MECHANICAL AND PHYSICAL PROPERTIES OF MORTAR OF PARTIALLY REPLACED FINE AGGREGATES WITH SAWDUST

O. Nanayakkara[1]*, J. Xia[1]

[1] Department of Civil Engineering, Xi'an Jiaotong-Liverpool University, Suzhou, China PR

*Corresponding author; e-mail: ominda.nanayakkara@xjtlu.edu.cn

Abstract

Sawdust, a waste material produced from timber manufacturing process, is considered as an excellent bio based material. Sawdust is used in many applications; however, the use of sawdust with cementitious materials is minimum. The main reason for this is due to the fact that the sawdust is a bio based material where the durability of sawdust added cementitious materials is unknown. In addition to that, fresh, physical, and mechanical properties of concrete or mortar with sawdust are not well established. Therefore, the aim of this study is to explore the potential to use sawdust as a fine aggregate replacement material in typical Portland cement mortar. This study first aimed to investigate a proper pre-treatment method for sawdust which can be mixed in mortar. Results show that boiling sawdust with Sodium Hydroxide of 2% concentration for 2 hours and washing with boiling water for 30 minutes can produce better mechanical properties in comparison to original sawdust or sawdust boiled with water only. Adding sawdust decreases the density of mortar while increasing the water absorption capacity from 10% for normal mortar to 25% for mortar with 50% sawdust replacement level. Sawdust in mortar has a direct impact on its mechanical properties where compressive and flexural strength can be significantly reduced. However, even at 50% replacement level of sawdust, a reasonable compressive strength can be achieved which might be considered as sufficient for low grade applications. Sawdust addition can also significantly increase the drying shrinkage of mortar. Drying shrinkage of 1000 microns at 28 days' age can be easily passed by mortar mixes with high sawdust content of above 30%. This study proves that the fine aggregates replacement with sawdust in mortar brings many disadvantages; however, still maintaining some reasonable mechanical properties. The effect on durability properties should be investigated further.

Keywords:

Sawdust, Mortar, Fine aggregates, Treatment, Shrinkage

1 INTRODUCTION

In recent years, significant effort is made by researchers in aiming to develop sustainable building materials. The main reason for this is due to the fact that the conventional building materials such as cement, sand, and gravel are responsible for severe environmental pollution and carbon dioxide emission. As a solution for achieving sustainable building materials, variety of cement replacement materials which are usually by-products of other industries and variety of aggregate replacement materials have been under extensive investigations. Ground granulated blast-furnace slag and fly ash have been effectively and widely used in concrete for the purpose of reducing or fully replacing the use of cement [1]. On the other hand, the use of aggregate has also significant environmental concerns as the amount of aggregate is usually 60-75% in concrete and mortar and it is coming from natural rivers or rock quarries. The replacement of typical aggregate with other possible materials has also gained a significant attention recently. Recycled aggregates which are usually coming from construction demolition waste (CDW) has been identified as a replacement for natural aggregates although the fresh properties and mechanical properties are slightly inferior for concrete made with recycled aggregates as compared to their normal counterparts [2].

Mortar is the main component in concrete as well as it is widely used as the main building material in low cost building constructions especially in the constructions using bricks, blocks, or masonry. Alternative methods and materials that can be used to produce mortar should be investigated considering that mortar needs huge amount of sand which are at the moment from natural river sand and crushed rocks. Sawdust, a waste material from timber manufacturing process, can be used as a potential sand replacement material and proved to be effective according to the literature information.

