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Mechanical Properties of Plastic, Steel, Organic Fibre Concrete: A Review

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Abstract
The mechanical properties of fibrous concrete reviewed in this research are flexural tensile, compressive, and split tensile strength. This paper is a review of many researchers on plastic, steel, and organic fiber concrete. The plastic fiber reviewed in this paper is a concrete mixture with mineral water glass waste with a volume fraction of 0.25% and L/d 37.5; steel fiber is the straight type while organic fibrous fiber is coconut husks, jute, the leaves of palm oil plants, sisal, hemp, banana leaves, pineapple leaves, bamboo bark, horse dung, rice straw, and *gelam*-bark. The performance of the three mechanical properties of non-fibrous concrete in each study is calculated in percentage. The mixtures that have superior mechanical properties are 0.5%, 2% steel-fibrous concrete (St0.5 and Sj2), 2% with aspect ratios of 75 and 50 (Ss0.5), 0.6% bamboo-bark fibrous concrete (B0.6) and 0.4% *gelam*-bark fibrous concrete (G0.4). The St 0.5 and Ss 0.5 showed increased tensile strength in the splitting test, but the increase for St 0.5 of the compressive strength was below B0.6 and G0.4. The B0.6 shows an increase in the splitting test of 45% while G0.4 shows an even increase of ± 7.5% in the three mechanical properties. Flexural tensile strength is not a function of compressive strength. The reduction in the level of ease of mixing in *gelam* bark fibrous concrete (G0.4) is the lowest compared to bamboo fibrous concrete with a volume fraction of 0.6 and steel-fibrous concrete. The flexural strength and compressive strength of plastic-fiber concrete are 2.1% and 4.7% higher, respectively than non-fiber concrete. The addition of plastic fiber is easier to mix than the addition of steel fiber.
Keywords: concrete, fiber, mechanical properties, organic, plastic, steel
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1. Introduction

Concrete has very strong compressive resistance which is a factor in predicting other concrete properties (ACI 318 2014). Because of this advantage, concrete is the material of choice for road pavements that can bear large loads. Concrete that is used as pavement must withstand running loads which may lead to continuous changes in the stress of the concrete starting from compressive tension to flexural tension and vice versa. Because of these demands, the flexural strength of concrete is a requirement especially for making rigid pavements.

As the strength of concrete in resisting tensile is only around 10% of fc', this flexural tensile strength is not considered to contribute to the bending of reinforced concrete beams. Concrete with fibres is an effort to improve the properties of concrete in resisting tension, cracking, and resistance to repeated loads. Greater ductility performance and toughness were observed with increase fibre volumes. The main advantage of reinforcing concrete with fibres from weak materials is the behaviour of the composites after cracking. The post-crack toughness produced by low elastic modulus fibres in cementitious materials allows the use of this composite construction in a large scale (Santos *et al*. 2015). No consistent or conclusive correlations between fibre volumes and the compressive strength of concrete were found (Zhong *et al*. 2021).

Plastic is very difficult to manage, the time required for plastic to decompose in the soil can be tens or even hundreds of years (Buleleng Admin 2018). Plastic waste in Indonesia reaches 64 million tons a day (VOI 2022). Many researchers have paid attention to the mixture of plastic waste in concrete. Polypropylene fibres also resist tensile very well (Santos *et al*. 2015). Compressive strength increased by 61.5% in 30mm x 5 mm x 1mm fibre plastic concrete by 0.25% volume fraction (Abdo & Jung 2019). The best compressive strength occurred at 2% additional fibre size 15-25 mm with a thickness of 5-6mm with an increase of 3.8% (Hasan *et al*. 2019). The highest split tensile strength increased by 23.29% in concrete mixed with PET bottle waste (Armidion & Rahayu 2018). The best compressive strength and flexural tensile strength occurred in an additional 5% of chopped mineral water plastic (Indah 2017). Flexural tensile strength increased by 25.8% in concrete mixed with HDPE with L/d 5 by 5% by volume of concrete (Romel & Yunan 2015). The compressive strength and flexural strength of an additional 10%, 15%, and 20% HDPE in the form of coarse aggregate decreased (Soebandiono *et al*. 2013).

