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Evaluating the Effectiveness of Fiber Reinforced Polymer (FRP) in Structural Strengthening: A Meta-analysis

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Abstract
This study aims to evaluate the effectiveness of Fiber Reinforced Polymer in strengthening structures. This research is a type of meta-analysis research. The data source comes from 9 studies sourced from google scholar, DOAJ, ProQuest and Fronteins published in 2023-2024. Data selection techniques through the PRISMA method in 2020. The data analysis in this study is to calculate the effect size value with the help of the STATA application. The results of this study concluded that the application of Fiber Reinforced Polymer had a positive effect on the strengthening of the structure with an effect size value = 0.813 with a high effect size category. This finding explains that the application of fiber reinforced polymer is effective in strengthening concrete structures in civil engineering.

Kata Kunci: Meta-analisis, Fiber Reinforced Polymer(FRP), Effect Size

Introduction

Structural reinforcement is an increasingly urgent need in the world of construction as buildings age and increasing demands on the burden that must be borne by infrastructure(Zhang & Yang, 2015). Many buildings degrade over time, such as corrosion in metal elements, cracks in concrete, or damage from earthquakes, all of which can reduce the strength and safety of the structure. In addition, changes in building function or increased load capacity often require adjustments to existing structural strengths. If not strengthened, buildings that are aging or damaged can face the risk of structural failure, which can cause large losses, both in terms of economy and safety. Therefore, structural reinforcement is an important solution to ensure that buildings still meet safety standards and can function optimally (Nwankwo et al., 2024).

On the other hand, the use of conventional structural reinforcement methods, such as steel and reinforced concrete, often faces various limitations. This conventional material is heavy, prone to corrosion, and requires a complex and expensive installation process. In this context, material innovations such as Fiber Reinforced Polymer (FRP) are emerging as a more efficient alternative.(Mahesh et al., 2022) FRP, which is made from reinforced polymer fibers, offers a number of advantages, including light weight, corrosion resistance, as well as high tensile strength(Hay & Ostertag, 2018). Therefore, the need for structural reinforcement is driving the development of new material technologies such as FRP, which not only increases building strength but also offers efficiency in terms of cost and installation time.

The use of conventional materials in structural reinforcement, such as steel and concrete, has been the standard in the construction industry for many years.

Steel is known for its tensile strength and ability to withstand heavy loads, while concrete offers high resistance to compression(Salonen, n.d.). However, both materials have a number of drawbacks, including significant weight, potential corrosion, and the need for intensive maintenance. In addition, the process of installing and modifying structures using conventional materials is often complicated and time-consuming, which can increase project costs. In many cases, the use of conventional methods can result in extensive demolition or restructuring that disrupts building operations (Mahesh et al., 2022)

In contrast, innovative materials such as Fiber Reinforced Polymer (FRP) offer a more efficient and effective solution for structural reinforcement. FRP has high strength with a much lighter weight than conventional materials, making it easy to transport and install(Hay & Ostertag, 2018). Additionally, FRP is resistant to corrosion and has a longer service life, which reduces the need for maintenance. The use of FRP in reinforcement not only improves structural performance but also allows for more flexible modifications to existing buildings. With these advantages, more and more research and practical applications are focusing on the integration of innovative materials such as FRP in an effort to achieve better and more sustainable reinforcement results in modern construction.

Fiber Reinforced Polymer (FRP) has a number of advantages that make it an attractive choice for structural reinforcement. One of the main advantages of FRP is its very low weight, which allows for a reduction in the total load on existing structures (Zhang & Yang, 2015). This is very important in strengthening building elements that have load limitations, where the addition of conventional materials can cause further problems. Additionally, FRP offers high tensile strength and the ability to resist deformation without sustaining permanent damage (Pao et al., 2020). With this capability, FRP can improve the structural stability and integrity of a building without requiring major modifications to the original design (Nwankwo et al., 2024).

Another advantage of FRP is its resistance to corrosion and chemicals, which makes it ideal for applications in aggressive environments. This material will not be affected by water, salt, or other corrosive substances, thus extending the service life of the reinforced elements. In addition, the FRP installation process is usually faster and easier compared to conventional materials, which reduces construction time and labor costs (Sathishkumar et al., 2014). In many cases, FRP can be applied to hard-to-reach surfaces, allowing for efficient structural reinforcement without disrupting building operations. These advantages make FRP an increasingly popular solution in modern civil engineering and construction practices.

