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Review Article

Inclusion of Waste Paper on Concrete Properties: A Review

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Abstract

The environmental degradation in the vicinity of landfills or mills is caused by waste paper disposable. Each year, the industry's paper waste is increasing gradually. As a result, additional places are required for landfills, which consume energy, deplete natural resources, and increase expenditure and environmental pollution. Pollution can be reduced by adding WP to a concrete mixture in concrete production. This review paper investigates the physical and chemical properties of waste paper. Besides that, the mechanical properties of concrete containing waste paper, such as compressive, flexural, and splitting tensile strengths, are also studied in this review paper. All reviews of the intended studies include experimental tests. From the reviews, all strengths were increased with the inclusion of waste paper, either by addition, substitution, or replacement with fine aggregate, coarse aggregate, or cement. By using waste paper, not only would concrete have advantages and benefits, but also environmentally friendly construction materials could be produced from time to time. It has been noted in most studies that the inclusion of waste paper brings significant benefits. It can be concluded that waste paper potentially has favorable properties for concrete production. The concrete performance will improve in terms of compressive, flexural, and splitting tensile strengths with waste paper inclusion at certain percentages compared to ordinary concrete with no waste paper content.

Keywords: Concrete; Compressive Strength; Flexural Strength; Splitting Tensile Strength; Waste Paper.

1. Introduction

Nowadays, carbon dioxide gas (CO_2) is emitted from construction sites due to cement use, a major concern for all nations. On the other hand, people's desire to live in an eco-friendly environment continues to grow. This study is being conducted to address these issues. A new composite material called papercrete is created by incorporating Waste Paper (WP) into concrete. Papercrete also reduces cement usage because it is an ecological building material [1]. Papercrete might be an 80-year-old substance that was recently used. Fibrous cementitious material comprises Portland cement, and recycled paper is called papercrete. Durable building materials are created using paper cement pulp by combining these two materials with water, pouring them into a mould and then drying them. Papercrete is a limited-application material due to the fact that only certain percentages are allowed to be used. For decades, intrepid environmentalists have been building homes and other structures with materials that recycle waste paper into an alternative construction material made with cement and other ingredients [2].

They asserted that these papercrete constructions are exceptionally well insulated and durable. According to the given result, papercrete construction is a structurally and economically viable solution [3]. Papercrete is a relatively new type of construction material made from WP and Portland cement, or clay. Due to the significant amount of recycled material, it is known as an environmentally beneficial material. They used the term "adobe and fibrous cement" for their

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invention, which was independently stated by Elaiwi et al. (2020) [4]. The dead load of the main structure will be reduced as a result of this alternative building material called papercrete [5]. Papercrete is composed primarily of water and various types of paper, including daily paper, cardboard, magazines, garbage mail, publicizing pamphlets, and more types of paper. Most published research on paper recycling comes from paper mills [6–13].

Apart from that, it may refer to a productive alternative to landfills, incinerators, or other waste disposal methods and also a cost-effective product [14]. In the case of papercrete, the paper fibres contribute to the mix's bulk, resulting in a lightweight and durable material. Utilizing WP in structural concrete would be smart and environmentally friendly, contributing to reducing the construction process' negative effects. WP is an essential source of cellulose fibre, as well as one of the most prevalent types of waste found in all activity areas. Thus, the concrete mixture containing paper-mill pulp is examined as a possible landfill solution. Additionally, the cost-effectiveness of utilizing the sample supply of WP strengthens the case for investigating this alternative. Additionally, Shermale and Varma (2017) [15] noted that incorporating WP into construction materials can lessen their density. This WP incorporation is the best way to use WP wisely and properly. Therefore, it was chosen to research papercrete by evaluating its workability and other properties in order to reduce construction costs [3]. Inner walls in high-rise buildings in seismically active locations can be papercrete because of the lightweight nature of papercrete. In addition to this, by utilizing papercrete, the structure's dead weight, foundation depth required, and steel utilized can be dramatically reduced, lowering labour and energy costs [16].

Thus, papercrete can provide several benefits and a broad range of applications in concrete. Papercrete encourages WP recycling, particularly in communities with no recycling activities. It conserves landfill space and keeps chemicals used in paper manufacturing and printing out of the water supply [17]. This paper discusses the physical and chemical properties of waste paper. Moreover, the mechanical properties review of concrete containing WP is also discussed in this paper. Based on this review and previous research, it is clear that WP innovation can provide benefits for concrete performance. So, the necessity of WP usage in concrete is essential because it can increase the compressive, flexural, and splitting tensile strengths and should be applied for concrete production. The research gap is that regular paper was used for much research before this, and other types of WP have never been used. For instance, newspaper, manilla paper, and other kinds of WP should be used to test which kind of WP gives the highest and lowest concrete strength. The reinforced concrete containing WP has also never been conducted. WP could be used in the future to make reinforced concrete stronger. Researchers could then do a lot of tests to see if WP could make the structure stronger or not.

2. Waste Paper Properties

Burgess and Binnie (2010) stated that the specific choice of test materials and techniques could help to produce specific results and discussions [18]. The paper properties must be understood and how they react to different conditions, including humidity, temperature, radiation and pollution. The environmental condition triggers hydrolysis, oxidation and crosslinking breakdown reactions.

2.1. Physical Properties

Basis weight, substance or grammage is one of the most important properties of WP and paperboard. A density conversion factor that converts grams per square meter to grams per square inch is used to calculate the paperweight. The number of grams in a square meter, pounds in a thousand square feet, or weight in kilograms or pounds in reams of a certain dimension can be stated in this way. The customer is more interested in the size of the paper than the weight. The area got by the customer depends on materials weight. For example, 20 m^2 area is equal to 1 kg paperweight received by the customer. Ream weight is a relative expression that shows the buyer how many reams the manufacturer provided for a certain weight. From the standpoint of production rate, basis weight is critical for papermakers. Production rate/day of machine deckle and machine speed (MT) = Deckle of machine (m) × Speed of machine (m/min) × Basis Weight (g/M^2) × 1440/1000000. Tables 1 and 2 present the physical properties and grading of WP.

Table 1. WP physical properties [19, 20]

Content of Moisture (%)	2.67
Specific Gravity (SSD)	0.98
Density (kg/m^3)	800
Absorption (%)	89
Organic Materials (%)	70
Inorganic Materials (%)	30
Thickness value (µM)	105-110
Moisture value (%)	4-4.5
Smoothness value (mls/min)	100-300
Bursting stremgth value (kPa)	250-300
Tear resistance value (mN)	500-600
Friction static coefficient	0.5-0.65
Friction kinematic coefficient	0.35-0.5

Table 2. WP grading [21]

Size of Sieve (mm)	Passing Weight (%)
9.51	100
4.75	88
2.36	18
1.18	2
0.6	0

2.2. Chemical Properties

In some articles, the non-cellulosic components (lignin) react more vigorously. But ironically, the fact that chemical probes are hard to find and make the WP the most difficult to be monitored and measured. Table 3 shows the chemical composition of WP.

Table 3. WP chemical composition [22, 23]

Element	Percentage (%)
Oxygen	15.83
Calcium	14.94
Silica	60.57
Aluminium	2.06
Magnesium	3.59
Sulphur	1.07
Potassium	0.16
Ferum	0.92
Sodium	0.22

3. Structure of Waste Paper

WP is strong, predominantly made with wood cellulose, a fibrous material. Cellulose is composed of long sugar-like molecules that bind together smaller sugar molecules [19, 24]. The cellulose chain links are sugar known as ß-D glucose. The cellulose chains consist of fibres of celluloses bundled together by the hydrogen bonds from OH groups, as shown in Figure 1. The chains also pack together and form stable, hard crystalline regions, allowing for more outstanding support and balance. The papercrete strength comes from the hydrogen bonding between each other [21]. Silica, calcium oxide, alumina, and magnesium oxide are the main components of WP.

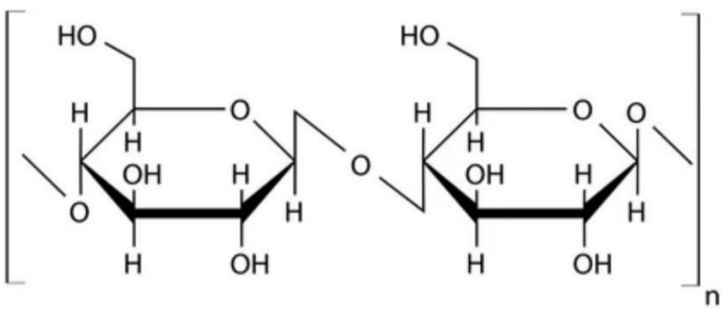

Figure 1. Cellulose [19, 24]

For all practical purposes, the cellulose microfibrils are perfectly elastic up to the failing point. The modulus of elasticity may be calculated when the fibre is stressed parallel to its axis, given that cellulose has an elastic modulus of 25 GPa, which is controlled by the microfibrillar helix chiral angle. The angle of microfibril has greater natural variability, causing the often closer mean value to the fibre axis than any other angle. Because of this, the modulus of elasticity of fibre is almost the same as cellulose [25, 26]. The fibres of practically all kinds of wood are almost chiral. Macroscopic effects due to microscopic asymmetry include twisting and chiral curl, as depicted in Figure 2.