Bio-composites made up with gypsum and 20% of sawdust addition has shown promising mechanical properties where the achieved compressive strength of 13 MPa [3]. Content of sawdust can affect negatively for the compressive strength; however, reduction in density which would be beneficial. Sand replacement with different biomass wastes have been investigated for indoor applications and a reduction in compressive strength has been observed; however, recommends for plastering and rendering applications [4]. Waste sawdust can be effectively used in producing normal weight concrete and light weight concrete [5]. Adding sawdust in concrete affect many properties where some of them are negative while some of them are positive. Promising properties on fresh state and mechanical strength of sawdust incorporated fly ash geopolymer paste has been identified in recent research [6]. Sawdust content has a direct impact on the setting time, density, compressive strength, and flexural strength of geopolymer paste. The properties of sawdust incorporated building materials, such as wood-crete, depends on the initial treatment condition on the sawdust. The sawdust treated with either hot water or boiling with alkali added water has positive effect on the performance of wood-crete [7]. The compressive strength can be increased by about 30% and 260% for hot water boiling treatment and hot water with 4% Sodium Hydroxide (NaOH) treatment, respectively. Sawdust can also be used as the only fine material in making wood-crete. The compressive strength, however, could be very low as 0.8 MPa though the composite material has a very good thermal conductivity which is about 0.05 W/mK [8]. Sawdust is also widely used in making low density panels; however, panels cannot be used for structural purposes or load bearing purpose because of very poor mechanical properties [9].

Sawdust added building materials' durability properties have not been considered extensively although the effect of sawdust on the durability could be very crucial and significant. According to the reported literature, incorporation of sawdust with cementitious materials can reduce the drying shrinkage [10]. The drying shrinkage is one of the main properties of cementitious materials as it could directly affect the durability properties. In addition to the capacity to absorb water or moisture from air can also directly related to the durability of sawdust added mortar or concrete. It has been reported that the Portland cement with wood fibre waste can significantly absorb water as result of hydrophilic nature of wood [11].

There are minimum research studies in the literature which have focused on adding significantly large amount of sawdust in mortar or concrete. Also, majority of studies except very few have considered of adding sawdust without applying any pre-treatment which might not bring the prominent results related to mechanical and physical properties. Therefore, this study aims to investigate the pre-treatment method of sawdust and physical/mechanical properties of sawdust added mortar.

2 EXPERIMENTAL SETUP

2.1 Cementitious materials

Normal Ordinary Portland Cement (OPC) with the strength class of 42.5 and the specific gravity of 3.15 was used in this study. The amount of cement was kept at 512 kg/m^3.

2.2 Fine aggregate

Fine aggregate of river sand with all particles smaller than 2.36 mm was used in the experiments. The fine aggregate has about 85% passing percentage at 1.18 mm and 50% passing percentage at 600 µm. The measured specific gravity of fine aggregate is 2.65.

2.3 Sawdust

The sawdust is a commercially available source unknown type with different particle sizes and shapes. However, to maintain a good mortar mix, the large and long particles were removed by sieving. The maximum particle size was kept at 1.18 mm. Sieved sawdust has about 65% passing percentage at 600 µm and 30% passing percentage at 300 µm. *Fig. 1 (a)* shows the particles used in this study obtained after sieving (small) and *Fig. 1 (b)* shows particles left after sieving (large). Large particles are not efficient in obtaining a workable mortar mix due its nature where particles are long and thin than round and solid. *Fig. 2* shows the particle size distributions of both fine aggregate and sawdust. The estimated effective specific gravity of sawdust using preliminary tests was taken as 0.33.

