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STRENGTH PROPERTIES OF 10 MILLIMETERS TIMBER CLINKER AGGREGATE CONCRETE

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Abstract: This paper presents some experimental results and discusses the used of timber clinker as partial aggregate replacement in producing concrete. A number of tests were conducted to identify the physical properties of timber clinker aggregate such as density, aggregate impact value (AIV) test and aggregate crushing value (ACV) test, slump, X-Ray Fluorescence (XRF) test and compressive strength of timber clinker aggregate concrete. Two series of concrete mixes with Supracoat SP1000(C0, C10, C20, C30) and without Supracoat SP1000(CA0, CA10, CA20, CA30) with various percentage of 0%, 10%, 20% and 30% 10 mm sieve size timber clinker aggregate used as partial replacement in producing concrete. A total of forty 150 x 150 x 150 mm cubes samples were prepared for both series of concrete mixes and tested at 7, 14 and 28 days of water curing. The results obtained showed that timber clinker aggregate concrete gained highest compressive strength for both series of concrete mixes C20 and CA20 which was 37 MPa and 34 MPa respectively. The optimum percentage used of timber clinker aggregate in producing concrete was 20% where if exceeded will decreased the compressive strength and Supracoat SP1000 added tend to improve the concrete slump. The physical properties test indicated the contribution to the concrete strength development. The results obtained and observation made in this study suggest that timber clinker aggregate successfully used as partial replacement in producing concrete and performed better strength development

Keywords: *Timber clinker, compressive strength, strength properties, slump, sustainability.*

1.0 Introduction

Current global issues related to environmental sustainability for concrete in construction more emphasize on material resources in producing concrete. To ensure future sustainability of concrete in construction, alternative ingredient materials for concrete such as aggregates need to be sourced for. The demand of aggregate in producing concrete is significant due to about 75% of concrete volume is aggregate and the consumption of concrete in the world is estimated 10 to 15 billion metric tones per year where annual production of concrete is estimated to be 7 billion cubic meter worldwide[1,2]. The shortage of construction aggregate and scarcity that natural coarse aggregate will diminish for both construction and maintenance purposes in some countries [3,4].

As such, initiatives have been set up address the issue of sustainability of concrete as a construction material. An alternative aggregates for sustainable construction focused on the development of environmental-friendly and economical process for the exploitation of solid wastes in construction [2]. In Malaysia, the concrete which used recycled aggregate is considered new and these efforts had shown that recycled aggregate has become an important alternative material in construction industry currently [4,5]. The ultimate purpose of recycling materials is to minimize the impact of human activities on the environment and the planet [6]. In 2012, Malaysia Biomass Industries Confederation mentioned that the development of biomass industry represents several different industries brought together by the utilization of renewable organic matters including oil palm waste, timber waste, rice husk, coconut trunk, fibers, municipal solid waste, sugar cane biogases etc. The disposal of such waste poses an environmental problem as landfills are limited.

Currently, Malaysia have produced significant amount of agricultural wastes from palm oil, saw logs, paddy, wood and tropical fruits where wood industry is the third contributors for the biomass production [7,8]. The production of wood based biomass resources in Malaysia was estimated 2492 kilotons per year [9]. As a result, a huge amount of timber clinker from boiler bottom ash generated where disposal solution needed to achieve environment sustainability. The previous research indicated that the utilization of solid wastes such as ash, boiler clinker, recycled aggregate from site tested concrete cubes and demolish recycled aggregates in producing concrete were limited which average optimum percentage used was vary between 10% to 30% partial replacement[10, 11, 12, 13, 14, 15, 16]. The solutions proposed by various researchers to produce concrete by using waste materials depends on the sources of the wastes materials generated [17]. It was also affected by concrete mixes design, aggregates size, water-cement ration, optimum percentage used of wastes materials, surface texture and shape, and also cementitious admixture effects. The results findings showed that the strength development of waste materials concrete performed approximately the same strength with normal concrete at the age of 28 days subjected to water curing which was exceed 30 N/mm^2[18, 19, 20, 10, 21].

