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COMPRESSIVE STRENGTH OF WASHED BOTTOM ASH AND WASTE PAPER SLUDGE ASH MORTAR FILLED IN COLD-FORMED STEEL COLUMN

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ABSTRACT: The impact of washed bottom ash (WBA) and waste paper sludge ash (WPSA) mortar on the compressive strength when filled in a built-up face-to-face cold-formed steel (CFS) stub column is studied and analysed. With the intention to solve the integrity issue of column structural elements, especially buckling and environmental issues that existed from the traditional material in mortar, and serious and uncontrolled dumping of waste material, the combination of CFS and mortar with the usage of waste material is proposed. Two CFS channel sections are connected in face-to-face configuration to form a symmetrical section and fill the hollow section with WBA and WPSA mortar. Three parts of the experimental activity are designed, including material properties of CFS, mechanical behaviour of WBA and WPA mortar, and mechanical behaviour of built-up face-to-face CFS stub column. The mechanical behaviour of built-up CFS stub columns with a varied height of columns at 150 mm, 250 mm, and 350 mm is tested. The result of the mechanical behaviour testing illustrates the compressive strength of all specimens reduced with increasing height of the column and shows having in reduction of the buckling either filled with normal or WBA and WPSA mortar. For heights of 150 mm, 250 mm, and 350 mm, the difference in ultimate load between built-up CFS stub columns filled with normal mortar and WBA and WPSA mortar is in the range of 36% to 48%.

Keywords: Washed Bottom Ash, Waste Paper Sludge Ash, Mortar, Built-up Cold-formed Steel, Stub Column

1. INTRODUCTION

Mortar is the mixing process of sand, cement, and water as a bonding agent, which is not similar to concrete, which adds gravel to the mixes. Mortar is numerous utilisations in residential and buildings as wall plaster, binder of brick and block, and sand brick production. Additionally, mortar is used to cover the voids and to fill the unbalanced gaps. The mix proportion of the mortar, especially cement mortar, followed the cement-to-sand ratio that varies from 1:2 to 1:5. The high usage of the mortar is influenced to shift the traditional material to waste material such as sand or cement replacement. Alkhazraji et al. [1] mentioned that the high production cost of natural sand in several countries is causing the responsible party to determine other materials prospects for substituting the sand in mixes. There is a lot of study on replacing sand in partial and full percentages with waste material such as crumb rubber [2], soda lime glass [3], palm oil fuel ash [4], bottom ash [5], quarry waste [6], etc. Additionally, many researchers have conducted experimental testing of the mortar by replacing the cement with waste material such as ceramic powder [7], Red Gypsum [8], Napier grass [9], Bentonite [10], etc.

The utilisation of traditional materials as the main ingredient in mortar is an affected environmental problem and human health problems. Thus, several activities and studies are produced to ensure that traditional material is able to shift to waste material. The use of waste material could help to reduce the environmental problem and enhance the human health program. Several studies have determined the best choices to lower atmospheric CO_2 concentrations while also lowering the production cost of construction materials. However, Malaysia is still limited in studying other suitable materials to substitute cement [8]. Gomez-Balbuena et al. [6] reported that mortar or concrete with cement utilization faces disadvantages, for example, dry shrinkage, low tensile strength, low chemical resistance, and delayed hardening process, and these issues could be reduced by using other materials to upgrade the mortar or concrete behavior.

Bottom ash (BA) is collected from the electric power plant, which uses coal as an energy material, and from the final process, there are two types of waste materials produced. The two types of waste material are formed and recognized as BA and fly ash. The BA is heavier and coarse compared with fly ash and is usually collected from the furnace or boiler, but fly ash goes out from the precipitator. BA is used as fine aggregate in partial and full percentages in concrete or mortar, such as in Kumar et al. [11], Gencel et al. [12], and Hasim et al. [13]. From the previous study, there is no information on BA used in mortar in full replacement of natural sand, and I noticed that the study on BA is still in progress.

Waste paper sludge ash (WPSA) is taken from the waste paper recycling factory in small particles that could be categorized as the same as fly ash. Some of the study of the WPSA as mortar or concrete ingredient material is done by Mohd Sani et al. [14], Ahmad et al. [15], Bui et al. [16], and Elbasri et al. [17]. According to observations of the previous study, there is no evidence that WPSA can fully replace cement in mortar, and that the WPSA as a cement replacement in concrete or mortar is still under research.

