EFFECT OF COCONUT FIBRES CONTENT ON THE MECHANICAL PROPERTIES OF MORTARS

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Abstract

A research work program is undertaken to promote the use of green materials in civil engineering as a good solution to reduce the negative effects on the environment. Natural fibres are known as green alternatives for building materials. In present study, the impact of the mass of fibre on the mechanical properties of coconut fibre-reinforced mortar is investigated. The experiments in both fresh and hardened states of mortars were conducted in accordance with EN standards. Samples without fibre and with 1, 2, 3 vol.% fibres were cast and cured for 7, 14, 28 days. The results in hardened state of mortar indicated that the addition of fibres can reduce the compressive strength but increase the flexural strength of mortar in comparison with the mortar without fibre. The increase of water absorption capacity with the fibre content increase was also recorded with the increase of fibre content. Mortar incorporating 2% coconut fibres with 1.5 cm average length has the best mechanical properties. Moreover, a remarkable decrease of the workability of mortar incorporating coconut fibres was observed. However, the quantity of heat emitted in accordance with the development of the temperature of samples of freshly made mortars is decreased with the increased of fibre content.

Keywords:

Coconut fibre; mortar; workability; heat of hydration; compressive strength; flexural strength.

1 INTRODUCTION

Nowadays, reliance on the traditional concrete is increasing significantly and it is one of the main materials for building construction with over ten billion tons of concrete being produced each year worldwide [Meyer 2005]. However, some researchers even have reported that conventional concrete could actually harm the environment more than it is helping. The reason is due to the large volumes and the energy-intensive production of cement clinker which has a greenhouse gases emission between 5 and 8 % of the world's total [European Commission 2017]. In regard to this, green materials are predicted to grow steadily into the foreseeable future in order to replace conventional building materials to reach the sustainable development goals. Some common recycled materials incorporated in concrete or mortar were taken advantage such as agricultural by-products [Akil 2011; Niyigena 2016; Ramli 2013; Zhou 2013; Zia 2017], industrial by-products [Bicer 2018; Chan 2004; O'Rourke 2009; Abdulkareem 2018; Afroz 2017] or other waste residues [Bui 2018; Khan 2016; Nguyen 2013]. Among them, natural fibres are known as green alternatives for building materials which can give a lower impact on the environment thanks to their friendly-environment characteristics.

