Results in Engineering 16 (2022) 100740

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

A comprehensive review on waste paper concrete

B.A. Solahuddin

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang Darul Makmur, Malaysia

ARTICLE INFO

Keywords:
Concrete
Slump
Modulus of elasticity
Stress-strain
Water absorption

ABSTRACT

Aggregate, sand, water and cement are the mixtures for concrete. Waste paper concrete (WPC) incorporates waste paper (WP) in a concrete mixture. Each year, WP production increases gradually. As a result, additional places are required for landfills, which consume energy, deplete natural resources and increase environmental pollution. The environmental pollution could be lessened by using WP in concrete. So, this comprehensive paper reviews the potential of WP by adding or substituting with fine aggregate, coarse aggregate and cement in concrete at 0%, 5%, 10%, 15% and 20%. This paper also reviews the WP's structures, physical and chemical properties. Moreover, the fresh, structural and durability properties of WPC, such as slump, modulus of elasticity, stress-strain and water absorption, are also reviewed in this paper. From this review, the concrete's fresh, structural, and durability properties increase with the incorporation of WP at 5% and 10% and decrease at more than 10%. There are some hydrated cement particles, as observed through the SEM. At 10% WP addition, the hydrated cement particles tend to increase the concrete strength more than the strength at 5% WP addition. It is apparent that the incorporation of WP brings significant desirable characteristics compared to ordinary concrete, which has no waste paper contents. WP can potentially have favourable properties to be used in concrete production by improving its properties and performance.

1. Introduction

Water, aggregate, cement and fine aggregate, called sand, are the materials used for making a concrete mixture. A new composite material called waste paper concrete (WPC) is created by incorporating waste paper (WP) into a concrete mixture. Nowadays, carbon dioxide gas (CO_2) is emitted from construction sites due to cement usage, a significant concern for all nations. On the other hand, people's desire to live in an eco-friendly environment continues to grow. This study is conducted to address these issues. Moreover, excessive WP disposal can cause environmental pollution to occur. To reduce and prevent environmental pollution is by using WP in concrete production. WPC also reduces cement usage because it is an environmentally friendly construction building material that reduces pollution to occur, as defined by Ref. [1]. This WPC is a durable building construction material created using WP by combining with water and other materials, pouring them into a mould and then drying them before curing, whether air or water curing before experimental tests are conducted. WPC is a new material with a limited application range due to the fact that only certain percentages are allowed [2]. This is because higher percentages of WP are unsuitable, which might reduce the concrete strength, as stated by Ref. [2].

This WPC mixture is a well-insulated and durable material. Besides that, the previous experimental results show that WPC is a structurally and economically viable solution [3]. Due to the significant amount of recycled material, it is known as an environmentally beneficial material. It is also an adobe and fibrous new invention material [4]. Moreover, WPC could reduce the dead load of the main structure compared to normal concrete made up of water, coarse aggregate, cement and sand without WP content [5]. Various types of WP can replace regular WP, such as cardboard, magazine, pamphlet and any other types. Most WP found comes from paper mills or landfills [6–13]. Apart from that, WPC may relate to a productive alternative to landfills, incinerators or other waste disposal methods and also a cost-effective product [14]. WP contains fibre material, which contributes to the mixed bulk, producing lightweight concrete. Utilising WP in structural concrete would be wise, contributing to reducing the adverse effects on the construction process. It is an essential source of cellulose and fibre, as well as one of the most prevalent types of waste found in all disposal and dump activity areas. Thus, a concrete mixture containing WP is a possible landfill problem solution by reducing WP disposal. Additionally [15], noted that incorporating WP in concrete can also lessen its density. This WP incorporation is the best way to use WP wisely and adequately. Therefore, it is selected to do more research on WPC by evaluating its material properties and characteristics in order to evaluate the potential for replacing

E-mail address: solahuddin.08@yahoo.com.

https://doi.org/10.1016/j.rineng.2022.100740
Received 26 August 2022; Received in revised form 28 October 2022; Accepted 28 October 2022
Available online 6 November 2022

conventional concrete usage [3].

WPC would provide several benefits and a broad range of construction and civil engineering applications. Subsequently, the inner walls in high-rise buildings in seismically active regions could use WPC because of its lightweight nature property. In addition, by utilising WPC in building construction, the structure's dead weight and the foundation depth required would increase, making it stronger, and the utilised steel number would be reduced, lowering labour, energy and material costs [16]. In conclusion, the production of WPC encourages WP recycling, particularly in communities that do not practice it. Therefore, it conserves landfill space and reduces chemical usage in new paper manufacturing and production processes [17]. This comprehensive review paper reviews the WP structure, WP's chemical and physical properties and the advantages of using WPC. Besides that, the experimental results of fresh, structural and durability properties of concrete containing WP, such as slump, modulus of elasticity, stress-strain and water absorption, are compared to conventional concrete without WP content based on previous research stated in this paper. Based on this comprehensive review, the novelty is the concrete strength becomes better with the inclusion of WP at 5% and 10%.

2. Waste paper structure

The cellulose microfibrils are elastic up to the point when they are broken with each other. Cellulose has an elastic modulus of 25 GPa, determined by the microfibrillar helix chiral angle. The modulus of elasticity could be estimated when the fibre is parallel strained to its axis. The angle of microfibrils is more prone to natural variation than any other angle, resulting in a closer mean value to the fibre axis. As a result, the fibre's modulus of elasticity is nearly identical to cellulose properties [18,19]. Almost all types of wood have chiral fibres. Fig. 1 depicts the twisting and chiral curl of WP fibres resulting from the microscopic asymmetry image.

Wood celluloses are fibrous substances of a primary constituent of WP to make it stronger. There are long sugar molecules that bind smaller sugar molecules together in cellulose [21,22]. β-D glucose sugar is used to make the cellulose chain connections. Cellulose fibres are linked together by hydrogen bonds, as delineated in Fig. 2. Furthermore, the chains form solid, hard crystalline zones that provide better support and balance. The hydrogen bonding between WP structures strengthens the WP [23]. It is composed of silica, calcium oxide, alumina and magnesium oxide elements.

2.1. Waste paper properties

Burgess and Binnie (2010) [24] argued that particular results and discussions could be produced with the precise selection of test materials and methodologies. The properties of WP, including humidity, temperature, radiation and pollution, should be investigated. The surrounding environment affects the hydrolysis and oxidation reactions resulting in the crosslinking breakdown process.

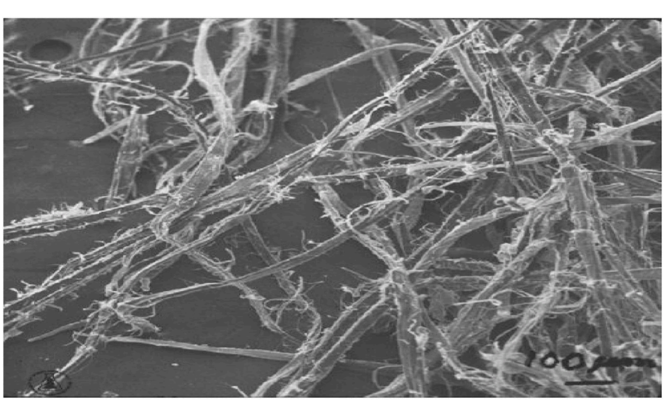

Fig. 1. Microscopic asymmetry image of WP fibres [20].

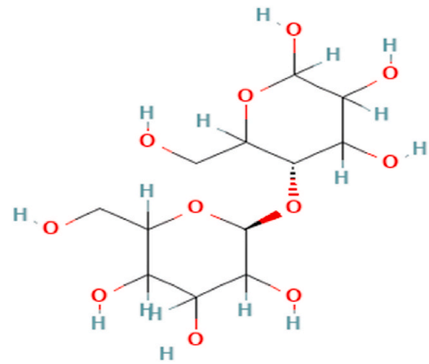

Fig. 2. Elements in a cellulose fibre [21,22].

2.2. Chemical properties

Lignin, a non-cellulosic component, reacts more strongly in particular particles. But ironically, the fact that chemical probes are hard to discover and make the WP the most difficult to be monitored and quantified. Table 1 displays the WP's chemical composition.

2.3. Physical properties

Weight, substance or grammage is one of the essential properties of WP. The WP weight is calculated using a density conversion factor that changes g/m^2 to $g/inch^2$. Counting g/m^2, p/ft2, or kg/ream of a specific dimension could be done. The size and weight of WP are important to determine its properties. The space amount of WP depends on the material weight. For example, a customer receives 1 kg of WP if he has 20 m^2 of space. There are several ways to represent how many reams of a given weight are available from one pound. Basis weight is crucial for WP in terms of production rate. Tables 2 and 3 present the WP's grading and physical properties.