Ilham, 2022 researched the flexural strength and compressive strength of polypropylene (PP) fibrous concrete from aqua plastic cups with the size of 30-50 mm long and 5mm wide. The test results showed that the flexural strength increased by 2.1% at the age of 56 days and the compressive strength increased by 4.7% at the age of 28 days.

On the 4% steel fibre plate, the initial crack is at least 0.1 mm with a load greater than the non-fibre plate load (0%) with a load of 1200 kg, whereas in the plate without steel fibre the crack width is 1.3mm with a load of 1160 kg (Ananda *et al*. 2019). If this flexural tensile strength is exceeded, cracks occur which may lead to reduced strength and stiffness of the concrete (ACI 318 2014). Adding fibre to the concrete mix can increase the flexural strength of the concrete (Shweta & Kavilkar 2014, Rana 2013). Compressive strength, tensile strength, bonding strength, and bond stress of steel-fibre-reinforced concrete increase around 13.25%, 48.70%, 10.43%, and 10.53%, respectively (Suprapto 2010). Wafa (1990) published research on concrete with steel fibres of 0.5%, 1%, and 1.5% until failure in sustaining the number of blows of 3, 4, and 11 times compared to the toughness of concrete without fibres.

Vegetable fibers follow a hierarchical structure of material in macro, micro and nanometric scales that have been used as reinforcement in cementitious materials. In nanoscale, the nano fibrillated cellulose has the advantage of having strong mechanical performance and high specific surface, which contributes to improve the adhesion of fiber and matrix (Correia *et al*. 2018).

Rice straw-fibrous concrete has been studied and reported in Ataie (2018). An attempt has been made to design a high strength fiber-reinforced concrete by proportioning the mix with natural organic fibers obtained from pulverized horse manure/dung (Sahu & Tiwari 2017). Replacement of fine aggregates of horse dung (6% cement weight; 8% sand replacement) also helped in achieving good compressive and flexural strength (Sharma *et al*. 2018). Bamboo fibe rconcrete has also been observed (Hidayat *et al*. 2016).

To improve the compatibility of kenaf and pine apple leaf fibers with polymer matrix, an investigation on the effects of alkali, silane and combined alkali and silane treatments on the mechanical (tensile), morphological, and structural properties was done (Asin *et al*. 2016). Vajje and Murthy (2013) have examined the compressive strength of concrete with jute, sisal, hemp, banana and pine apple leaf fibers. Concrete compressive strength testing with fiber from jute, palm oil leaves and polypropylene has been observed (Olaoye *et al*. 2013). Concrete with coconut husk fiber has been studied (Hasan *et al*. 2012). Studies on sisal and abaca in the form of layers have been published (Pablo 2011). Natural fibers from bananas, reed, palm and coconuts were used to reinforce cement composite (Al-Zubaidi 2018). The effect of the length of the *gelam* wood fibers (*melaleuca cajuputi*) on the tensile strength of polyester matrix composites has been observed (Saifullah & Abdurahman 2017). The mechanical properties of concrete with *gelam* bark fibrous OPC cement have been studied (Niken *et al*. 2020).

The tensile strength of *gelam* bark fibres can be greater if alkalized by immersing it in a 5% NaOH solution for 2 hours (Arif & Sidiq 2017, Kosjoko 2014, Witono *et al*. 2013).

This study aims to assess the performance of plastic, steel and organic fibre concrete to be applied appropriately.

2. Materials and Method

Materials for this study are from the literature as shown in Table 1.

There are two aspects that are observed in this study: the mechanical properties of concrete and its workability. All data or materials of plastic, steel and organic fibers concrete are taken from the research papers in Table 1covered a span of 32 years (1990-2022).

