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Load-Strain Behaviour of Shredded Waste Paper Reinforced Concrete Beam

Load-Strain Behaviour of Shredded Waste Paper Reinforced Concrete Beam

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Abstract. Cement, sand, coarse aggregate, water and reinforcing bar are the materials to make a reinforced concrete beam. The waste paper has been dumped as waste and causes environmental pollution behind mill or landfill. The industry paper wastage for every year is increasing gradually. More spaces are being needed for landfills, uses energy loss of natural resources and increase of expenditure and various types of pollutions. Utilizing waste paper as an addition in concrete and reinforced concrete beam productions will reduce environmental pollutions. This research investigates the load-strain behaviour of reinforced concrete beam containing shredded waste paper using 10% copier and 10% cardboard waste paper as additions in the concrete mixture to the concrete shear strain and concrete bending strain of reinforced concrete beam. There are three types of beam shear reinforcements with stirrup spacing (SS)=100 mm, 150 mm, and 200 mm. All specimens are subjected to air curing at 28 days. The result of concrete bending and shear strains are higher by 10% shredded copier waste paper (SCPWP) and 10% shredded cardboard waste paper (SCBWP) with reducing shear reinforcements (SS=200 mm) and (SS=150 mm) compared to full shear reinforcement (SS=100 mm). This research shows that 10% SCPWP and 10% SCBWP improves the concrete bending and shear strains with reducing reinforcements. Furthermore, the results also show that 10% SCBWP has higher concrete bending and shear strains than 10% SCPWP for full and reduce shear reinforcements. This study indicates that shredded copier and cardboard waste paper can be used as additional materials in reinforced concrete beam production.

1. Introduction

Reinforced concrete is widely used in the construction industry due to its advantages such as strong, robust, economical and durable. Nowadays, the houses carbon dioxide (CO_2) gas emission is attributed to cement usage, which is a massive issue for all nations. Consequently, people's crave for eco-living is increasing. This research is conducted to address these kinds of problems. Using waste paper in concrete can produce new and modern construction material. By using waste paper, the cement amount used reduces as it provides an environmentally friendly construction material [1]. Portland cement and waste paper are the materials that make a fibrous cemented material called papercrete. Papercrete might be a material initially developed 80 years ago that has recently been rediscovered. It should be noted that papercrete has a limited-range concept [2]. For decades, as an alternative building material stated by [2], a committed environmentalist has designed homes and structures made of cement, other materials and waste paper. They argued that this papercrete structure is perfect and durable for insulating and durability. A paper reinforced structure is a structurally and economically viable alternative based on the indicated result within a size range [3]. Portland cement or clay with repulped paper fibre develop a new construction material that called papercrete. They identified their discovery of adobe and fibrous cement and found themselves independently [4].

Due to the alternative building material known as papercrete, the main structure's dead load can be diminished [5]. Water and any paper types such as cardboard, sparkling magazine stock, daily paper, waste mail advertising or any other types of papers are the fundamental components of papercrete. The paper mill publishes most of the paper recycling works [6-11] or manufacturing cement board [12-13]. Other than that, it can end up a reasonable and productive substitute in landfills, incinerators, or other utilize choices [14]. Moreover, waste paper can be used correctly by using it in construction materials to reduce its density, as stated by [15]. The building expenses can be reduced by measuring the quality, workability, and other papercrete properties [16]. Furthermore, due to its lightweight characteristic, papercrete can also be used for the interior wall of a high-rise building in seismically active regions. Moreover, papercrete usage will decrease the dead load of the structure, the depth of foundation required, and the percentage of steel used, so the labour amount and energy expense will be decreasing significantly [17]. Papercrete can grant numerous benefits and wide utilization in concrete. In addition to that, papercrete persuades waste paper recycling, particularly in a community without recycling activity. It cuts the waste space, holds paper production and chemical printing out of the water table [18]. This research aims to investigate the load-strain behaviour of reinforced concrete beam containing three different types of concrete mixtures. There are 0%, which is the control, 10% addition of shredded copier waste paper (SCPWP) and 10% addition of shredded cardboard waste paper (SCBWP) in the concrete mixture. The investigated load-strain behaviour of the reinforced concrete beam is concrete bending strain and concrete shear strain.

