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Engineering Properties of Lightweight Mortars Containing Wood Waste Particles

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Keywords

Lightweight Mortar

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Abstract

Utilization of wood waste particles (WWP) is important for environmental and economic concern. This study focuses on the behavior of mortars having WWP with various amounts. Incorporation of WWP brings about the advantages such as decrease in the mass and cost of the mortar. In the present study, the proportions of the wood waste particles replacing the crushed sand in the mortars by volume were 0, 10, 20, 30 and 40 %. Physical, mechanical and capillary absorption properties have been investigated. In addition, microstructure of the mortars has been examined with optical microscope. As compared to control specimen, dry bulk density decreased from 2.2 to 1.5 kg/m^3, apparent porosity increased about 2 folds, and water absorption increased about 4 folds, for sample in which 40 % of crushed sand was replaced with WWP. Mechanical values reduced with increasing WWP amount. On the other hand, during compressive and flexural strength tests, samples containing WWP presented a gradual decrease in strength, thus they exhibited a more ductile behavior.

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1. INTRODUCTION

Some wastes emerging from industrial applications remain unutilized and cause storage problems, or they are used inefficiently in some fields such as filling material, etc. There are attempts that seek alternative ways to exploit these materials effectively (Akhavan Kazemi et al., 2015; Gupta et al., 2015; Nazmul Huda et al., 2016; Mostonejad et al., 2017; Dhinakaran & Sreekanth, 2018; Gulmez & Kockal, 2021). However, most of them require energy and cost due to many additional operations such as burning at high temperatures or penetrating into alkali solutions to improve binding abilities. Some of these industrial wastes are used in the construction sector, which brings about solutions for environmental and economic problems. Wood waste is one of the industrial wastes which can be used as a component of construction materials especially for energy efficiency. The huge quantity of wastes formed as a result of the wood treating processes in numerous countries causes difficulties for their handling. This may actually be an opportunity for the utilization of these wood wastes as a construction material (Udoeyo et al., 2006).

Manufacturers of wood products and furniture produce chips and sawdust. They are generated as a result of furniture machining operations in which the wood is cut, drilled or milled for obtaining the final article. The wood dust particles are accumulated by filtering. The wood waste is mainly utilized in the form of ash that is formed by combusting the waste sawdust or wood shavings.

There are many investigations conducting experimental studies on concrete containing wood waste ash (Udoeyo et al., 2006; Sashidhar & Rao, 2010). In the study of Udoeyo et al. (2006) wood waste ash (WWA),

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which was obtained from sawdust and wood shaving, was added into concrete at ratios of 0, 5, 10, 15, 20, 25, and 30% by weight of cement. The mechanical and physical properties of the matrix were examined. Sashidhar and Rao (2010) performed durability studies on concrete with wood ash additive. It was found that 28 day cube compressive strength decreases with increasing WWA content from 0 to 30%.

However, production of ash requires high energy for combustion, and therefore it is highly expensive process. Thus, attempts have been made to recycle wood waste as aggregate in concrete in recent years (Taoukil et al., 2013; Gloria & Filho, 2016; Thandavamoorthy, 2016; Akkaoui et al., 2017;). In the study of Thandavamoorthy (2016), concretes, having wood aggregate 0, 15, 20 and 25 % instead of crushed stone, were prepared. The mix proportion was 1:1.26:2.76 and water/binder was 0.45. Addition of wood aggregate generally resulted in a reduction in compressive strength, however, there was a slight increase in compressive and indirect tensile strength values when 15% wood particle was used. The increase in wood aggregate was seen to increase acid and alkali attack and water absorption rates. In a comprehensive review by Momoh and Osofero (2020), utilization of oil palm trunk fibers was stated to increase the strength of cement composites. This was attributed to the high intrinsic strength of the fibers.

Some of the studies in the literature on utilization of wood waste aggregate focus on the thermal properties of the obtained concretes. In the study of Gloria and Filho (2016), wood shaving/cement ratio was changed in 1:0.5 and 1:3.0 ratio. Thermal conductivity was seen to decrease down to 0.06 from 0.535 W/mK, with the increase in the wood shaving/cement to 1:0.5 from 1:3.0. On the other hand, compressive strength values for the respective samples were 0.44 and 15.97 MPa. In the study of Taoukil et al. (2013), wood shavings and sawdust were utilized in order to lighten the concrete and to alter thermal properties. It was seen that with 10 % addition of sawdust or shavings, thermal conductivity value was about half of that observed in control sample. On the other hand, porosity increased and bulk density decreased.