There are many vegetable fibres used as non-conventional materials including sunflower stalk, textile waste and stubble fibre [Binici 2013], straw [Binici 2009], jute [Kim 2016], coconut [Basu 2015] or hemp [Sair 2018]. Out of these, coconut fibre is known as a potential candidate for reinforcement the matrix which can provide higher mechanical properties of the composite thanks to their most ductile and energy absorbent properties [Ali 2011] in comparison composite without fibre [Andiç-Çakir 2014]. The mechanical properties of mortar incorporating natural fibre remain a topic of interest for many researchers. A detail literature research is reported here about the mechanical of coconut fibre and its composites. Besides, according to Alves et al. [Alves 2013], although the tensile strength of coconut fibre is quite low, its strain reaches about 18.8%, while other natural fibres are in a range of 0.6-3.3%. This conclusion is in the line of the observations already made in a series of studies [Munawar 2007; Tran 2015; Yan 2016; Ezekiel 2011; Oda 2012; Ramli 2013]. Khedari et al. [Khedari 2001] studied the effect of fibre length and fibre content on compressive strength of specimen. The composite specimen was produced using 1:1:1.5 proportion (cement: sand: water by mass) mortar reinforced in the range of 10-30% of coconut fibre by mass of cement. They concluded that the compressive strength of fibre-mortars is less than that of mortar without fibre, but are still in the standard range for hollow non-load bearing concrete masonry units (2MPa; ASTM C 109/C 109-95). Therefore, it is possible to construct wall, ceiling, and roofing of housing. The optimum ratio of fibre component was found in 20% by mass of cement. Several research reports also mentioned the ability to use mortar inclusion coconut fibres in buildings [Rejeesh 2017; Va 2014]. Roofing material was considered as an important utilization particularly when fibre mortar was studied as a replacement for asbestos in rural house construction. And more this type of material is a beneficial reuse thanks to its low heat conductivity (66% less than the thermal conductivity of control composite) and low dry density [Lertwattanaruk 2015; Agopyan 2005; Alavez-Ramirez 2014]. Additionally, inclusion of coconut fibres in mortar is also considered as surface plastering for masonry structures to overcome the brittle response of the standard mortar [Sathiparan 2017]. Although the improvement of compressive and flexural strength was not observed, fibres in mortar have the ability to act as crack arrestor which leads to a reduction in crack propagation and gradual damage [Zia 2017]. Moreover, another advantage of mortar incorporating fibre is lower bulk density than mortar by 52% which can provide convenience for transportation. An investigation on the strength and durability of coconut fibre reinforced concrete in aggressive environments [Ramli 2013], the compressive underwent a decrease , while the flexural strength was observed in increase by 9% with the increase of fibre content for four different contents 0.6%, 1.2%, 1.8%, 2.4% expressed by volume of binder in all considered environments. In conclusion, the authors recommend that the dosage of coconut fibres should be less than 1.2% of the binder volume in order to reduce their natural degradation. These results are in agreement with the findings of [Hwang 2016] in which the data have shown that the compressive strength of specimens decreased from 65 to 33 MPa and the flexural strength increased up to 7.5% with the increase of fibre between 0% and 4% (by mortar volume). The congestion or clustering of fibre which reduces the bond between the fibres and the matrix makes a decrease in the stress that contributes to failures could explain this behaviour. On the contrary, the data in [Yan 2016] indicated that fibre inclusion can give higher in both compressive and flexural strengths (up to 6.3% and 14.2% for compressive and flexural strength, respectively) compared to plain concrete. A significant reduction from 75mm to 37mm in the slump with an addition 1% of fibre (by mass of cement) in concrete was found in present study. Despite a low slump, reasonable workability was observed for coconut fibre reinforced concrete because of the hydrophilic characteristic of fibre. They also suggested some approaches to improve the workability of concrete with fibre such as adding more water or superplasticizer, even using round-shaped gravels instead of crushed stones. Compared with the plain concrete, fibre addition slightly decreased the density of fibre reinforced concrete by 1.7% because of possible enhancement of porosity resulting from the fibre inclusion and the low density of the coconut fibre which was approximately 1.2 g/cm^3 in comparison with 2.18 g/cm^3 of plain concrete.

In order to clarify the influence of coconut fibre volume fraction on the mechanical properties of mortars, compressive and flexural strengths were determined through experimental results in present research work. Additionally, mortar properties in the fresh state were also investigated to enhance its workability.

2 MATERIALS AND METHODS

2.1 Materials

Raw fibre

Coconut fibres from Vietnam were used in present study in the form of raw fibre. Table 1 has shown the specifications of fibre. Before cutting fibres into 10-20 mm length, piths and coir dust were removed manually in order to avoid the effect on the properties of fibres. Fig. 1 shows the appearance and the process of fibre hand-preparation. This laboratory process is a time-consuming work and demands elaborately.

Cement

CEM I 52.5 N type I Ordinary Portland Cement (OPC) which was manufactured in accordance with EN 196-1 was used in present study. The main physical properties and chemical composition of cement are given in table 2.