3. Advantages of waste paper concrete

Joo et al. (2012) [28] studied lightweight concrete made up of WP. It was concluded that WPC was lighter and more pliable than regular concrete without WP contents. Earthquake-prone areas might use WPC as a building material. By incorporating WP in concrete production, less pollution and landfills will occur. An experiment on energy-saving lightweight concrete utilising WP was conducted by (Subramani et al., 2015) [29] in order to learn more about the properties of WPC. The weight of each concrete sample was weighed, and it was found that WPC had the lightest weight compared to ordinary concrete. After the experiment was completed (Subramani et al., 2015), [29] concluded that WPC could be utilised for any walls that did not bear any load imposed (Ravindra et al., 2017). [30] experimented on developing and investigating the WPC cubes' properties. WPC cubes were made of cement, sand and WP in various mixed proportions and were used to test the mechanical properties. It was found that WPC was easy to work with, lighter than standard concrete without WP contents and produced a high-quality finishing surface. WPC was studied and showed some interesting properties [31]. WPC had better density, water absorption property, compressive strength and fire resistance compared to regular concrete. Soundness and efflorescence tests were also carried out. According to the experimental test results, it could be concluded that WPC could be utilised for internal partition walls, slabs, columns and beams. Subsequently, WPC was a fantastic choice for building construction material since it had the best sound absorption and thus, could be used in large areas, such as halls and auditoriums, for better performance.

Table 1
WP chemical composition [25,26].

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

Table 2
WP's grading [23].

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

4. Fresh property of waste paper concrete

This section presents the slump results of WPC.

4.1. Slump

Balwaik and Raut (2011) [32] experimented on concrete containing 0%, 5%, 10%, 15% and 20% of WP to replace Portland cement partially. The slump test was conducted according to IS 1199–1959 and increased to 5% cement replacement with WP, while above 5%, the slump value decreased. The slump value increased from 69 mm to 71 mm and decreased from 71 mm to 58 mm in M − 20 concrete, while for M − 30 concrete, the slump value increased from 50 mm to 52 mm and decreased from 52 mm to 45 mm. The high absorption limit of WP caused the concrete workability to decline. Increasing the content of WP required more water to achieve the targeted slump value. Adding a high amount of water rather than admixtures can improve the WP concrete workability. Thus, economical concrete could be achieved. The physical properties, carbon content and the amount of WP addition affected the concrete reduction workability. The diminishing water demand became larger, increasing WP content to about 20%. The concrete mix proportion and slump value are shown in Table 4 and Fig. 3.

In other previous research, Ilakkiya and Dhanalakshmi (2018) [33] studied the fresh property by performing slump tests on concrete containing 0%, 5%, 10% and 15% of WP contents. The slump cone was uplifted vertically and gradually after the fresh concrete was fully compacted. Shock and vibration-free were ensured when the slump test was conducted. When the WP was added up to 10%, the slump value increased, but the slump decreased when more than 10% added WP. The increased slump values were shown by the 5% and 10% WP addition compared to 0% addition from 75 mm to 78 mm for 5% and 80 mm for 10%. There was a decrease in the slump when the WP addition was 15%, from 80 mm to 72 mm.

Zaki et al. (2018) [21] conducted slump tests following ASTM C143-12 on five WPC mixes containing 0%, 5%, 10%, 15% and 20% of WP as partial addition by weight of cement. One of the significant highlights characterising fresh concrete properties was the workability which could be described as concrete measurement ability to be transported, handled and mixed with fewer air voids. The slump value increased at 5% WP partial addition and decreased at above 5%, as delineated in Fig. 4. The water demand rose to about 20% in addition of WP content. The concrete slump value and fresh density decreased because of the WP's high water absorption property due to the high content of WP. More water is needed to acquire a similar slump as well as adding superplasticiser improved the concrete workability containing WP. More addition of paper will lower the density value. The percent of superplasticiser used is affected by the WP content. The superplasticiser percentage used depended on the WP content. It had been affirmed that including WP has an apparent opposing effect on the slump and fresh density, which demanded higher water or chemical admixture quantity to maintain the slump value possible as well.

Ramesh and Chandu (2018) [34] conducted an experimental program to explore WPC fresh property with 0%, 50% and 100% replacement of coarse aggregate with WP by performing slump tests on the fresh concrete mixtures. The concrete mix will be intended to evaluate the concrete having the necessary workability and characteristic strength at the very least of proper strength of concrete mix and should be equivalent to characteristic strength in addition to 1.65 times the standard deviation. The fresh concrete uniform workability was checked by conducting slump tests from batch to batch. In this study, an experimental activity of concrete was conducted, where coarse aggregate was replaced with WP. This undertaking contained a test perception where the correlation between conventional concrete, WPC 50% and WPC 100%. As the results obtained, the slump value increased by 47.06% with WPC 50%, while for WPC 100%, the slump value increased by 88.24% compared to the slump of conventional concrete. The slump value of fresh concrete increased as well as increased WP, which was replaced with coarse aggregate. The higher the coarse aggregate replacement with WP, the higher the slump value.

Malik (2013) [35] researched M − 25 concrete behaviour with a 0.45 water-to-cement ratio by replacing cement with 0%, 5%, 10%, 15% and 20% WP and performing slump tests according to IS 1199–1959 on each concrete mixture. The WP disposal issue might decrease from time to time and enhance concrete performance by using WP in concrete. A high level of silicon dioxide (SiO_2) in WP might strengthen the concrete. 0.45 water-to-cement ratio was used in M − 25 concrete grade. Increasing WP content affected the concrete workability by decreasing the slump value. 5% cement replacement with WP recorded the highest slump value and above 5% replacement gradually decreased the slump value. The fresh concrete workability decreased due to cement's lower water absorption than WP particles. Table 5 and Fig. 5 show the concrete mix proportion and slump value.

Gallardo & Adajar (2006) [9] investigated the workability of concrete containing 0%, 5%, 10% and 15% of WP replacement with fine aggregate. The concrete mix proportion was a procedure by which one shows up at the correct combination of cement, aggregate and water to make concrete according to the specifications. One reason for mix proportioning was to get a product that would play out the most fundamental prerequisites for the workability of fresh concrete. 75–100 mm (3–4 inches) is the desired slump range of all mixes. The mixes that did not fall in the slump range were remixed and more water was added. Using an alternative material known as WP was studied by observing the feasibility. Based on the study results, the concrete workability reduced with above 10% partial fine aggregate replacement with WP, but the concrete workability increased with 5% and 10% replacement compared to 0%. Percentage replacement higher than 10% resulted in the slump value reduction. The presence of silica compound in WP was essential because of its main role in structuring and bonding the concrete bond. During experimental procedures, there was a problem with the concrete mix workability caused by the high water absorption rate of WP. Extra water was the permanent solution for this sort of issue as well as the higher water content will reduce the concrete strength. The type of superplasticiser used in the concrete mixtures containing WP was ASTM Type D/G. This superplasticiser played roles by producing higher concrete strength and workability and producing lower density at a lesser water content. The validation of this experiment was valid and approved for 0% replacement of WP in a concrete mixture. The slump value of concrete containing WP decreased as the replacement percentage increased along with the admixture addition. WP could be used in concrete by replacing partial fine aggregate, producing low-cost housing

Table 3
WP's physical properties [21,27].

Strength of bursting value (kPa)	Coefficient of friction static	Coefficient of friction kinematic	Value of tear resistance (mN)	Value of smoothness (mls/min)	Moisture content (%)	Absorption (%)	Value of thickness (μM)	Value of moisture (%)	Organic materials (%)	Density (kg/m^3)	Inorganic materials (%)	Specific gravity (SSD)
250–300	0.5–0.65	0.35–0.5	500–600	100–300	2.67	89	105–110	4–4.5	70	800	30	0.98

Table 4
Concrete mix proportion for M – 20 and M – 30 [32].