In the present study, mortar samples were produced by adding wood waste particles (WWP) in order to reduce the amount of crushed sand in mortar. This composite material can be used in panels that function as partitions and in applications where lightness should be at the forefront. The advantages are believed to be three-fold. First, a waste product is utilized and its negative effects on storage and cost of its elimination are decreased. Secondly, the substitution of WWP with crushed sand reduces the weight of the mortar, which brings about a structural advantage. Thirdly, by this means, the cost of the mortar decreases. This is expected to decrease the density of the mortar, resulting in improvement of thermal insulation properties. The properties of WWP containing mortar samples were compared with those of the control samples which had only crushed sand as aggregate.

2. MATERIAL AND METHOD

Binding material used in mortar was CEM I 42.5R. Specific gravity and Blaine specific surface of cement are 3.13 and 3610 cm^2/g, respectively. Table 1 represents the constituents of the cement. Fine aggregate was calcareous sand provided from Burdur region, Turkey. Wood waste particles were shavings collected from a local manufacturer of wood products and furniture. Gradation curves of calcareous sand and wood waste particles are shown in (Figure 1) SSD state specific gravity and fineness modulus of waste particle were 1.1 and 3.43, respectively. The fine aggregate was crushed sand with a specific gravity, absorption, and fineness modulus of 2.71, 1.7% and 2.80, respectively. Some properties of wood waste and crushed sand are given in Table 2.

The proportions of the waste particles replacing with the crushed sand by volume were 0%, 10%, 20%, 30%, 40% and the notations for those specimens were CS, WWP10, WWP20, WWP30, WWP40, respectively. All aggregates were introduced into the mix in saturated surface dry (SSD) state. The water/cement and total cement values were maintained the same, as 0.60 and 300 kg/m^3, respectively.

Table 1. *Chemical composition of the cement*

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Loss on Ignition
Percentages	63.80	21.10	4.07	3.61	1.08	2.40	2.74