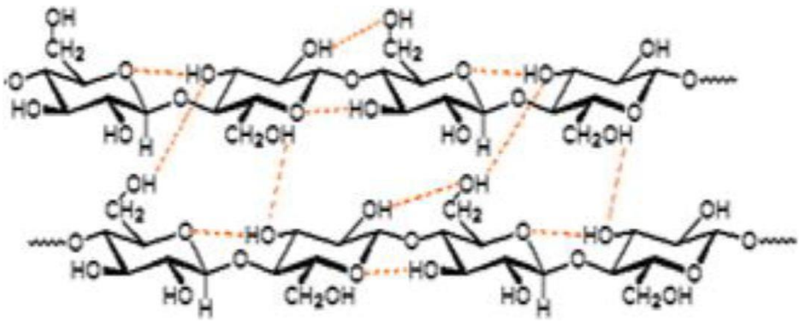
2. Materials and Methods

This research uses cement, sand, coarse aggregate, water, shredded mixed and cardboard waste papers. Ordinary Portland Cement (OPC) used Orang Kuat brand produced by YTL Cement Marketing Sdn. Bhd. to ensure the cement has the same chemical properties and compositions. This type of cement follows [19] for Portland cement specifications. A local supplier supplied the river sand used in this study. It was obtained from the concrete laboratory at the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang (UMP). The sand used as fine aggregate. Physical properties of sand meet the requirements of [20]. Gravel was used as coarse aggregate in this research. The minimum and maximum sizes of gravel are 5 mm and 20 mm. The gravel physical properties meet the prerequisites of [20]. The reinforcing bars used for compression and tension were 2Y12 and 2Y16 while for the stirrup was R6. Mixed and carboard waste paper were used in this research by collecting them from the office. Both types of paper were then shredded using a paper shredder machine. All sizes and dimensions of shredded waste paper (SWP) used in this research were the same after shredded. Figure 1 and 2 show the shredded copier waste paper (SCPWP) and shredded cardboard waste paper (SCBWP) used in this research.

Figure 1. Shredded copier waste paper (SCPWP)

Figure 2. Shredded cardboard waste paper (SCBWP)

A paper is primarily made of wood cellulose fibre which is known to be a fibrous material. Cellulose is a natural polymer made by smaller molecules composing associated sugar with a long chain. A sugar type: ß-D glucose is the bonding of the cellulose chain. The polar-OH cellulose bristles make up many hydrogen bonds with OH groups to approach and bundle together the chains, as shown in Figure 3 [21-23]. The chains also pack in orderly places to form hard and strong crystalline regions to enable more balance and strength in the bundled chains.



—— Cellulose linear polyglucose joined by ß 1-4 bonds

------ Intra and intermolecular hydrogen bonds

Figure 3. Paper chemical structure (Cellulose hydrogen bond)

Table 1 and Table 2 show the fibre and strength properties of two waste paper types before disintegration [24].

Table 1. Fibre properties before disintegration

Type of waste paper	Fibre average length (mm)	Medium fibre content (%)	Long fibre content (%)	Fine fibre and and non-fibre contents (%)
Copier	0.40	12	16	66
Cardboard	0.45	23	30	58

Table 2. Strength properties before disintegration

Type of waste paper	Percentage (%)	Strength of Bending (N/mm^2)	Internal Bond (N/mm^2)	Modulus of Elasticity (N/mm^2)	Thickness Swelling (%)
Copier	0	16	0.28	1600	3
	5	20	0.31	1900	5
	10	26	0.35	2300	10
	15	10	0.23	1200	16
Cardboard	0	16	0.28	1600	3
	5	24	0.33	2100	7
	10	28	0.39	2400	13
	15	14	0.26	1300	18

Table 3 and Table 4 show the fibre and strength properties of two waste paper types after disintegration [24].

Table 3. Fibre properties after disintegration

Type of waste paper	Fibre average length (mm)	Medium fibre content (%)	Long fibre content (%)	Fine fibre and and non-fibre contents (%)
Copier	0.42	14	18	68
Cardboard	0.47	25	32	60

Table 4. Strength properties after disintegration

Type of waste paper	Percentage (%)	Strength of Bending (N/mm^2)	Internal Bond (N/mm^2)	Modulus of Elasticity (N/mm^2)	Thickness Swelling (%)
Copier	0	18	0.30	1800	5
	5	22	0.33	2100	7
	10	28	0.37	2500	12
	15	12	0.25	1400	18
Cardboard	0	18	0.30	1800	5
	5	26	0.35	2300	9
	10	30	0.41	2600	15
	15	16	0.28	1500	20

