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# Residual Properties of Fiber Reinforced Concrete (FRC)

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**Abstract**

Fibre-reinforced concrete (FRC) was composite material that incorporates discrete fibres into the concrete mixture to improve its mechanical properties. The fibres used in FRC can be made of materials such as steel, glass, synthetic fibres, or natural fibres. The behaviours of a material that persist after being exposed to a process or environment are known as residual properties. The residual strength of the concrete was a crucial component of its residual characteristics. This refers to a structure's ability to support weight and withstand further deformation even when it was weak. This study used an experiment to examine the characteristics of concrete using various shapes, mainly cubes and prisms. The cube size was 100 mm x 100 mm x 100 mm, while the prisms size was 100 mm x 100 mm x 350 mm. Compressive strength test and flexural tests are the two main tests that were used in this experiment. The primary material that was used as a crucial component in this experiment was polypropylene fibre. The residual of fibre concrete was evaluated by different percentages of fibre content, which are 1%, 1.5%, and 2%. The test evaluation was done after the concrete reaches age of 28 days. The total sample for this experiment was 24. According to the findings of this study, addition of fibre reduces the workability of a concrete mix. In a similar manner, the presence of fibres in the concrete reduces compressive strength. However, the compressive strength remained within the experimentally specified range. In fact, this study examined flexural tests, and it was discovered that the highest load values were obtained from concrete with 2% of fibre. In addition, the research was also conducted in terms of peak strength, peak load deflection, and residual value, with a high fibre percentage dominating the highest value in the study. The residual load and strength for this study was discovered to occur only at a deflection of 2 mm. Finally, the results of the flexural test were found to increase in parallel with the percentage of fibres in concrete.

## 1. Introduction.

Concrete was an engineering product that has been used extensively and for a very long time throughout the world. It was a composite of fine and coarse aggregate, cement, and water (Al-Kadhim et al., 2021). The capacity to cast concrete in any shape or form makes it the most used construction material in the world. As a result, concrete was excellently suited for a variety of uses. However, due to its high brittleness and low tensile strength, concrete structures longevity and safety are affected by cracks that are simple to generate in engineering applications (Zhou et al., 2017).

Concrete that has been reinforced with tiny fibres is known as "fibre-reinforced concrete (FRC). Fibre-reinforced concrete was described as concrete formed of hydraulic cement comprising fine and coarse aggregates combined with discontinuous discrete fibres (Christoforo et al., 2023).

Next, steel, alkali-resistant glass, synthetic, and natural fibres are among the categories of used fibres. As compared to conventional concrete, FRC has a variety of benefits, including enhanced durability, hardness, and crack resistance, which are reasons it was so commonly used in construction. The addition of fibres to concrete enhances its tensile behaviour and increases its toughness, which was a measurement of the amount of energy lost during bending tests. This allows concrete to transfer stresses across broken sections (Sandokan Lorente et al., 2022).

The use of fibre-reinforced concrete can also contribute to sustainability by reducing the amount of cement required in the concrete mix and reducing carbon emissions associated with concrete production. Additionally, using waste products as fibre reinforcements, like recycled plastic fibres, helps reduce waste and advance a circular economy.

Materials' traits or behaviours that persist after going through a particular procedure or being exposed to a certain environment are referred to as their residual properties. The long-term behaviour and performance of materials can be improved with residual characteristics. It was essential to carry out damage tolerance studies, evaluating the residual characteristics of the structure after impact, to ensure that a damaged structure will not dramatically fail over service life and will preserve maximum structural efficiency (Santiuste et al., 2010).

Hence, the focus of this study was to examine characteristics of residual properties of fibre-reinforced concrete (FRC) and determine the residual flexural value. The research was measuring the compressive strength and residual flexural performance. Through this research, a comprehensive understanding of the effects of polypropylene fibre content and their residual properties on the performance and characteristics of concrete will be obtained.

## 2. Experiment and physical properties of material.

This part includes a description of the investigation's materials as well as experimental tests and methodology. The techniques described by European standards (BS EN) and the American Society for Testing and Materials (ASTM) were used to create the standards and specifications used in this study.

### *2.1 Material*

Samples were analyzed by preparing the raw ingredients, which included water, polypropylene fibre, coarse and fine aggregate, and regular Portland cement. The diameter of coarse aggregate particles can reach several inches and greater than 4.75 millimetres and for fine aggregate, it was typically smaller than 4.75 millimetres. For polypropylene fibre the length of was between 48 mm and 54 mm and the selected diameter range is not more than 0.30 mm. Figure 1 depicts the polypropylene fibre used in this experiment.