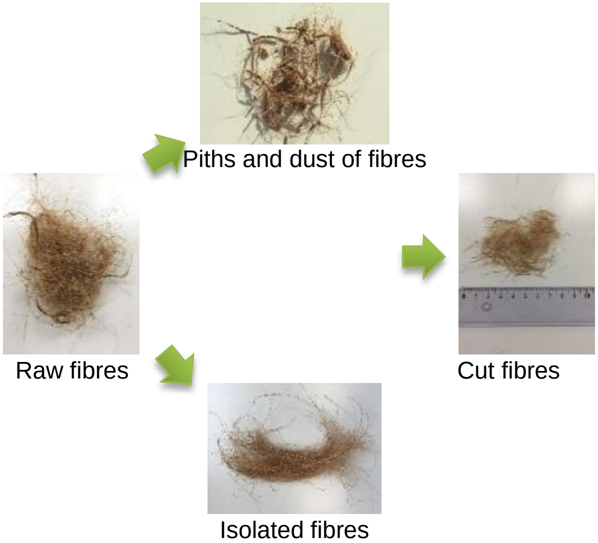

Fig. 1: The process of preparation of fibre

Sand

Alluvial quartz sand was used in the experiments. Grain size distribution of the cement and sand are given in Fig. 2.

Superplasticizer

CHRYSO Fluid Optima 352 EMx was added with the ratio of 1% by mass of cement as a superplasticizer for a significant water reduction and enhancement the workability of the fresh mixture in accordance with the suggestion of Yan et al. [Yan 2016].

Tab. 1: Specifications of coconut fibre.

Items	Unit	Test value
Diameter	mm	0.250
Length	mm	10 - 20
Absolute density	g/cm^3	1.41
Water absorption after immersion of 48 hours	%	133
Tensile strength at failure	MPa	123.6
Tensile strain at failure	%	26.9
Water content	%	7.60

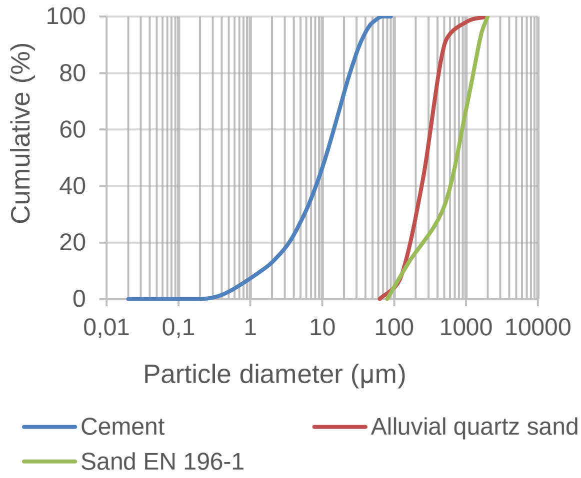

Fig. 2: Grain size distribution of cement and sand.

Tab. 2: Characteristics of cement.

Chemical properties (%)	
Loss on ignition	2.2
SiO_2	19.4
Al_2O_3	4.6
Fe_2O_3	3.9
TiO_2	0.3
CaO	64.3
MgO	1.2
SO_3	2.6
K_2O	0.86
Na_2O	0.06
P_2O_5	0.3
S^{2-}	< 0.02
Cl^-	< 0.007
C_3A+0.27* C_3S	20.2
Physical and mechanical properties	
Blaine fineness (cm^2/g)	4200
Density (g/cm^3)	3.16
Compressive strength (MPa)	
1 day	23
2 days	34
7 days	48
28 days	62
Initial setting time (min)	150

2.2 Experimental methods

Preparation of mortars

In present study, the mortar mix design was produced in accordance with EN 196-1 standard. In the preparation of mixtures, fibres were considered as fine aggregates for reducing alluvial quartz sand. The mass of fibres and sand is always equal to 1350g in total. For the four mortars containing fibres, the fibre's incorporating rates were at 0%, 1%, 2%, 3% volume of mortar. All of the four mixtures proportions are presented in table 3. As can be seen from the results, the addition of fibre provided a remarkable reduction of 11.06% of density for mortar which can be a useful characteristic since consideration coconut fibre-reinforced composite as lightweight material in building construction. The mixing procedure must be done carefully in order to achieve the homogeneous dispersion fibre in the mixture. The total time of a mixing procedure is six minutes as shown in Fig. 3.