BA and WPSA are vividly increased due to the enlarging human population and rapid development of the country, which needed electricity and paper in all daily activities, either personal or organisational. Besides, BA and WPSA are selected as replacements in concrete owing to their environmental, performance, and economic advantages. These materials mitigate waste disposal issues while promoting environmentally sustainable and economically efficient building methods. BA, which is coarsely conditioned and porous, is suitable for use as gravel or sand replacement with further processes such as grounding and sieving. According to the size of WPSA, they are appropriate to replace cement in the mortar or concrete. However, some further processes should be engaged. According to previous studies, there are no data and info on the BA and WPSA that are used together in mortar or concrete. Based on the hypothesis, WBA and WPSA are feasible and classified as sustainable replacements for traditional mortar materials because they will function well in terms of mechanical behavior and structural integrity when employed in steel columns.

2. RESEARCH SIGNIFICANCE

In general, the significance of the study could be determined from several key perspectives, such as improving the structural stability, enhancing the load-bearing capacity, minimizing buckling failure, improving construction efficiency, optimizing material usage, improving fire resistance, and improving seismic and vibration resistance. The main problems that should be solved in the study are environmental issues of the waste material and the structural integrity of the column.

3. BUILT-UP COLD-FORMED STEEL

Cold-formed steel (CFS), known as thin-walled structure material, is largely used in construction activity or infrastructure activity such as wall frames and storage panels, roof truss systems, etc. CFS with a variety of shapes, dimensions, steel grade and cross-section areas are becoming popular due to a lot of advantages such as lightweight, easy to handle and install, and corrosion resistance. Senthilkumar et al. [18] reported that the CFS is widely used in the construction industry because of their excellent manufacturing adaptability and good strength-to-weight characteristics. Rahnavard et al. [19] stated the other advantages that existed of the usage of CFS when compared with hot-rolled steel are shorter construction times, easier fabrication and flexibility to produce a variety of cross-section forms. CFS is made by using the process of rolling, pressing and bending of the steel sheet in the ambient temperature and is classified as having less usage of energy. CFS is not similar to hot-rolled steel in the producing and shaping process of the steel component. Currently, CFS is being used as a structural element in buildings and infrastructure, for instance, the beam or column. Beam and column are normally noted to have a large loading that is applied on them. For example, column structure is able to sustain the axial compression load and bending moment either in short or slender conditions. Sabbagh et al. [20] mentioned that the effective use of steel structure elements in construction not only enhances structural performance merely but can significantly lower global CO_2 emissions.

In the problem statement, two problems should be tackled in the construction activity: the effect of the broad usage of traditional material, especially sand and cement, and the failure of the compression member, especially the steel structure. The environmental impact has always been discussed by environmental agencies and researchers and happened from the sand and cement quarry. Normally, sand quarrying at the riverside produces a lot of environmental issues such as river water pollution, riverbank landslides, turbidity of the river water etc. Furthermore, the cement quarry is generally near the mountain, and the hill produces a lot of environmental issues such as noise pollution, air pollution, landslides, etc. Thus, the traditional material should be reduced slowly to avoid the environmental impact and provide an alternative way to use other materials which are also capable of using less production cost and energy usage. Lastly, the raw materials of cement and natural sand are becoming scarce because the material used cannot be renewed.

When cement is utilized in large quantities, more natural resources and electricity are consumed [7]. Sidek et al. [8] stated that cement manufacture has long been recognized as one of the leading sources of CO_2 emissions because of the calcination process of raw materials and the maintenance process of high temperatures in kilns using burning fuels. Wan Ibrahim et al. [9] mentioned that the world’s estimated 1.6 billion tonnes of cement manufacture accounts for about 7% of the CO_2 emissions worldwide due to the burning of limestone. Furthermore, the limited area of dumping the waste material is becoming critical and producing a lot of side effects that go unaware, such as groundwater contamination, soil pollution, hazardous gas emissions, and human respiratory diseases or lung cancer.

CFS, either compression or flexural member, tend to fail and affect their structural integrity due to high load or action applied to it. CFS with a thin surface opened section and unsymmetrical section is always exposed to buckling failure. The buckling failure of CFS is divided into four categories such as local, distortional, lateral, and global buckling, as shown in Fig. 1. For flexural members, CFS normally fails to buckle, and another extra failure is due to web crippling. Sabbagh et al. [21] reported that in order to minimize total material consumption and waste and improve structural behavior for facing the global climate extremity, a more effective structural element used in construction is essential.