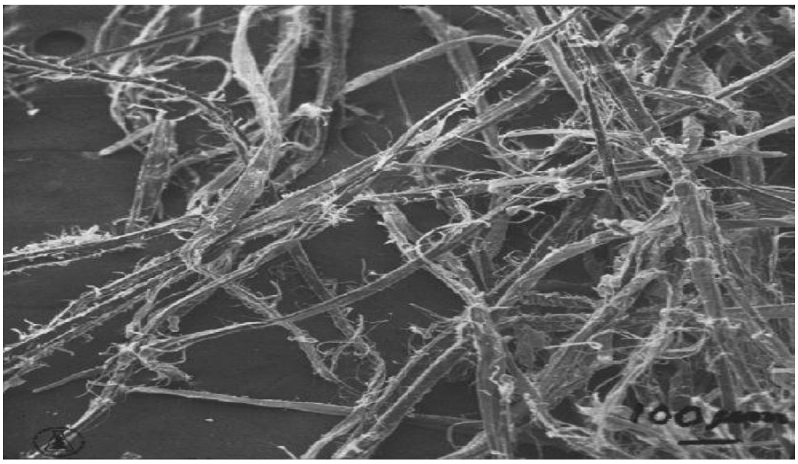

Figure 2. Microscopic image of WP fibres [27]

4. Overview of Experimental Methodology of Concrete Properties

Most of the experimental studies considered for this review have used the general method shown in Figure 1.

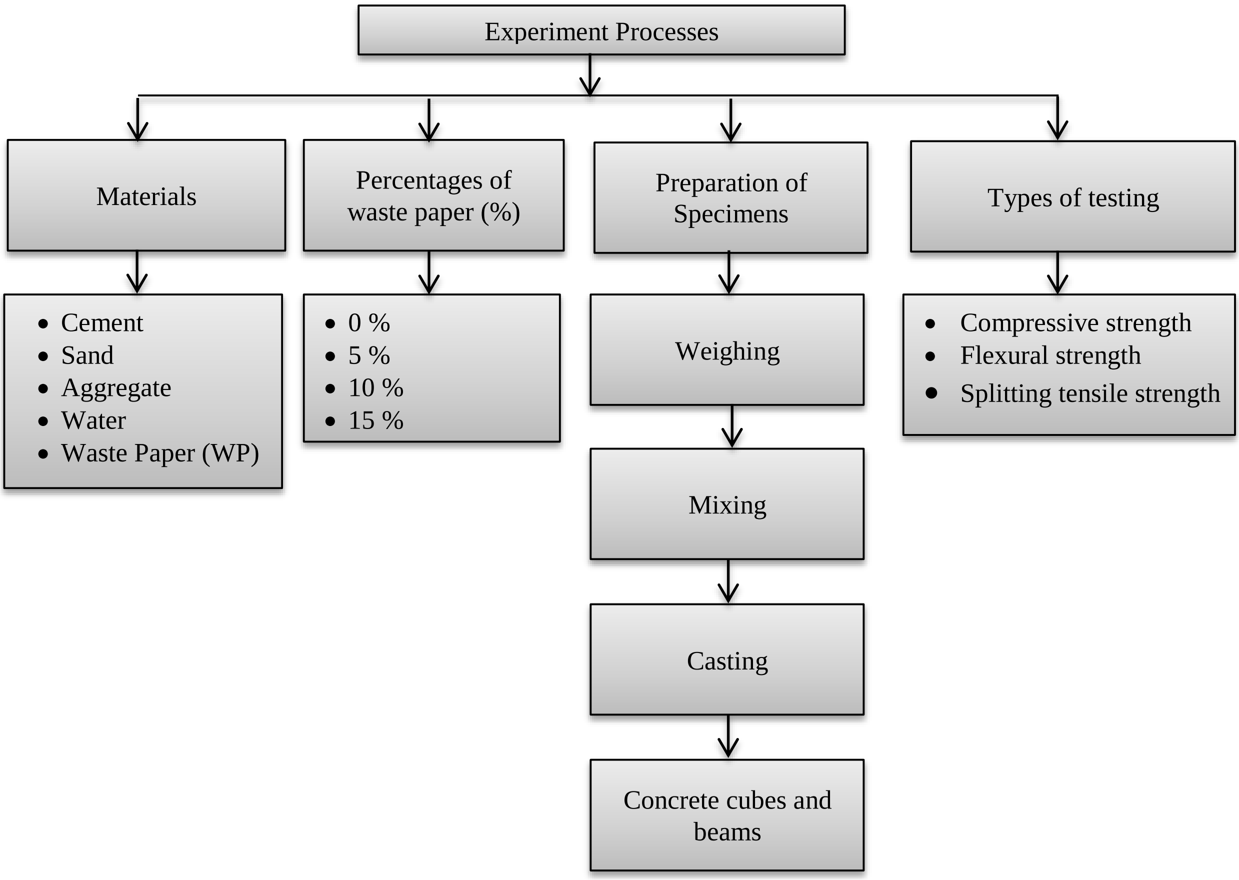

Figure 3. Flowchart of research methodology

5. Mechanical Properties of Waste Paper Concrete

This section presents the mechanical properties of WP concrete, such as compressive strength, flexural strength and splitting tensile strength.

5.1. Compressive Strength

Balwaik and Raut (2011) [28] investigated the concrete performance at 14 and 28 days by 0%, 5%, 10%, 15% and 20% partial cement replacement with waste WP. The mixture of paper mill balance was essentially identical to the 0% mixture, indicating a significant initial strength gained. Including WP produced higher and lower strength than the reference mixture at a particular percentage. Nonetheless, the mechanical properties of concrete remained consistent with prior research findings by the WP effect. The reduction of concrete compressive strength up to about three months curing was caused by the cement replacement with WP depending on volume or weight basis. 5% to 10% replacement was the most appropriate percentage. In general, 10% replacement showed the strength increment, and the strength decreased continuously as well as the WP was further added. Figures 4 and 5 show the 14 and 28 days compressive strength.

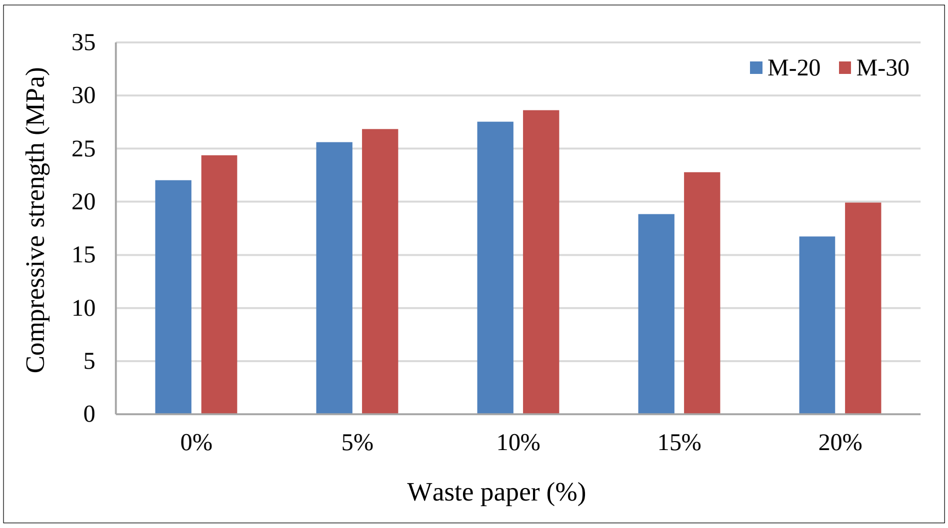

Figure 4. Compressive strength at 14 days [28]

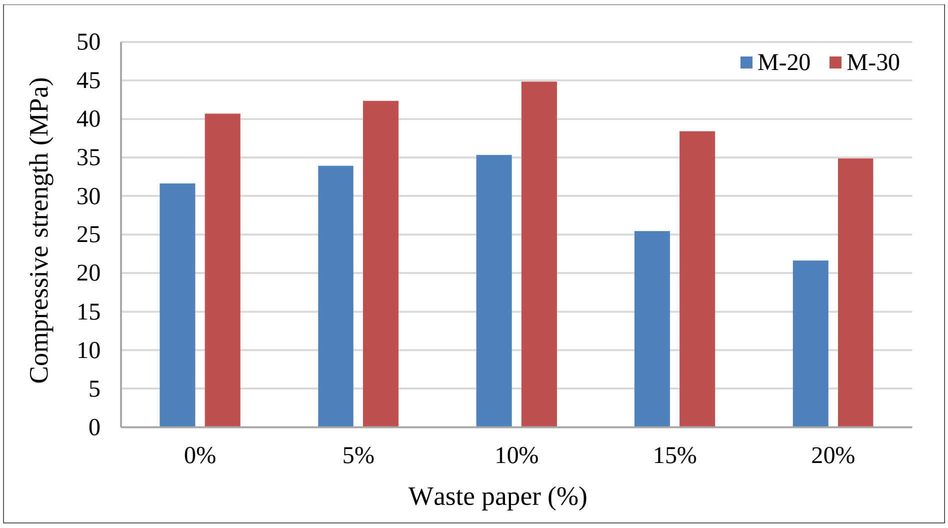

Figure 5. Compressive strength at 28 days [28]

Ilakkiya and Dhanalakshmi (2018) [29] investigated the concrete performance containing WP content at percentages of 0%, 5%, 10%, and 15% at 7, 14 and 28 days curing by investigating the compressive strengths. Initially, the inclusion of WP made the strength better. Nevertheless, additional WP addition drastically diminished the strength. The increase of strength was recorded at percentages of 5% and 10% of addition of WP at all curing days for 7, 14 and 28 when compared to the control mixture, but the mixture containing 15% WP demonstrated a loss in compressive strength. The low silica composition due to WP increment caused the strength to drop.