Mix	WP (%)	Cement (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	W/C Ratio
M-20	0	383	1220	550	0.5
	5	364	1220	550	0.5
	10	345	1220	550	0.5
	15	326	1220	550	0.5
	20	307	1220	550	0.5
M-30	0	426	1220	550	0.5
	5	405	1220	550	0.5
	10	383	1220	550	0.5
	15	362	1220	550	0.5
	20	341	1220	550	0.5

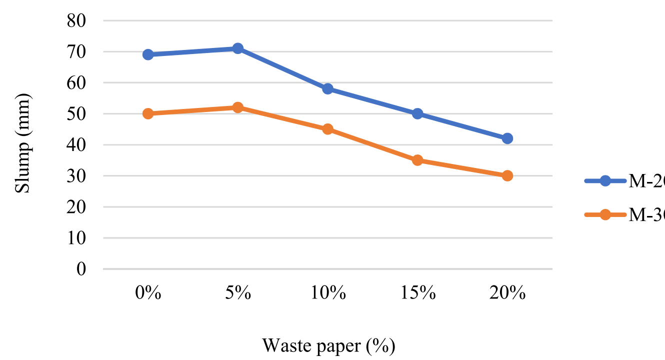

Fig. 3. Slump value [32].

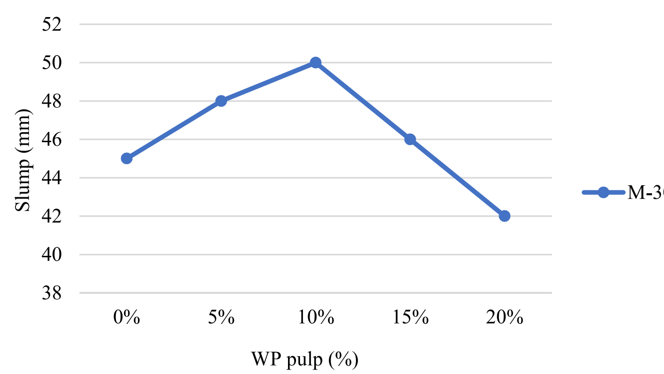

Fig. 4. Slump value [21].

Table 5
Mix proportion [35].

WP (%)	WP (kg/m^3)	W/C Ratio (kg/m^3)	Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
0	0	0.45	191.6	425.80	543.5	1199.36
5	21.29	0.45	191.6	425.80	543.5	1199.36
10	42.58	0.45	191.6	425.80	543.5	1199.36
15	63.87	0.45	191.6	425.80	543.5	1199.36
20	85.16	0.45	191.6	425.80	543.5	1199.36

projects. Table 6 and Fig. 6 show the specimen mix proportion and slump value.

Based on research by Ravindra et al. (2015) [36], the amount of WP increased in four preliminaries as T-1, T-2, T-3 and T-4, corresponding to 0%, 10%, 15% and 20% addition of WP in M – 25 concrete mixtures. WP had naturally high water absorption characteristic and thus, needed preliminary testing to achieve a workable mix. The slump value was recorded between 70 mm and 80 mm and declined with the rising of WP

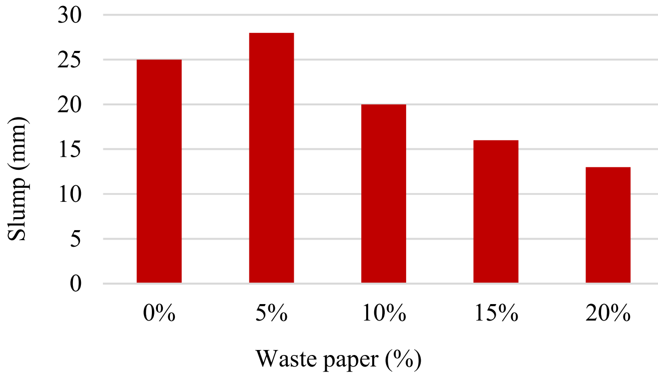

Fig. 5. Slump value [35].

content. 10% of WP addition reduced the slump value by 6.3% and stayed consistent at 6.3% with 15% addition compared to 0% but diminished at 20% addition by 12.5%. It could be concluded that 10% utilisation of WP in the concrete mix might be conveniently permitted. Compared with the control mix, the expense of concrete production was reduced by 1.5%, 2.2% and 3.0% with 10%, 15% and 20% addition of WP, respectively. Table 7 shows the optimum percentages of WP for the slump.

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

Jung et al. (2015) [37] evaluate the suitable WP replacement on cement mortar replaced with WP at 0%, 5%, 10%, 15% and 20% replacement against the cement weight. The cement mortar explored different avenues regarding the WP to find an optimum mixing ratio of different W/C ratios and the impact of compressive strength as per WP replacement ratio. The trials were separated into 45%, 60%, 75% of W/C ratios to evaluate the mortar mechanical and physical properties with the change of W/C ratio, replacement rate and type of WP. 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 high absorption rate of the newspaper and the best combination of the cement composite. The 5% replacement to cement weight showed the highest compressive strength compared to 0%, 10% and 15% replacement because hydrate formations actively occurred when the WP was replaced in a small amount.

In a separate study, Jung et al. (2015) [37] investigated the significance of the interaction between the strength change graph in the mortar test and the concrete brick test value. The compressive strength of concrete containing WP with 0%, 10%, 15% and 20% of cement weight was measured with three different W/C ratios of 60%, 70% and 80%. The concrete size was based on the Korean brick size standard as per KS F 4004. All the compressive strength were over 8 MPa, which were in accordance with the KS standard. At 28 days, the best W/C ratio was 70% with a mixture containing 10% WP, which also recorded the highest compressive strength compared to 0%, 15% and 20% WP and 60% and 80% W/C ratios. The higher absorptive force of WP caused the bond strength between the WP and cement paste to weaken.

Asha et al. (2017) [38] examined the effect of replacing coarse aggregate replaced with WP by volume in concrete ranging from 0%, 2.5%, 5%, 7.5%, 10% and 12.5%. The IS 10262: 2009 standard was used to produce two types of concrete grades comprising the M20 and M25 concrete mixes. Additionally, concrete's toughened properties were also investigated. The WP replacement of aggregates was deemed acceptable as the percentage limit for replacing aggregates was under an acceptable range for both M20 and M25 concrete grade mixes. Although the government did not approve this concrete type, the proposed mixes could be used in the construction industry and also serve as an excellent option to apply affordable WP for construction purposes.

5.2. Flexural strength

Meanwhile, Selvaraj et al. (2015) [39] investigated the flexural strength of eight concrete mixes at 7 and 28 days with water curing comprising one control and seven concrete mixes with 0%, 2.5%, 5%, 10%, 15%, 20%, 30% and 35% addition of WP by weight of OPC. The ratio of the mix was 1:1.5:2 (cement:sand:coarse aggregate) with a W/C ratio of 0.4. The study found that the demand for water mixing increased with the increasing WP addition, which was due to the cellulosic fibre materials leading to high water permeability characteristic. At 28 days, a

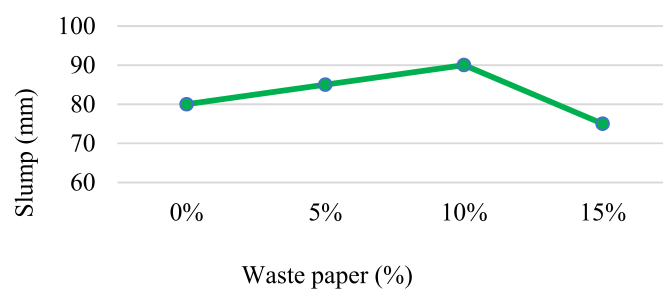

Fig. 6. Slump value [9].

Table 7
Optimum percentages of WP for the slump.

References	Percentages of WP (%)	Optimum percentages (%)
Balwaik & Raut (2011) [32]	0%, 5%, 10%, 15%, 20% of WP as partial replacement of cement	5%
Ilakkiya &Dhanalakshmi (2018) [33]	0%, 5%, 10%, 15% of WP addition	5%, 10%
Zaki et al. (2018) [21]	0%, 5%, 10%, 15%, 20% of WP as partial addition by weight of cement	5%
Ramesh & Chandu (2018) [34]	0%, 50%, 100% replacement of coarse aggregate with WP	50%, 100%
Malik (2013) [35]	5%, 10%, 15% and 20% replacement of WP with cement	5%
Gallardo & Adajar (2006) [9]	0%, 5%, 10%, 15% of WP replacement with fine aggregate	5%, 10%
Ravindra et al. (2015) [36]	0%, 10%, 15%, 20% addition of WP	0%

Table 6
Specimen mix proportion [9].

WP (%)	WP (kg)	Cement (kg)	White Sand (kg)	3/4 Gravel (kg)	Water (kg)	Water Adjustment (kg)	Total Water (kg)	Superplasticizer (ml)
0	0	20.80	28.28	42.08	7.20	−0.50	6.70	208
5	0.74	20.80	27.02	42.08	7.20	1.50	8.70	208
10	1.50	20.80	25.76	42.08	7.20	1.50	8.70	208
15	2.24	20.80	24.48	42.08	7.20	2.0	9.20	208

drastic increase of flexural strength was recorded for all mixes except for the control (0%), 2.5% and 5% WP mixes. The cellulose fibre contributed to the sufficient bending stress and upsurged flexural strength.