**Fig. 1** Polypropylene fibre.

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*2.2 Concrete mixture.*

The study aimed to achieve an objective compressive strength of 30 MPa and flexural strength value by preparing concrete mixes with varying amounts of polypropylene fibre (0%, 1%, 1.5%, and 2%). The Design of Engineering (DoE) method has been utilized to perform calculation and design. Each fine and coarse aggregate's material particles are sieved to make sure it passes through a 20 mm mesh, hold onto a 10 mm mesh for coarse aggregate, and pass through a 5 mm mesh for fine aggregate. Samples of concrete are soaked in water for 28 days as part of the curing process. Concrete mix design determines the amount of cement, fine aggregate, coarse aggregate, and water will be required. Table 1 and 2 shows concrete mix design for cube and prims.

**Table 1** Concrete mix design for 1 $m^3$ cube.

| Percentage (%) | Cement (kg) | Fine aggregate (kg) | Coarse aggregate (kg) | Water (litter) | Polypropylene fibre (kg) |
|---|---|---|---|---|---|
| 0 % | 0.41 | 0.79 | 0.96 | 0.21 | 0 |
| 1% | 0.41 | 0.79 | 0.96 | 0.21 | 0.0041 |
| 1.5 % | 0.41 | 0.79 | 0.96 | 0.21 | 0.0062 |
| 2 % | 0.41 | 0.79 | 0.96 | 0.21 | 0.0082 |

**Table 2** Concrete mix design for prisms.

| Percentage (%) | Cement (kg) | Fine aggregate (kg) | Coarse aggregate (kg) | Water (litter) | Polypropylene fibre (kg) |
|---|---|---|---|---|---|
| 0 % | 1.64 | 3.16 | 3.86 | 0.82 | 0 |
| 1% | 1.64 | 3.16 | 3.86 | 0.82 | 0.0164 |
| 1.5 % | 1.64 | 3.16 | 3.86 | 0.82 | 0.0246 |
| 2 % | 1.64 | 3.16 | 3.86 | 0.82 | 0.0328 |

*2.3 Testing for concrete.*

The specifications and standards used to test concrete in compliance with the American Society for Testing and Materials (ASTM) and British and European standards (BS EN) are listed in the table below. The table lists the standard being followed and the kind of test being performed.

**Table 3** Specification and standard used for testing.

| Description | Testing | Standard | Material |
|---|---|---|---|
| Fresh concrete | Slump test | BS EN 12350-2 :(2019) | Concrete workability |
| Hardened properties | Compressive Strength test. | BS EN 12390-3:(2019) | Concrete |
| | Flexural Strength test. | ASTM C 1609 | |

## 3. Result and Discussion.

### *3.1 Slump test.*

The observed decrease in slump value with increased fibre content in Table 4, was consistent with prior research in the sector. Islam et al., 2023, for example, found a similar tendency in their study of fibre-reinforced concrete, supporting the hypothesis that increasing fibre content results in decreased workability as indicated by the slump test. Furthermore, the drop in slump value can be linked to the fibres' tendency to interlock, resulting in a more rigid and less flowable concrete mixture. Hajali and Ahmed (2016), thoroughly discussed this phenomenon, emphasising the effect of fibre geometry and distribution on the properties of concrete. In addition, the constant link between fibre content and decreased slump values, as well as agreeing with previous literature, supports the conclusion that an increased amount of fibre negatively impacts the workability of concrete. For this study the desired slump value was between 30 mm and 60 mm in order to evaluate the workability of concrete mixed with polypropylene fibre.

**Table 4** Slump test result.

| Percentage (%) | Slump test (mm) | Types slump |
|---|---|---|
| 0.00 | 69.00 | True slump |
| 1.00 | 34.00 | Zero slump |
| 1.50 | 25.50 | Zero slump |
| 2.00 | 16.00 | Zero slump |

### *3.2 Compressive strength.*

This experiment was carried out on 12 concrete cubes. The samples for 0%, 1%, 1.5%, and 2% were cured in tap water for 28 days. The compressive strength of these samples was determined after being subjected to the maximum load until the concrete cracked.

The pattern was visible in figure 2, where compressive strength reaches its maximum at 0% polypropylene fibre concentration. This initial peak implies that the lack of polypropylene fibres contributes to the concrete mixture's optimal compressive strength. As the percentage of polypropylene fibre in the mix grows, compressive strength decreases noticeably, indicating a potential disruption caused by the presence of fibres in the mix. This phenomenon was similar to the findings of Nkomo et al. (2022), who evaluated the effect of polypropylene fibres on the compressive strength of concrete.

Their research found that while fibres can improve certain characteristics, they can also complicate achieving and maintaining optimal compressive strength. Despite the observed reduction in compressive strength with the addition of polypropylene fibres, the resulting strength values remain within the acceptable range for concrete applications, achieving the desired strength of 30 MPa. This was consistent with the general notion that fibre-reinforced concrete can provide a balance of enhanced qualities and potential trade-offs.