Zaki et al. (2018) [19] researched the WP addition by weight of cement at percentages of 0%, 5%, 10%, 15%, and 20% at 7, 28 and 56 days by performing and calculating the intermediate compressive strength values of three cube specimens complying to B.S. 1881: part 116, 1983. The test results showed an increase in strength due to hydration process. The compressive strengths of waste WP concrete mixtures were less than the 0% control mixture, except for 5% mixture at 7, 28 and 56 days. The strength decreased when concrete mixtures contained more than 5% and greater levels of WP. Apart from that, the concrete sample volume rose with WP incorporation, and more incorporation weakened the concrete strength and affected the mechanical properties. In addition to this, the strength reduced with increasing WP percentage. On the other hand, the compressive strength values reduced by 10%, 15% and 20% when the WP was added. In comparison, the strength of 5% mix was greater than 0% reference mix. The strength increased caused by the mixed calcium with alumino-siliceous material.

Malik (2013) [23] experimented the mechanical property of concrete cubes at 7 and 28 days with total dimensions of 150 mm for length, width and height by including WP partially substituted with cement at percentages of 5%, 10%, 15%, and 20%, thereby also reducing the WP disposal issue and improving the concrete qualities. The compressive strength test followed IS 516-1959. The ash from WP contained a greater concentration of silicon dioxide, SiO2. Therefore, it may raise the concrete strength. 5% of cement replacement with WP increased the compressive strength but thereafter dropped. It was 15% greater than the reference mix, equating to a concrete mix without WP, 0% at 28 days. The strength of the 0% mixture was greater than 10%, 15% and 20% mixtures. The strength increased by 10% at 7 days and 15% at 28 days with 5% cement replacement with WP. 5% replacement resulted in a compressive strength increment of 15% at 28 days.

Chakraborty et al. (2015) [30] researched concrete cubes performance at 7 and 28 days by partial cement replacement with WP with 0%, 10%, 20%, 30%, 40% and 50% replacement. The tests used a 250 MT capacity compression testing machine. It was seen that for up to 20% cement replacement level, the compressive strength of M15 low-grade concrete increased compared to OPC concrete. In contrast, the corresponding strength value declined for a high-grade concrete specimen. A low concrete grade was discovered suitable used WP as partial cement replacement but discovered unsuitable for a high concrete grade. Subsequently, 10% replacement level of WP showed the highest compressive strength. Hence, in this study, it could be considered that 10% was the optimum level amongst the various replacement levels used. Thus, WP usage could be utilized in low-grade concrete works, which otherwise had been dumped over terrains and caused many ecological risks.

Suri (2018) [31] classified WP group named by T-1, T-2, T-3, T-4 and T-5, which corresponded to WP addition of 0%, 5%, 10%, 15%, and 20%. All combinations were proportioned according to the weight ratios of the M-20 concrete grade. Due to WP high water absorption capacity, preliminary testing was conducted to achieve a workable mix with sufficient water and water to cement ratio determination for the combinations incorporating WP. This experiment collected a total of 30 samples. The curing was 7 and 28 days long, with three cube specimens conducted for compressive strength test for each WP increment rate. 10% and 15% addition of WP increased the compressive strengths by 3.0% and 1.41%, respectively, compared to the control mixture, but adding 20%, WP decreased the compressive strength by 1.16%. Additionally, a 5% addition of WP did not substantially increase, but 10% and 15% addition might be permissible. Asha et al. (2017) [32] investigated 0%, 10%, 12.5%, 15%, 17.5% and 20% replacement of coarse aggregate by volume with WP in M20 and M25 concrete grade following IS 10262:2009 concrete preparation. The papercrete toughened properties were investigated. Based on the observed strength for M20 and M25 concrete grades, the acceptable percentage range was 10% to 12.5% replacement from the experimental results at 28 days. Although the government did not approve this papercrete, it could be used in the building industry and efficiently recycle WP for good things. Tables 4 and 5 and Figure 6 show the M20 and M25 mix proportions and compressive strength results.

Table 4. M20 mix proportion (%) (Asha et al., 2017) [32]

Materials	CM	PC1	PC2	PC3	PC4	PC5
OPC	70	70	70	70	70	70
Fine aggregate	25	25	25	25	25	25
Superplasticizer	5	5	5	5	5	5
Coarse aggregate	52	46.8	45.5	44.2	42.9	41.6
WP	0	10	12.5	15	17.5	20
Water	100	100	100	100	100	100

Table 5. M25 mix proportion (%) (Asha et al., 2017) [32]

Materials	CM	PC1	PC2	PC3	PC4	PC5
OPC	70	70	70	70	70	70
Fine aggregate	25	25	25	25	25	25
Superplasticizer	5	5	5	5	5	5
Coarse aggregate	50	45	43.75	42.5	41.25	40
WP	0	10	12.5	15	17.5	20
Water	100	100	100	100	100	100

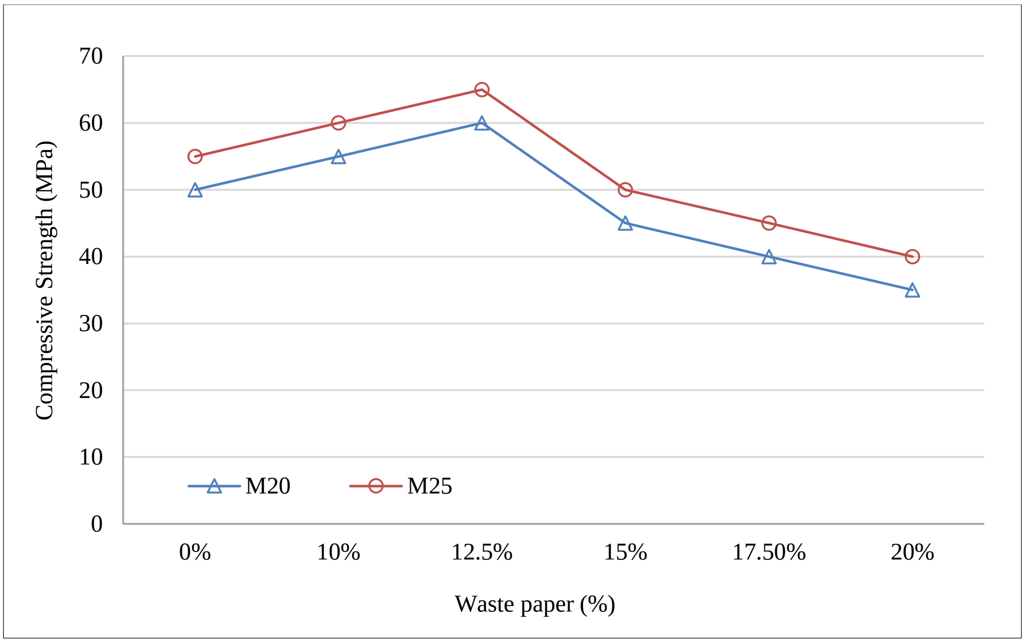

Figure 6. Compressive strength of M20 and M25

Cherkina and Korolchenko (2019) [20] casted M30 concrete cubes based on IS: 10262-1982 and IS: 456-2000 by replacing cement with WP at 0%, 5%, 10% and 15% at 7a and 28 days, respectively. This code presented a generally applicable method for choosing mixture proportion for high strength concrete and optimizing this mixture proportion based on trial batches. Concrete cubes were cast with cement replacement by paper at 0%, 5% and 10%. It was observed that the compressive strengths were nearly equal to the normal concrete with cement replacement with paper at percentages of 5% and 10%, while at 15 % replacement, the compressive strength was equaled to normal concrete without paper content. Hence, it could be concluded that cement could be replaced by 5% and 10% of paper content in concrete in the future from time to time.

Jung et al. (2015) conducted research on cement mortar replaced with WP at 0%, 5%, 10%, 15% and 20% of replacement rate against the cement weight to evaluate the suitable WP rate. The trials were separated into 45%, 60%, 75% of W/C ratios to discover mortar physical and mechanical properties with W/C ratio change, replacement rate, and WP type. Mortar using waste newspaper recorded the highest compressive strength compared to mortar using waste advertisement flyer and waste copying paper. This highest strength was due to the newspaper material with the highest absorption rate and it had the best combination with cement composite. The 5% replacement rate against cement weight showed the highest compressive strength compared to 0%, 10% and 15% replacement rate because hydrate formations actively occurred when the WP was replaced in a small amount. Jung et al. (2015) also experimented on concrete compressive strength containing WP replaced with 0%, 10%, 15% and 20% of cement weight with three different W/C ratios of 60%, 70% and 80%. This experiment sets the significance of the interaction between the strength change graph in the mortar test and the concrete brick test value. All the compressive strength results were satisfied because the compressive strength values were over 8 Mpa in accordance with the KS standard. Based on the experimental results, the best W/C ratio was 70%. A mixture containing 10% cement replacement with WP showed the greatest compressive strength at 28 days compared to 0%, 15%, and 20% replacement and 60% 80% w/c ratios. The higher absorptive force of WP caused the development of absorption with the increment of WP proportion in the concrete brick. A higher amount of replaced WP could be determined to reduce the cement paste and WP bond strengths. Table 6 shows the optimum percentage of WP for compressive strength [33].

Four concrete mixes incorporating WP at 0%, 5%, 10% and 15% as an extra material were mixed with cement, sand, and coarse aggregate with a ratio of 1:2:3 by weight as studied by Mamta et al. (2018) [34]. The maximum coarse aggregate size was 20 mm. According to the test results, the compressive strength of the mixture decreased with increasing waste paper content. In 7 days compressive strength test, the strength reduced from 16.03 to 11.0 N/mm^2, while at 28 days, it increased from 19.0 to 15.67 N/mm^2 with 5% and 10% of WP addition. The high water to cement ratio in the mixture caused the decrease of the compressive strength.

Nivedita & Ajay (2020) [35] conducted an experiment of M20 and M25 concrete grades containing 0%, 5%, 10%, 15% and 20% cement replacement with WP. The compressive strengths increased with 5% and decreased with 10%, 15% and 20% cement replacement with WP for both concrete grades at 14 and 28 days. 5% was the optimum and best percentage for increasing compressive strength.