The flexural test was also conducted to determine the high strength concrete mixes of 20% and 40% replacement with 100% of Recycled Coarse Aggregate (RCA) [40]. Concrete grade of M25 was prepared consisting of tested beam specimens at 7, 14 and 28 days of water curing. The load was applied with a suitable loading rate and tested to maximum stress until rupture. The fracture was demonstrated on the tension surface within one-third of the mid-span. At 7, 14 and 28 days, there was an improvement of the flexural strength in 20% concrete with RCA compared to the control concrete with 100% RCA and 40% concrete with RCA. In short, lightweight concrete could be produced by using 20% concrete with RCA replacement.

Apart from that, a study was conducted to investigate the concrete performance by replacing 20% concrete and sand with 6%, 8%, 10%, 12% and 14% glass fibre [41]. All the materials were added by weight to the respective of tested under flexural test. The flexural strength was calculated based on the modulus of rupture, bend strength and fracture strength. The result showed that the flexural strength of 20% concrete containing 12% glass fibre was higher than control concrete and considered the optimum level to achieve high flexural strength at 7, 14 and 28 days. The addition of glass fibre to the mix composition can increase the fracture energy of cement-based material and reduce the concrete self-weight.

5.3. Splitting tensile strength

Furthermore, the splitting tensile strength tests on the high strength concrete mixes of 20% and 40% of concrete with RCA Subramani and Shanmugam (2015) [40] showed that the concrete strength was increased in 20% concrete with RCA compared to 100% RCA and 40% concrete with RCA. In another study, Raghuwanshi et al. (2018) replaced cement with WP accordingly in the range of 0%, 5%, 10%, 15% and 20% by weight for the M − 25 mixture. Cylinders with a size of 300 mm × 150 mm (*l* x *d*) were casted to conduct the splitting tensile strength test at 14 and 28 days following the IS 5816-1999 standard. The load was applied to the upper surface of the specimen. The result showed that 5% WP addition was the ideal mix proportion to achieve the highest splitting tensile strength and a further increase of WP reduced the strengths continuously for the M − 25 mixture at both 14 and 28 days.

Besides the compressive and flexural strengths, Ilakkiya and Dhanalakshmi (2018) [33] reported the splitting tensile strength of the WP concrete. 1500 mm × 300 mm (*w* x *l*) of cylinder concrete was used. The specimens were dried outdoors and placed on the steel jig with a balanced rate of loading range of 0.11–0.023 MPa/s following ASTM C496-90. During testing, two plywoods were placed with one at the top of the specimen and the other at the bottom of the specimen. The splitting tensile strength was higher for the mix with 10% addition of WP than the reference mix, which subsequently diminished with an increased WP content. Overall, the splitting tensile strength increased for the concrete mixtures containing 5% and 10% WP compared to the control mixture but reduced with 15% addition of WP.

Zaki et al. (2018) [21] also studied the splitting tensile strength of concrete containing 0%, 5%, 10%, 15%, 20% WP. The test was based on the ASTM C496-11 standard at 7, 28 and 56 days. According to the result, the splitting tensile strength of concrete mixtures with WP was less than the mixture without WP for all test ages, except for the concrete containing 5% and 10% addition of WP, to exhibit slightly higher splitting tensile strength than 0% WP addition. The splitting tensile strength decreased with the increasing WP content due to cohesion loss and fragile binding. Adding WP in the concrete mixture proved to hold the concrete volume. Thus, the concrete strength was reduced by any development or expansion of the WP chemical reaction with cement.

6. Structural properties of waste paper concrete

This section presents the structural properties of WP concrete, such as modulus of elasticity and stress-strain.

6.1. Modulus of elasticity

Seyyedalipour et al. (2014) [42] determined the structural property of M − 25 and M − 40 concrete cylinders by investigating the modulus of elasticity by 0%, 10%, 20%, 30% and 40% cement replacement with WP obtained following IS 10262:2009 at 56 days water curing. The modulus of elasticity difference was generated solely by the various percent replacement of WP, as the mix proportion of all different concretes was constant. The deflection of the concrete samples containing varying concentrations of fly ash was accessed by performing experimental tests of modulus of elasticity at 56 days. The modulus of elasticity was calculated by measuring the difference between stress and strain on the upper and lower levels. Thus, the disposal cost could be saved, and greener concrete could be produced using WP M − 25 and M − 40 concrete mixtures with 10% replacement of WP recorded a higher modulus of elasticity than M25 and M − 40 conventional concrete mixtures with 0% replacement of WP with 56 days of water curing. The modulus of elasticity diminished with higher than 10% replacement of WP like 20%, 30% and 40%.

Even though WPC has a mixing design ratio, it was not certified for use in residential buildings. Thus, two testing steps were conducted to determine the original mixing design ratio and the mechanical parameters of WPC, including its strength of modulus of elasticity and failure mode. First, the paper-cement and sand-cement ratios were maintained at 0.6 and 0.7, respectively. At the same time, 1 to 16 was the varied water-cement ratio used to determine the water-cement ratio impact. The second stage test determined the material's suitable mixing design ratio and mechanical properties by varying water-cement, paper-cement and sand-cement ratio parameters. Chung et al. (2015) [43] described that the paper-cement ratio changed the mechanical properties of WPC and was closely related to the specimen modulus of elasticity and failure mode. Several WPC specimens with different mixing design ratios were tested. Based on the test result, the paper-cement ratio influenced the structural properties of WPC by proving that the ductile failure mode occurred and the modulus of elasticity increased with increasing of the paper-cement ratio.

0%, 1%, 2.5%, 5%, 7.5% and 10% of WP replacing cement for preparation of M25 concrete cylinders was designed according to IS 10262–2009 with a total of 6 specimens with 28 days of water curing performed by Ramachandru & Natarajan (2018) [44] (see Table 8). The workability was acquired by adding a superplasticiser. The mix and water-cement ratios used for M25 were 1:1.9:3.5 and 0.52. The superplasticiser was mixed for 2 min in order to obtain a homogenous mix. All specimens should be tested at a moisture content to obtain the best results. The test results showed that at 7.5% replacement, the value of WPC's modulus of elasticity was 25563.8 Mpa, 8% greater than ordinary concrete, which was 23164.98 MPa. When more paper was replaced, there was a reduction in the concrete strength for many reasons.

Table 8
Optimum percentages of WP for modulus of elasticity.

References	Percentages/Ratios of WP (%)	Optimum percentages/ratios (%)
Seyyedalipour et al. (2014) [42]	0%, 10%, 20%, 30% & 40% of WP as partial replacement of cement	10%
Chung et al. (2015) [43]	paper:cement, sand:cement = 0.6, 0.7	0.6
Ramachandrudu & Natarajan (2018) [44]	0%, 1%, 2.5%, 5%, 7.5%, 10% of WP replacing cement	1%, 2.5%, 5%, 7.5%

6.2. Stress-strain

Fig. 8 shows the stress-strain curves of WPC based on various replacements of WP contents. It illustrates that the WP replacement content had remarkably influenced the stress-strain curves of WPC According to Yun et al. (2011); Seyyedalipour et al. (2014) [1,42], the stress-strain curves demonstrate that the ultimate strain ranges were 0.002–0.003, 0.005–0.007 and 0.008–0.010 when the WP replacement contents of WPC were 5%, 10% and 15%, respectively. Higher WP replacement contents caused higher ultimate strain of the stress-strain curves. The graph showed that group PB, which had 10% replacement content of the WP, was more ductile after the peak load than group PA, which contained 5% replacement content. Group PC containing 15% replacement content was more ductile than group PB The highest ductility was shown by 15% replacement content of the WP, followed by 10% and 5%. Based on the experimental results, WPC's ductile ability increased due to the combination of WP and cement paste cellulose fibres. The paper-cement ratio influenced WPC's stress-strain and higher percentages of the paper-cement ratio produced higher stress-strain values.

WPC consisting of Portland cement and additional additives was studied by Santamaria et al. (2007) [45]. The experimental procedures utilised only two mixes tested in different ratios. Low cost of production and ease of fabrication were the criteria used for the choice. In conclusion, from the stress-strain graph, the large deformation could be sustained by WPC, a ductile material. The cementitious building products that used cellulose fibres recovered from wastewater paper recycling were examined [46]. Fig. 7 shows the compression of Phase 1 and Phase 2 materials for stress-strain behaviour. Both phases have WP in their mixtures. Phase 2 (cement addition prior to dewatering) had higher compressive stress than Phase 1 (cement addition after dewatering). This proved that water acted as a chemical binder assister between the WP and other materials in the concrete mixture. The water, together with WP, helped to increase the concrete strength.