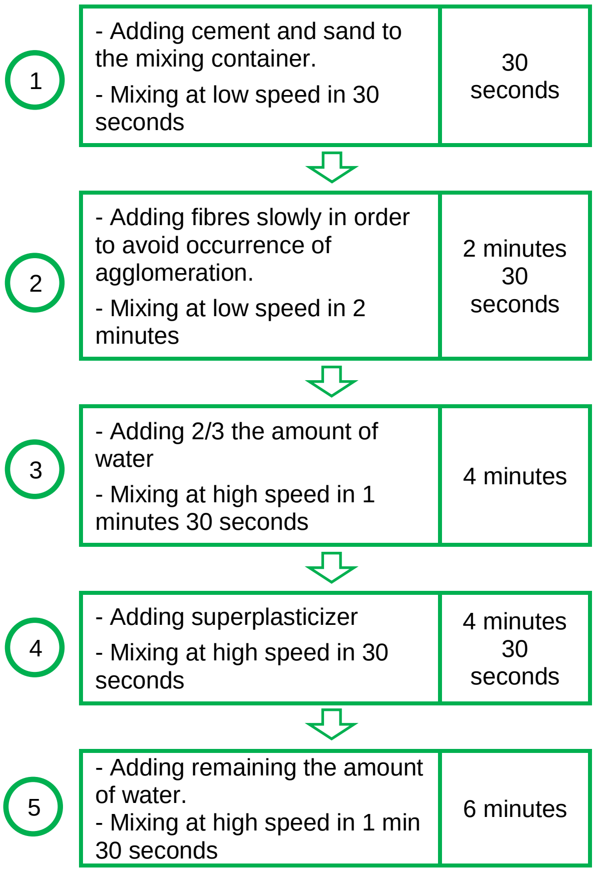

Fig. 3: Mixing procedure of mortar containing fibre.

Fresh state tests

Slump flow values of fresh mortars were determined in accordance with EN 1015-3 standard with a small cone (D_0=100 mm, D_1=70 mm). At least four tests were performed to get an average result. Measurement the diameter of the mortar in two directions was done. Some tests were removed and replaced by other ones when the two individual flow values deviate from their mean value by more than 10%. The slump flow value of samples is calculated according to equation 1 below.

$$Sf = \frac{D-D_0}{D_0} x100\% \quad (1)$$

where Sf: slump flow value (%), D_0: the internal diameter at the bottom of truncated conical mould (100 mm), D: the average diameter of the mortar in two directions at right angles.

Tab. 3: Mix proportion and density of coconut fibre cementitious composite.

Specimen No.	W/C	Sand (g)	Cement (g)	Water (g)	Superplasticizer (g)	Fibre (g)	Density (kg/m³)
OPC	0.5	1350	450	225	4.5	0	2277
OPC1	0.5	1339.20	450	225	4.5	10.80	2222
OPC2	0.5	1328.41	450	225	4.5	21.59	2123
OPC3	0.5	1317.61	450	225	4.5	32.39	2055

The quantity of heat of mortars during the first one day was conducted according to EN 196-9 standard as shown in Fig. 4. The semi-adiabatic method consists of introducing a sample of freshly made mortar into a calorimeter in order to determine the quantity of heat emitted in accordance with the development of the temperature from ambient temperature. The heat of hydration is expressed in joules per gram of cement. The temperature increase of mortar is compared with the temperature of an inert sample in a reference calorimeter at 25°C.

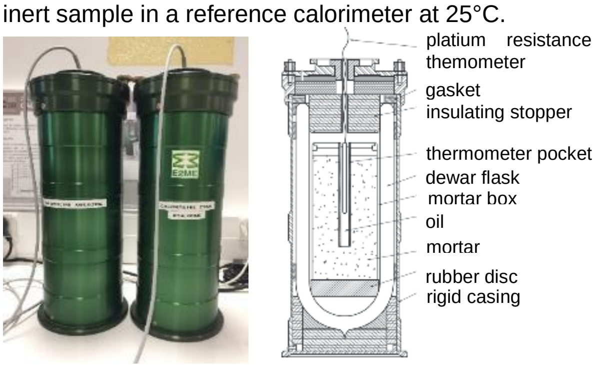

Fig. 4: Semi-adiabatic calorimeters of hydration test (EN 196-9).