Table 6. Optimum percentages of WP for compressive strength

References	Percentages of WP (%)	Optimum Percentages (%)
Balwaik & Raut (2011) [28]	0, 5, 10, 15, 20% of WP as partial replacement of cement	5, 10%
Ilakkiya & Dhanalakshmi (2018) [29]	0, 5, 10, 15% addition of WP	5, 10%
Zaki et al. (2018) [19]	0, 5, 10, 15, 20% of WP as partial addition by weight of cement	5%
Malik (2013) [23]	5, 10, 15 and 20% replacement of WP with cement	5%
Chakraborty et al. (2015) [30]	0, 10, 20, 30, 40, 50% partial replacement of cement with WP	10%
Suri (2018) [31]	0, 5, 10, 15, 20% addition of WP	10, 15%
Asha et al. (2017) [32]	0, 2.5, 5, 7.5, 10, 12.5% of coarse aggregate replacement with WP by volume	10, 15%
Cherkina and Korolchenko (2019) [20]	0, 5, 10, 15% of cement replacement with paper	15%
Jung et al. (2015) [33]	0, 5, 10, 15, 20% of cement mortar replacement with WP	5%
Jung et al. (2015) [33]	0, 10, 15 and 20% of cement replacement with WP by cement weight	10%
Mamta et al. (2018) [34]	0, 5, 10, 15% addition of WP	5, 10%
Chandrakar & Singh (2020) [35]	0, 5, 10, 15, 20% cement replacement with WP	5%

5.2. Flexural Strength

Balwaik and Raut (2011) [28] investigated concrete cubes performance at 14 and 28 days using 0%, 5%, 10%, 15% and 20% partial cement replacement with waste WP. Utilization of discarded WP in lieu of landfill disposal. The concrete mechanical property was determined by performing flexural strength tests according to IS 516-1959 using a two-point loading method for simply beams. The best results were replaced with WP at 5% and 10%. 10% replacement recorded the maximum strength and reduced gradually at 15% and 20% replacement. Ilakkiya and Dhanalakshmi (2018) [29] investigated concrete mixtures at 7, 14 and 28 days using extra material known as WP with 0%, 5%, 10% and 15% addition with a ratio of 1.1.5:3 placed at the open-air condition. The load was applied at a pace that continuously increased the maximum stress until rupture occurred. The flexural strengths value increment showed by WP addition at 5% and 10% and the strength reduced with further WP addition compared to 0%. The decrease of flexural strength was affected by the increase of WP amount due to less composition content of silica. Concrete containing WP could help to reduce environmental pollution and also helped to cut the building cost. This technique was the optimal way to dispose of WP effectively. Figure 7 shows the results of flexural strength at 7, 14 and 28 days.

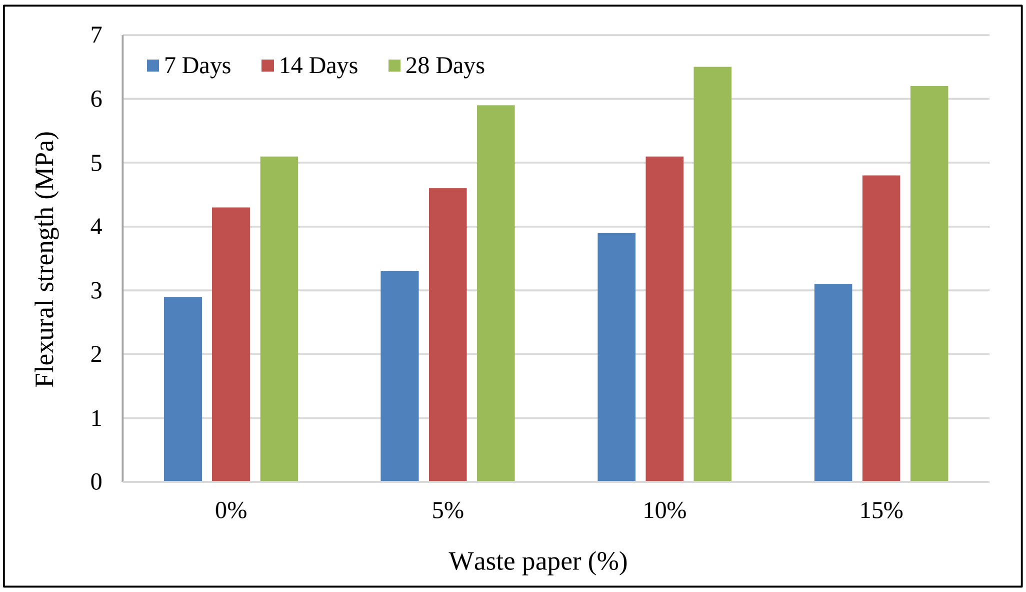

Figure 7. Flexural strengths at 7, 14 and 28 days [29]

The flexural strengths of concrete prism samples at 7, 28 and 56 days in similarity with ASTM C78-15 were studied by Zaki et al. (2018) [19] with 0%, 5%, 10%, 15% and 20% of WP addition. 0.02 MPa/sec rate and a two-third point loading system were used. The increase in strength was caused by the hydration process along with curing ageing progression. In conclusion, the percentages of 10%, 15% and 20% WP partial addition by cement weight recorded less flexural strengths than the reference mix, which contained 0% WP for all test ages at 7, 28 and 56 days aside from the 5% concrete mixture. The reference mix showed slightly lower flexural strength compared to WP addition with 5% percentage. Figure 8 shows the flexural strengths at 7, 28 and 56 days.

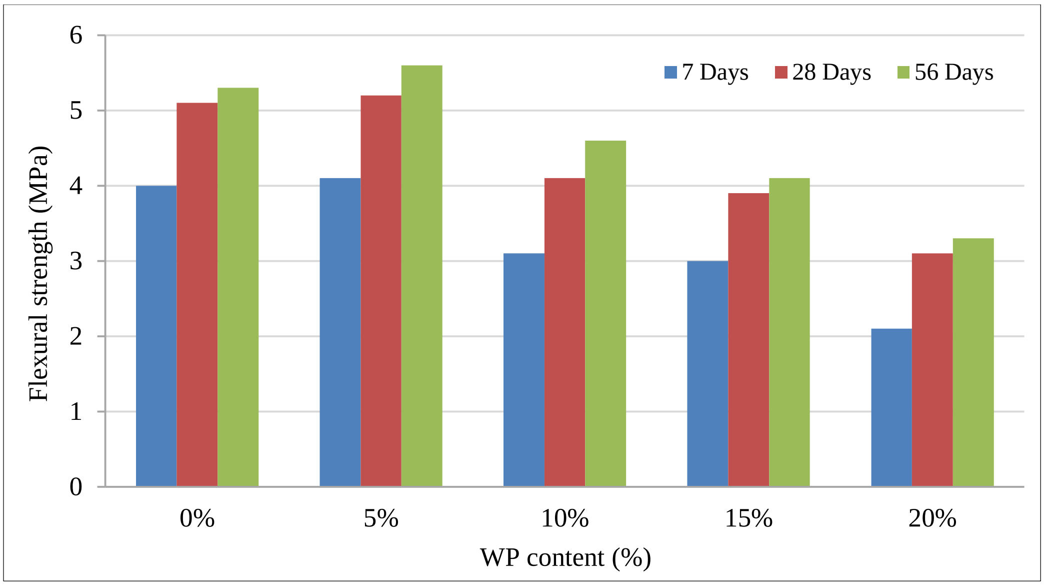

Figure 8. Flexural strengths at 7, 28 and 56 days [19]

This study investigated the concrete mixtures containing WP as an additive for use in housing projects. Shukeri and Ghani (2008) [14] developed four concrete mixes: a controlled mix and three mixes containing WP as an additive with 5%, 10%, and 15%. The determination of flexural strength value was based on BS 1881: Part 118: 1983 standard. The mixture of 5% revealed a greater strength than the mixtures of 0%, 10% and 15%. This increased strength may be attributed to the fact that 5% had lower water to cement ratio than the 0%, 10% and 15% concrete mixtures. According to study findings, the concrete flexural strength became minor as well as the WP content increased. Yet, the control mixture had less flexural strength than the concrete mixture containing 5% of WP. Therefore, it is imperative to keep in mind that concrete mix containing WP showed a significant connection between flexural strength and density strength. Table 7 and Figure 9 show the mix proportion of concrete and line bar of flexural strength.