However, the use of timber clinker as alternative partial aggregates replacement in producing concrete currently more innovative, inexpensive materials and towards environmental sustainability. Since timber clinker is abundant in Malaysia, therefore this study aims to examine and explored the suitability use of timber clinker as partial aggregates replacement in producing concrete which will give an impact on reutilize the waste materials generation in construction materials. It is proposed in this experimental work to study the strength properties, optimum percentage use and concrete mix design of timber clinker aggregate concrete.

2.0 Methodology

The raw materials for this study are Ordinary Portland Cement (OPC) with class strength 42.5, natural fine and coarse aggregate 10 mm sieve size, water, Supracoat SP1000 and 10 mm sieve size timber clinker aggregate. The timber clinker was obtained from the combustion process with a temperature vary between 350 °C at the bottom of boiler during cleaning process at Demak Laut Free Industrial Zone, Kuching, Sarawak. The ash settle at the bottom of the boiler will be taken out and collected namely timber clinker as shown in Figure 1. The timber clinker collected will be crushed into 10 mm sieve size. Supracoat SP 1000 is added to the concrete mix with the dosage of 800 ml per 100 kg cement. It act as high range water reducing admixture and it meets ASTM C494 requirements for type A water reducing admixture and type F water reducing and high range admixtures. The size of natural coarse aggregate is limited to 10 mm maximum which comply with BS EN 12620.

Figure 1: By-product waste - timber clinker aggregate

The determination of chemical composition of timber clinker aggregate will be done by using Standardless Method of X-Ray Fluorescence (XRF) test. Bulk density test of coarse and fine aggregates will be conducted according to BS 812: Part 2:1995 and BS 3797:1990. The standard cylinder with dimension of 150 mm diameter and 300mm height was used for this purpose. The aggregate impact value (AIV) test is carried out to access the suitability of aggregate as regards the toughness for use in construction work. The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slow compressive load. The oven dried and accurately weighed aggregates are subjected to a total of 15 blows of specified weight and fall and percentage of fines formed in terms of the total weight of the sample is expressed as the aggregate impact value.

The aggregate crushing value (ACV) is an indirect measurement to determine the crushing strength of the aggregates. Low aggregate crushing value indicates the aggregate is strong as the crushing fraction is low. Thus, this test also uses to access the suitability of aggregates for various type of construction work due the crushing strength of the aggregate. The results of ACV was obtained by the mean of the crushing value in the two tests is reported as the aggregate crushing value. The limits of ACV test for cement concrete shall not exceed 30% while for wearing surfaces shall not exceed 45% (MS 30:Part 8:1995; BS 812:Part 110:1990).

The workability of fresh timber clinker aggregate concrete will be measured to the nearest 5 mm by using the rule and the results is valid if it yields a true slump, this being a slump in which the concrete remains substantially intact and symmetrical according to BS 1881 : Part 102 : 1983. The timber clinker aggregate concrete dry density will be recorded after 28 days curing before conducting the compressive strength to determine the weight reduction compared with control specimens. The compressive strength was carried out at the age of 7, 14 and 28 days of water curing and subjected to the maximum compression axial loads applied. The results will be recorded and the average value will be taken as the compressive strength of the series of concrete strength.

There were two series of concrete mix which consist of Supracoat SP1000(C) and without Supracoat SP1000 (CA). Each series of concrete mixes consists of four types of mix proportion with partial aggregate replacement of 10 mm sieve size coarse timber clinker aggregate ranging from 0%, 10%, 20% and 30%. Series 1 concrete mix consist of Supracoat SP1000 with the dosage of 800ml per 100 kg cement while series 2 concrete without Supracoat SP1000. A total of forty 150 x 150 x 150 mm cubes specimens were prepared for each series of concrete mixes respectively to determine the concrete compressive strength. The mix proportions for the present study are tabulated in Table 1 and Table 2.