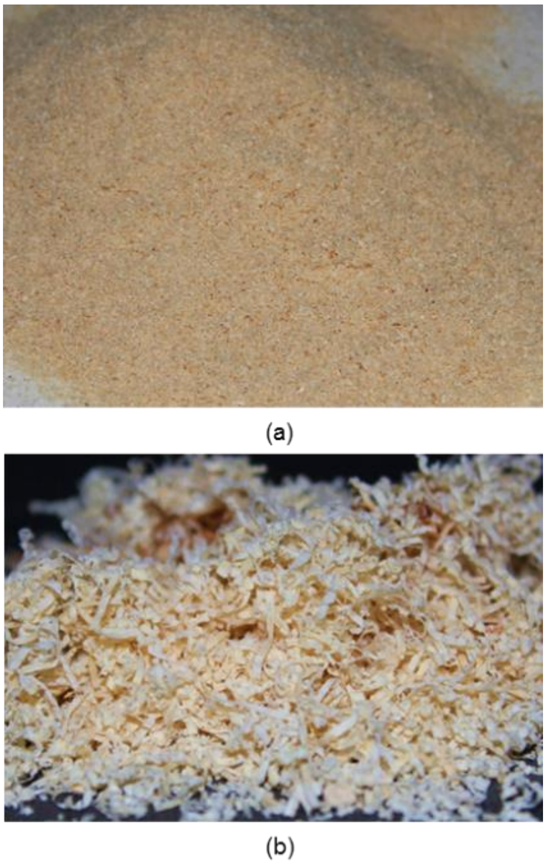

Fig. 1: Sawdust particles (a) small (b) large.

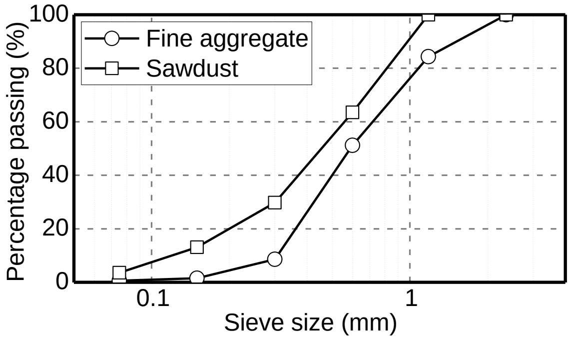

Fig. 2: Particle size distribution of fine aggregate and sawdust.

Sawdust used in this study was investigated for the effect of the pre-treatment method. The recommended pre-treatment method is to boil sawdust with an alkaline material where Sodium Hydroxide (NaOH) was used [8]. The control group of sawdust was not boiled while other sawdust samples were boiled with NaOH of different alkaline percentages varying from 2% to 5% as shown in *Tab. 1*. All sawdust samples were boiled for 2 hours keeping the mass ratio of sawdust to water as 1 to 5. Additional samples were also investigated for the effect of washing of sawdust with hot water for 30 minutes where this was carried out in two steps of 15 minutes in each washing. For washing, sawdust was boiled with water only after boiling with NaOH. Sawdust samples were then oven dried before use in mortar mixing.

Tab. 1: Sawdust samples of pre-treatment groups

Group Number	NaOH (%)	Boiling (hours)	Washing (hours)
1	0	0	0
2	2	2	0
3	3	2	0
4	4	2	0
5	5	2	0
6	0	2	0
7	2	2	0.5
8	4	2	0.5

2.4 Mortar specimens

All specimens used for strength tests and moisture absorption test were water submerged and cured for 28 days. The compressive strength and flexural strength of mortar was measured at 28 days for sawdust pre-treatment groups (*Tab. 1*) and 7 days and 28 days for sawdust added (*Tab. 2*) groups. Compressive strength was measured using 50×50×50 mm cube specimens and the flexural strength was measured using 40×40×160 mm specimens. The flexural strength of mortar specimens was carried out using three-point bending test. The clear span between supports were kept at 100 mm [BS EN 1015-11].

Additional cube specimens with size of 50×50×50 mm were cast to measure the water absorption capacity of all groups. The water absorption was measured at the age of 7 and 28 days from the casting. Specimens were submerged in water until the measurement date. Initially the mass of specimens was measured after the removal of surface water. Then specimens were oven dried at a temperature of 105 ^{0}C for 24 hours. The moisture absorption capacity was then determined relative to the fully dried mortar specimens [BS EN 1353].

The size of specimen used to measure drying shrinkage was 25×25×280 mm with an effective gauge length of 250 mm. Periodic length comparator readings were obtained at the age of 3, 7, 14, 21, 28, 56 and 90 days from the casting date. Specimens used to measure the drying shrinkage were water submerged for 48 hours after demoulding and then all the specimens were stored in controlled environment with a temperature of 20 ^{0}C and relative humidity of 60% [ASTM C596-09].