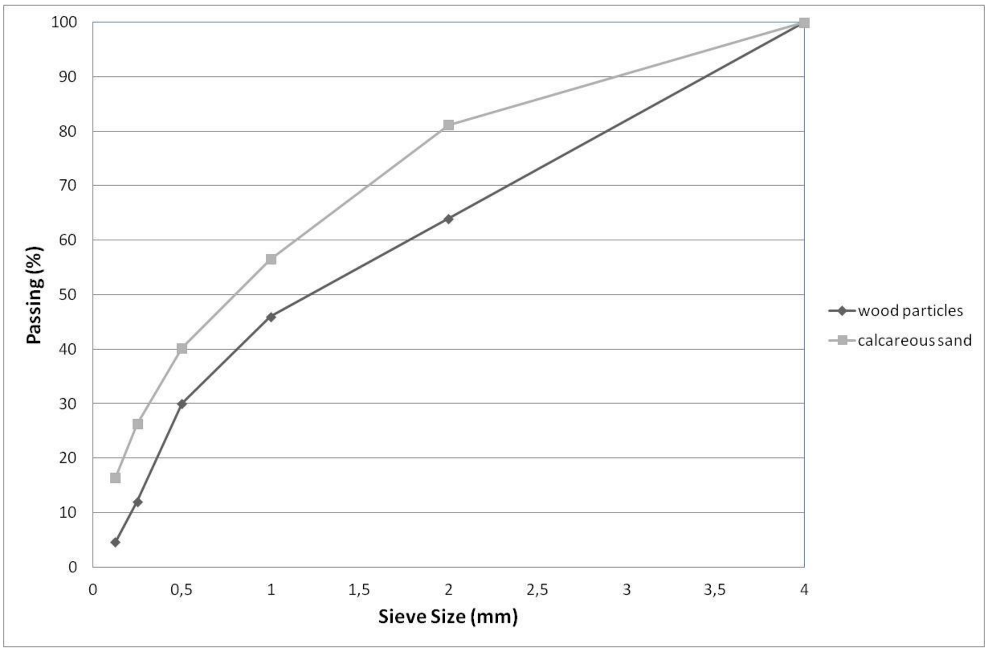


Figure 1*. Gradation of calcareous sand and wood particle aggregates*

Table 2. *Some properties of aggregates used in the study*

Aggregates	Specific Gravity (g/cm^3)	Rodded Bulk Density (g/dm^3)	Loose Bulk Density (g/dm^3)	Rodded Void Ratio (%)	Loose Void Ratio (%)
CS	2,71	1746	1611	35,4	40,4
WWP	1,1	113	93	89,7	91,6

Prismatic specimens 40x40x160 mm in size were cast according to ASTM C192. Mixtures were cast in layers. The specimens were demoulded after 1 day and all mortars were kept in a tank to be cured for 7 and 28 days before testing.

Consistency, bulk density, water absorption, porosity, compressive strength, flexural strength, capillary absorption coefficient were determined. Compressive and flexural strength values of the control sample and samples containing WWP were determined by a Shimadzu Autograph 50kN universal tester, with a rate of 0.5 mm/s. The porosity values were determined on 40x40x160 mm^3 prismatic specimens according to the procedure described in ASTM C 642 by the equation given below:

$$P = [(W2 - W1)/(W2 - W3)] \times 100 \tag{1}$$

P is the porosity (%); W1 is the mass of oven-dried sample in air (g), W2 is the mass of surface-dry sample in air (g) and W3 is the mass of surface-dry sample in water (g).

3. RESULTS AND DISCUSSION

Produced samples were characterized in terms of density and porosity, water absorption and capillarity, microstructure; split tensile, compressive and flexural strength.

3.1. Density and Porosity

Fresh unit weight values of the obtained specimens are presented in (Figure 2) Fresh unit weight values of the samples were found to decrease with the increase in the WWP content. It can be seen that fresh unit weight of control specimen was 2250 kg/m^3, on the other hand fresh unit weight of the WWP40 specimen was 1750 kg/m^3.

Dry bulk density values presented a similar trend with that of fresh unit weight data, as shown in (Figure 3) It was decreasing with increasing WWP content of the samples. Dry bulk density of control sample was 2.1 kg/m^3 whereas that of the WWP40 sample was 1.5 kg/m^3. Dry bulk density values of the samples were similar after 7 days and 28 days. SSD bulk density values of the samples presented a similar trend with that of dry bulk density data, as shown in (Figure 4) They were about 15 % higher than dry bulk density values. Gloria and Filho (2016) used wood shavings in cement and they also observed a decrease in the density, as a result of the increase in the amount of wood shavings in cement. Sadiku (2015) also revealed that wood particles decreased the density of wood-cement composites.

Apparent porosity values of the samples exhibited an opposite trend to that was observed for fresh unit weight and dry bulk density. Apparent porosity was found to increase with the increase in WWP content, as shown in (Figure 5) Apparent porosity was 15 % in the control sample and it was slightly over 35 % in the WWP40 sample. In all the samples, apparent porosity values after 7 days were slightly higher than that after 28 days.

3.2. Water Absorption and Capillarity

Water absorption and coefficient of capillarity values are presented in Figure 6 and Figure 7, respectively. Water absorption and coefficient of capillarity values of the samples exhibited a similar trend to that was observed apparent porosity values. Differences in porosity of mortars can be due to the ingredients selected for recipe also affecting quality of interfacial transition zone (Kockal 2013; 2015; 2016). Water absorption and capillarity coefficient was found to increase with the increase in WWP content. They were 7 % and 0.0007 cm/s$^{1/2}$, respectively, for the control sample and they were about 25 % and 0.0045 cm/s$^{1/2}$, respectively, for the WWP40 sample. In all the samples, water absorption and coefficient of capillarity values after 7 days were higher than those after 28 days. This can be attributed to the fact that water penetrable voids and capillary pores decreased due to the enhancement of microstructural properties of cement paste matrix resulting from continuing hydration. However, in contrast to water absorption of WWP40 sample, which is observed to decrease by time (Figure 6), capillarity of these samples did not change within time (Figure 7).