Table 7. Mix proportion of concrete [14]

Materials	0%	5%	10%	15%
Cement (kg)	12	11.5	11	10.5
Sand (kg)	24	23	22	21
Gravel (kg)	36	34.5	33	31.5
WP (kg)	0	0.58	1.1	1.58
Water (kg)	7.2	6.9	6.6	6.3
Additional water (kg)	0	0.9	2.2	1.1
Total water (kg)	0	7.8	8.8	7.4

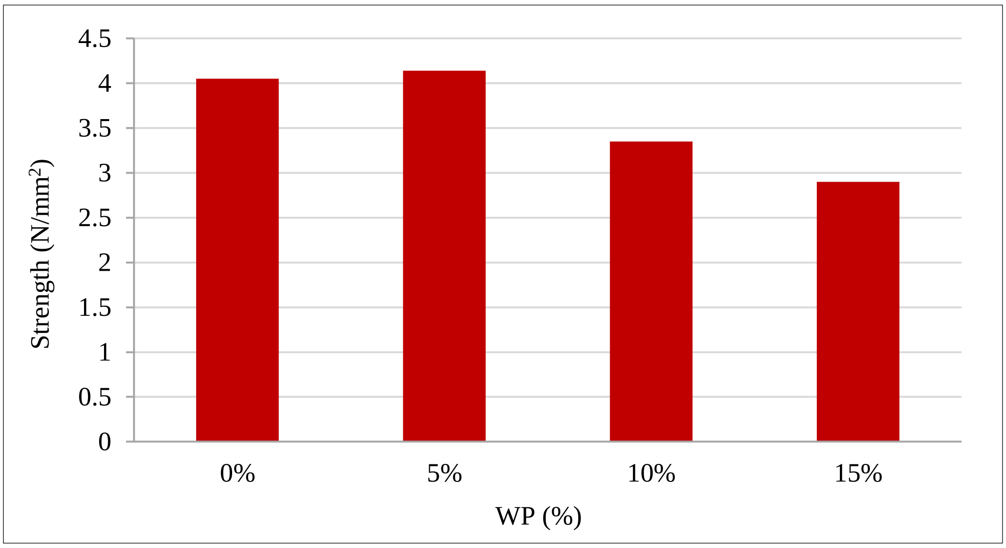

Figure 9. Line bar of flexural strength [14]

The cement has been supplanted by WP as needed to be in the scope of 5% to 20% by Seyyedalipour et al. (2014) [36]. In addition, the concrete setting was improved by the silica and magnesium properties, which affected the WP to behave like cement [37]. A total of ten concrete combinations were formulated and manufactured. The college donated materials for the experiment, including water, sand, Portland cement and coarse aggregate. Sufficient water and WP content were made to produce a concrete mixture and their strength was compared to the normal concrete without WP content. Early strength gain was indicated by the enhancement of the flexural strength. Concrete mixtures containing WP showed higher strength than reference concrete mixture [38]. The flexural strength decreased with excessive amounts of WP added in the concrete mixtures. The waste WP significantly influenced the concrete mechanical properties. At 5% and 10% addition of waste WP showed positive performance by increasing their flexural strengths, respectively and the strength gradually decreased with subsequent waste WP addition. 5% to 10% was the most appropriate percentage of waste WP addition to cement in concrete.

The addition of 0%, 2.50%, 5%, 10%, 15%, 20%, 30%, and 35% of WP by weight of OPC was studied by Selvaraj et al. (2015) [38]. They produced eight papercrete beams, which were one control beam and seven papercrete beams. W/C and cement: sand: coarse aggregate ratios were selected 0.4 and 1: 1.5: 2, respectively in this study. A curing tank was used to cure all the specimens for 28 days. The water mixing demand grew as well as the increase of WP percentage resulted in the increased requirement of cellulose polymers water absorption. The flexural strength increased dramatically, as the percentages of WP addition were 10%, 15%, 20%, 30%, and 35%, except for 2.5 and 5%. The cellulose fibre allows for sufficient bending of these increasing levels of flexural strength to accommodate the bending force generated during the flexural test. This application was assessed to be suitable for partitions, structural beams, roofing sheets and boards due to the bending stress created. A large amount of impact pressure was absorbed by cellulosic fibre material. Thus, partition boards, pavement tiles, other lightweight structural components and ceiling boards might all be manufactured using this papercrete material. Table 8 and Figure 10 show the papercrete mix proportion and the results of flexural strengths

Table 8. Papercrete mixture [38]

Mix ID	Cement (%)	Sand (%)	Coarse aggregate (%)	WP by cement weight (%)	W/C
C	1	1.5	2	0	0.4
P1	1	1.5	2	2.5	0.4
P2	1	1.5	5	5	0.4
P3	1	1.5	2	5	0.4
P4	1	1.5	2	15	0.45
P5	1	1.5	2	20	0.45
P6	1	1.5	2	30	0.45
P7	1	1.5	2	35	0.5

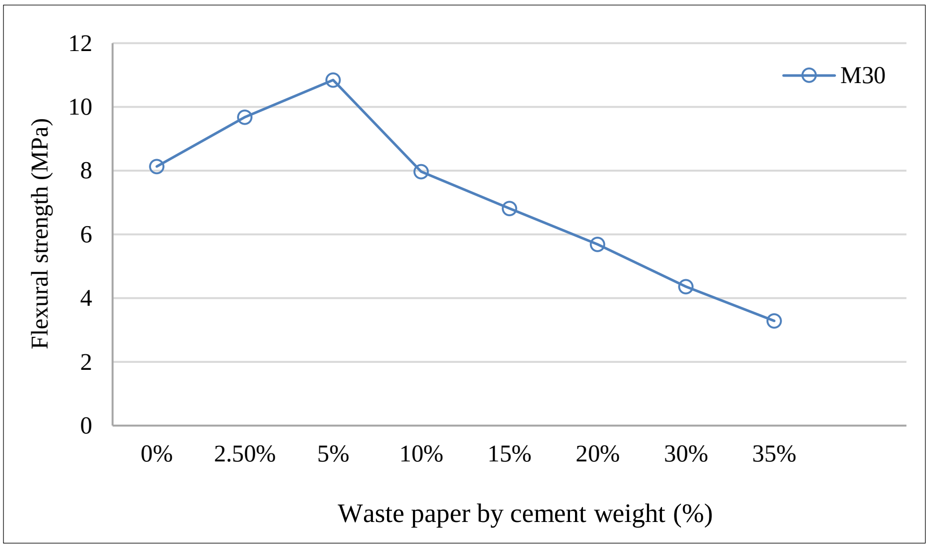

Figure 10. Flexural strength [38]

At 7 and 28 days, 5%, 10%, and 15% were the various percentages used in the M30 concrete mixture by replacing fine aggregate with recycled WP for determining concrete beam flexural strengths [39]. 10% and 15% replacement showed better results by showing the improvement of flexural strength at 7 days, but at 28 days, 5%, 10% and 15%

showed bad flexural strength improvement by reducing their strengths compared to 0% mixture. 15% replacement at 7 days and 0% replacement at 28 days showed the highest strength compared to the other mixtures.

The flexural tests were conducted by replacing the coarse aggregate in high strength concrete mixes with 100% of recycled coarse aggregate (RCA), 20% and 40% of papercrete with RCA [40]. The mix design grade used was M25. The flexural test determined a beam or slab resistance to bending failure. It was determined using an unreinforced load on a 6" × 6" concrete beam with a span three times the depth (typically 18 inches) and quantified using the term Modulus of Rupture (MR) in psi, approximately 12% to 20% of the compressive strength. At 7, 14 and 28 days, there was an improvement of flexural strength of 20% papercrete with RCA compared to control concrete with 100% RCA and 40% papercrete with RCA. Finally, lightweight concrete could be produced using 20% papercrete with RCA.

An investigation was made to investigate papercrete and glass fibre behaviour for specimens of concrete beams by replacing 20% papercrete and sand with glass fibres by 6%, 8%, 10%, 12% and 14% [41]. All materials were added referring to sand weight. The papercrete and glass fibre properties, mechanical and physical, were obtained by performing several laboratory tests. They were dried in the open air curing for 7, 14 and 28 days. The 20% papercrete flexural strength containing 12% sand replacement with glass fibre was higher than conventional concrete. 20% papercrete with 12% of glass fibre was the optimum level to get high flexural strength values at all days curing, which were 7, 14 and 28 days. Less weight concrete will reduce the total dead load of a building. Furthermore, adding glass fibre to the mix composition will increase the fracture energy of cement-based material. Table 9 shows the optimum percentage of WP for flexural strength.

Table 9. Optimum percentages of WP for flexural strength

References	Percentages of WP (%)	Optimum percentages (%)
Balwaik & Raut (2011) [28]	0, 5, 10, 15, 20% of WP as partial replacement of cement	5, 10%
Ilakkiya & Dhanalakshmi (2018) [29]	0, 5, 10, 15% addition of WP	5, 10%
Zaki et al. (2018) [19]	0, 5, 10, 15, 20% of WP as partial addition by weight of cement	5, 10%
Shukeri and Ghani (2008) [14]	0, 5, 10, 15% addition of WP	5%
Seyyedalipour et al. (2014) [36]	0, 5, 10, 15, 20% replacement of WP to cement	5, 10%
Selvaraj et al. (2015) [38]	0, 2.5, 5, 10, 15, 20, 30, 35% addition of WP by weight of OPC	2.5, 5%
Shilin et al. (2016) [39]	0, 5, 10, 15% replacement of fine aggregate with WP	10, 15% (7 days), 0% (28 days)
Subramani & Shanmugam (2015) [40]	Replacing coarse aggregate with 100% of recycled coarse aggregate (RCA), 20 and 40% of papercrete with RCA	20% papercrete with RCA
Selvarasan et al. (2017) [41]	Replacing 20% papercrete and sand with glass fibres by 6, 8, 10, 12 and 14%.	20% papercrete with 12% glass fibre
Peng et al. (2019) [42]	0, 5, 10, 15% coarse aggregate replacement with WP	5, 10%
Solahuddin & Yahaya (2021) [43-48]	0, 5, 10, 15% of WP addition	5, 10%

An experiment contained four concrete mixtures with 0%, 5%, 10% and 15% coarse aggregate replacement with WP was conducted by Peng et al. (2019) [42]. BS 1881: Part 118:1983 standard was used to test the flexural strength of concrete mixtures. 5% and 10% demonstrated more strength than mixture of 0% and 15%. 10% coarse aggregate replacement with WP recorded the highest strength compared to 0%, 5% and 15%.

Solahuddin & Yahaya (2021) [43-48] added WP with percentages of 0%, 5%, 10%, and 15% in concrete mixtures and conducted flexural strength tests at 7 and 28 days of water curing. The concrete flexural strengths increased at 5% and 10% addition of WP while at 15% addition, the strengths started to drop compared to 0% addition of WP. However, even the specimen strengths containing 15% WP drop compared to the specimens containing 5% and 10% WP, their strengths were still lower than the control specimen. This experiment showed that the acceptable percentages of WP addition were 5% and 10%. At 7 days, 10% of WP addition recorded the highest flexural strength, which is 6.1 MPa while the lowest strength is recorded at 15% of WP addition, which was 4.6 MPa. At 28 days, 10% of WP addition records 7.4 MPa flexural strength value which was the highest value, while the lowest strength was recorded at 15% of WP addition, which was 5.8 MPa.