Water absorption

According to the European Standard EN 12087, water absorption test was performed on the cubic specimens 40 x 40 x 40 mm^3 after the curing time of 28 days. At least five test specimens were used to get an average result.

Mechanical testing

Compressive and flexural strengths of mortars were determined in accordance with EN 196-1. These tests were performed on hardened 40 x 40 x 160 mm^3 prisms after 7, 14 and 28 days of curing time, at a constant rate loading of 0.5kN/s. The reported result is an average of three to six tests.

3 RESULTS AND DISCUSSION

3.1 Fresh state mortar properties

Workability

Fig. 5 has shown the evolution of slump flow of samples. In the fresh state, control mortar is so fluid with slump flow of approximately 70%. As observed, while the fibre content is increased, the slump flow is decreased remarkable which reflecting a reduction of workability. The reduction of the slump flow gains at roughly 7% at the fibre content of 3%. Some reports [Mo 2016; Kylili 2017; Page 2017; Hwang 2016] also have confirmed the poor workability of samples reinforced fibres. The higher absorptive significantly (133% of coconut fibre in comparison with roughly 7% of mortar) and retentive nature of coconut fibre may be responsible for this phenomenon.

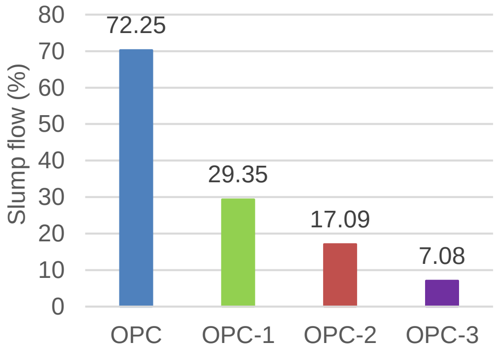

Fig. 5: Slump flow of mortars by flow table.

Heat of hydration

The temperature rise of mortar samples gains at 62.2°C in maximum and depends mainly on the characteristic of cement and the fibre content. The heat flow measured for these mixtures in the period time of 6 to 15 hours is presented in Fig. 6 (fitted curves) while Fig. 7 shows the effect of fibre content on the mortars with the cumulative heat release measured from semi-adiabatic calorimeters. Tab. 4 also summarizes the main characteristics values of the semi-adiabatic hydration and heat flow curves where Q_{max} is the maximal heat reaction in joules per gram of cement, t_{max} is the time of maximum heat flow in minute and I_{max} is the maximum intensity of heat flow in joules per hour per gram of cement. As can be seen from these data results, the same trends of the relationship between the heat of hydration and the development of temperature were found even for all formulation of mortars. In addition, the replacement of sand with coconut fibres results in reduction of produced reaction heat *i.e. the peak of heat flow*.

There is a decrease in the overall heat of hydration between 318 J/g of cement and 268 J/g of cement with the increased of fibre content, which reflects the lower organic of reaction for the fibre is lower than the cement reaction with water. The maximum of heat emitted was found in the mortar without fibre at the value of 318 J/g of cement after 24 hours of testing. A slight decrease of temperature is also measured when fibre content increases. The maximal temperature is 62.2°C, 58.9°C, 57°C, and 51.9°C, respectively for mortars with fibre content at level of 0%, 1%, 2%, and 3%. As observed in Fig. 6, the rate of heat released during the hydration could ease the comparison of the different mixes and evidence the delay induced by the addition of coconut fibres into the mortar. The heat flow peak of control mortar is 42.26 J/h.g of cement at the time of 516 min, followed by mortars incorporating fibres. In order to explain this phenomenon, water content of fibre reinforced mortars is considered. The high water absorption capacity of coconut fibres induces the lower free water content in cementitious matrix which makes restriction of Ca^{2+} and OH^- diffusion [Abdulkareem 2018]. Therefore, pozzolanic reactions in Portland cement are delayed and the early hydration occurs slowly.