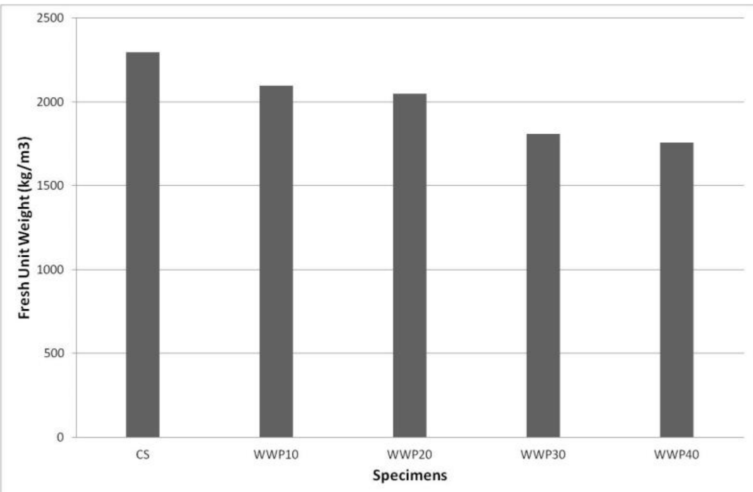


Figure 2. *Fresh unit weight values of the specimens*

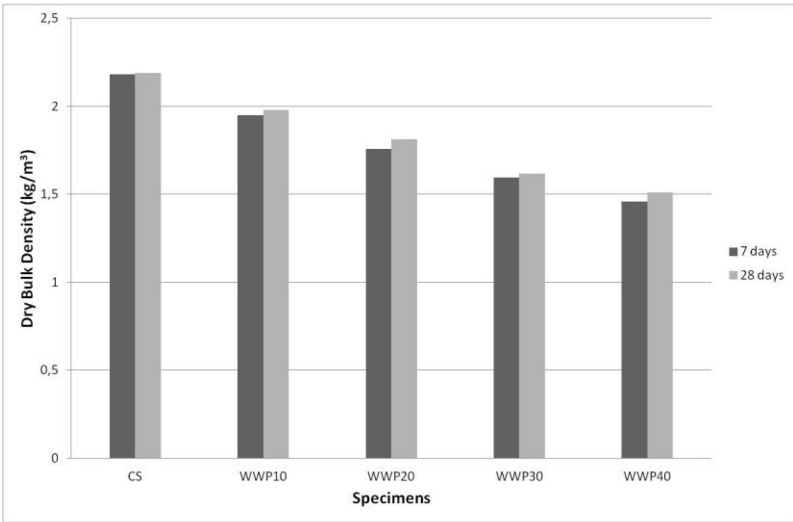


Figure 3. *Dry bulk density values of the specimens*

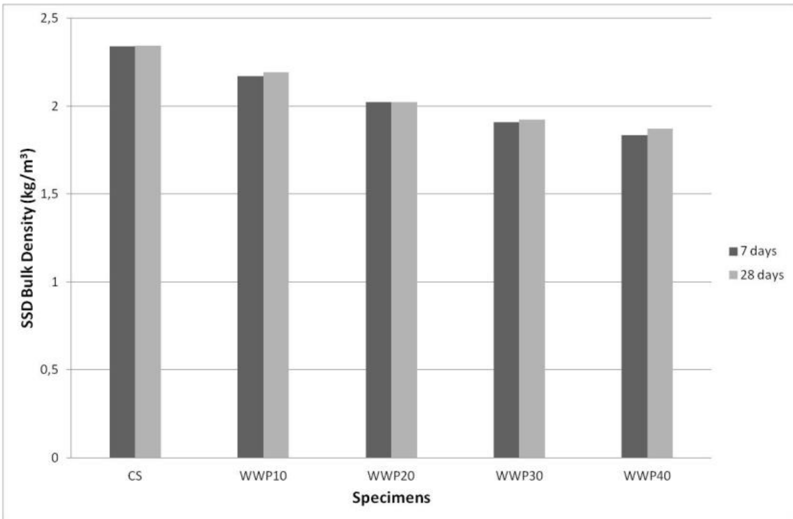


Figure 4*. SSD bulk density of the specimens*