5.3. Splitting Tensile Strength

Balwaik & Raut (2011) [28] experimented on concrete cylinders splitting tensile strength at 28 days containing 0%, 5%, 10%, 15%, and 20% of partial cement replacement with WP as per IS 5816-1999 standard. The concrete grade used were M20 and M30. Generally, partial cement replacement with WP up to 10% increased the strength and reduced gradually with further WP replacement. 5% to 10% was the optimum mix proportion for WP replacement. WP addition in concrete by 0%, 5%, 10% and 15% was studied by Ilakkiya & Dhanalakshmi (2018) [29]. The flexural strengths of

1500 mm width and 300 mm length WP concrete cylinder specimens dried outdoor with open-air were determined by chosen 1:2 ratio of diameter to length of the cylinder specimen. The test was subjected to a splitting tensile test under a UTM with a balanced loading rate of 0.11 to 0.023 MPa/sec in accordance with ASTM C496-90 after curing for 28 days. While testing the specimens, two plywoods were being placed, one was at the top of the specimen and the other one was at the bottom of the specimen. The splitting tensile strength was observed more than the reference mix at 10% addition of WP and it diminished at more than 10% of WP. The increase of splitting tensile strength was showed by WP addition at 5% and 10% and the strength reduced at 15% addition compared to 0% mixture without WP. Figure 11 shows splitting tensile strength for M-20 and M-30 concrete specimens at 28 days.

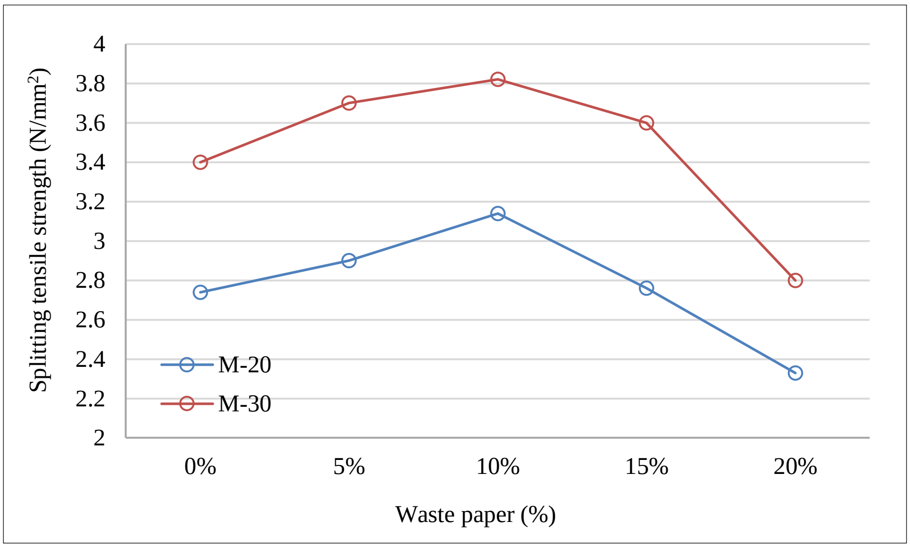

Figure 11. Splitting tensile strength [29]

Zaki et al. (2018) [19] studied WP as partial addition by weight of cement with 0%, 5%, 10%, 15% and 20% percentages on the concrete mechanical property by conducting splitting tensile strength tests based on ASTM C496-11. The results of WP concrete mixtures were less than the mixture without WP instead of 5% mixture for 7, 28 and 56 test ages. The slightly higher splitting tensile strengths were shown by 5% concrete mixture containing partial addition of WP compared to 0% partial addition. The splitting tensile strength decreased due to cohesion loss and fragile binding of cellulosic material. Therefore, the concrete volume was held by the addition of WP in a concrete mixture and concrete strength debilitation will occur due to the certain percentage of WP partial addition. Figure 12 show the strengths of splitting tensile at 7, 28 and 56 days.

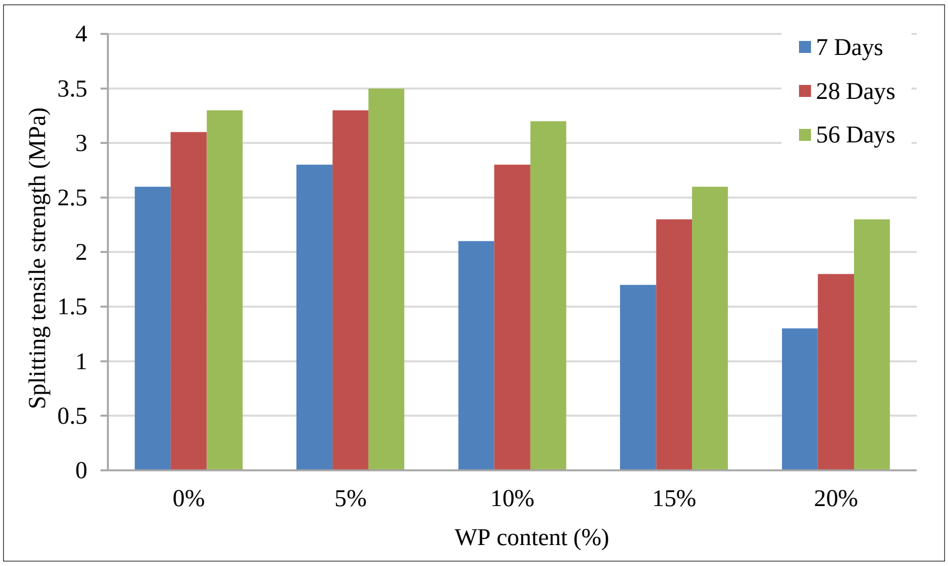

Figure 12. Strengths of splitting tensile at 7, 28, 56 days [19]

Malik (2013) [23] summarized the behaviour research of concrete cylinders with 5%, 10%, 15% and 20% replacement of WP with cement by performing splitting tensile strength tests based on IS 5816-1999 and cured under the normal condition at 7 and 28 days. 5% of cement replacement with WP was the optimum percentage causing a higher splitting tensile strength than the reference mix and at 10%, 15% and 20%, the strength decreased. Shukeri and Ghani

(2008) [14] studied five concrete mixtures, which were 0% was the control mixture and the other four mixtures were concrete containing WP as an additive material at the percentages of 5%, 10% and 15%. All mixtures used 1:2:3=cement:sand:gravel mix proportion ratio. A workable mix could be obtained by sufficient water amount because WP had high water absorption characteristic. The 5% WP mixture showed the highest tensile strength obtained compared to the mixture of 0%, 10% and 15% of WP. At 7 and 28 days, 6.1% and 5.8% stronger in tension was shown by the concrete mixture containing WP compared to the control mixture. The higher the WP amount, the lower the concrete splitting tensile strength and a good concrete performance was shown by 5% of the WP concrete mixture.

Chakraborty et al. (2015) [30] experimented at 7 and 28 days on five distinctive replacement levels of concrete cubes with WP with the percentages of 10%, 20%, 30%, 40% and 50% and OPC concrete with 0% cement replacement level with water curing. The following conclusion could be made that WP utilization as partial cement replacement was discovered effectively in low-grade concrete of M15 but unsuitable for high-grade concrete of M20 and M25. Besides that, up to 20% of cement replacement level caused the concrete strength increment of splitting tensile compared to OPC concrete. Of the various replacement levels such as 0%, 10%, 20%, 30%, 40%, 50%, at 20% replacement level in M15 concrete grade was the maximum strength and optimum level by showing the maximum splitting tensile strength produced.

Seyyedalipour et al. (2014) [34] researched the concrete mechanical property containing WP as partial cement replacement at the percentages of 0%, 5%, 10%, 15% and 20%. The splitting tensile strength tests were conducted for M20 and M30 concrete grades containing WP and without WP which was the control mixture. From the experimental results at 28 days, Cement partial replacement with WP at 5% and 10% increased the splitting tensile strength and 10% replacement produced the maximum strength compared to 0%, 5%, 15% and 20% replacement for concrete grades of M20 and M30.

There was research conducted by Selvaraj et al. (2015) [36] on 80 mm diameter and 250 mm long eight concrete cylinder samples consisted of seven papercrete mixes with 2.5%, 5%, 10%, 15%, 20%, 30% and 35% addition of WP and one control concrete without WP at 28 days by curing in a water tank. The w/c and ratios used were 0.4 and 1:1.5:2. The splitting tensile strength showed improvement with 5% addition of WP compared to the control mixture and almost equivalent to the control concrete with 10% of WP addition and any further addition higher than 10% led to strength decreasing. The amount of WP higher than 10% caused the decrease of splitting tensile strength because the material deformation had occurred while applying the load. The splitting tensile strength tests were experimented with by replacing the coarse aggregate in high strength 300 mm length and 150 mm diameter concrete cylinders mixed with 100% recycled coarse aggregate (RCA) and 20% & 40% of papercrete with RCA [40]. M25 mix design grade was used. Finally, the concrete strength increased by using 20% papercrete with RCA compared to 100% RCA and 40% papercrete with RCA.