3 RESULTS PRE-TREATMENT OF SAWDUST

3.1 Compressive and Flexural Strength

The amount of sawdust used to investigate the effect of pre-treatment method is approximately 15% of volume of initial fine aggregate content. For this results, the amount of sawdust is not important as the objective is to identify the suitable pre-treatment method of sawdust. Test results are taken at 28 days of age of mortar specimens. *Fig. 3* and *Fig. 4* show the compressive and flexural strength variations of specimens, respectively, for group 1 to 8. Results show that the sawdust without boiling and sawdust boiled with NaOH but without washing does not enhance the strength. Sawdust which boiled with water only, group 6, has some strength enhancement in comparison to the group 2-5. This might be due to the negative effect of remaining NaOH left on sawdust particles on the cement hydration reaction where the hydration be can affected. However, the highest strength among all the groups are from group 7 and 8 where the sawdust in these groups were boiled first with NaOH and then boiled with water only with the aim of washing or removing the NaOH. This can prove the negative effect of remaining NaOH on the strength in group 2-5. In addition to that, this can prove that, boiling with water only is not efficient in enhancing the strength. These results can confirm that the original chemicals in sawdust which is also a bio based material can effect negatively on the strength if mixed with typical cementitious materials. At the same time, the biological effect can be reduced by boiling with NaOH for a certain period of time and the properly washing the remaining NaOH on the sawdust particles.

Fig. 5 shows the water absorption results of mortar sample for group 1-8. Water absorption results show that the variation of results is not significant among different groups. This is due to the fact that the water absorption is significantly affected by the amount of sawdust than the treatment method. However, the results show that water absorption value is comparatively low in group 7 and 8. This has close relationship with compressive strength as strength generally increases with a dense structure.

Therefore, for the next series of specimen, sawdust was boiled with NaOH for 2 hours and washed using boiled

Tab. 2: Mortar mix design.

Group Number	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Sawdust (kg/m^3)	Sawdust replacement (%, volume)
1	256	512	1432	0	0
2	256	512	1288	18	10
3	256	512	1146	36	20
4	256	512	1002	54	30
5	256	512	860	72	40
6	256	512	716	90	50

water. The amount of NaOH was selected as 2% with respect water content as it is cost effective in comparison to 4% and there is no significant difference in results according to the previous discussion.

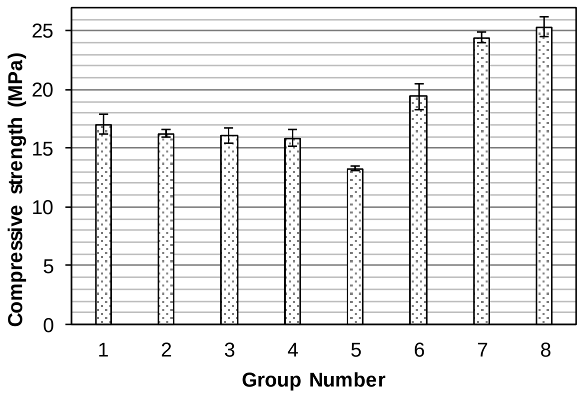

Fig. 3: Compressive strength of pre-treatment groups.

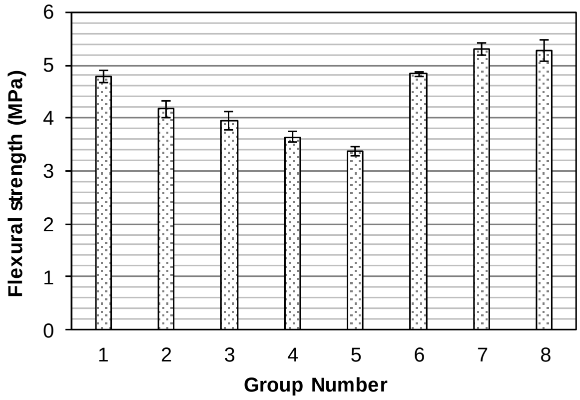

Fig. 4: Flexural strength of pre-treatment groups.