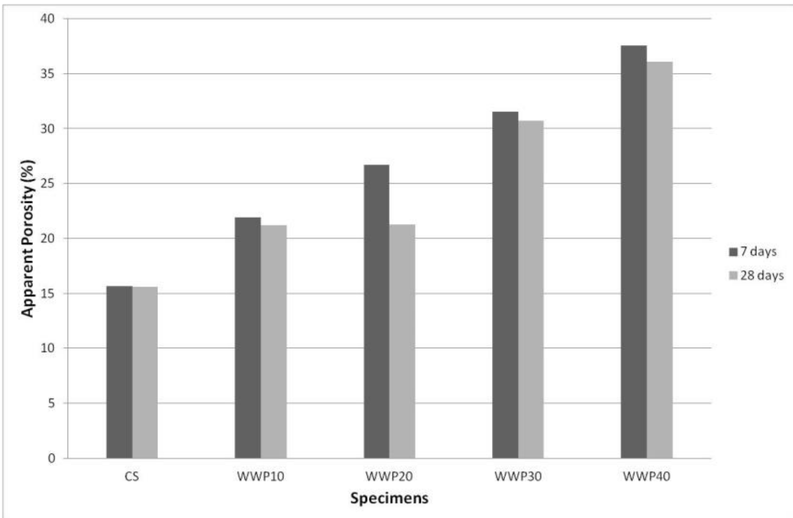


Figure 5. *Apparent porosity values of the specimens*

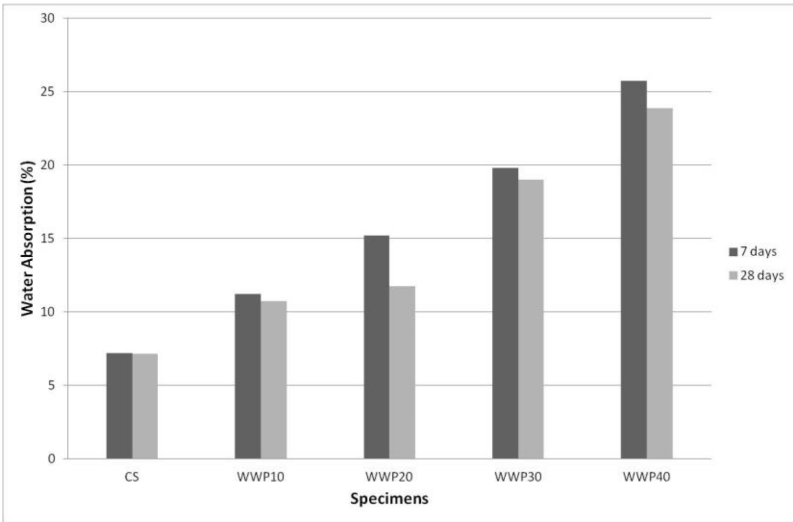


Figure 6. *Water absorption values of the specimens*

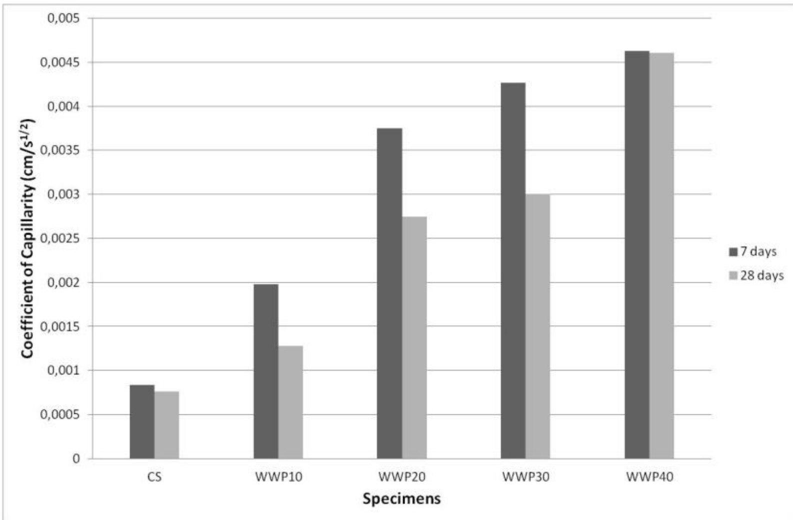
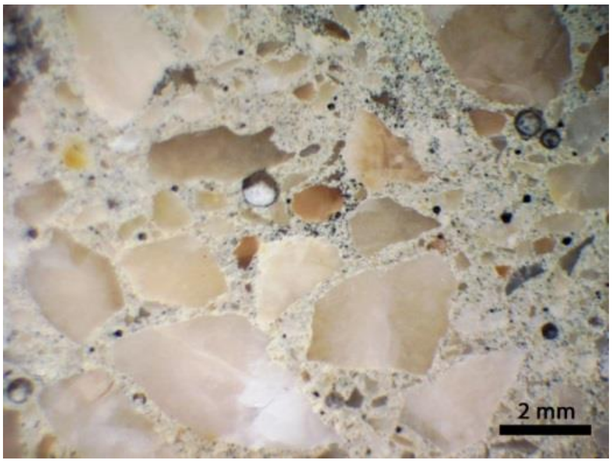