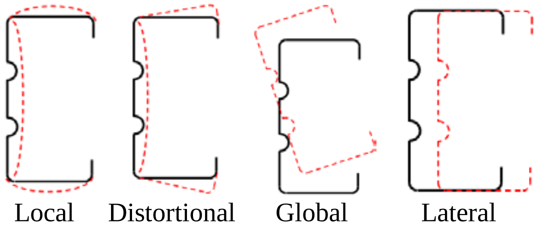

Fig. 1 The types of CFS failure under buckling [22]

With the intention of the problem statement, the individual CFS section is organised and formed into closed-section or symmetrical sections by combining more than one individual CFS section with the same or different shape. The simplest built-up CFS section is combined with two individual CFS sections in a face-to-face configuration or hollow section and a back-to-back configuration or I-section as illustrated in Fig. 2. The study on built-up CFS in face-to-face and back-to-back configurations continues to this day. Some examples of built-up CFS proposed by the previous study are shown in Fig. 3 and Fig. 4. There is a variety of shapes and dimensions introduced for beam and column structure to determine the suitability, stability and safety of the section. Craveiro et al. [23] reported that the individual CFS section is classified as Class 4 with monosymmetric cross-sections which is prone to sensitivity to local buckling and the centre of shear and gravity do not coincide, thus the built-up CFS formed has a much larger load-bearing capability due to its adaptability. Normally, all built-up CFS are categorised as symmetrical and able to lessen the global slenderness and increase the compressive strength of the column. The failure temperature of built-up CFS may reach 515°C during 8 minutes of resistance time at 50% utilisation and 443°C within 7 minutes at 70% utilisation, according to Muftah et al. [24]. Lastly, there is limited information on the design method and flowchart in the code of practice for varying types of built-up CFS sections when alluding to the previous study.

Built-up CFS sections are becoming safer, more flexible and more stable when the section is combined with other materials such as concrete, mortar, timber board, cement board, plastic board, etc.

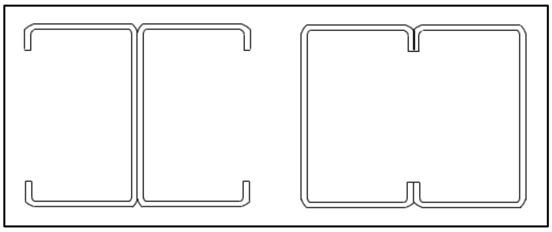

Fig. 2. Example of the face-to-face and back-to-back configuration

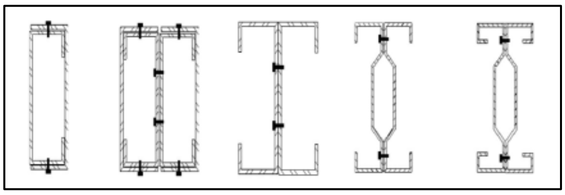

Fig. 3 Example of the built-up CFS section by using a self-drilling screw [25]

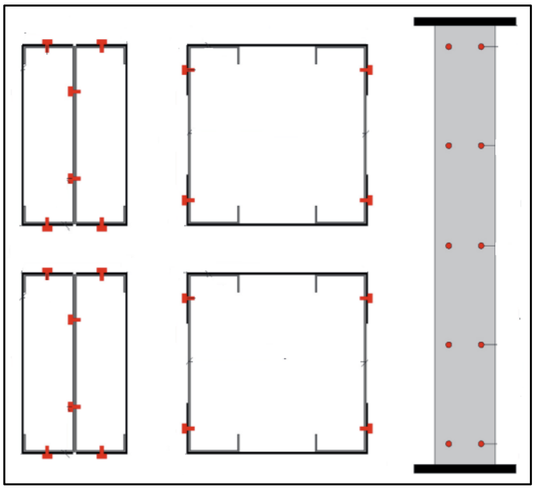

Fig. 4 Example of the built-up CFS section using four channels (all dimensions in mm) [23]