The mixing process of concrete was done by using standard concrete making procedures. The concrete was mixed using a concrete mixer. Before mixing, all the specimens were weighed according to the mix design. SCPWP and SCBWP used as addition in concrete with 0%, 5%, 10% and 15% by weight of the mixture. A total of 7 mixes is used in this experiment. The cement: sand: aggregate ratio used in this research is 1:0.75:1.5 by the weight of the materials, and 0.5 is the water to cement ratio used. This ratio fixes for all specimens. This experiment uses a concrete mix proportion, as presented in Table 5.

Table 5. Concrete mix proportion

Concrete Mixture	Cement (Kg)	Sand (Kg)	Coarse Aggregate (Kg)	Shredded Waste Paper (%)	Shredded Waste Paper (Kg)	W/C
0%	150	112.5	225	0	0	0.5
10% SCPWP	150	112.5	225	10	56.25	0.5
10% SCBWP	150	112.5	225	10	56.25	0.5

The mechanical properties of concrete shear and bending strains were investigated using reinforced concrete beam (RCB) with a size of 1500 mm length x 150 mm wide x 200 mm height. Air curing was imposed on all the specimens. The RCB shear and bending strains were determined by performing a four-point bending test using a MST hydraulic machine with maximum load capacity of 300 kN.

3. Results and Discussion

The section presents the load-strain curves such as concrete bending strain and concrete shear strain results for reinforced RCB.

3.1 Concrete Bending Strain

Figure 4,5,6 and Table 6 show the load-strain curves and concrete bending strain test results of RCB with three types of shear reinforcements at 28 days with air curing. There are three types of shear reinforcements which are full shear reinforcement with stirrup spacing (SS=100 mm) and reduce shear reinforcements with stirrup spacing (SS=150 mm) and (SS=200 mm). The specimen result is affected by the types of SWP and SS. The concrete bending strain increases with 10% SCPWP and 10% SCBWP addition in the concrete mixture with reducing shear reinforcements (SS=150 mm) and (SS=200 mm) compared to full shear reinforcement (SS=100 mm). The 10% SCBWP records the highest concrete bending strain values which are 2127 με for SS=100 mm, 2347 με for SS=150 mm and 2572 με for SS=200 mm compared to 10% SCPWP and 0%. 10% SCBWP with SS=200 mm records 2572 με concrete bending strength value which is the highest, while the lowest concrete bending strain value is recorded at 0% with SS=200 mm, which is 1784 με.

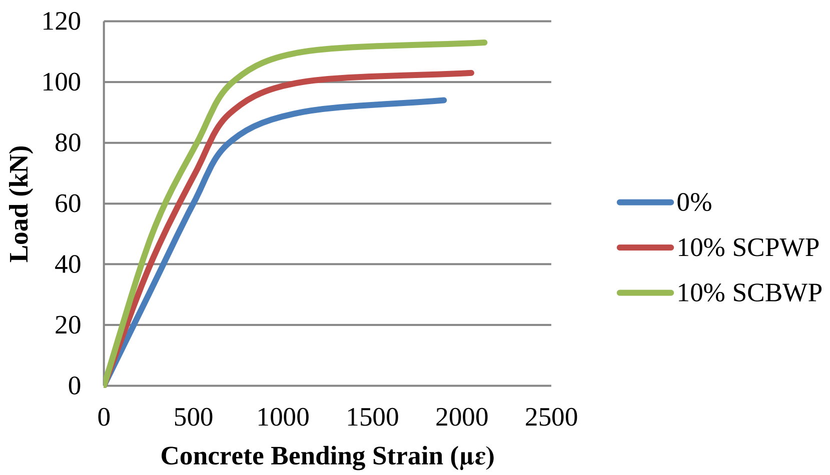


Figure 4. Load-strain curves for beam with full shear reinforcement (SS=100 mm)