Table 1 Fibrous Concrete Research

Year	Author	Fibre	Code	Year	Author	Fibre	Code
1990	Wafa	Steel	St 0.5, 75	2018	Sharma et al	Horse dung	H6
			St 1, 75				H8 sr
			St 1.5, 75	2018	Jathia et al	Steel	Sj 1, 50
2011	Pablo	Sisal	S2 1				Sj 2, 50
		layer	S4 1				Sj 3, 50
			S6 1				Sj 4, 50
2012	Hasan et al	Cocunut husk	C4				Sj 5, 50
			C8 sr	2018	Ataie	Rice straw	R1
2012	Shende	Steel	Ss 1, 50				R2
2013	Olaoye et al	Jute		2020	Niken et al	Gelam	G0,4;28
2013	Vajje & Murthy						G0,6; 28
2013	Olaoye et al	Oil palm					G0,8; 28
2013	Vajje & Murthy	Sisal					G0,4;90
2013	Vajje & Murthy	Hemp					G0,6; 90
2013	Vajje & Murthy	Banana					G0,8; 90
2013	Vajje & Murthy	Pine apple		2022	Ilham	Cup plastic	P 3.7, 56
2016	Hidayat et al	Bambu	B0,2				
			B0,4				
			B0,6				

Note: Code, Fibre, ff = fibre fraction (%) and sr = sand replacement, specimen age (days).

The aspect ratio (fibre length / diameter) is not used in assessing organic fibrous concrete due to the difficulty in determining the diameter of the fibre. The aspect ratio in the study on steel-fibrous concrete by Wafa (1990) was 75, Shende *et al*. (2012), and Jhatial *et al*. (2018) were 50.

The principle is to calculate the increase or decrease in the performance of fibrous concrete compared to the performance of non-fibrous concrete in the author's own research and contrast it with the fibres used in the studies listed in Table 1. The same method is done in the flexural, compressive, split tensile strength and slump. If the difference is negative, this means that there is a decrease in strength compared to that of the non-fibrous concrete. From this comparison, fibrous concrete with a negative margin is negligible. Particular attention is paid to the comparison with plastic fibrous concrete against steel-fibre concrete.

Workability is measured by the slump test. As fibrous concrete slump is shorter than the slump of the non-fibrous concrete, this type of slump is more difficult to mix. The standard convenient ratio of the slump of fibrous concrete to non-fibrous concrete is 1. The smaller the ratio, the greater the decrease in the ease of mixing or the more difficult the mixing.

Upon comparing the mechanical properties and workability of the concrete mixture, the accurate mixture of certain fibres in concrete will be known.

3. Result and Discussion

The tensile strength of concrete is expressed by the modulus of rupture (ACI 318 2014). The difference between the modulus of rupture of fiber and non-fibrous concrete is presented in Figure 1.