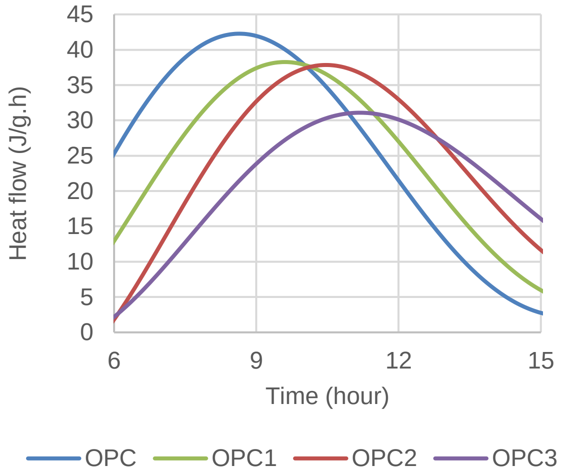

Fig. 6: Heat flow of studied mortars.

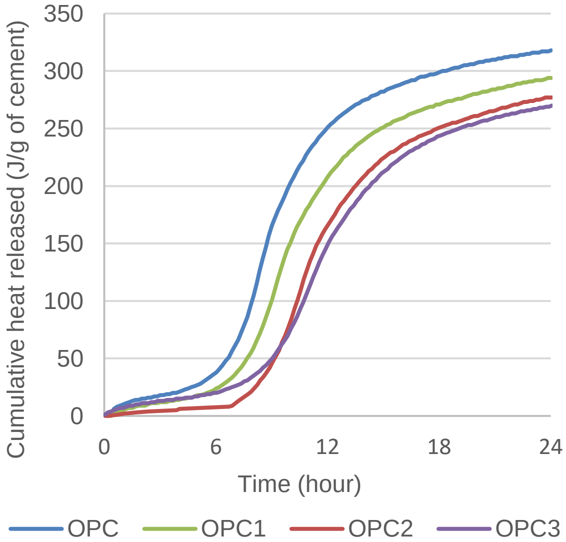

Fig. 7: The semi-adiabatic curve of mortars.

3.2 Hardened state mortar properties

Water absorption capacity

Fig. 8 has shown the results of water absorption of mortar. As can be seen from this graph, a significant increase in water absorption was reported with the increase of fibre content. Water absorption achieves in the maximum value of 7.69% at the 3% of fibre content which reflects the effect of hydrophilic characteristic of coconut fibre that absorbs manufacturing water. This factor consequently used for the correction of the effective water content for the composite mix design [Page 2017].

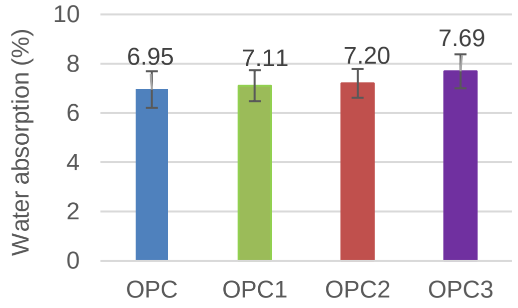

Fig. 8: Water absorption capacity of mortars.

Mechanical properties

The mechanical properties of fibre-reinforced mortar depend on not only properties of fibres but also fibre content and fibre orientation as well as the interfacial adhesion between fibres and the cementitious matrix. In order to give an easier comparison between the mechanical performances of the various composites, data results are presented in Fig. 9 and Fig. 10.

The control mortar has a compressive strength of 47.32 MPa and a flexural strength of 7.83 MPa at 28 days. As expected, the compressive and flexural strengths of mortars increase with the increase in curing age in all the mixes. An observation the decrease of the compressive strength of mortars with the increase of fibre content was found during the time period of the test. The compressive strength was decreased by approximately 16% for 28-day specimens as fibre content range between 0% and 3%. The minimum of compressive strength was found in mortar incorporating 3% fibre content while 28-day compressive strengths of all samples were under that of reference sample but these values meet the demand of European standards for rendering and plastering mortar in masonry. This result was confirmed in the previous studies [Verma 2013; Asdrubali 2015]. The explanation for this observation is due to the pectin, ash and other impurities included the fibre component which induces the reduction of bond between fibres and cementitious matrix. Additionally, another reason is the higher air content and porosity with the higher fibre content which makes a decrease in the compressive strength.