7. Discussion

Balwaik & Raut (2011) [32] concluded that the high absorption limit of WP caused the concrete workability to decline. The increasing content of WP requires more water to achieve the targeted slump value. Adding a high amount of water rather than admixtures can improve the WPC's workability. Thus, economical concrete can be achieved. The diminishing in water demand becomes larger. Possible unfavourable consequences could include failure of the WP concrete and trouble adhering the WP concrete to the substrate. The concrete workability is reduced due to too much higher WP inclusion and primarily due to the change in the WP's carbon content, replacement amount and physical properties.

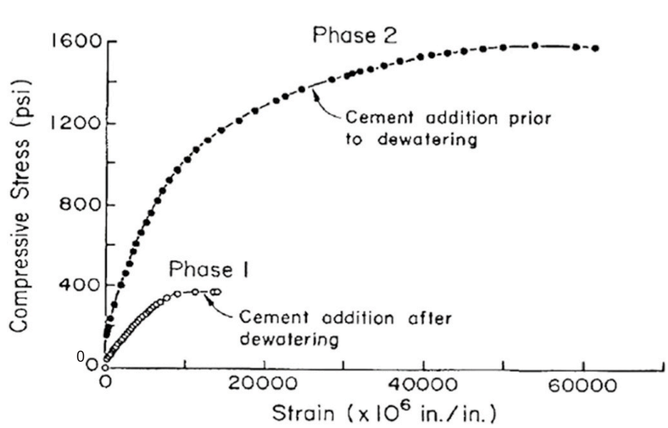

Fig. 7. Phase 1 and Phase 2 materials in compression for stress-strain behaviour [46].

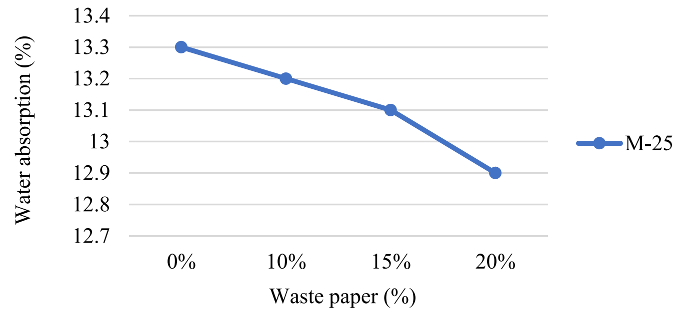

Fig. 8. 28 days water absorption [36].

As the percentage of WP increases, the water demand will decrease from time to time.

The slump decreases when the percentage of WP increases because of the low silica content [47]. Additionally, using WP in concrete is intended to keep the building cost as low as possible while simultaneously minimising pollution. Therefore, this WP usage is the most effective technique to be disposed of. Zaki et al. (2018) [21] stated that the concrete slump value decreases because of the high WP water absorption property due to the high percentage of the WP. More water is needed to acquire a similar slump as well as adding superplasticiser improves the concrete workability containing WP However, more addition of WP will reduce the density value. The percent of superplasticiser used is affected by the WP content. It has been affirmed that including WP has an apparent opposing effect on the slump and fresh density, which demands higher water or chemical admixture quantity to maintain the slump value as much as possible.

The presence of silica compounds in the WP is essential because of their main role in structuring and bonding the concrete bond [9]. There is a problem with the concrete mix workability caused by the high water absorption rate of WP during experimental procedures. Extra water is the permanent solution for this sort of issue as well as the higher water content will reduce the concrete strength. The type of superplasticiser used in the concrete mixtures containing WP was ASTM Type D/G. This superplasticiser plays a role by producing higher concrete strength, workability and lower density at a lesser water content. The validation of this experiment is valid and approved for 0% replacement of WP in the concrete mixture. The slump value of concrete containing WP decreases as the replacement percentage increases along with the admixture addition. Therefore, the WP can be used in concrete production by addition or partial replacement either with cement, sand or aggregate.

8. Durability properties of waste paper concrete

This section presents the durability property of WP concrete specially for water absorption, carbonation, fire resistance and efflorescence test results.

8.1. Water absorption

WP was replaced with cement in a range of 5%–20% by weight for concrete cubes with 150 mm all sides length for M − 20 and M − 30 concrete grades [32]. The concrete water absorption increased with increasing WP percentages. This phenomenon was normal for most WP in terms of its quantity for the hydration process. The standard solution to this problem was that the cement hydration required additional water amount. However, the concrete strength will be reduced due to the high content of water. Zaki et al. (2018) [21] studied the water absorption property of 100 mm all sides length concrete cubes containing 0%, 5%, 10%, 15% and 20% of WP as partial addition by weight of cement. ASTM C642-13 complied with the test of water absorption. The water absorption of the concrete mixtures was prompted and the density was reduced by adding more WP in the concrete mixtures except for the 5%

WP mixture. Subsequently, lightweight concrete could be produced based on the results exhibited by the dry density of concrete containing WP.

Ghani & Mohammad Shukeri (2008) [14] prepared four concrete mixes with a ratio of 1:2:3 by weight of cement, sand and aggregate separately containing WP, which are controlled mix (0%), 5%, 10% and 15% by weight as additional material in concrete. The higher WP content influenced the increase in water absorption. 13.9%–62.3% was the water absorption rate for 7 days, while 10.8%–118.4% was the water absorption rate for 28 days compared to the control mixture. Based on research by Malik (2013) [26], M − 25 concrete mixtures with 0%, 5%, 10%, 15% and 20% partially cement replacement with WP were tested for water absorption tests at 28 days with 0.45 w/c ratio. After removing the cube specimens from the mould, the average dry weight was measured and the weight of the cube specimens at 28 days was measured after being completely submerged in water for 28 days. Each concrete cube specimen measured the water absorption percentage and gave an indirect measure of durability. The water absorption percentage increased with 5%, 10% and 15% fly ash contents. 5% WP content recorded the lowest waste absorption value, while 15% recorded the highest value.

M − 25 concrete grade consisted of four concrete mixtures with 0%, 10%, 15% and 20% of WP as additional material in concrete prepared by Ravindra et al. (2015) [36]. The higher the amount of WP, the lower the concrete water absorption, as shown in Fig. 8. 12.93%–13.34% was the value of the water absorption rate recorded at 28 days. 0.1%, 0.2% and 0.4% were the ceaselessly diminished percentages of concrete water absorption with 10%, 15% and 20% of WP addition compared to 0%.

Akinwumi et al. (2014) [48] studied the appropriateness of WPC made up of waste newspaper and waste office paper to be used as material in building construction by determining the water absorption capacity with ratios of 1:1:0.2, 1:1:0.4, 1:1:0.6 and 1:1:0.8 for cement: sand: WP for each of the concrete mixtures. After 24 h of water curing, each cube mass before curing was deducted from its mass to calculate the water mass absorbed. The ratio of sand to cement used was chosen and 1.0 sand-binder ratio had the best mechanical properties and produced economic concrete obtained by Yun et al. (2011) [1].

Akinwumi & Gbadamosi (2014) [49] said that increasing WP content will increase the water absorption of concrete. WPC made up of newspaper commonly absorbed more water than WPC made up of office paper, aside from 60% of newspaper-cement ratio. The newspaper has lower grams per square metre (grammage), so it absorbs more water than office paper. The inter-fibre bonding of cellulose fibre in newspaper became simpler to get loosed and debilitated and this will cause it to absorb more water. WPC showed better structural properties made up of newspaper compared to office paper. Nevertheless, external and near-ground walls should not use WPC made up of newspaper and office paper because of its high water absorption property.

The wet pulp in the fibrous cement form was used to prepare the WPC samples. The total samples were twelve, which comprised ten cement mix samples and different WP percentages. The others were WP only and cement only without adding WP with 0.4 w/c ratios used for all samples. Office paper was used for the water absorption test. Water absorption increased with the immersion time. There was an increase from 41.4% to 146.9% of water absorption when the WP content rose from 50% to 83.3% [50]. The WPC sample with WP without cement showed the highest percentage of moisture content, which value was 7.231% and the WP content affected the moisture content of WPC samples by decreasing it with decreasing WP content. WP demonstrated fast water take-up over the initial few minutes because of its cellulosic material naturality, sanctioning it to take up more and more water. The capillary action reacted to water molecules in the material and voids were also filled when WP was immersed in water for a long time. WP particles could absorb water, which could be clarified because they were porous material characteristics, so the increased WP content would increase the porosity. The particles tended to clump together while mixing was the cause for the high value of porosity, increasing the WP content, and entrapping water to occupy the spaces, thus transforming into voids. The high content of WP might be ascribed to the water percentage absorbed by cellulose fibres in WP, which was impacted by cellulose material and void volume presented.