0%, 5%, 10%, 15% and 20% cement replacement by weight was replaced with WP for 300 mm length and 150 mm diameter M-25 concrete cylinders and performed splitting tensile strength tests following IS 5816-1999 standard [49]. The opposite side of the specimens was applied by loads. The splitting tensile strength performed was one of the essential and significant properties of concrete. The optimum mix proportion was 5% replacement of WP with cement and found to be more than 0% replacement and a further increase reduced the strengths continuously for M-25 concrete mixture for both 14 and 28 days. Table 10 shows the mix proportion of M-25 concrete, while Figure 13 shows the M-25 splitting tensile strengths at 14 and 28 days. Table 11 shows the optimum percentage of WP for splitting tensile strength

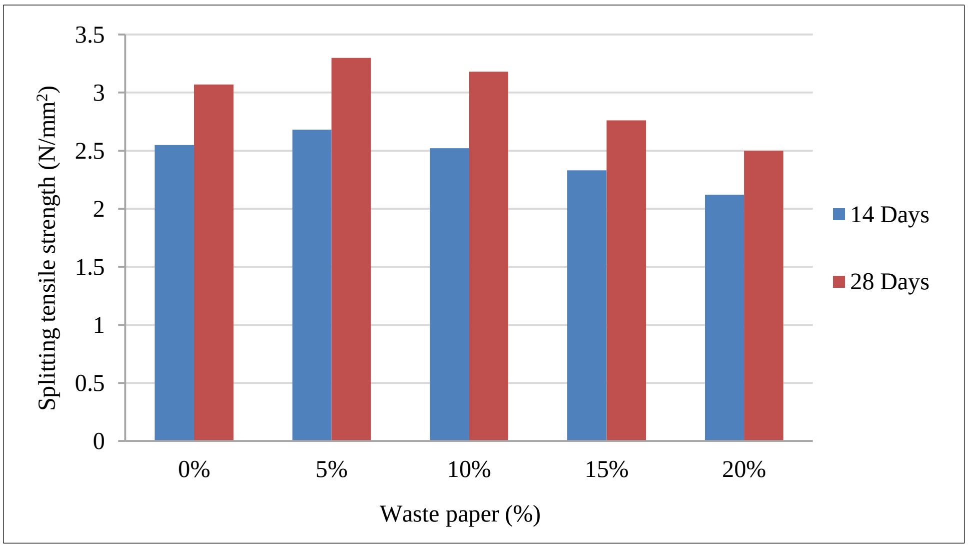

Figure 13. M-25 splitting tensile strengths at 14 and 28 days [45]

Table 10. M-25 concrete [45]

Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (L)	WP (%)	WP (kg)
372	719.39	1143.53	186	0	0
353.4	719.39	1143.53	186	5	18.6
334.8	719.39	1143.53	186	10	37.2
316.2	719.39	1143.53	186	15	55.8
297.6	719.39	1143.53	186	20	74.4

Table 11. Optimum percentages of WP for splitting tensile strength

References	Percentages of WP (%)	Optimum percentages (%)
Balwaik & Raut (2011) [28]	0, 5, 10, 15, 20% of WP as partial replacement of cement	5, 10%
Ilakkiya & Dhanalakshmi (2018) [29]	0, 5, 10, 15, 20% of WP as partial addition by weight of cement	5, 10%
Zaki et al. (2018) [19]	5, 10, 15, 20% of cement replacement with WP	5%
Malik (2013) [23]	0, 5, 10, 15% addition of WP	5%
Chakraborty et al. (2015) [30]	0, 10, 20, 30, 40, 50% of cement replacement with WP	10, 20%
Seyyedalipour et al. (2014) [34]]	0, 5, 10, 15, 20% of WP as partial replacement of cement	5, 10%
Selvaraj et al. (2015) [36]	0, 2.5, 5, 10, 15, 20, 30, 35% addition of WP	2.5, 5, 10%
Subramani & Shanmugam (2015) [40]	Replacing coarse aggregate by 100% of recycled coarse aggregate (RCA), 20 and, 40% papercrete with RCA	20% papercrete with RCA
Raghuwanshi et al. (2018) [49]	0, 5, 10, 15, 20% of cement replacement with WP	5%
Muttashar et al. (2020) [50]	0, 5, 10, 15, 20% of partial cement replacement with WP	10%

Five concrete mixes incorporating WP at 0%, 5%, 10%, 15%, and 20% as partial cement replacement were mixed with sand and coarse aggregate with a ratio of 1:2:5 by weight as studied by Muttashar et al. (2020) [50]. The maximum coarse aggregate size was 20 mm. According to experimental test results, the splitting tensile strength of the mixture decreased with increasing waste paper content at 15% and 20%. In 7 days, the compressive strength test increased from 12.08 to 14.17 N/mm^2, while at 28 days, the compressive strength increased from 25.43 to 27.77 N/mm^2 with 10% of partial cement replacement with WP.

5.4. Discussion

5%-10% replacement of WP with Portland cement and 5%-10% addition of WP in concrete increase compressive, flexural, and splitting tensile strengths compared to 0% of WP contents, which were proved by several experimental results investigation. Balwaik & Raut (2011) [28] said that in order to accelerate the hydration process, there would be an increase in the amount of WP. As a result, more water is required to activate the cement hydration to improve the overall concrete strength, which is the most commonly employed remedy to this problem. Consequently, the concrete strength decreases with greater water content. The results show an increase in strength as the curing process continued. For all mixes, except for those with 5% addition of WP, the findings of compressive, flexural and splitting tensile strengths of concrete were lower than reference mixes [19].

The strength increases caused by the mixed calcium with alumino-siliceous material. Moreover, the strengths increase at 5% of WP addition compared to 0% because WP contained a substantial alumina-siliceous material mixed with calcium. It can be deduced that the strength advancement iss heavily based on the alkali and pozzolanic activities of the WP, which was triggered by the hydration process. As a result, there is a weak bonding between the calcium hydrate silicate (C-S-H) and cellulosic material. Adding WP to the concrete mix will help maintain the specimen volume and any growth in the mixture. Concrete mixes with 5% WP resulted in the same strength regardless of the specimen ages, and the strength falls as the quantity of WP increases. Chakraborty et al. (2015) [30] stated that WP usage could be utilized in low-grade concrete works, which otherwise has been dumped over terrains and caused many ecological risks. For low-strength concrete (M15), replacement of WP is successful, but for high strength concrete (M30), it is determined to be unsatisfactory. So, if every bag of cement costs 500 takas, a savings of up to 50 takas is possible. Additionally, with the help of WP, 66,000 bags of cement may be made each year. Therefore, additional research is required to investigate the possibility of using WP as a cement replacement material, and it is also important to increase the number of cement replacements used in concrete buildings to reduce pollution and save the environment.

The 5% replacement rate by cement weight shows the highest compressive strength compared to 0%, 10% and 15% replacement rate because hydrate formations actively occur when the WP is replaced in a small amount, as stated by Jung et al. (2015) [33]. WP replaces the cement mortar as the most effective replacement based on the basic mortar test.

When the WP replacement rate is 5%, the compressive strength appears to be at its optimum value. The data says that the hydration form will occur when a little amount of WP is substituted with cement mortar. The researchers believe that the gap-filling of WP boosts the compressive, flexural and splitting tensile strengths to increase. The higher absorptive force of WP causes the development of absorption with the increment of WP proportion in concrete. Thus, a higher amount of replaced WP can be determined to reduce the cement paste and WP bond strengths. In addition to this, the silica and magnesium properties improve the concrete chemical properties, which affect the WP to behave like cement behaviour [35]. Consequently, there is an increase in cement paste in the sand mixture, which causes the dropping in both strengths. The flexural and splitting tensile strengths of papercrete increase due to the increase of cement paste amount [34]. The test results show that the strengths reduced rapidly when the replacement ratio of WP increases. Using water in WP involves a cement hydrate reaction, causing a decrease in both strengths since more water is needed for the cement hydrate reaction involved. The cellulose fibre allows for sufficient bending of these increasing levels of compressive, flexural and splitting tensile strengths to accommodate the bending force generated during the tests [36]. A large amount of impact force is absorbed by the cellulose fibre material in the papercrete structure. The amount of WP higher than 10% causes the decrease of both strengths because the material deformation has occurred while applying the load. This application is assessed as suitable for partitions, structural beams, roofing sheets and boards due to the bending stress created. Thus, partition boards, pavement tiles, other lightweight structural components and ceiling boards might all be manufactured using this papercrete material.

Mixtures with 5% and 10% show marginally higher compressive, flexural and splitting tensile strengths compared to the control mixture since the paper is made from cellulose. Cellulose is considered a fibre material and consists of a molecule containing carbon and hydrogen atoms. Water is a molecule composed of hydrogen and oxygen atoms. When mixing WP in water, the oxygen atoms from the water molecule snatch the hydrogen atoms from the cellulose, creating more hydrogen bonds, which are the basis for papercrete strength [19]. Next, the WP contains much alumina-siliceous content united with calcium, thereby enhancing its strength. The enhancement of strength is abundantly related to WP hydraulic and pozzolanic activities that are actuated by the alkalis, and to some extent, the hydration process discharges calcium hydroxide, $Ca(OH)_2$. Additionally, the hydration products cover the WP's surface with 5% and 10% addition of WP. In this way, it results in lessening the minor void and porosity in the matrix. The compact matrix improves the mechanical strength of the composite with WP addition. Solahuddin et al. (2013) [46] stated that the carbonate composite transmigration causes a de-bonded between the WP and matrix with less calcium carbonate ($CaCO_3$) content. 10% addition of WP shows the ideal and optimum result for concrete's compressive, flexural and splitting tensile strengths. Kalapad et al. (2019) [51] observed that, after examining the microstructure of concrete specimens with different WP contents, the strength enhancement with 10% addition is primarily credited to the physical properties of paper. Papercrete has superior compressibility to ordinary concrete. It can partially relieve the stretch concentration, and also, the fine aggregate holds the concrete matrix together. The compact matrix improves the mechanical properties of concrete with WP. Paper particle's fibre content improves the concrete matrix cohesion. Based on the SEM investigation, the interfacial progress zone differentiates the great bonding of particles with cement paste.