Tab. 4: Hydration characteristics of cementitious matrices.

Specimen reference	Measured value Q_{max} (J/g)	Maximum temperature measured value (°C)	The time of maximum heat flow t_{max} (min)	Maximum insensity of heat flow I_{max} (J/h.g of cement)
OPC	318	62.20	516	42.26
OPC1	294	58.90	576	38.26
OPC2	277	57.00	630	37.84
OPC3	268	51.90	672	31.08

As foreseen, the flexural strength increases significant thanks to the addition of fibres. In detail, mortar sample with 2% fibre content gave a considerable higher flexural strength of 16.7% and 14.5% in comparison with sample without fibre and with 1% fibre content, respectively. This issue was explained by [Savastano 2000] that debonding can take place at the interface and the fibre may then be pulled out through the matrix, generating considerable frictional energy losses which contribute to failure.

Concerning the bending behavior of mortars, Fig.11 has shown the evolution of the force applied as a function of the displacement of the measured point of support at the center of the specimen for a sample of non-fibrous mortar and for mortar incorporating 2% fibre content. Two different types of behavior can be observed. The first curve corresponding to the sample of the reference mortar is characterized by an elastic part following by a linear behavior before occurring failure suddenly (fragile character). On the contrary, the second one is related to fibre presence. The behavior is the same first one until the first cracking appears in order to avoid brittle fracture suddenly thanks to fibres in mortar. The fibres of the crack tip are then solicited in tension and induce in an increase of the load.

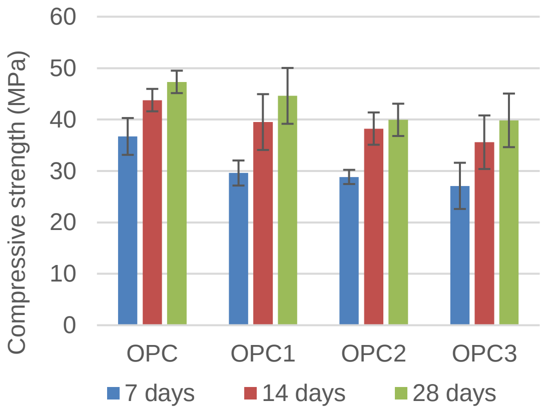

Fig. 9: Compressive strength of mortars.

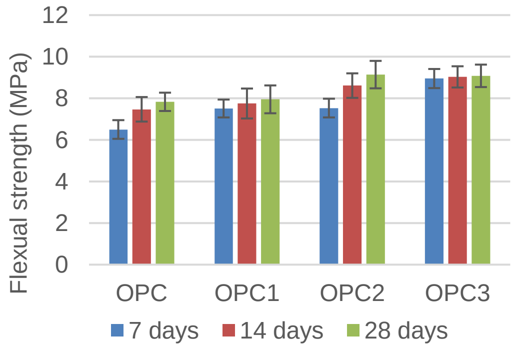

Fig. 10: Flexural strength of mortars.

In terms of toughness index, ASTM C1018 was used as the main guide. In present study, the toughness index I_5 was taken into as the energy equivalent to the area under the load-deflection curve up to a deflection of three times the first-crack deflection divided by the area up to the first crack. For the sake of clarity, the principle of calculation of toughness index I_5 is given in Fig. 12 while Fig. 13 indicates the toughness index I_5 value of mortars.