However, many researchers have used concrete as a filler in built-up CFS for enhancing the strong and durable section. This is because concrete is a more versatile and flowable material compared with other materials that could fill the gap easily. Normally, the combination of more than one material in the structural element is known as a composite structure where every material has its own behaviour to help each other sustain the applied load. Senthilkumar et al. [18] mentioned that CFS with concrete is expressed as having higher strength and ductility behaviour due to their capacity to withstand inner buckling and postpone outer buckling from achieving yield strength. Rahnavard et al. [19] noted that the CFS with concrete is categorised as an excellent structural behaviour in a variety of circumstances such as earthquakes or fire and is appropriately utilised in a tall building. Concrete is classified as a low thermal conductivity and expansion when exposed to fire and next prevents the steel structure in general and overall structure in specific from failing in a short period. There is a lot of the design code calculated on the composite column including BS EN1994-1-1:2004, ANSI/AISC and AS5100:2004. Fig. 5 shows an example of the shape and cross-section of the built-up CFS filled with concrete. Nowadays, many researchers are studying to replace normal concrete with special concrete which is more lightweight and cheaper for example rubberised concrete [21], geopolymer recycled brick aggregate concrete [26], ultra-high-performance concrete [27] and washed bottom ash concrete [22]. Dos Santos et al. [28] reported that steel with concrete structure has undertaken numerous modifications to make the element more slender and lighter, directly able to minimise the cross-section and establish a less complex process. According to an analysis of earlier research, the mechanical behaviour of built-up CFS filled with concrete is currently being studied and is still regarded as a hot topic for research. Besides, there is no information on the built-up CFS filled with normal or special mortar in previous studies.

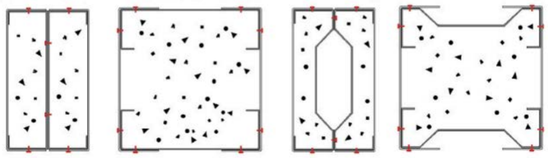

Fig. 5 The example of the built-up CFS filled with concrete [19]

There are two objectives in the study, firstly is to determine the mechanical behaviour of mortar made by WBA and WPSA in the full percentage of the sand and cement replacement. Secondly, the study is to determine the mechanical behaviour of WBA and WPSA mortar that filled directly in the hollow section of the built-up CFS in the face-to-face configuration of the stub column. From the mechanical behaviour value of the stub column, the failure mode of the specimens is observed and analysed clearly in the result and discussion section.

4. MATERIAL PREPARATION AND EXPERIMENTAL SETUP

BA is collected and washed by using clean and clear water and submerging it in the water tank for the required hours. This process is completely done to decrease the carbon content of BA and dried at ambient temperature for the required hours by laying them in flat conditions to achieve constant drying circumstances. The floating objects observed from the process of submerging are collected and thrown out as they are not used in concrete. If the impurities, carbon and floating object such as insects, leaves, wood particles, etc is not collected, they could influence the quality and strength of the concrete or mortar. After the dried process, the BA is collected and stored in the big poly tank. The storage tank must avoid air circulation and moisture. Lastly, the BA is sieved by using a high-capacity sieve pan and shaker to obtain BA that passes a size of 5 mm and then the BA is recognised as washed bottom ash (WBA). WBA takes a small amount for physical and chemical behaviour testing before being used in mortar. WBA is in light grey and natural sand is in yellow. WBA physically is more lightweight, finer and porous when compared with natural sand. Fig. 6 illustrates the WBA and natural sand.

(a) (b)

Fig. 6 The diagram of (a) natural sand and (b) WBA

WPSA is collected in the factory and stored in the storage tank for a natural drying process at ambient temperature. Similar to the BA in the tank, the WPSA should avoid moisture and air circulation. WPSA is sieved by using the sieve pan that is a similar passing size to the cement. Lastly, WPSA is taken in a small amount for physical and chemical behaviour testing. WPSA is white but Portland cement is grey as shown in Fig. 7.

(a) (b)

Fig. 7 The diagram of (a) Portland cement and (b) WPSA

CFS channel section with double web stiffeners and lipped on the flange which is available in the construction market is selected. The CFS channel section is possessed of 75 mm of web element, 34 mm of both flange elements, 8 mm of lipped element, 1 mm of thickness, 148 mm^2 of area and 550 MPa steel grade. Senthilkumar et al. [18] reported that the CFS with stiffeners on the web element along the cross-section could reduce buckling failure. CFS is clean and cut on the web element, flange element and web stiffeners accordingly to coupon tensile specimen for material properties testing referred to BS EN 10002-1-2001. The material properties testing is crucial to confirm that the material parameters of CFS are appropriate for designing the material strength. Material properties of CFS must be examined to guarantee that the CFS material meets the quality standards indicated in the supplier catalogue.