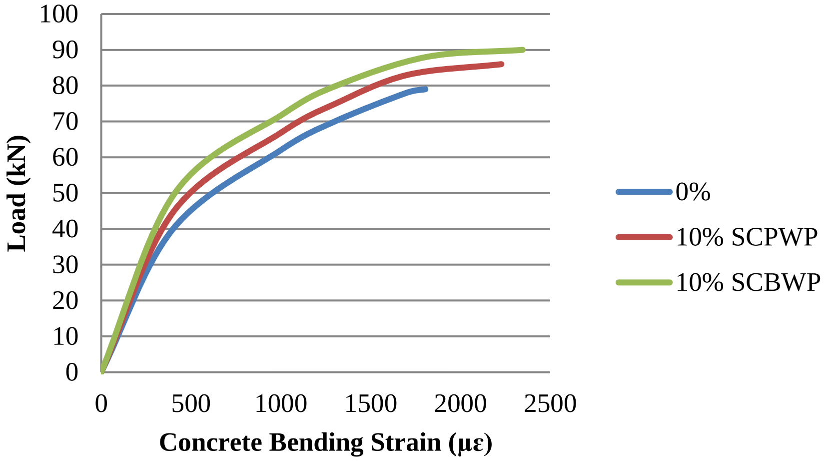


Figure 5. Load-strain curves for beam with reducing shear reinforcement (SS=150 mm)

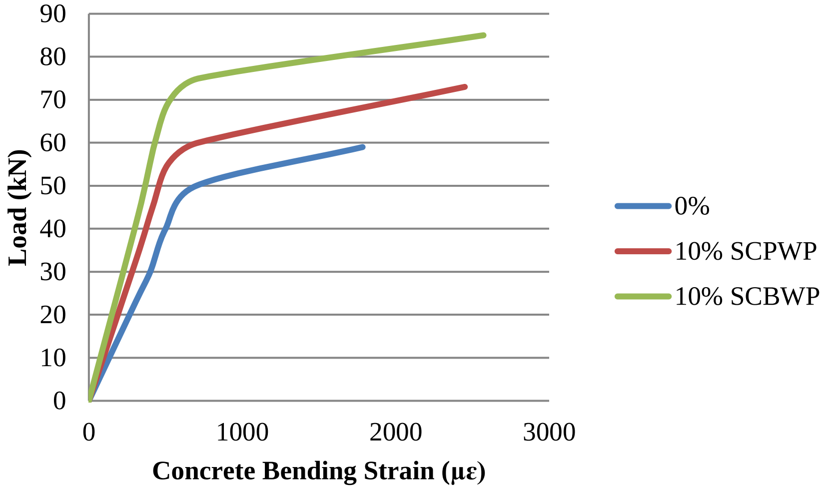


Figure 6. Load-strain curves for beam with reducing shear reinforcement (SS=200 mm)

Table 6. Result of concrete bending strain for RCB

Stirrup Spacing (mm)	Concrete Mixture	Concrete Bending Strain (με)
100	0%	1900
100	10% SCPWP	2053
100	10% SCBWP	2127
150	0%	1805
150	10% SCPWP	2228
150	10% SCBWP	2347
200	0%	1784
200	10% SCPWP	2450
200	10% SCBWP	2572

Concrete mixtures with 10% SCPWP and 10% SCBWP for reduce shear reinforcements (SS=150 mm) and (SS=200 mm) for RCB show marginally higher and improve the concrete bending strain compared to the full shear reinforcement (SS=100 mm) since the paper is made from cellulose.

Cellulose is considered as a fibre material and consists of a molecule containing carbon and hydrogen atoms. Water is a molecule composing hydrogen and oxygen atoms. When mixing paper in water, the oxygen atom from the water molecule snatches the hydrogen atom from the cellulose creating hydrogen bond. This bonding of hydrogen provides the basis for papercrete strength [22-23]. Furthermore, the paper contains a large amount of alumina-siliceous content which is united with calcium, thereby enhancing its strength [22-23]. The enhancement of strength is abundantly related to waste paper hydraulic and pozzolanic activities that actuated by the alkalis, and the hydration process discharges calcium hydroxide, $Ca(OH)_2$ to some extent [22-23]. From the concrete bending strain, it can be observed that the strength of 10% SCBWP is more than 10% SCPWP. SCBWP is thicker and heavier than SCPWP. SCBWP contains more fibre average length, a higher proportion of medium and long fibre contents, higher strength of bending, internal bond and modulus of elasticity than SCPWP [24]. So the cellulose in SCBWP is higher than SCPWP. SCBWP has more carbon and hydrogen atoms than SCPWP since cellulose consists of carbon and hydrogen atoms. More oxygen atoms from the water grab the hydrogen atoms from the cellulose because there are many hydrogen atoms in SCBWP. This reaction will create more hydrogen bonds. More hydrogen bonds will produce higher concrete bending strain. Moreover, SCBWP would be more rigid and long-lasting compared to SCPWP. It is also more costly and expensive than SCPWP.