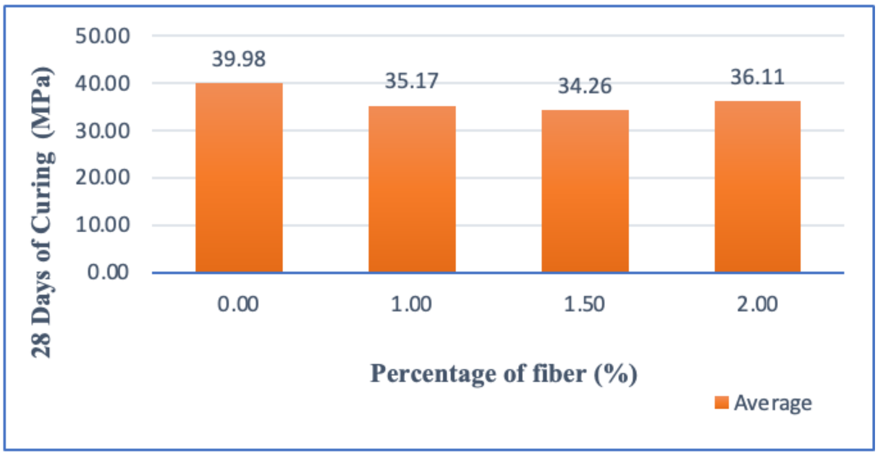


**Fig. 2** Average compressive strength of concrete for 28 days.

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*3.3 Flexural strength tests.*

This experiment involved the use of 12 concrete prisms. For 28 days, samples of 0%, 1%, 1.5%, and 2% of fibre were cured in tap water. The flexural strength of these samples was evaluated after had been subjected to the maximum load until the concrete cracked.

The results based on Figure 3 demonstrate that the average peak load began to grow with the addition of polypropylene fibre. It reveals the effectiveness of polypropylene fibre in holding a load. The capacity for load resistance was inferior as compared to concrete without fibre. For 0% of fibre, the average peak load was 6.964 kn, which was the lowest value of peak load compared to concrete with fibre existing. Following that, the average peak strength also shows that peak strength began to increase as the polypropylene fibre percentage increased. The highest value is 2.936 kN, while the lowest value is 2.09 kN.

After that, the peak load deflection value yields inconsistent results. At 0% fibre, the value is 1.2567 mm, and it begins to decrease for the 1% sample. The peak load deflection is gradually increasing for 1.5% fibre. It's because the peak load value is higher than 1% of the peak load value. Next, the value for 2% fibre began to decrease. Show that the 2% fibre can hold concrete particles with less deflection. All of the average results indicate a positive influence on concrete value. Overall, peak load and peak strength values increased as the proportion of fibre increased but peak load deflection decreased as the quantity of fibre increased.

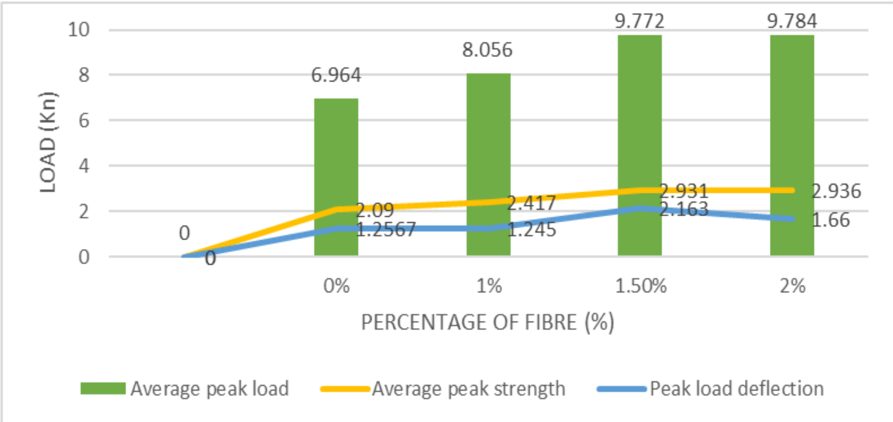


**Fig. 3** Average result of flexural strength test.

The average residual load and residual strength values for each sample are shown in figure 4. In this situation, residual value occurs only at 2 mm deflection and not at 0.5 mm deflection. The higher residual load value was at 2% sample, and the lower residual load value was at 0% sample. The residual load on the graph shows an inconsistent value. It was due to the decrease in residual load value that happened at 1.5% sample. Alongside the residual strength value, the line graph also displays the inconsistency value. The value increases for 0% and 1% samples but starts to decrease when the sample reaches 1.50%. For 2% of the sample, shows a higher value for residual strength. It was reasonable to conclude that increasing the percentage of fibre in concrete raises the residual value.