CFS is cut into several sizes of 150 mm, 250 mm and 350 mm for producing various stub column specimens with different heights. CFS is attached in face-to-face configuration and connected by using spot weld with three numbers at the end of the built-up section, top and bottom sides and middle side with 100 mm centre to centre. The length of connection of 100 mm centre to centre at the middle side followed the study of Sang et al. [29]. Thus, the dimension of the built-up section from the upper view is exhibited as a square shape with 75 mm x 68 mm as shown in Fig. 8. There three different slenderness are chosen based on the height of the column as cut before to determine the mechanical behaviour of the column. The complete view of the built-up is shown in Fig. 5.

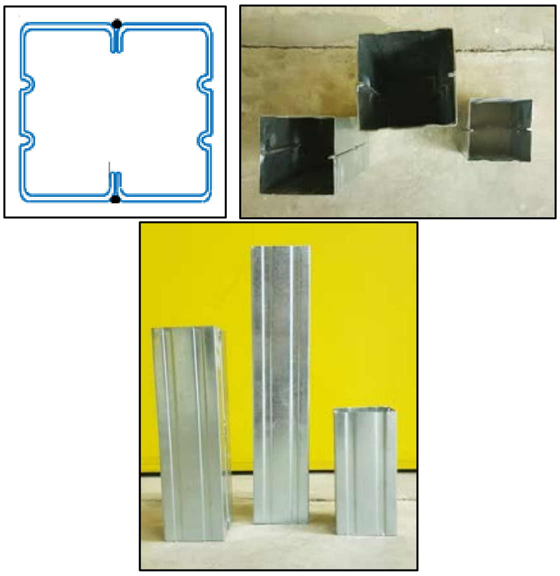

Fig. 8 The top and front view of the built-up face-to-face CFS section

The mortar mixing refers to the ratio of cement to sand which is noted to obtain 1:1 and the water to cement ratio is 0.50 is chosen. The ratio of cement to sand 1:1 is chosen due to both materials replace a traditional material with a full percentage and both materials are reported to have high water absorption. A superplasticiser of the type of Glenium C380 is used in the study to improve the workability and strength of the mortar. Normally, the superplasticiser improves workability by reducing the need for excess water and making the mortar easier to fill into the built-up CFS stub column. Besides, the superplasticiser increases compressive strength by enabling efficient pozzolanic reactions and promoting homogenous microstructure, which lastly improves the strength of the built-up CFS stub column when the mortar is filled. WBA with the full percentage of sand replacement and WPSA with the full percentage of cement replacement are utilised. The mortar is mixed by using the electric pan mixer and filled in mortar mould for material properties testing for 3, 7, 28 and 40 days of curing age. There are four mixes; 100C100S (100% of cement and 100% of sand), 100C100WBA (100% of cement and 100% of WBA), 100WPSA100S (100% of WPSA and 100% of sand) and 100WPSA100WBA (100% of WPSA and 100% of WBA). 100C100S is categorised as a normal specimen which used all traditional materials. Lastly, the appropriate mix is given an acceptable value (not too high because the steel material also assisted to sustain the applied load) and is selected and placed directly into the built-up face-to-face CFS stub column for further work.

The axial compression load of the built-up CFS stub column is ascertained by an experimental programme using 18 specimens with three different heights and the description of the specimens is tabulated in Table 1. In the study, the efficacy of a connection system that uses three numbers of spot welds for a certain centre-to-centre length which has not received much attention is also assessed. The coupon tensile specimen has conducted the testing by using a 100 kN capacity Universal Testing Machine. The compressive strength of mortar for 7 and 28 days of curing is tested by using a 2000 kN Automatic Compression Machine (ACM). The cross-section area for all specimens is 0.0048 m^2. The built-up face-to-face CFS stub column with normal mortar and with WBA and WPSA mortar is tested by using 2000 kN ACM. The ultimate load and failure mode of the built-up face-to-face CFS stub column is observed and analysed.