3.2 Concrete Shear Strain

Figure 7,8,9 and Table 7 show the load-strain curves and concrete shear strain test results of RCB with three types of shear reinforcements at 28 days with air curing. There are three types of shear reinforcements which are full shear reinforcement with stirrup spacing (SS=100 mm) and reduce shear reinforcements with stirrup spacing (SS=150 mm) and (SS=200 mm). The specimen result is affected by the types of SWP and SS. The concrete shear strain increases with 10% SCPWP and 10% SCBWP addition in the concrete mixture with reducing shear reinforcements (SS=150 mm) and (SS=200 mm) compared to full shear reinforcement (SS=100 mm). The 10% SCBWP records the highest concrete bending strain values which are 2578 με for SS=100 mm, 2747 με for SS=150 mm and 2965 με for SS=200 mm compared to 10% SCPWP and 0%. 10% SCBWP with SS=200 mm records 2965 με concrete bending strength value which is the highest, while the lowest concrete bending strain value is recorded at 0% with SS=200 mm, which is 2198 με.

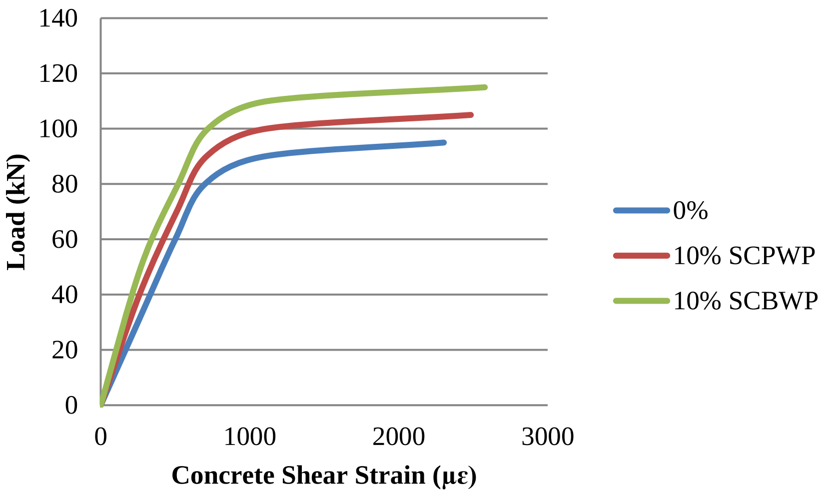


Figure 7. Load-strain curves for beam with full shear reinforcement (SS=100 mm)

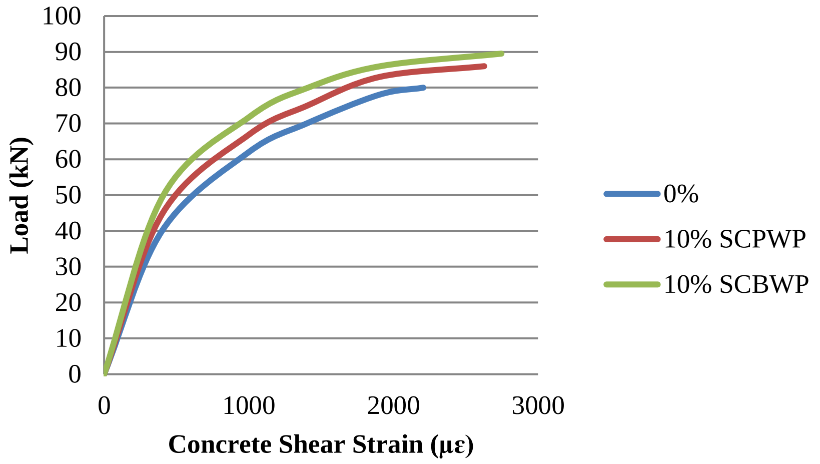


Figure 8. Load-strain curves for beam with reducing shear reinforcement (SS=150 mm)

