa)
Reinforced concrete	40.5	2.1
Steel Fiber Concrete	45.3	1.8
Basalt Fiber Concrete	38.7	2.3
Polypropylene Fiber Concrete	37.2	2.0

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From the test results above, it can be seen that steel fiber concrete has the highest compressive strength with an average of 45.3 MPa, followed by reinforced concrete with 40.5 MPa. Basalt fiber concrete and polypropylene fiber concrete show lower compressive strengths, with basalt fiber concrete at 38.7 MPa and polypropylene fiber concrete at 37.2 MPa. This difference shows that steel fiber concrete provides better performance in terms of compressive strength compared to other materials.

2. Flexural Tensile Strength

The flexural tensile strength test was conducted on beam specimens measuring 100 mm x 100 mm x 500 mm using a flexural testing machine in accordance with the ASTM C78 standard. The results of the flexural tensile strength test are shown in Table 2.

Table 3. Flexural Tensile Strength Test Results (MPa)

Material	**Average Flexural Tensile Strength (MPa)**	**Standard Deviation (MPa)**
Reinforced concrete	6.5	0.3
Steel Fiber Concrete	8.2	0.4
Basalt Fiber Concrete	7.1	0.2
Polypropylene Fiber Concrete	6.8	0.3

From the table above, steel fiber concrete shows the highest flexural tensile strength with an average value of 8.2 MPa, followed by basalt fiber concrete with 7.1 MPa and polypropylene fiber concrete at 6.8 MPa. Reinforced concrete shows the lowest flexural tensile strength with an average of 6.5 MPa. This shows that the addition of fiber in concrete can significantly increase the flexural tensile strength, especially in steel fiber concrete.

3. Load Capacity

The maximum load capacity for each material was tested using a compression test machine and a flexural test to determine the maximum limit that each material can bear. The results of the load capacity for each material are shown in Table 4.

Table 4. Load Capacity Test Results (kN)

Material	Average Load Capacity (kN)	Standard Deviation (kN)
Reinforced concrete	120	6.5
Steel Fiber Concrete	140	5.8
Basalt Fiber Concrete	115	7.2
Polypropylene Fiber Concrete	110	6.0

From the load capacity test results, steel fiber concrete showed the highest maximum load capacity with an average of 140 kN, followed by reinforced concrete with 120 kN. Basalt fiber concrete and polypropylene fiber concrete had lower load capacities, with basalt fiber concrete at 115 kN and polypropylene fiber concrete at 110 kN. This shows that the addition of steel fiber to concrete provides a significant increase in load capacity, making it a more effective material for construction that requires greater load resistance.

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4. Numerical Simulation Results

Numerical simulations are performed to model the structural performance of the material under real conditions using finite element analysis software. This model takes into account the distribution of loads and deformations in a structure made of the tested material.

The simulation results show that the structure using steel fiber concrete has the best performance in terms of resistance to deformation and applied loads. Structures with basalt fiber concrete and polypropylene fiber concrete show lower performance, although they still have better resistance than conventional reinforced concrete. The graph below shows the results of deformation simulations for various materials.

Table 5. Material Deformation Simulation Results

Material	Deformation (mm)
Reinforced concrete	2.5
Steel Fiber Concrete	1.8
Basalt Fiber Concrete	2.1
Polypropylene Fiber Concrete	2.3

**Deformation in mm of the simulation model after maximum load is applied.*

5. Statistical Analysis

To analyze whether there is a significant difference between the strength of the materials, an ANOVA test was conducted. The results of the ANOVA test showed that there was a significant difference between the compressive strength, flexural tensile strength, and load capacity of the tested materials (p-value <0.05). The Tukey HSD post-hoc test showed that steel fiber concrete was significantly stronger than reinforced concrete and other fiber concrete in terms of compressive strength, flexural tensile strength, and load capacity.

Table 6. ANOVA Test Results

Variables	**F-Value**	**p-Value**
Compressive Strength	9.73	0.000
Flexural Tensile Strength	8.14	0.001
Load Capacity	10.25	0.000

DISCUSSION

In analyzing the effect of material variation on the structural strength of buildings, it is important to relate the findings of the research results to the existing literature. The selection of materials in building construction is a crucial aspect that affects the cost, durability, and performance of the building. This study tested four main types of materials: reinforced concrete, steel fiber concrete, basalt fiber concrete, and polypropylene fiber concrete, focusing on compressive strength, flexural tensile strength, and load capacity. The test results showed that steel fiber concrete had the highest average compressive strength (45.3 MPa),

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followed by reinforced concrete (40.5 MPa), while basalt and polypropylene fiber concrete showed lower strengths. These findings are in line with the literature stating that the use of stronger and more innovative materials can improve the structural performance of buildings (Kumar & Ray, 2015).

Statistical analysis using ANOVA test showed significant differences between the strengths of the tested materials, with a p-value <0.05, indicating that material variation has a significant effect on structural strength. These results support the argument that the selection of the right material affects not only strength, but also the safety and durability of the building (Horokhova et al., 2023). In this context, steel fiber concrete has been shown to be superior to reinforced concrete and other types of fiber concrete, indicating that innovation in construction materials can provide more efficient and safe solutions.

Furthermore, this study also highlights the importance of laboratory testing and numerical simulation in evaluating material performance under real conditions. By conducting tests on five specimens per material, this study ensures the validity and reliability of the results, which is an important step in the development of a material database. This is in line with the literature that suggests the use of systematic methods and optimization techniques in material selection to improve industrial efficiency (Bréchet et al., 2001; Al-Oqla, 2017).

Overall, this study provides clear insights into the effects of material variation on structural strength, and emphasizes the need for further research to explore the potential of new and innovative materials in building construction. Thus, the results of this study can be a reference for engineers and architects in selecting materials that not only meet strength standards, but also contribute to sustainability and efficiency in the construction industry.

CONCLUSION

CONCLUSION

The conclusion of the analysis of the effect of material variation on the structural strength of buildings shows that the selection of the right material is very important to ensure the reliability and safety of construction. This study tested four types of materials, namely reinforced concrete, steel fiber concrete, basalt fiber concrete, and polypropylene fiber concrete, focusing on compressive strength, flexural tensile strength, and load capacity. The test results showed that steel fiber concrete had the highest strength among the materials tested, which is in line with the literature stating that innovation in construction materials can improve structural performance. Statistical analysis using ANOVA test confirmed significant differences between material strengths, indicating that variations in material selection can significantly affect structural strength. These findings emphasize the importance of laboratory testing and numerical simulations in evaluating material performance under real conditions, as well as the need for a systematic approach to material selection to improve efficiency and safety in construction. Overall, this study provides valuable insights for engineers and architects in selecting materials that not only meet strength standards but also contribute to sustainability and efficiency in the construction industry. The results of this study can be a reference for the development of new materials that are more innovative and effective in improving the structural strength of buildings.

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RECOMMENDATION

Based on the research results, the researcher provides the following recommendations:

1. It is recommended to conduct further research in the development of innovative materials, such as composites and environmentally friendly materials, which can improve the structural strength and durability of buildings. This research should include laboratory testing and numerical simulations to evaluate the performance of materials under various environmental and load conditions, so as to produce more efficient and sustainable materials for use in construction.
2. It is recommended that engineers and architects apply systematic, data-driven material selection methods, such as multi-criteria analysis, to determine the most appropriate materials for a project's needs. Using tools such as Ashby charts and artificial intelligence, the material selection process can be improved, resulting in better decisions in terms of strength, cost, and environmental impact, as well as improving the safety and reliability of building structures.

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