Table 1. The description of the specimens of built-up face-to-face CFS stub column

Symbols	Description of Specimen	Height (mm)
BF2FCFS150N	Built-up Face-to-face CFS stub column with normal mortar	150
BF2FCFS150M	Built-up Face-to-face CFS stub column with WBA and WPSA mortar	150
BF2FCFS250N	Built-up Face-to-face CFS stub column with normal mortar	250

BF2FCFS250M	Built-up Face-to-face CFS stub column with WBA and WPSA mortar	250
BF2FCFS350N	Built-up Face-to-face CFS stub column with normal mortar	350
BF2FCFS350M	Built-up Face-to-face CFS stub column with WBA and WPSA mortar	350

5. RESULT AND DISCUSSION

Three parts of testing are observed and the data obtained in the testing is elaborated here in the result and discussion section. All parts have their relationship to ensure the result and information data are obtained accurately and understand clearly the factors that affected the mechanical behaviour of the built-up face-to-face CFS stub column for further activities.

5.1 Material Properties of Cold-formed Steel

The result of material properties of CFS at web, flange and web stiffeners are tabulated in Table 2. According to the findings, the element with the lowest ultimate load value is a web and the element with the greatest ultimate load value is the web stiffener. For flat elements, the comparison rate between the ultimate stress and yield stress varies from 1.75% to 2.5% and for web stiffeners, the percentage difference between the ultimate stress and yield stress is 3.02%. The ultimate stress of the web element is increased when the flat surface bends to convert the flange element and web stiffeners with 5.79% and 26.24%, respectively. Furthermore, the yield stress of the web element is similar to the ultimate stress which increases with increasing the process of bending. The percentage difference of yield stress of the web element with the flange element is 6.43% and with the web, the stiffener is 25.77%. All calculated modulus of elasticity from the testing data is more than 200 GPa. The ratio between ultimate stress and yield stress for all elements is 1.01 to 1.03 and the ratio between ultimate stress and factory yield stress for the web element is 0.97, the flange element is 1.04 and the web stiffener is 1.32. The failure mode of web stiffener coupon tensile specimens is represented in Fig. 9. According to BS EN 1993-1-1 (2005), the web and flange element ratio of ultimate stress to yield stress value is reported to be much higher than 1.10 and recognised as having good ductility. Finally, the CFS channel section with reasonable data as evidenced by the data provided by the steel manufacturer is appropriately used as a structural element.

Table 2. The material properties of the CFS channel section

Element	Ultimate Load (N)	Ultimate Stress (MPa)	Yield Stress (MPa)	Modulus of Elasticity (GPa)
Web	6708	537	524	205
Flange	7127	570	560	200
Web Stiffener	9103	728	706	204

5.2 Mechanical Behaviour of WBA and WPSA Mortar

The result of the mechanical behaviour of WBA and WPSA in the ratio of 1:1 is compared with normal mortar as tabulated in Table 3 and Fig. 10. The surface condition of both mortar specimens with 100% of sand and 100% of WBA is intensely different whereas the specimen of 100% of sand is smoother and not rough when compared with 100% of WBA. The highest ultimate load and compressive strength value recorded for 3, 7, 28 and 40 days is the 100C100WBA specimen. The combination of cement with WBA is suitable for developing compressive strength from the beginning when compared with 100C100S (normal) mix because WBA is porous and able to absorb more water and the mix is more viscous. Whilst as the normal mix is shown as not suitable with the proportion of 1:1 which detected the mix is too runny and not viscous such as at a proportion of 1:2 or 1:3.

Fig 9 The web stiffeners failure mode.

Additionally, the lowest value of ultimate load and compressive strength among all specimens are 100WPSA100WBA. The ultimate load and compressive strength for all specimens as usual is increased when the age of the curing increases. The curing mortar is an important process to ensure proper hydration, the development of optimal strength, and durability, and also to prevent cracking and shrinkage. From the figure, the early strength of 100C100S at 3 days is approximately the same as 100WPSA100S because of the comprehensive use of sand, however, after 3 days the value is varied due to WPSA which does not enhance the strength. The percentage difference of ultimate load between 100C100S (normal) with 100C100WBA, 100WPSA100S and 100WPSA100WBA for 7 days of curing is recorded to have 15.13%, 14.73% and 48.22%, respectively. Next, the comparison value of the ultimate load between 100C100S (normal) with 100C100WBA is 6.00%, 100WPSA100S is 33.15% and 100WPSA100WBA is 46.70% for 28 days. The relationship of compressive strength with the curing age of the mortar is demonstrated in Fig. 10. Specimen of 100WPSA100WBA has been classified as an appropriate specimen for further action which is able to fill in the built-up face-to-face CFS stub column due to the percentage difference of early and mature compressive strength with other materials less than 60%. The example diagram of the WBA and WPSA mortar mix after being tested is shown in Fig. 11. From Fig. 11, WBA and WPSA are classified as brittle mortar when distinguished from other specimens.