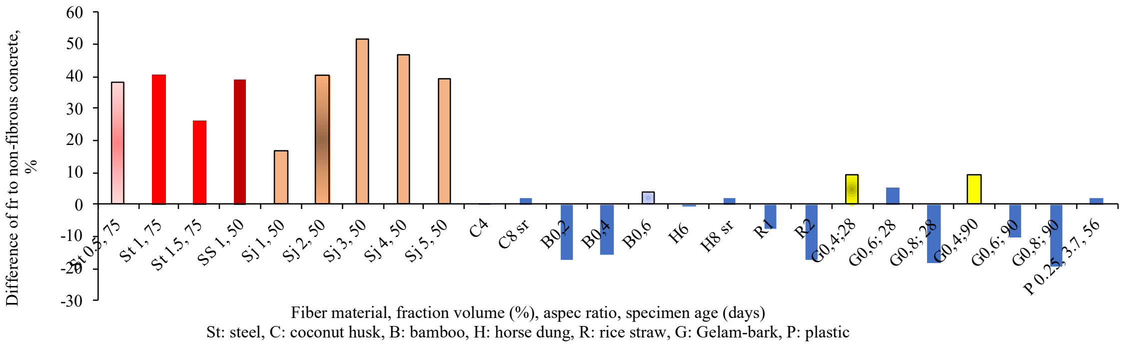

Figure 1. Modulus of rupture

Steel-fibrous concrete shows an increase of between 25-50% (Figure 1). Steel-fibrous concrete with a volume fraction of 1% and an aspect ratio of 75 (Wafa 1990) and 3% with an aspect ratio of 50 (Jhatial *et al*. 2018) showed better tensile performance than other volume fractions. Fibrous concrete in which some portion of sand was replaced with coconut husk fiber (C8 sr) and horse dung (H8 sr) showed a slight increase in flexural strength, namely 0.3 and 0.1%, followed by bamboo fiber concrete B 0.6 and gelam- bark G 0.4 (9.1%). Gelam-bark fiber-concrete is the most superior in increasing the flexural strength at the age of 28 and 90 days compared to other organic fibrous concrete with flexural strength of 9.1% and 9.4%. Gelam-bark fiber-concrete G 0.6 showed an increase at the age of 28 days, but at the age of 90 days there was a decrease. A bending test was conducted only on the gelam bark fibrous concrete of 90 days, however, no other researchers did so. Different volume fraction of fiber causes different and even reverse behaviour. The flexural strength of rice straw fibrous concrete is lower than that of non-fiber concrete. The flexural strength of plastic-fiber concrete is slightly higher (2.1%) than without fiber (Figure 1).

All researchers from Table 1 performed a compressive strength test because all other behaviours such as modulus of elasticity and modulus of rupture are functions of compressive strength in non-fibrous concrete (ACI 318 2014). The differences in the compressive strength of fibrous concrete against non-fibrous concrete from the research listed in Table 1 are presented in Figure 2.

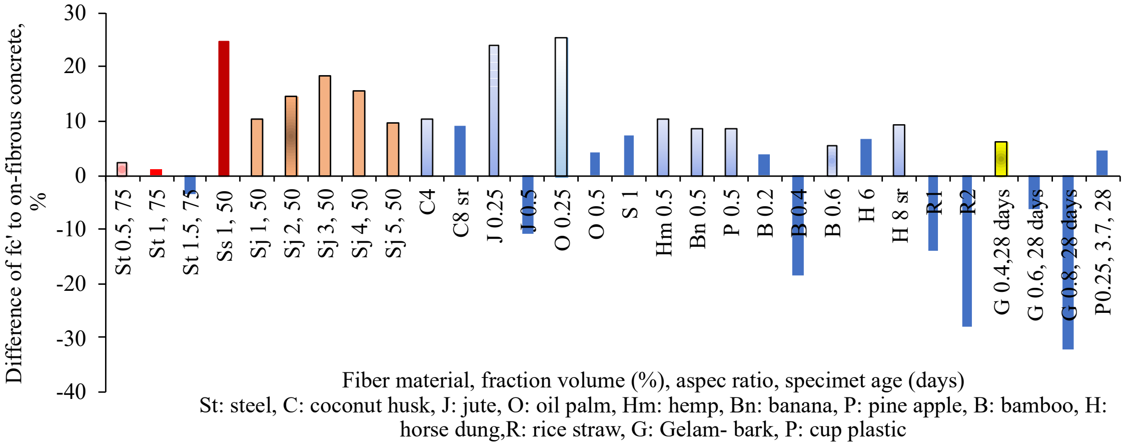

Figure 2. Compressive strength

All steel fibre concrete with an aspect ratio of 75 showed a very small increase in fc', even at the volume fraction of 1.5 it decreased, while at an aspect ratio of 50, it showed an increase in fc' of 10-25% (Figure 2).

Most of the organic fibrous concrete experienced an increase in compressive strength, except for jute (J0.5), bamboo (B 0.4), rice straw, and gelam bark (G 0.6 and G 0.8. Compressive strength of plastic fibre concrete increased by about 4% (Figure 2).

From the research reviewed, there were only 3 studies that had carried out the splitting test: Wafa (1990) for steel-fibre concrete, Hidayat *et al*. (2016) for bamboo-fibre concrete and Niken e*t al*. (2020) for Gelam-bark fibre concrete (Figure 3).