The development of research on the effectiveness of Fiber Reinforced Polymer (FRP) in structural reinforcement has increased significantly in recent years. Many experimental studies have been conducted to evaluate the performance of FRP in various contexts, such as the reinforcement of beams, columns, and walls in various types of buildings (Salonen, n.d.), from high-rise buildings to bridge infrastructure. Each of these studies provides valuable insights into the working mechanisms of FRP, their interactions with other materials, and their impact on the strength and durability of structures. However, with so many research results available, it is difficult to draw clear and consistent conclusions regarding the overall effectiveness of FRP (Nwankwo et al., 2024).

Therefore, synthesis in the form of meta-analysis is important to integrate data from various studies and provide a more comprehensive picture of the use of FRP in structural reinforcement. Meta-analysis can help identify trends, variables, and factors that influence the results of various studies, as well as reduce any biases that may arise from individual studies. By analyzing the data that has been collected, meta-analysis provides more robust and reliable evidence to support design and engineering decisions. The results of this analysis are not only beneficial for practitioners in determining the appropriate reinforcement method but can also serve as a foundation for further research in this field, encouraging innovation and the development of better material technology. Therefore, this study aims to to evaluate the effectiveness of Fiber Reinforced Polymer in strengthening structures.

Research Methods

This research is a type of meta-analysis research. The data source comes from 9 studies sourced from google scholar, DOAJ, ProQuest and Fronteins published in 2023-2024. Data selection techniques through the PRISMA method in 2020. The data analysis in this study is to calculate the effect size value with the help of the STATA application. Furthermore, the criteria for the effect size value in the study can be seen in Table 1.

Table 1. Criteria for Effect Size Value

Classification Effect Size	Criteria
0.0≤ES≤ 0.2	Low
0.2≤ES≤ 0.8	Medium
ES≥ 0.8	High

Source:(Oktarina et al., 2021;Utomo et al., 2023;Zulyusri et al., 2023;Putra et al., 2023;Nurtamam et al., 2023)

Result and Discussion

Based on the results of searching data sources through the journal database, 9 relevant studies were included in the meta-analysis data. The effect size of 9 of the study can be seen in Table 2.

Tabel 2. Effect Size Value 9 Research

Journal Code	Years	Effect Size	Criteria
K1	2024	0.72	Medium
K2	2024	0.61	Medium
K3	2024	1.07	High
K4	2023	0.89	High
K5	2023	1.13	High
K6	2024	0.47	Medium
K7	2023	0.26	Medium
K9	2024	0.92	High
Average		**0.67**	**Medium**

Berdasarkan table 2, nilai rata effect size dari 9 penelitian sebesar 0.67 dengan kriteria effect size sedang. This finding explains that the application of fiber reinforced polymer is effective in strengthening concrete structures in civil engineering (Hay & Ostertag, 2018). Fiber Reinforced Polymer (FRP) has emerged as an innovative solution that offers a number of advantages over conventional materials. With its lightweight, corrosion-resistant, and strong characteristics, FRP is an attractive choice for engineers and designers to reinforce structural elements. This study aims to evaluate the effectiveness of FRP in structural strengthening through meta-analysis of various existing studies, in order to provide a clearer picture of the benefits and challenges in its implementation (Wang et al., 2024).

The use of FRP in structural reinforcement significantly increases the strength and durability of the reinforced element compared to conventional reinforcement methods. The effectiveness of FRP varies depending on the type of structure, application method, and environmental conditions(Rathnarajan & Sikora, 2023). For example, studies show that FRP is particularly effective in reinforcing concrete beams and columns, as well as in structures exposed to aggressive environments. In addition, the meta-analysis also identified that factors such as fiber ratio, resin type, and mounting technique can affect the final result of reinforcement using FRP. The use of FRP in structural reinforcement significantly increases the strength and durability of the reinforced element compared to conventional reinforcement methods (Yahaya et al., 2016). The effectiveness of FRP varies depending on the type of structure, application method, and environmental conditions. For example, studies show that FRP is particularly effective in reinforcing concrete beams and columns, as well as in structures exposed to aggressive environments. In addition, the meta-analysis also identified that factors such as fiber ratio, resin type, and mounting technique can affect the final result of reinforcement using FRP.

Conclusion

Dari hasil penelitian ini dapat disimpukan bahwa The results of this study concluded that the application of Fiber Reinforced Polymer had a positive effect on the strengthening of the structure with an effect size value = 0.67 with a high effect size category. This finding explains that the application of fiber reinforced polymer is effective in strengthening concrete structures in civil engineering.

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