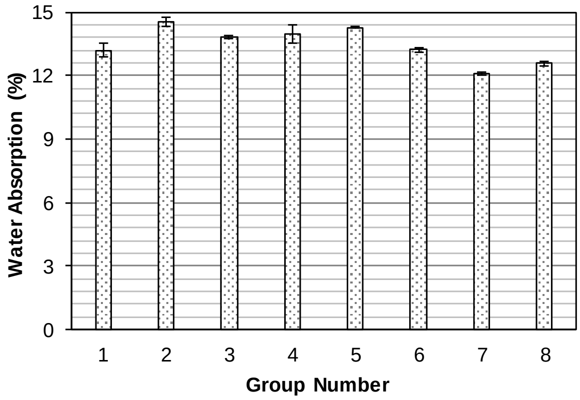

Fig. 5: Water absorption of pre-treatment groups.

4 RESULTS AND DISCUSSIONS

4.1 Workability and Physical Behaviour

The workability of mortar with sawdust is very low. *Tab. 3* shows the typical slump test conducted for mortar groups with varying sawdust contents. The slump is 70 mm for normal mortar while the slump is significantly reduced with the replacement of sand with sawdust. This could be attributed to the very high water absorption capacity of dry sawdust and the rough surface condition of sawdust. By visual observation, it was clearly witnessed that the water content of mortar appeared low. The cohesion of mixes was extremely low. However, at the compaction it was observed that the compaction only by vibrating table is poor, therefore, compaction only by hand was used in this study. The compaction degree could be affected by the density of sawdust which is low and the sawdust incorporated mortar is less cohesive. It was also observed that the mortar with sawdust behaves like a sponge where the mortar is trying to swell after the removal of the pressure applied for compaction. This implies that the strength of sawdust incorporated mortar could be significantly affected by the method of compaction and the energy input.

Tab. 3: Workability of mortar mixes.

Group (Sawdust %)	1 (0)	2 (10)	3 (20)	4 (30)	5 (40)	6 (50)
Slump (mm)	70	30	10	0	0	0

4.2 Density

Density is an important value of sawdust added mortar as one of the objectives of this types of mortar is to reduce its density. After preliminary density tests, the appropriate sawdust content per unit volume was decided. Hypothetically if all fine aggregates are replaced with sawdust, 180 kg of sawdust should be added to produce in 1 m^3 of mortar. This observation is accurate as the estimated density is approximately equal to the wet density of mortar as shown in *Fig. 6*. The estimated density of normal mortar with 0% sawdust replacement is 2208 kg/m^3. According to the estimated density, approximately 5% of density reduction can be observed by replacing 10% of fine aggregate with sawdust. This results show that the density can be significantly reduced by introducing a small amount of sawdust as its density is very low compared to fine aggregate. Saturated surface dry (SSD) density of mortar measured at 7 days is slightly higher than the density measured at casting. This is due to the filling of small amount of voids at the casting with water. However, it is worth to report that the dry density at 7 days is significantly smaller than the SSD density. This is attributed to the large amount of voids available in mortar due to the addition of sawdust. Dry density of normal mortar with 0% sawdust content is 2070 kg/m^3 while the density is 1350 kg/m^3 at a sawdust content of 50%. If the mortar can be used in dry environment, this density reduction could be very effective.

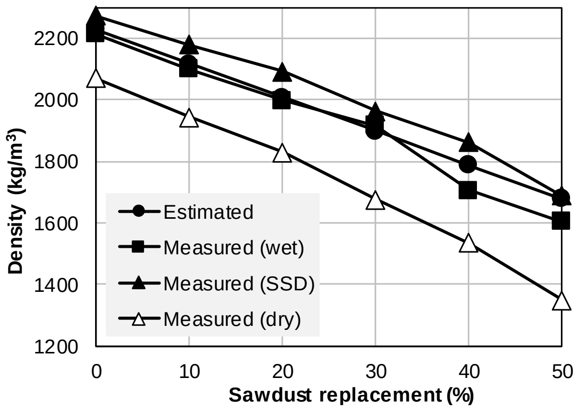

Fig. 6: Density of mortar with sawdust replacements.