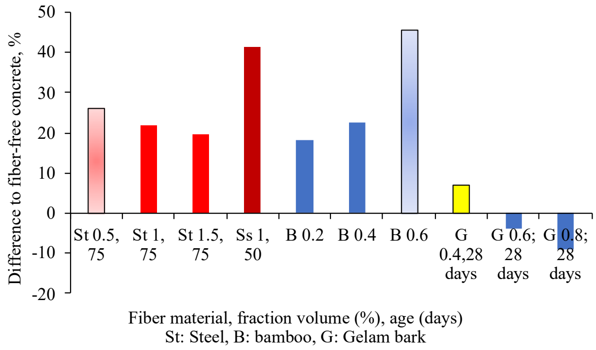

Figure 3. Splitting test

Bamboo-fibre concrete shows good performance in the split tensile strength test. The split tensile strength is the same as that of steel-fibre concrete (B 0.2 and B 0.4) but stronger than that of steel-fibre concrete (B 0.6). The higher the volume of the bamboo fibre fraction, the better it is to resist split pull; the higher the volume of the steel fibre fraction, the lower its strength in holding split tensile. For gelam-bark fibre concrete, only a volume fraction of 0.4 showed a 7% increase in split tensile strength of non-fibrous concrete (Figure 3). This phenomenon is also similar in the flexural and compressive performance of gelam-bark fibre concrete (Figure 1,2,3).

The fibrous concrete of Table 1, which shows an increase in its mechanical properties, is presented in Figure 4.

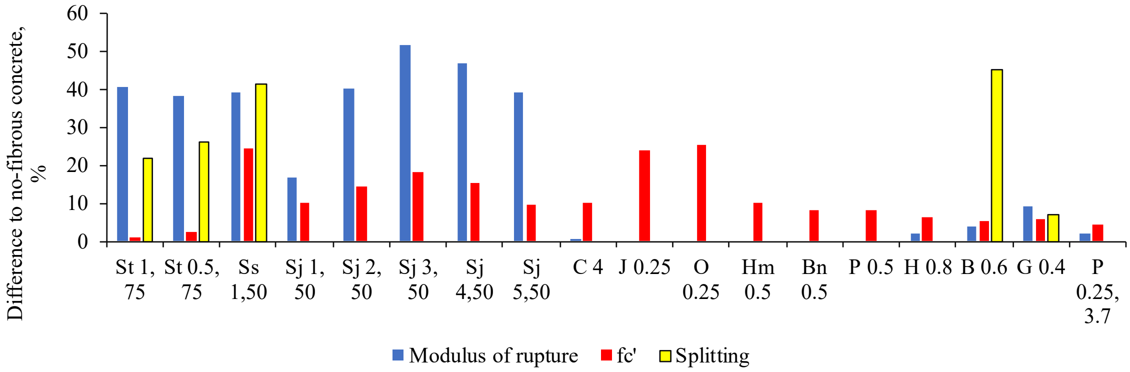

Figure 4. Improved mechanical properties of fibrous concrete

Gelam-bark fibrous concrete showed an even increase in all three mechanical properties, whereas steel-fibrous concrete showed a low probability of increase in compressive strength. Bamboo fibrous concrete showed a significant increase in the splitting test but low in flexural strength. The increase in flexural strength and split tensile is very significant in steel-fibre concrete, but the increase in compressive strength needs to be observed more closely. Ss 1.50 showed the best treatment for the three mechanical properties of concrete, followed by Sj 3.50. Plastic fibre concrete shows an increase in compressive strength and flexural strength (Figure 4).

Comparison of the workability of reinforced concrete with steel, bamboo and gelam bark fiber is shown by the slump of concrete fiber and the slump of each non-fibrous fraction.