Table 3. The result of the ultimate load of mortar mixes with different specimen

Specimen	Ultimate Load (kN)			
	3	7	28	40
	days			
100C100S	42.10	64.50	90.80	133.50
100C100WBA	66.80	76.00	96.60	145.80
100WPSA100S	43.10	55.00	60.70	78.90
100WPSA100WBA	12.60	33.40	48.40	63.50

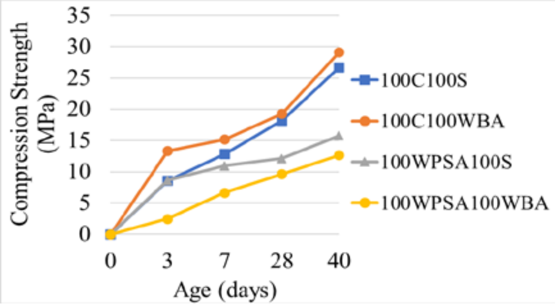

Fig. 10 The compressive strength versus age of mortar mix specimen

Fig. 11 The example of hardened WBA and WPSA mortar mix after being tested

5.3. Compressive Strength of Built-up Face-to-face CFS Filled with WBA and WPSA Mortar

The compressive strength result, mass and failure mode of the built-up face-to-face CFS stub column filled with normal (BF2FCFSN) and WBA and WPSA mortar (BF2FCFSM) are tabulated in Table 4. The mass of specimens either built-up CFS filled with normal or WBA and WPSA mortar is increased with increasing the height of the column. The mass of WBA and WPSA mortar is lighter because both materials used for filling in the built-up face-to-face CFS stub column are classified as porous and lightweight. Fig. 12 shows the relationship between the specimen mass in kg and column height in mm is categorised as a linear relationship. The mass of the column is important to ensure the significance of the specific structural design is maintained such as seismic resistance, structural stability, cost efficiency, strengthened support condition, thermal and energy efficiency and material optimisation. Two equations represented the relationship between the mass of the built-up CFS stub column filled with normal and WBA and WPSA mortar with the coefficient of calculation R^2 derived from the testing. The comparison study of the mass of the built-up face-to-face CFS with normal and WBA and WPSA mortar for 150 mm is 40.67%, 250 mm is 38.22% and 350 mm is 39.28%. The percentage difference of the mass between BF2FCFS150M and BF2FCFS250M is 43.24% and between BF2FCFS250M and BF2FCFS350M is 26.75%.

Table 4. The result of the built-up face-to-face CFS filled with mortar either normal or WBA and WPSA stub column

Specimen	Mass (kg)	Ultimate Load (kN)	Compressive Strength (MPa)
BF2FCFS150N	1.876	295.16	61.49
BF2FCFS150M	1.113	188.86	39.35
BF2FCFS250N	3.174	282.80	58.91
BF2FCFS250M	1.961	169.56	35.33
BF2FCFS350N	4.409	218.30	45.48
BF2FCFS350M	2.677	114.10	23.77

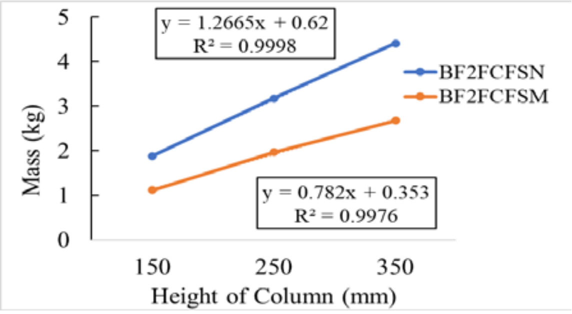

Fig. 12 The line graph of the mass of the specimen versus the height of the column.

The percentage difference of ultimate load between BF2FCFSN and BF2FCFSM for the height of 150 mm, 250 mm and 350 mm is 36.01%, 40.03% and 47.73%, respectively. The percentage difference of ultimate load and compressive strength between BF2FCFSN and BF2FCFSM is increased with increasing the height of the column. The highest value of compressive strength is BF2FCFS150N and the lowest value of compressive strength is BF2FCFS350M. The ultimate load and compressive strength of built-up face-to-face CFS stub columns either filled with normal mortar or WBA and WPSA mortar is reported to reduce with increasing the height. The relationship between the compressive strength of BF2FCFSN and BF2FCFSM is shown in Fig. 13. The figure shows that the line patterns of both are quite similar in height of 150 mm to 350 mm. The WBA and WPSA mortar with suitable strength development have shown the ability to influence the compressive strength of the column and reduce the structural integrity issue.