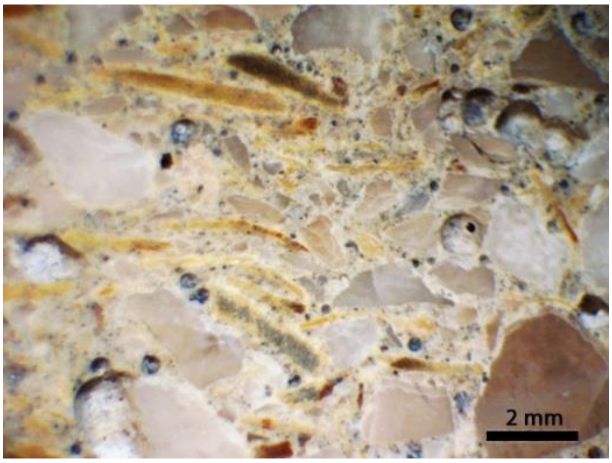
Figure 7. *Coefficient of capillarity values of the specimens*

3.3. Microstructure

Microstructural illustrations of the specimens are presented in (Figure 8) It can be observed that the aggregates are homogenously distributed in the microstructure of control sample and there is small amount of porosity (Figure 8a). Samples containing 20 % and 40 % WWP are presented in (Figure 8b, 8c), respectively. The yellowish-brown fractions in these images are WWP. The amount of these particles can be seen to increase with the increase in the WWP amount in the mortar. The size of the WWPs is similar to the size of the calcareous sand aggregates. They are 1-3 mm in length and about 0.5 mm in thickness. They are seen to have acicular morphology and mostly needle-like shape. Sizes pronounced here satisfy the data given in (Figure 1) which illustrates the particle size distribution of aggregates. It can be inferred from the cross-sectional images of entire body (representative typical images are given in (Figure 8) that porosity in cement paste matrix among the aggregate particles increases with the increase in the WWP amount. This finding is in accordance with the results of the porosity and capillarity test, which were given in the previous sections; and they are also in accordance with the results of the mechanical tests, which will be presented in the following sections. The reason of increasing porosity with increase in WWP amount may be the seepage of water from WWP in saturated surface dry condition into the cement paste, leading to the rise in water-cement ratio.



(a)



(b)

(c)

Figure 8. *Optical micrographs of the* ***a)*** *control sample, and samples containing* ***b)*** *20 % and* ***c)*** *40 % WWP*