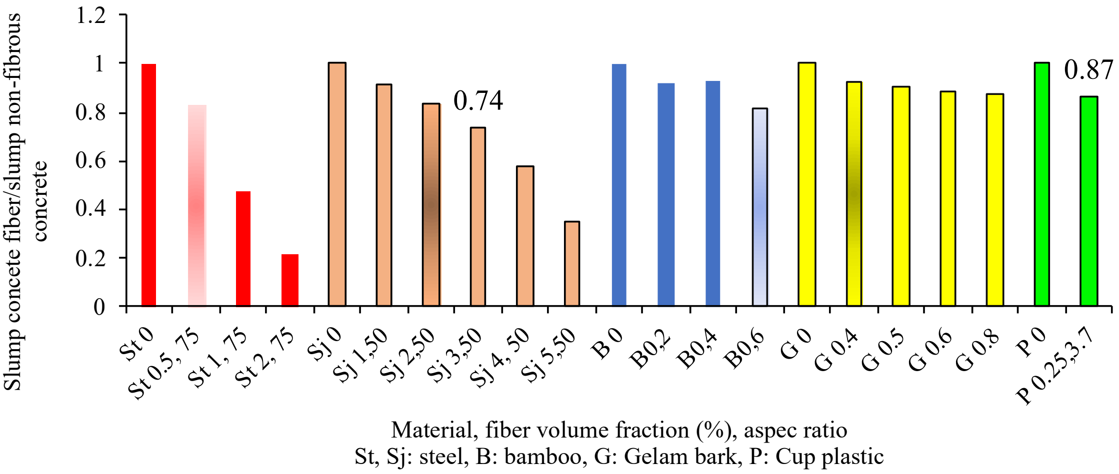

Figure 5. Slump ratio between concrete fiber and non-fibrous concrete

The shorter the slump, the more difficult it is to mix. Adding steel fibers in the mixture showed greater shortening of the slump. The least shortening of slump is in the gelam bark fibrous concrete. There is no slump data on Ss 2.50, slump of plastic fiber concrete compared to Sj 3.50 (concrete steel fiber with fiber volume fraction of 3 and aspect ratio of 50). The level of ease of working of plastic-fiber concrete against steel-fiber concrete is 0.87 and 0.74. So, plastic fibrous concrete is easier to work with than fibrous concrete (Figure 5).

Mechanical properties of the set cement composite depend on the fibre content and fibre type that have different sizes. This is in accordance with Al-Zubaidi.'s 2018 statement.

Summary

The summary can be drawn are:

1. There are three types of fibers that show increased flexural strength, compression and split tension strength when added as a mixture in concrete, namely steel, bamboo with a volume fraction of 0.6% (B 0.6) gelam bark with a volume fraction of 0.4% (G 0.4) and plastic (P 0.25).
2. The flexural strength of gelam bark-fiber concrete is 2.3 times the flexural strength of bamboo-fibrous concrete, while the compressive strength is almost the same between the two types.
3. Bamboo fiber concrete shows the highest split tensile strength, even higher than steel-fiber concrete.
4. Steel fiber concrete Ss 1.50 with a volume fraction of 1 and an aspect ratio of 50 showed an increase in flexural tensile strength, compressive strength and split tensile strength, followed by Sj 3.50 and Sj 4.50. Steel fiber, gelam wood, bamboo and plastic fibers show an increase in tensile strength, flexural strength and

compressive strength

4. Conclusion

In this study, the conclusions that can be drawn are:

1. The volume and size of fiber used affects the performance of the mechanical properties, therefore adding fiber should be carefully applied.
2. Steel fiber concrete shows the best mechanical properties compared to organic and plastics, but its workability is lower than fiber plastic concrete
3. Concrete with gelam wood fibers, and bamboo showed an increase in flexural tensile strength, compressive strength and split tensile strength
4. Plastic fiber concrete showed an increase in flexural tensile strength and compressive strength against fibreless concrete, but the increase was lower than that of gelam bark and bamboo fibers.
5. The mechanical properties of fibrous concrete should not be based on the formula used for fibrous concrete but should be tested.
6. Flexural strength is not a function of compressive strength.

It is suggested that the research on steel, organic and plastic fibrous concrete be continued with a blow and shrinkage test to determine its performance in sustaining strikes until its first crack and until failure and to test its resistance to rot and deformation. Flexural strength testing should also be carried out at the age of 90 days of the concrete, as the mechanical properties may change within a certain period of time.

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