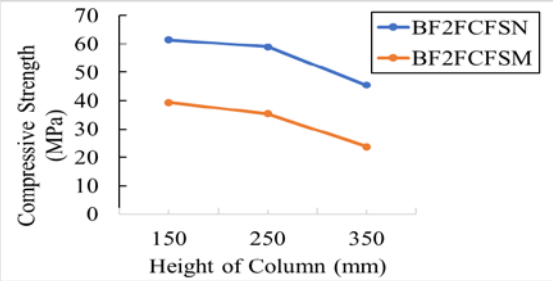

Fig. 13 The relationship of the compressive strength with the height of the stub column

The failure mode of both specimens either filled with normal mortar or with WBA and WPSA mortar is noted as having local and distortional buckling. The clear and complete failure mode of all specimens is illustrated in Fig. 14.

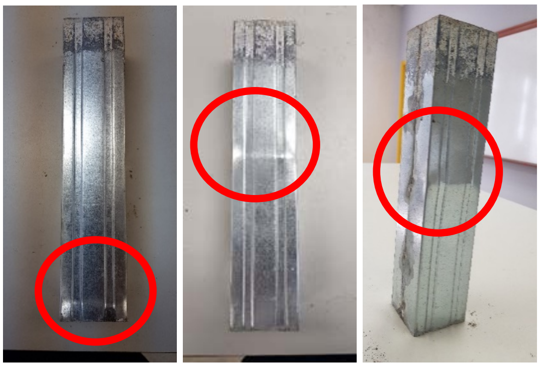

Fig. 14 The example of the failure mode of the BF2FCFS350N and BF2FCFS350M

The red circle represents the failure of the buckling for BF2FCFS350N and BF2FCFS350M. The buckling of the BF2FCFS350N is shown less when compared with BF2FCFS350M. The web element is deformed out of the origin of the built-up CFS section in the beginning and last period of the testing, the flange element is also deformed out of origin. The failure of the built-up CFS filled with mortar is less deformation when compared with built-up CFS without filling of the mortar as referred to in the study by Mohd Sani et al. [22]. As a result, the mortar can react as the material that is suited for lessening the buckling or deformation.

6. CONCLUSION AND RECOMMENDATION

An experimental observation, investigation and evaluation of material properties of CFS, mechanical behaviour of the mortar and mechanical behaviour of built-up face-to-face CFS stub column comprising two different filling materials and three different heights of the column are presented. The following summarises the whole findings:

1) The material properties of the CFS channel section are shown that the ultimate stress is around 500 MPa to 700 MPa and the modulus of elasticity for web, flange and web stiffeners element is more than 200 GPa. From the result of the material properties testing, the result data of the material properties of the section is classified as good in ductility and suitable for future work.
2) The mechanical behaviour of the four specimens is stated to elaborate that the ultimate load and compressive strength are dramatically increased with increasing the age or date of curing. The specimen of 100C100WBA has shown the highest value of compressive strength among all specimens because the combination of full replacement of sand with proportion 1:1 is appropriate. However, the lowest value of compressive strength is 100WPSA100WBA specimen and the value is not less than 60% so the most suitable to fill in the built-up face-to-face CFS column by checking their performance and cost of production.
3) The mechanical behaviour of the built-up face-to-face CFS stub column filled with normal mortar is shown the highest value of compressive strength when compared with WBA and WPSA mortar due to lightweight specimen and porous circumstances. The percentage difference of the compressive strength for built-up CFS columns with normal mortar, and WBA and WPSA mortar is noted to have a range of 36% to 47%. The compressive strength of all columns either filled with normal or with WBA and WPSA mortar is decreased when the column height increases.

For further study, the specimen with different slenderness ratios should be discussed or compared the result with numerical analysis by using computer software. Besides, the WBA and WPSA mortar should be added more proportion of replacement in mortar mixes either partial or full percentage. The experimental activity should be more focused on establishing the link between the mechanical behaviour and the chemical characteristics, as well as on water absorption, workability and other strength tests including flexural and tensile tests.

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