4.3 Water Absorption

The measured water absorption results are shown in *Fig. 7*. Water absorption percentage of normal mortar is

9.4% at 28 days while it is 28.1% for mortar with 50% sawdust replacement. The water absorption of sawdust added mortar is significantly high as a result of the high absorption capacity of sawdust. The water absorption capacity at 28 days is slightly less than that of 7 days as a result of continuing hydration process of cement. However, the variation becomes opposite at sawdust replacement level of 50% where the water absorption at 28 days is higher than that of 7 days.

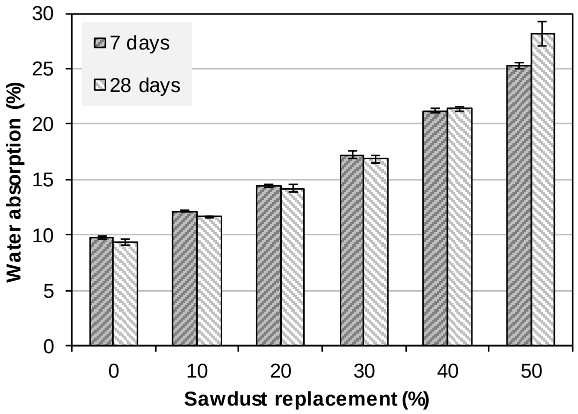

Fig. 7: Water absorption of mortar specimens.

4.4 Compressive and Flexural Strength

The compressive and flexural strength values of mortar specimens with varying sawdust replacement are shown in *Fig. 8*. The compressive strength of normal mortar specimens with no sawdust is approximately 28 MPa and 36 MPa at 7 days and 28 days, respectively, where mortar provides a very good strength at 28 days. However, the replacement of fine aggregate with sawdust significantly reduces the compressive strength where the compressive strength at 28 days is approximately 8 MPa for mortar with 50% sawdust replacement. This is an obvious result as sawdust does not provide enough strength as fine aggregate in mortar phase and sawdust particles may acts like voids for compression. The flexural strength of normal mortar is 7 MPa and is gradually decreasing with addition of sawdust. The behaviour follows compressive strength data and adding sawdust does not effective for mechanical properties of mortar. However, even at 40-50% sawdust addition, the compressive strength reaches approximately 10 MPa which is reasonably good for low grade applications.

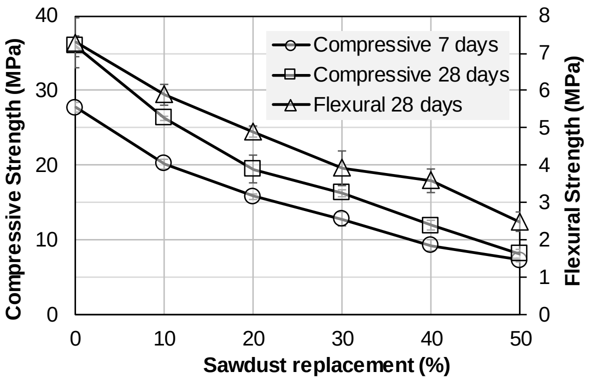

Fig. 8: Compressive & flexural strength results.

4.5 Failure by Compression

Compressive strength results show that the addition of sawdust significantly affects the strength. The failure mode of typical mortar made with fine aggregate only is brittle. The views of failure mode of the compression cubes of this study are shown in *Fig. 9(a)*, *Fig. 9(b)*, and *Fig. 9(c)* which represents mortar specimens with sawdust content of 0%, 20%, and 50%, respectively. *Fig. 9(a)* confirms the brittle failure of normal mortar. However, when the sawdust content increases, the failure mode tends to become ductile as in *Fig. 9(b)* and *Fig. 9(c)*. The reason for this behaviour is mainly due to the spongy and fibrous nature of sawdust. Fibres in cementitious materials could enhance its ductile behaviour which is a well-known fact.