Selvakumar et al. (2018) [51] studied the WPC cubes' durability property by conducting water absorption tests at 14 and 28 days with 0%, 10%, 20% and 30% of WP addition by weight of cement. The ratio used was 1:3:6 of cement:sand:coarse aggregate. The highest water absorption value of WPC was recorded at 30% of WP addition by cement weight, while the lowest water absorption was recorded at 0% addition. Therefore, 10% addition of WP by weight of cement produced the optimum water absorption values at both 14 and 28 days. 0%, 5%, 10%, 15%, 20%, 25% and 30% of WP were added in concrete to study the durability property of concrete by performing water absorption tests at 7, 14 and 28 days [52]. The longer the curing period, the higher the water absorption of concrete. This is because, from the SEM, WP contains many fibres with high water absorption properties. That's why more water is absorbed when a longer curing period is applied. Based on the experimental results, the more percentage of WP used the more water absorption and increasing the percentage of WP could produce more lightweight concrete. Fig. 9 and Table 9 show the water absorption at 14 and 28 days and the optimum percentages of WP for water absorption.

8.2. Carbonation, fire resistance and efflorescence

This study tested the density, water absorption and fire resistance of paper made from waste paper and office paper to see if it would suit building materials. Journal paper was found to have superior properties over office paper in every mixing ratio tested, including higher bulk density, water absorption, and fire resistance. Bulk density and compressibility decreased with increasing WP content, whereas water absorption and fire resistance rose. It was proposed that WP could be utilised to create lightweight, fire-resistant hollow or solid concrete that could be used efficiently and sustainably as a construction material.

The impacts of WP on operational capability, strength, and transport parameters like water absorption, diffusiveness, permeability, and conductivity are conducted. It showed that replacing 12% of the Portland cement with WP increased fire resistance and conductivity by 84% and 86%. Some samples were mixed up at a water-to-cement ratio of 0.38, let dry for up to 28 days, and then conditioned at a constant mass temperature of 50 °C. Concrete's carbonation strength can be significantly weakened by several factors, such as pressure, temperature, and concentration. A speeded carbonation chamber sped up the carbonating process, and the carbonation strength of concrete was analysed by measuring the carbonation depth. The experiment results showed that as tensile stress was raised, both types of WPC's resistance to carbonation strengthened. Increasing the WPC's exposure temperature significantly increased its compression strength and carbonation resistance. The higher the temperature, the deeper the carbonation.

Chlorine and chlorine-based compounds, sulphur, hydrogen sulphide, and sulphur dioxide are the primary contributors to

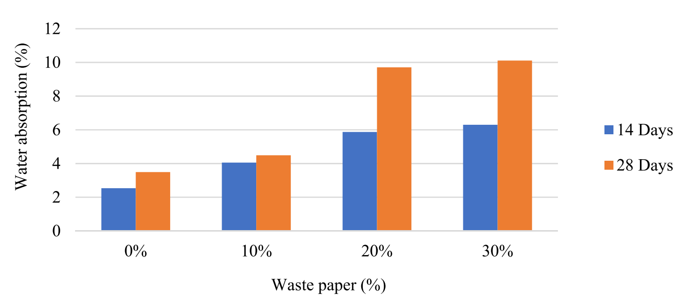

Fig. 9. Water absorption of WP at 14 and 28 days [51].

Table 9
Optimum percentages of WP for water absorption.

References	Percentage/ratio of WP (%)	Optimum percentages/ratios (%)
Balwaik & Raut (2011) [32]	0%, 5%, 10%, 15%, 20% of WP as partial replacement of cement	20%
Zaki et al. (2018) [21]	0%, 5%, 10%, 15%, 20% of WP as partial addition by weight of cement	20%
Ghani & Mohammad Shukeri (2008) [14]	0%, 5%, 10%, 15% addition of WP	15%
Malik (2013) [26]	0%, 5%, 10%, 15%, 20% as partial cement replacement with WP	20%
Ravindra et al. (2015) [36]	0%, 10%, 15%, 20% of WP as addition	0%
Akinwumi et al. (2014) [48]	cement:sand:WP = 1:1:0, 1:1:0.2, 1:1:0.4, 1:1:0.6, 1:1:0.8	1:1:0.8
Salem & Al-Salami (2016) [50]	0%, 50%, 83.3% addition of WP	83.3%
Selvakumar et al. (2018) [51]	0%, 10%, 20%, 30% of WP addition by weight of cement	30%
Tantray (2019) [52]	0%, 5%, 10%, 15%, 20%, 25%, 30% addition of WP	30%

environmental pollution occurring from WP mills. The efflorescence test aims to identify the deposits of soluble salts formed near the surface of porous material when the water is dissolved. No efflorescence, minimal efflorescence, moderate efflorescence, heavy efflorescence, and severe efflorescence are the five characteristics used to identify the WPC condition. The curing age was 28 days. The efflorescence test data for the various percentages of replacement types are summarised in Fig. 10. A small film of less than 10% salts was presented on the control concrete brick, the same for 20% and 30% of the WP replacement. 40% of the WP replacements are in moderate condition for the deposition of salts on the concrete brick surface area.

9. Discussion

These results can be explained through the adhesion bonding between water molecules and paper structure. Adhesion is the attraction of one molecule to other molecules of different particle types and can be desirable to water [53]. High-quality concrete has a water absorption percentage of less than 10% [54]. According to Castro et al. (2011) [55], a significant laboratory investigation is essential to determine the cementitious system's durability by performing a water absorption test. Moreover, Bozkurt and Yazicioglu (2010) [56] stated that the curing regime influences concrete absorption. Past researchers have discussed and concurred that the best curing regime method is the immersion of samples in water [57–68]. Thus, it is essential to provide proper curing to produce less permeable concrete, higher strength and greater resistance to physical or chemical attacks in an aggressive environment.

10. Conclusion

In conclusion, many previous studies on WPC were carried out. It is apparent that the incorporation of WP brings significant desirable characteristics compared to ordinary concrete without WP contents. It can also be concluded that WP has the potential for its favourable properties. 5%–10% replacement of WP with cement and 5%–10% addition of WP in concrete increased the fresh property and mechanical properties such as compressive strength, flexural strength and splitting tensile strengths, which were proved by many previous experimental investigations. Many studies before this also reported that the replacement of cement with WP benefits the structural property of concrete by increasing its modulus of elasticity compared to plain concrete with 0% WP. Subsequently, the structural property of concrete is also investigated by determining the stress-strain and ultimate strain values. They

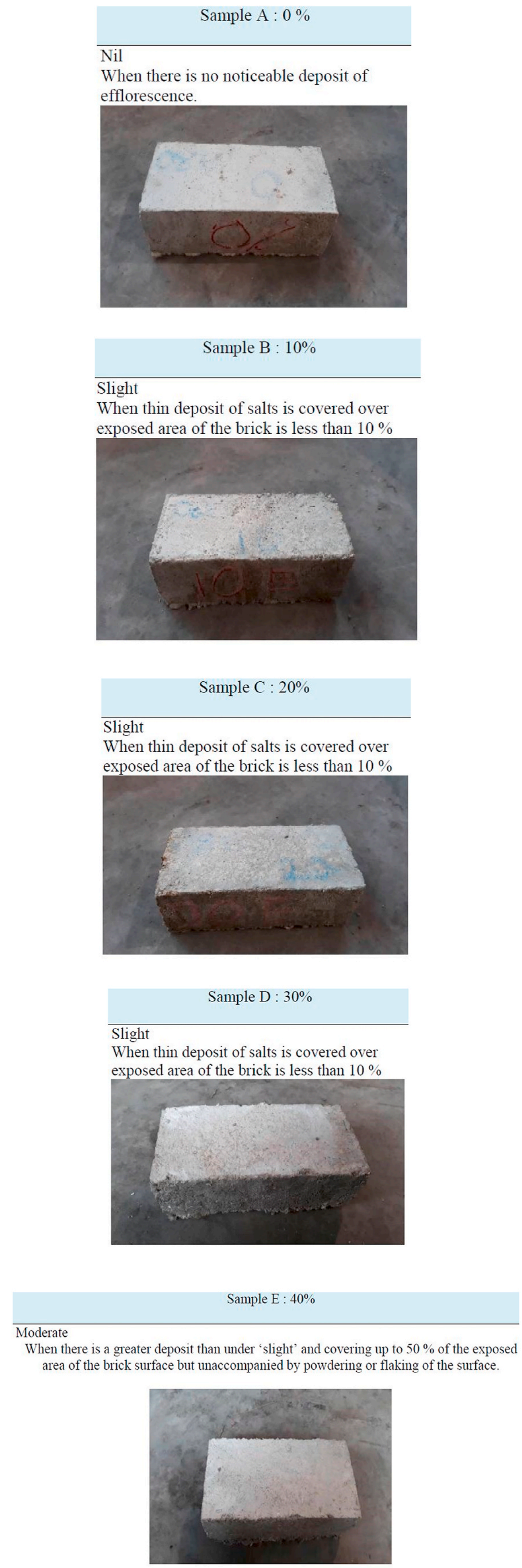

Fig. 10. Efflorescence test for concrete [52].