3.4. Compressive Strength

The compressive strength values of the control specimen and specimens containing WWP are presented in Figure 9. The control specimen had 27 MPa after 7 days and 38-40 MPa after 28 days. The compressive strength values of WWP mortars were smaller than that of the CS mortar and they showed a reduction in compressive strength with the rise in the WWP amount. WWP 40 sample had a compressive strength of 5 MPa after 7 days and 6 MPa after 28 days. The stress-strain graphs of the control sample, WWP20 and WWP40, which were obtained after 28 days, are given in Figure 10. It can be seen that there was a sharp decrease of stress in the control sample after fracture. On the other hand, samples containing WWP present a gradual decrease in stress and therefore they exhibit a tougher behavior. In the studies of some other researchers (Bdeir, 2012; Mohammed et al., 2014; Thandavamoorthy, 2016), compressive strength values were also seen to decrease with the increase in the wood aggregate addition. They observed a slight increase in the compressive strength when 15 % wood waste was used. Gloria and Filho (2016) used wood shavings in cement and they reported a reduction in the compressive strength with the rise in the amount of wood shavings. If the wood in the mortar is exposed to moisture and water for a long time, it may rot. On the contrary, there is no decay in the short term. If the mortar samples are maintained in dry condition and/or insulated, wood rot is not observed. Considering that the wood in the mortar does not contribute positively to the strength, additional strength reductions are not expected after rotting.

3.5. Flexural Strength

Flexural strength values of the control sample and samples containing WWP, which were determined after 7 days and 28 days, are presented in Figure 11. The flexural strength values of the control sample were 5.5 and

7 MPa after 7 and 28 days, respectively. The flexural strength values were seen to decrease with the increase in the WWP contents in the concretes. The flexural strength of WWP40 sample was 2 MPa. The reduction in the flexural strength with the rise in the WWP amount is an expected result. Since the WWP act as voids in the structure of the concrete, in which crack initiation is possible.

The flexural stress vs. strain graphs of the control sample and of the WWP20 and WWP40 samples are presented in Figure 12. It can be seen that after fracture, stress decreased abruptly in the control sample. However, stress decreased gradually after fracture of the WWP20 and WWP40 samples. This can be taken as an indication the toughness and ductility of the WWP samples was higher than the control sample. In the study of Thandavmoorthy (2016), flexural strength values were also seen to decrease with the increase in the wood aggregate addition. In their study, shredded wood waste was utilized. They observed a similar compressive strength when 15 % wood waste was used, as compared to control sample. Corinaldesi et al. (2016) reported that the replacement of sawdust with wood shavings at a similar ratio resulted in a decrease in mechanical strengths of about 30%. The reason could also be the geometry of wood particles which were flat and thin.