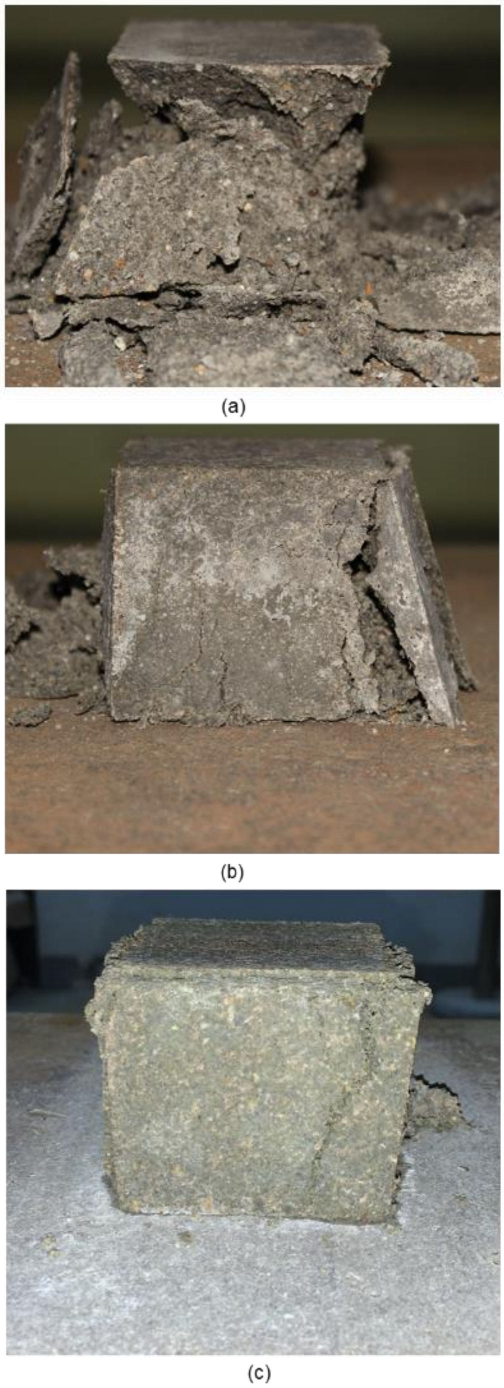

Fig. 9: Compression failure at different sawdust contents (a) 0%, (b) 20%, (c) 50%.

4.6 Drying shrinkage

The drying shrinkage measurements were calculated relative to the specimen length at the age of 3 days and shrinkage variation is shown in *Fig. 10*. The drying shrinkage is occurring as a result of the moisture evaporation from the mortar specimens and usually the drying shrinkage up to 28 days is considered, whereas *Fig. 10* reports drying shrinkage up to 90 days. The drying shrinkage of all specimens is increasing with time which is the usual behaviour in normal cementitious materials. Sawdust added mortar specimens' shows significant increment of the shrinkage with relevant content of sawdust. Shrinkage at 7, 28, and 90 days of normal mortar is 100, 408, and 891 microns, respectively. In comparison to the normal mortar the shrinkage of mortar with 50 % sawdust replacement level is increased by 637%, 447%, and 360% at 7, 28, and 90 days, respectively. This results show that drying shrinkage is significantly affected by the addition of sawdust. Also, with sawdust addition, the rate of drying shrinkage at early ages is higher than that of later ages. This is mainly due to the nature of sawdust where significant amount of water from sawdust is evaporated at early ages. The drying shrinkage of sawdust added mortar was still increasing even after 90 days.

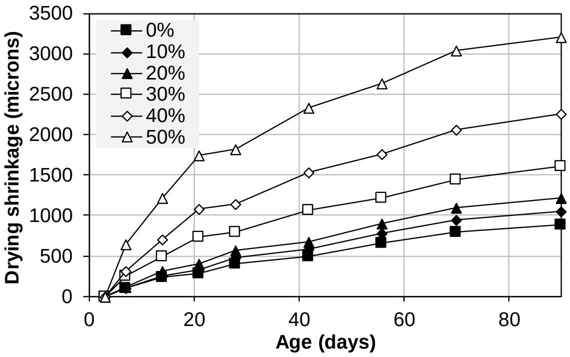

Fig. 10: Drying shrinkage of sawdust added mortar.