concluded that the higher the paper-cement ratio, the higher the stress-strain and ultimate strain values, except for 15% WP addition or replacement. Same for carbonation, fire resistance and efflorescence test results. The results increase with the inclusion of WP at 5% and 10%. Generally, it is determined that using WP in concrete production is warranted and technically feasible, although considerations shall be taken to ensure adequate performance.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgement

The author would like to acknowledge Universiti Malaysia Pahang (UMP), Malaysia for financially supporting this research through the UMP Postgraduate Research Grant Scheme (PGRS200373).

References

[1] H. Yun, H. Jung, C. Choi, Mechanical properties of WPC containing WP, in: ICCM International Conferences on Composite Materials, 2011, pp. 1–4.
[2] J. Santamaria, B. Fuller, A. Fafitis, Structural properties of a new material made of WP, WIT Transactions on Modelling and Simulation 46 (2007) 557–567, https://doi.org/10.2495/CMEM070561.
[3] L.C. Titzman, Analysis of Low-Cost Building Material for the Mixalco Process Analysis of Low-Cost Building Material for the Mixalco Process, 2006. December.
[4] Wikipedia, The free encyclopedia, https://en.wikipedia.org/wiki/WPC.
[5] A. Gunarto, I. Satyarno, K. Tjokrodimuljo, Newsprint Paper Waste Exploiting for WPC Panel, Institute of Research Center, Gadjah Mada University, 2008.
[6] J. Bai, A. Chaipanich, J.M. Kinuthia, M. O'Farrell, B.B. Sabir, S. Wild, M.H. Lewis, Compressive strength and hydration of wastepaper sludge ash-ground granulated blastfurnace slag blended pastes, Cement Concr. Res. 33 (8) (2003) 1189–1202, https://doi.org/10.1016/S0008-8846(03)00042-5.
[7] T.L. Chin, et al., A novel method to reuse paper sludge and Co-generation ashes from paper mill, J. Hazard Mater. 58 (Issues 1–3) (2018) 93–102. February 1998.
[8] Y. Chun, T. Naik, R. Kraus, Pulp and paper mill fibrous residuals in excavatable flowable fill, in: Presented at the International Conference on Sustainable Construction Materials and Technologies, 2007.
[9] R.S. Gallardo, M.A.Q. Adajar, Structural performance of concrete with paper sludge as fine aggregates partial, in: International Symposium on Environmental Engineering and 5th Regional Symposium on Infrastructure Development, May, 2006, pp. 1–8.
[10] R.N. Kraus, et al., Concrete containing recycled fibers from pulp and paper mills, in: Sixth CANMET/ACI International Conference June 2003, Recent Advances in Concrete Technology. Bucharest, Romania, 2003.
[11] T.R. Naik, T.S. Friberg, Y.M. Chun, Use of pulp and paper mill residual solids in production of cellucrete, Cement Concr. Res. 34 (7) (2004) 1229–1234, https://doi.org/10.1016/j.cemconres.2003.12.013.
[12] J.A. Fuwape, J.S. Fabiyi, E.O. Osuntuyi, Technical assessment of three layered cement-bonded boards produced from wastepaper and sawdust, Waste Manag. 27 (11) (2007) 1611–1616, https://doi.org/10.1016/j.wasman.2006.09.005.
[13] E.Y.A. Okino, M.A.E. Santana, M.R. De Souza, Utilisation of wastepaper to manufacture low density boards, Bioresour. Technol. 73 (1) (2000) 77–79, https://doi.org/10.1016/S0960-8524(99)00146-7.
[14] A.N.A. Ghani, R. Mohammad Shukeri, Concrete mix with wastepaper, in: 2nd International Conference on Built Environment in Developing Countries (ICBEDC), Penang, Malaysia, University Sains Malaysia (USM), 2008, pp. 567–575. *Icbedc*, http://eprints.usm.my/34459/1/HBP15.pdf.
[15] M.Y.D. Thiswaran, D.M.B. Varma, Properties of WPC concrete: building material, IOSR J. Mech. Civ. Eng. 14 (2) (2017) 27–32, https://doi.org/10.9790/1684-1402072732.
[16] Y.D. Thiswaran, Paper Crete : A Lightweight Concrete WPC : A Lightweight Concrete, 2018. March 2018.
[17] R. Malthy, D. Jegatheeswaran, Comparative study on WPC bricks with conventional bricks, ICID J. (January-March 2011).
[18] M.K. Gupta, R.K. Srivastava, Mechanical properties of hybrid fibers-reinforced polymer composite: a review, Polym.-Plast. Technol. Eng. 55 (6) (2015) 626–642, https://doi.org/10.1080/03602559.2015.1098694.
[19] M.T. Kortschot, The role of the fibre in the structural hierarchy of paper, in: The Fundamentals of Papermaking Materials, XIth Fundamental Research Symposium, (21–26 September 1997), 1997, pp. 351–394. Cambridge, United Kingdom.
[20] K.J. Niskanen, Paper Physics. Finnish Paper Engineers' Association. Papermaking Science and Technology, 2018. Available online: https://www.puunjalostusinsinoorit.fi/site/assets/files/4195/vol16_paper_physics_toc.pdf. accessed on May 2021.
[21] H. Zaki, I. Gorgis, S. Salih, Mechanical properties of papercrete, MATEC Web of Conferences 162 (January) (2018), https://doi.org/10.1051/matecconf/201816202016.
[22] N.K. Bui, T. Satomi, H. Takahashi, Influence of industrial by-products and waste paper sludge ash on properties of recycled aggregate concrete, J. Clean. Prod. 214 (2019) 403–418, https://doi.org/10.1016/j.jclepro.2018.12.325.
[23] J. Zhou, T. Kang, F. Wang, Pore structure and strength of waste fiber recycled concrete, Journal of Engineered Fibers and Fabrics 14 (2019), 155892501987470, https://doi.org/10.1177/1558925019874701.
[24] H.D. Burgess, N.E. Binnie, The development of a research approach to the scientific study of cellulosic and ligneous materials, J. Am. Inst. Conserv. 29 (2) (2010) 133–152, https://doi.org/10.1179/019713690806046046.
[25] R. Singh, H. Singh, Shear strength models for steel fibre reinforced concrete beams: current scenario, Civil Engineering Journal 7 (2) (2021) 399–406, https://doi.org/10.28991/cej-2021-03091661.
[26] M.I. Malik, Study of concrete involving use of waste glass as partial replacement of fine aggregates, IOSR J. Eng. 3 (7) (2013) 8–13, https://doi.org/10.9790/3021-03760813.
[27] V. Cherkina, D. Korolchenko, Investigation of the fire resistance of panels of porous papercrete, containing expanded polystyrene gravel, IOP Conf. Ser. Mater. Sci. Eng. 603 (5) (2019), 052009, https://doi.org/10.1088/1757-899x/603/5/052009.
[28] Development of Papercrete Due to Paper Mixing Ratio Joo-Hong Chung, Byoung-Hoon Kim,Hyun-Ki Choi and Chang-Sik Choi1, Department of Architectural Engineering, Hanyang University, Seoul, Korea, 133-791, international conference on sustainable building, Asia..
[29] Experimental Investigation of Papercrete Concrete T. Subramani, V. Angappan, International Journal of Application or Innovation in Engineering & Management (IJAIEM), vol. 4, May 2015. Issue 5.
[30] Experimental Investigation of Papercrete, B. Brick, Jose Ravindra Raj, R. Vijaya Sarathy, International Journal of Machine and Construction Engineering ISSN (Online): 2394 – 3025, vol. 2, Jun 2017. Issue 2.
[31] Papercrete, A study of paper effluent treatment sludge as partial replacement for cement jihal NTA, aswin antony, IJSTE - International Journal of Science Technology & Engineering 2 (Issue 11) (May 2016). ISSN (online): 2349-784X.
[32] S.A. Balwaik, S.P. Raut, Utilisation of WP pulp by partial replacement of cement in concrete, Int. J. Eng. Res. Afr. 1 (2) (2011) 300–309.
[33] R. Ilakkiya, G. Dhanalakshmi, Experimental Investigation on Concrete Using WP Monisha T 4 (4) (2018) 102–106.
[34] G.B.R. Ramesh, U.G. Chandu, WPC – a Sustainable Building Material. 119 (17) (2018) 87–93.
[35] M.I. Malik, Study of concrete involving use of waste glass as partial replacement of fine aggregates, IOSR J. Eng. 3 (7) (2013) 8–13, https://doi.org/10.9790/3021-03760813.
[36] L. Ravindra Singh, A. Saleem, B. Geeta, Application of paper waste in cement concrete, Journal of Engineering Research and Applications Www.Ijera.Com 5 (4) (2015) 95–98.
[37] H.S. Jung, H.K. Choi, C.S. Choi, An experimental study on development of construction concrete products using wastepaper, J. Ceram. Process. Res. 16 (2015) 104–109.
[38] P. Asha, S. Dipti, P. Rupali, P.P. Prerana, Effect of paper waste on concrete properties : sustainability approach, Journal, International Engineering, O F Approach, Sustainability 6 (4) (2017) 440–444.
[39] R. Selvaraj, R. Priyanka, M. Amirthavarshini, S. Prabavathy, EVALUATION OF CONCRETE: An Innovative Building Material. 6 (2015) 52–56.
[40] T. Subramani, G. Shanmugam, Experimental investigation of using concrete and recycled aggregate as A coarse aggregate, International Journal of Application or Innovation in Engineering & Management (IJAIEM) 4 (5) (2015) 323–332. http://www.ijaiem.org/Volume4Issue5/IJAIEM-2015-05-26-74.pdf.
[41] T. Selvarasan, K. Bharathidasan, I. Journal, Experimental Investigation Of Partial Replacement Of Sand With Glass Fibre 1 4 (5) (2017) 254–263.
[42] S.F. Seyyedalipour, D. Yousefi Kebria, N.R. Malidarreh, G. Norouznejad, Study of utilisation of pulp and paper industry wastes in production of concrete, Journal of Engineering Research and Applications Www.Ijera.Com 4 (1) (2014) 115–122. www.ijera.com.
[43] J.H. Chung, B.H. Kim, H.K. Choi, C.S. Choi, Development of WPC Due to Paper Mixing Ratio, Hanyang University, Seoul, Korea, 2015, pp. 1–4.
[44] K. Ramachandrudu, C. Natarajan, Mechanical properties and flexural behavior of WPC concrete, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN 15 (4) (2018) 31–36, https://doi.org/10.9790/1684-1504033136.
[45] J. Santamaria, B. Fuller, A. Fafitis, Structural properties of a new material made of WP, WIT Transactions on Modelling and Simulation 46 (2007) 557–567, https://doi.org/10.2495/CMEM070561.
[46] A.R.G. Azevedo, J. Alexandre, G. de C. Xavier, L.G. Pedroti, Recycling paper industry effluent sludge for use in mortars: a sustainability perspective, J. Clean. Prod. 192 (May) (2018) 335–346, https://doi.org/10.1016/j.jclepro.2018.05.011.
[47] J.D. Kalapad, M. Mansute, V. Swami, V. Sulbhewar, T.M. Khandale, A study on partial replacement of cement by waste paper pulp in concrete, International Journal of Innovations in Engineering and Science 4 (4) (2019) 2456–3463. www.ijies.net.