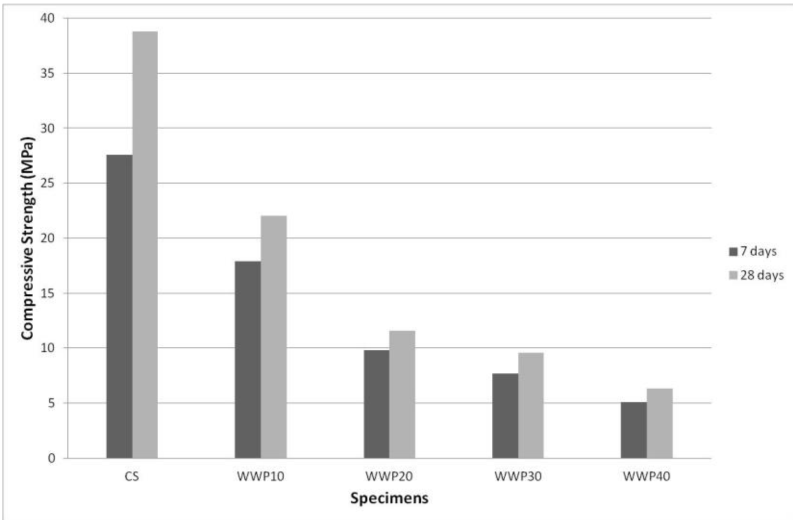


Figure 9. *Compressive strength values of the specimens*

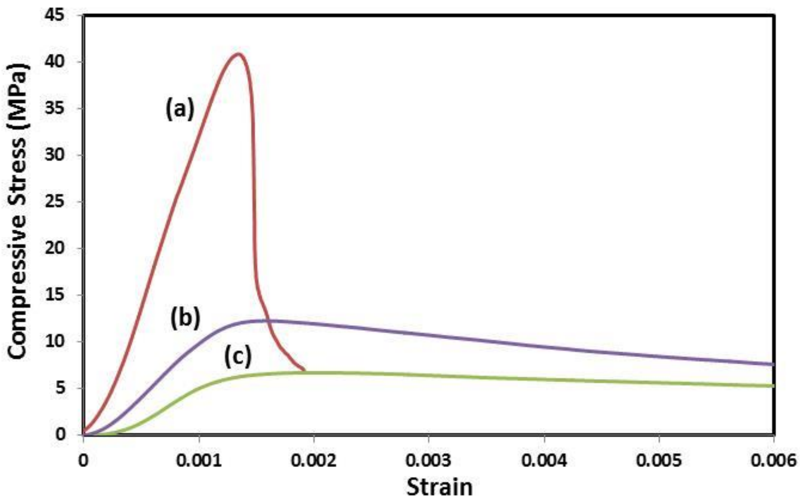


Figure 10. *Compressive stress-strain plots of* ***a)*** *control sample,* ***b)*** *WWP20,* ***c)*** *WWP40*

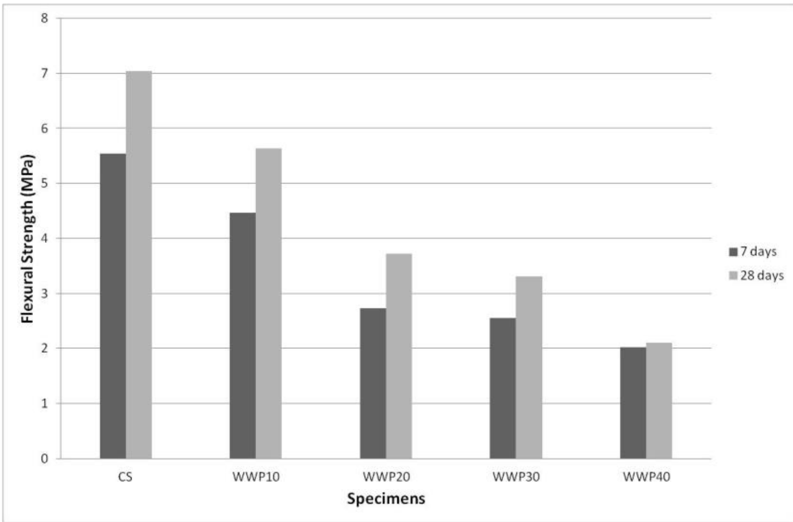


Figure 11. *Flexural strength values of the specimens*

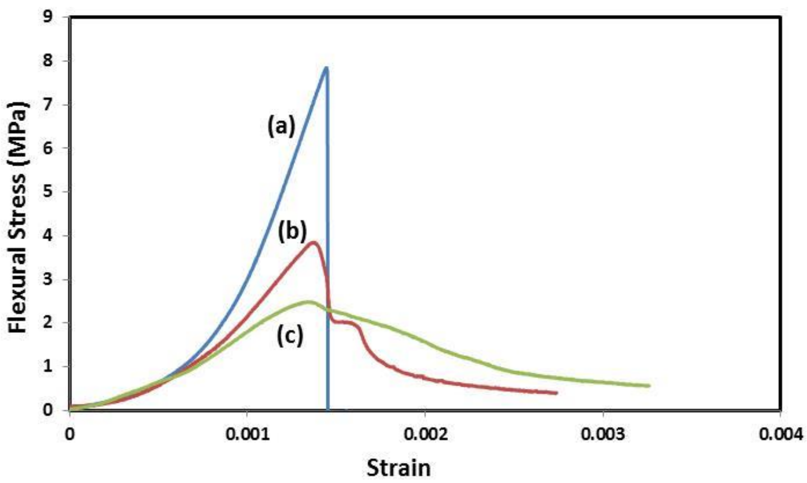


Figure 12. *Flexural stress-strain plots of* ***a)*** *control sample, and samples containing* ***b)*** *20 % WWP,* ***c)*** *40 % WWP*

4. CONCLUSION

Mortars having lower weight and lower cost were successfully produced by utilizing a wood waste in place of crushed sand. Dry bulk density decreased about 30%, whereas apparent porosity and water absorption increased significantly as a result of 40% replacement of crushed sand with WWP the mortar. Compressive and flexural strength values decreased with increasing WWP amount. However, during compressive tests, samples containing WWP presented a gradual decrease in strength, indicating their higher ductility.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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