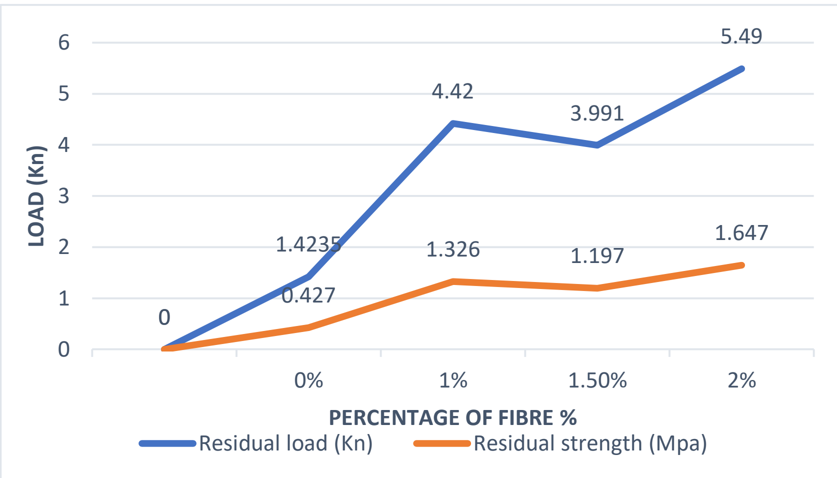

**Fig. 4** Average residual load and residual strength.

Equivalent flexural strength percentage, also known as equivalent flexural strength ratio, refers to a material's remaining flexural strength after it has cracked, represented as a percentage of its original flexural strength. According to the results, as the proportion of fibre increases, correspondingly rises the percentage of equivalent flexural strength. As observed in the bar chart, the corresponding flexural strength percentage for 0% was greater than 1% but begins to increase at 1.5% and 2%. The percentage of equivalent flexural strength with fibre clearly demonstrates the effectiveness of fibre as an additional material. Overall, a higher proportion of retained flexural strength has an advantageous impact on the concrete value. Figure 5 shows average equivalent flexural strength.

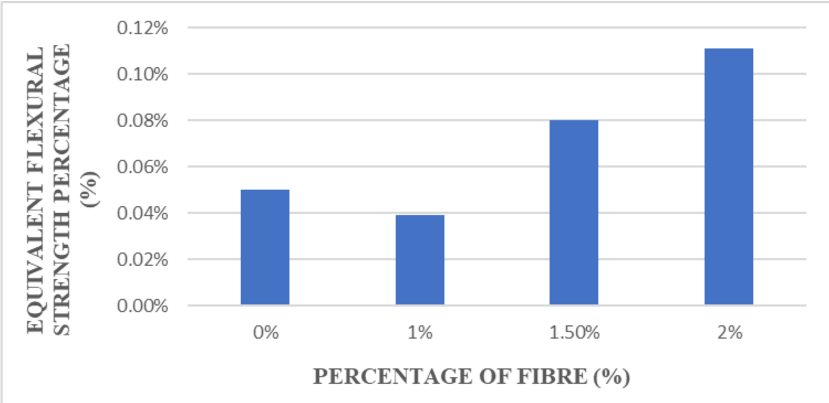


**Fig. 5** Average equivalent flexural strength percentage (%).

## 4. Conclusion

This study shows that with the presence of fibres, the residual properties of concrete can be improved. With an increase in the percentage of fibres, the ability of the balance to withstand the load even if it has been damaged increases. It can be seen in the results obtained based on the difference in fibre percentage. The sample with 2% fibre shows the highest average value for each data point obtained in the study. This shows that 2% of polypropylene fibre was very effective in improving the residual properties of concrete.

The residual flexural value in this experiment was shown with the residual strength and residual load value that obtain. The residual load and residual strength in this experiment was supposedly happen at 0.5 mm and 2 mm of net deflection based on ASTM C1609. However, since the data only obtain at 2 mm net deflection, it was used as main reference in this research. For residual strength and residual load show an increasing trend with a higher percentage of fibre.

In conclusion, this study can show that without a deep understanding of the research conducted, the main purpose of the study cannot be achieved, and the research conducted will not bring the desired results. Improvements for the future need to be implemented to ensure that the study is successful and according to the set standards.

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## Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Muhammad Fuad Abdul Rahman, Sallehuddin Shah Ayop, Muhamad Azim;* ***data collection:*** *Muhammad Fuad Abdul Rahman;* ***analysis and interpretation of results:*** *Muhammad Fuad Abdul Rahman;* ***draft manuscript preparation:*** *Muhammad Fuad Abdul Rahman, Sallehuddin Shah Ayop, Muhamad Azim.*
*All authors reviewed the results and approved the final version of the manuscript.*

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