5 SUMMARY

The results of this study reports experimental data of mortar specimens cast with sawdust as a replacement material for fine aggregates. In addition to that, results of a brief investigation of pre-treatment of sawdust are presented. Although the experimental cases are very limited, some interesting and valuable conclusions can be drawn as listed below.

1. Sawdust must be pre-treated if used with cementitious materials to achieve comparatively better mechanical properties. Boiling with NaOH for 2 hours and washing with boiling water for 30 minutes has shown better performance in mechanical properties.
2. Approximately, 5% of density reduction can be achieved by replacing 10% fine aggregates with sawdust.
3. The water absorption of sawdust added mortar is significantly high as a result of the high absorption capacity of sawdust. Total water absorption of normal mortar and mortar with 50% sawdust is approximately 10% and 25%, respectively.
4. Compressive strength of above 10 MPa at 28 days can still be achieved up to 40% sawdust replacement. However, compressive and flexural strength values are significantly affected by the addition of sawdust in to the mortar mix.
5. Drying shrinkage of 1000 microns at 28 days' age can be easily passed by mortar mixes with high sawdust content of above 30%. In general sawdust has negatively affected on the drying shrinkage. In comparison to the normal mortar the shrinkage of mortar with 50% sawdust replacement level is 637%, 447%, and 360% at 7, 28, and 90 days, respectively.

Further studies are needed to enhance the knowledge on the interaction between sawdust and cement and how it affects the hydration reaction. In addition to that the durability of sawdust added cementitious materials should be extensively investigated with the aim of practical use of these materials even at low cost constructions.

6 ACKNOWLEDGEMENT

Authors would like to thank Jingyan Wang, who was an undergraduate student, for her contributions in carrying out some experiments in this study. Also, the financial support for this study was received from the Research Development Fund (RDF-12-03-17) provided by Xi'an Jiaotong-Liverpool University.

7 REFERENCES

[1] Wardhono, A. et al; Comparison of long term performance between alkali activated slag and fly ash geopolymer concretes, Construction and Building Materials, 2017, 143, 272-279.

[2] Kisku, N. et al.; A critical review and assessment for usage of recycled aggregate as sustainable construction material, Construction and Building Materials, 2017, 131, 721-740.

[3] Dai, D.; Fan, M.; Preparation of bio-composite from wood sawdust and gypsum. Industrial Crops and Products, 2015, 74, 417-424.

[4] Giosuèa, C. et al.; Effect of Biomass Waste Materials as Unconventional Aggregates in Multifunctional Mortars for Indoor Application, Procedia Engineering, 2016, 161, 655-659.

[5] Ahmed, W. et al.; Effective use of sawdust for the production of eco-friendly and thermal-energy efficient normal weight and lightweight concretes, Journal of Cleaner Production, 2018, 184, 1016-1027.

[6] Duan, P. et al.; Fresh properties, mechanical strength and microstructure of fly ash geopolymer paste reinforced with sawdust. Construction and Building Materials, 2016, 111, 600-610.

[7] Aigbomian, E, P.; Fan, M.; Development of wood-crete from treated sawdust. Construction and Building Materials, 2014, 52, 353-360.

[8] Aigbomian, E, P.; Fan, M.; Development of Wood-Crete building materials from sawdust and waste paper. Construction and Building Materials, 2013, 40, 361-366.

[9] Akinyemi, A. B. et al.; Some properties of composite corn cob and sawdust particle boards. Construction and Building Materials, 2016, 127, 436-441.

[10] Duan, P. et al.; Fresh properties, mechanical strength and microstructure of fly ash geopolymer paste reinforced with sawdust. Construction and Building Materials, 2016, 111, 600-610.

[11] Torkaman, J. et al.; Using wood fibre waste, rice husk ash, and limestone powder waste as cement replacement materials for lightweight concrete blocks. Construction and Building Materials, 2014, 50, 432-436.