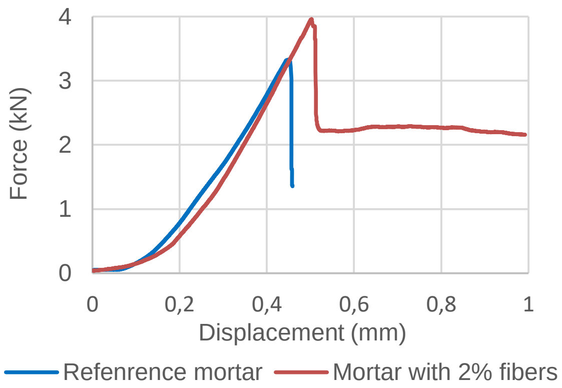

Fig.11: Typical curves of behaviour in bending 3 points of mortars after 28 of curing.

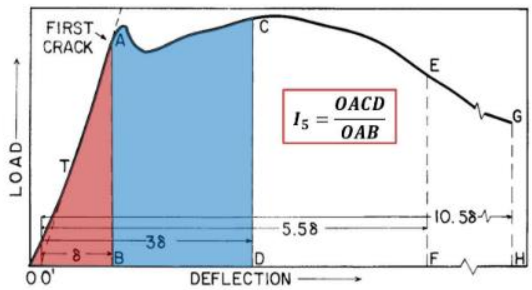

Fig. 12: Principle of calculation of toughness index I_5 in accordance with ASTM C1018

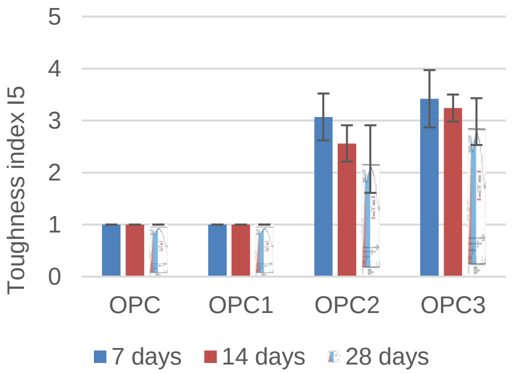

Fig. 13: Toughness index I_5 at different ages of mortars.

As can be seen from the data results, the amount of fibre influenced in different ways the cementitious matrix. At the all surveyed age of mortars, toughness index I_5 of mortar without fibre and mortar with 1% fibre content is always equal to 1. This means that for control mortar and mortar with low fibre content, all failures are in a fragile way as soon as the first matrix crack appears if there are no or not enough fibre. However, when the ratio of fibres is increased to 2% and 3%, there is an increase in the toughness index up to 3.42 in maximum for mortar with 3% fibre at the age of 7 days. The implication is coconut fibres may greatly increase the toughness and residual strength factors of mortars while producing a first crack strength only slightly greater than the flexural strength of reference mortar. But a significant reduction of I_5 was observed in mortar added 2% fibre at 28 days of curing when this value went down by 33%. The explanation for that is due to the degradation of fibre with the age in the alkaline environment of the cementitious matrix.

4 CONCLUSIONS

The objective of present study was to characterize coconut fibre-reinforced mortars. Coconut fibre is a potential candidate for reinforcement in composite and a sustainable option to replace a part of typical building materials because of their friendly-environment characteristic. From the data results obtained from experiments, the following main conclusions were drawn:

- A remarkable drop of ten times in workability of mortar including 3% fibre content was reported. In order to solve this problem, 1% superplasticizer (by mass of cement) was added to improve the properties of fresh mortars.

- Additionally, the same trend of the development of quantity of heat emitted in all case of fresh mortars during the first day was observed. The maximum of the heat of hydration decrease slightly and water absorption capacity of mortars increase up to 10.65% with the increase of fibre content from 0% to 3%. The maximum amount of heat emitted gained at 318 J/g of cement and 62°C for the reference mortar.

- With the increase of fibre content, while the flexural strength of mortars was increased significantly, the decrease in compressive strength was remained by 16% in maximum dependent of the fibre content when comparing the mechanical properties of control mortar at the same condition. Coconut fibre at 2% content seems to be an optimum for improving the flexural strength of mortars with enhancing of 16.7%.

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