More than 10% addition is unacceptable to be utilized in concrete. The property of WP, which is high porosity, causes a decrease in strength. Overall, the compressive, flexural and splitting tensile strengths decrease with increasing percentages of WP contents, starting from 15% and onwards. The strengths begin to drop because of cohesion loss as well as the cellulosic material binding of calcium-hydrate-silicate (C-S-H) gel is acutely poor [19]. The most reasons for reducing the strength are the amounts of WP addition, physical properties and carbon content. Adding WP to the concrete mixture will hold volume in the specimens, and any development will weaken the concrete strength. The reduction of compressive, flexural and splitting tensile strengths with the increment of WP percentages is because of low silica content in the composition. On the other hand, a higher addition of WP causes a thicker surface texture of WP and negatively impacts cohesion. This comes within the formation of inner voids and capillary channels in concrete, causing a reduction in its quality. Subsequently, Jung et al. (2015) [33] determined that a higher amount of replacing WP will weaken the bond strength between the WP and cement paste. Therefore, the WP's positive impacts can move the strength of concrete with lower WP contents. If WP content surpasses 10%, the concrete strength diminishes significantly, lessening cohesion caused by WP content. Above than 10% of WP addition, the result indicates some micrograph of micro-cracks produced from the bond zone due to the feeble bonding characteristic between the WP and cement paste [51]. Besides that, there is a presence of closed pores in the specimen by increasing the WP percentages, as Sangrutsamee et al. (2012) [52] indicated. The research is limited and constrained because the same WP type is used for all research and analysis. Maybe in the future, different types of WP shall be used. The inclusion of WP in reinforced concrete has never been conducted and needs to be studied to prove whether WP could increase the structural performance of reinforced concrete or not.

5.5. Scanning Electron Microscope of Concrete Containing Waste Paper

A Scanning Electron Microscope (SEM) of the transition area revealed that the cement paste is well-bonded with the particles. Figures 14 and 15 show that the WP hydration products covered the WP surface. The pores in the matrix are reduced, and smaller voids are seen in the matrix from the experimental results. Therefore, the addition of WP improves the mechanical properties of concrete. When considering the transmigration of carbonate composites, Figures 16 to 18 exhibited debonding between WP and cement paste with a modest amount of calcium carbonate ($CaCO_3$) compared to reference symbols. The results revealed microscopic images of microcracks created when the bond zone between WP and cement paste is insufficient. Additionally, increasing WP content causes closed pores in the concrete specimen.

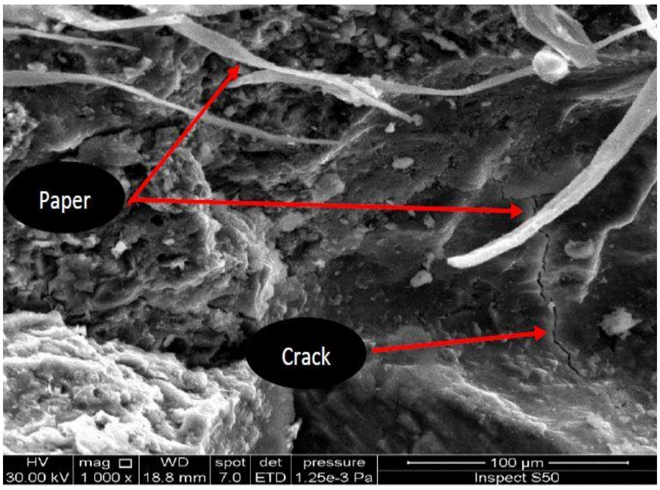

Figure 14. SEM of concrete containing 0% WP

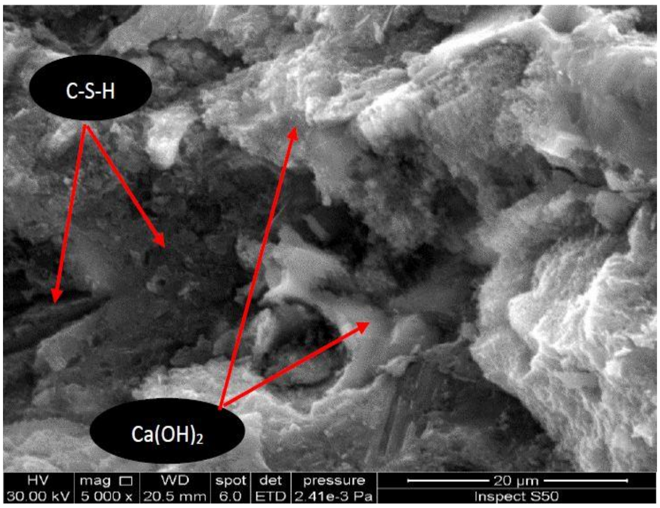

Figure 15. SEM of concrete containing 5% WP

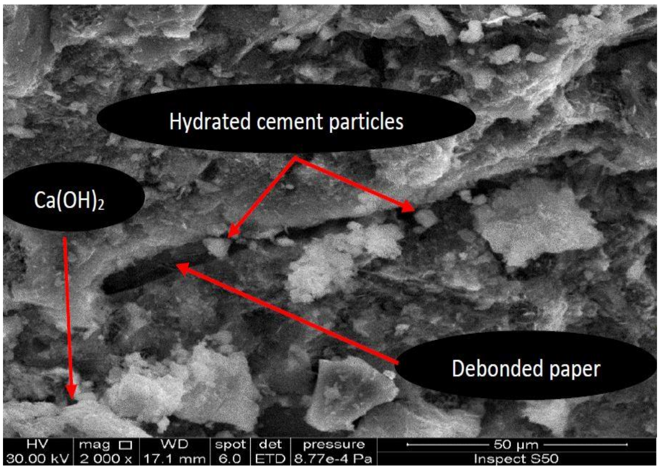

Figure 16. SEM of concrete containing 10% WP

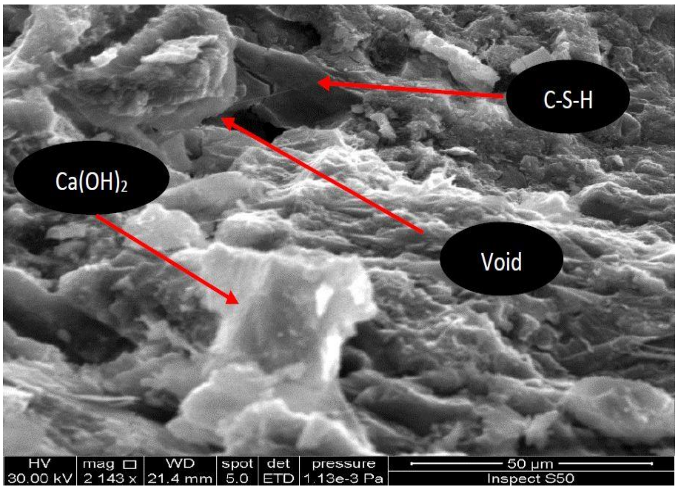

Figure 17. SEM of concrete containing 15% WP

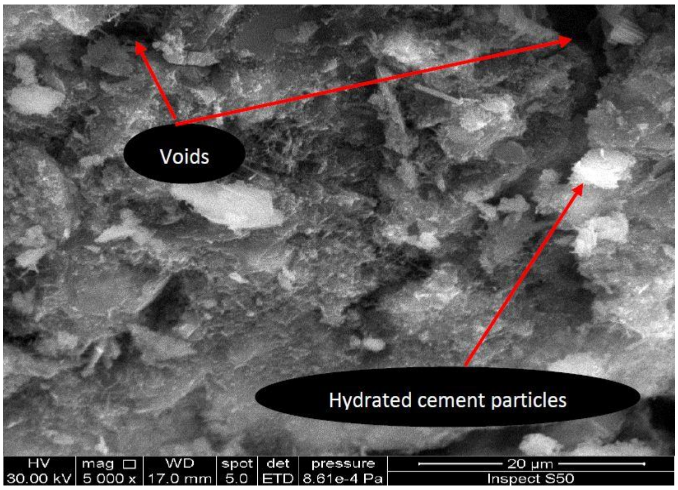

Figure 18. SEM of concrete containing 20% WP

6. Conclusion

A review of previous studies on the inclusion of WP in concrete, called papercrete, was carried out. It is apparent that the inclusion of paper brought about significant desirable characteristics compared to ordinary concrete. It can also be concluded that paper has the potential to have the favorable properties discussed above. Several experimental studies have shown that 5%–10% replacement of WP with Portland cement and 5%–10% addition of WP in concrete increase compressive, flexural, and splitting tensile strengths compared to 0% WP content. Generally, it is thought that using WP in the production of concrete is warranted and technically possible, but there are some things to keep in mind to make sure it works well.

However, further research is still required to ensure the adoption of this material on a broader scale. In particular, the type of WP used is regular paper. They did not use other types of WP, such as newspapers, manila paper, or any other types of WP. In the future, it is possible that other types of WP will be used to distinguish which type of WP produces the highest concrete strength. Furthermore, additional work is required to investigate further analysis and assess the influence of WP on reinforced concrete properties. As we know, WP has never been used in reinforced concrete production, either in reinforced concrete beams, columns, or slabs. Further research in the future will show the use of WP in reinforced concrete and prove that WP improves reinforced concrete structural performance.

7. Declarations

7.1. Author Contributions

Conceptualization, B.A.S.; investigation, B.A.S.; resources, B.A.S.; data curation, B.A.S.; writing—original draft preparation, B.A.S; writing—review and editing, B.A.S.; supervision, Y.F.M. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

Data sharing is not applicable to this article.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Acknowledgements

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7.5. Conflicts of Interest

The authors declare no conflict of interest.

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