[48] I.I. Akinwumi, O.M. Olatunbosun, O.M. Olofinnade, P.O. Awoyera, Structural Evaluation of Lightweight Concrete Produced Using Waste Newspaper and Office Paper, vol. 6, 2014, 7.
[49] I.I. Akinwumi, Z.O. Gbadamosi, Effects of curing condition and curing period on the compressive strength development of plain concrete, International Journal of Civil and Environmental Research 1 (2) (2014) 83–99.
[50] R.M. Salem, A.E. Al-Salami, Preparation of WP fibrous cement and studying of some physical properties, Civ. Environ. Res. 8 (3) (2016) 42–54, https://www.semanticscholar.org/paper/Preparation-of-Waste-Paper-Fibrous-Cement-and-of-Salem-Al-Salami/b12a5bcad54da1654e3f3f5ab2383d741b21020d%Ahttps://www.iiste.org/Journals/index.php/CER/article/view/29376.
[51] T. Selvakumar, R. Sathiya, B. Jayalakshmi, Experimental Study of WPC Concrete and Bricks, 2018, pp. 67–77.
[52] M.A. Tantray, Quality tests on light weight WPC concrete, Int. J. Innovative Technol. Explor. Eng. 8 (2019) 2278–3075.
[53] Academy Khan. https://www.khanacademy.org/humanities/ap-art-history/later-europe-and-americas/modernity-ap/a/frank-lloyd-wright-fallingwater, 2016.
[54] A.M. Neville, Properties of Concrete, fifth ed., 2011. Malaysia: Longman, Malaysia.
[55] J. Castro, D. Bentz, J. Weiss, Effect of sample conditioning on the water absorption of concrete, Cement Concr. Compos. 33 (2011) 805–813.
[56] N. Bozkurt, S. Yazicioglu, Strength and capillary water absorption of lightweight concrete under different curing conditions, Indian J. Eng. Mater. Sci. 17 (2010) 145–151.
[57] Solahuddin Bin Azuwa, *The Effect Of Shredded Paper As Partial Sand Replacement On Properties Of Cement Sand Brick*. Bachelor's Degree Thesis, Universiti Malaysia Pahang, 2017.
[58] B.A. Solahuddin, F.M. Yahaya, Effect of shredded waste paper on properties of concrete, IOP Conf. Ser. Mater. Sci. Eng. 1092 (1) (2021), 012063, https://doi.org/10.1088/1757-899x/1092/1/012063.
[59] B.A. Solahuddin, F.M. Yahaya, Load-strain behaviour of shredded waste paper reinforced concrete beam, IOP Conf. Ser. Mater. Sci. Eng. 1092 (1) (2021), 012063, https://doi.org/10.1088/1757-899x/1092/1/012063.
[60] B.A. Solahuddin, F.M. Yahaya, A review paper on the effect of waste paper on mechanical properties of concrete, IOP Conf. Ser. Mater. Sci. Eng. 1092 (1) (2021), 012063, https://doi.org/10.1088/1757-899x/1092/1/012067.
[61] B.A. Solahuddin, F.M. Yahaya, Structural behaviour of shredded waste paper reinforced concrete beam, International Journal of Advanced Research in Engineering Innovation 3 (1) (2021) 74–87. https://myjms.mohe.gov.my/index.php/ijarei/article/view/12968.
[62] B.A. Solahuddin, F.M. Yahaya, Inclusion of Waste Paper on Concrete Properties: A Review, vol. 7, Civil Engineering Journal-Tehran, 2021, pp. 94–113, https://doi.org/10.28991/CEJ-SP2021-07-07 (Special Issue-Innovative Strategies in Civil Engineering Grand Challenges).
[63] B.A. Solahuddin, A critical review on experimental investigation and finite element analysis on structural performance of kenaf fibre reinforced concrete, Structures 35 (November 2021) (2022) 1030–1061, https://doi.org/10.1016/j.istruc.2021.11.056.
[64] B.A. Solahuddin, F.M. Yahaya, Properties of concrete containing shredded waste paper as an additive, Mater. Today Proc. 51 (2022) 1350–1354, https://doi.org/10.1016/j.matpr.2021.11.390.
[65] B.A. Solahuddin, A review on structural performance of bamboo reinforced concrete, Mater. Sci. Forum 1056 (2022) 75–80, https://doi.org/10.4028/p-dx1x87. MSF.
[66] B.A. Solahuddin, Strengthening of reinforced concrete with steel fibre: a review, Mater. Sci. Forum 1056 (2017) (2022) 81–86, https://doi.org/10.4028/p-3g0h57.
[67] B.A. Solahuddin, A review on the effect of reinforcement on reinforced concrete beam-column joint behavior, in: Proceedings of Malaysian Technical Universities Conference on Engineering and Technology (MUCET) 2021, 2022.
[68] B.A. Solahuddin, Seismic performance of reinforced concrete beam-column joint: a review, in: Proceedings of Malaysian Technical Universities Conference on Engineering and Technology (MUCET) 2021, 2022.