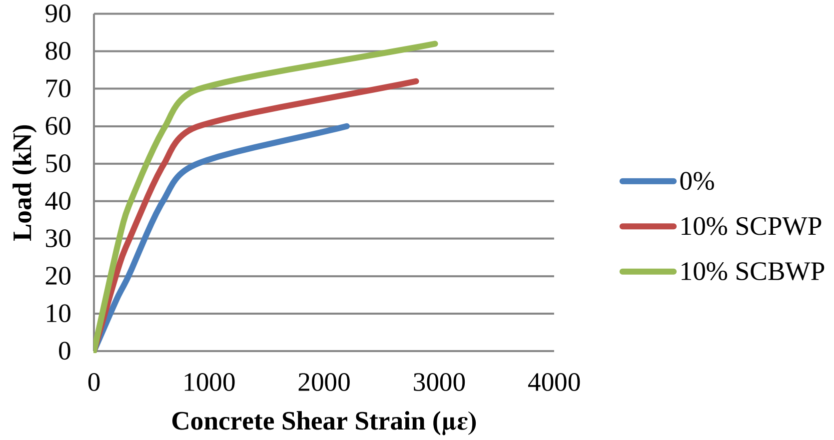


Figure 9. Load-strain curves for beam with reducing shear reinforcement (SS=200 mm)

Table 7. Result of concrete shear strain for RCB

Stirrup Spacing (mm)	Concrete Mixture	Concrete Shear Strain (με)
100	0%	2303
100	10% SCPWP	2484
100	10% SCBWP	2578
150	0%	2207
150	10% SCPWP	2628
150	10% SCBWP	2747
200	0%	2198
200	10% SCPWP	2800
200	10% SCBWP	2965

The result presents that the beams with 10% SCPWP and 10% SCBWP concrete mixtures for reduce shear reinforcements (SS=200 mm) show marginally higher and improve the concrete shear strain compared to the beam with full and reduced shear reinforcements (SS=150 mm) and (SS=100 mm). 3000 με is set as a maximum strain value for standard concrete [25]. In turn, this can reflect a structure's crack width. The strain values do not exceed 3000 με as proven in Table 4 and Table 5 for all types of beams such as 0%, 10% SCPWP and 10% SCBWP. The concrete shear strain values show cracks under service load are investigated by the inclusion of SWP in the beam. Regarding durability purpose, the most crucial parameter for the protection of steel bar from corrosion is the flexural crack width in most design codes. However, [26] stated that there is no specific limit to the shear crack width is set as the structure is assumed to be failed when a shear crack occurs. This occurrence may be due to the fibre content in SCPWP and SCBWP, which increases the strain value that avoids diagonal shear crack from occurring. It is primarily due to the fibre crack bridging mechanism, which transmits tensile stress through the crack surface. Moreover, the results also show that the 10% SCPWP and 10% SCBWP beams have reached their ultimate strain capacities under service loadings. Besides that, excessive diagonal tensile cracking can be prevented by using a fibre material. In conclusion, fibre acts as a crack bridging mechanism and hinders the crack growth, which causes an increase in the number of cracks and reduces the crack width. It is also observed that from the concrete bending and shear strain values, the incorporation of fibre in concrete, considerably minimizes the crack width under service load.

4. Conclusion

The concrete bending strain for RCB increases with 10% addition of SCPWP and SCBWP in the concrete mixture with reducing shear reinforcements (SS=150 mm) and (SS=200 mm). The concrete shear strain for RCB increases with 10% addition of SCPWP and SCBWP in the concrete mixture with reducing shear reinforcements (SS=150 mm) and (SS=200 mm). The 10% SCPWP and 10% SCBWP beams with reducing shear reinforcement (SS=200 mm) have higher concrete bending and shear strains than the beams with shear reinforcements (SS=150 mm) and (SS=100 mm). 10% SCPWP and 10% SCBWP improve the concrete bending and shear strains for full and reduce shear reinforcements compared to 0%. Generally, 10% addition of SCPWP and SCBWP is the most suitable concrete mix proportion. 10% SCBWP has higher concrete bending and shear strains than 10% SCPWP for all three types of reinforcements because SCBWP has higher cellulose, more fibre average length, a higher proportion of medium and long fibre contents than SCPWP. By using SWP in concrete and RCB, the disposal cost of a paper industry can be saved, and sustainable concrete and RCB can also be produced in the construction and civil engineering fields. The utilization of waste material such as SWP as additional alternative material in concrete and RCB will benefit the environment and economy in cost-effectiveness.

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