Table 1: Mix Proportions for Series 1 Concrete Mix(With Supracoat SP1000)

Mix ID	*Mix Proportion*							
	Cement (kg/m^3)	*Water (kg/m^3)*	*Natural Fine Aggregate (kg/m^3)*	*Natural 10 mm Coarse Agg (kg/m^3)*	*W/CR atio*	*Supraco at (ml)*	*Timber Clinker Aggregate (kg/m^3)*	*Timber Clinker Agg*
C0	410	205	682	1113	0.50	3280	0	0%
C10	410	205	682	1002	0.50	3280	111	10%
C20	410	205	682	890	0.50	3280	223	20%
C30	410	205	682	702	0.50	3280	334	30%

Table 2: Mix Proportions for Series 2 Concrete Mix (Without Supracoat SP1000)

Mix ID	Mix Proportion							
	Cement (kg/m^3)	*Water (kg/m^3)*	*Natural Fine Aggregate (kg/m^3)*	*Natural 10 mm Coarse Agg (kg/m^3)*	*W/C Ratio*	*Supracoat (ml)*	*Timber Clinker Aggregate (kg/m^3)*	*Timber Clinker Agg*
CA0	410	205	682	1113	0.50	0	0	0%
CA10	410	205	682	1002	0.50	0	111	10%
CA20	410	205	682	890	0.50	0	223	20%
CA30	410	205	682	702	0.50	0	334	30%

3.0 Data Analysis

The bulks densities of raw materials are summarized in Table 3. Based on the bulk density, timber clinker aggregate was 7.4% lighter than natural coarse aggregate for loose bulk density while for compacted bulk density, it was about 7% lighter compared with natural 10 mm sieve size coarse aggregate. The results also indicated that timber clinker aggregate is not fulfilled the requirement as lightweight aggregate according to BS 3797. The density of the lightweight aggregate must not more than 1200 kg/m^3 for fine aggregate and 1000 kg/m^3 for coarse aggregate.

Table 3: Bulk Densities of Raw Materials

Materials	*Loose Bulk Density (kg/m^3)*	*Compacted Bulk Density (kg/m^3)*
Cement	924	-
Natural Fine Sand	1298	1345
Natural Coarse Aggregate(10 mm)	1283	1339
Timber Clinker Aggregate(10 mm)	1188	1245

The chemical composition of timber clinker aggregate was tabulated in Table 4. The XRF result obtained indicated that timber clinker aggregate consist of 65.3% silicon dioxide(SiO2) which will create the pozzolanic reaction with the calcium hydroxide (Ca(OH)2) in Portland cement. The hydration products produced will fill the interstitial pores tend to reduce the permeability of the matrix. This will make the concrete more durable where the pores between the aggregate being filled due to pozzolanic reaction matrix and tend to increase the concrete strength. Timber clinker aggregate also showed the similar chemical properties of fly ash(FA) and palm oil fuel ash(POFA) especially Silica glass (SiO_2) content which contributed to concrete strength development[10].

Table 4: Chemical Compound of Timber Clinker Aggregate

Chemical Name	*Formula*	*Concentration (%)*
Orig	g	8
Added	g	2
Carbon dioxide	CO_2	0.10
Silicon dioxide	SiO_2	65.30
Calcium oxide	CaO	0.63
Chloride	CI	1.41
Aluminium oxide	Al_2O_3	15.50
Sodium oxide	Na_2O	1.44
Iron oxide	Fe_2O_3	5.12
Magnesium oxide	MgO	0.66
Potassium oxide	K_2O	5.68
Sulfur Trioxide	SO_3	1.17
Titanium oxide	TiO_2	1.37
Phosphoros	P	0 < LLD

Note:*Using Standard less method, measured from Na to U (refer to periodic table); ** 1% = 10, 000 ppm

The principle mechanical properties of timber clinker aggregate test results (AIV & ACV test) were tabulated in Table 5.

Table 5: Aggregate impact value and aggregate crushing value of Timber Clinker aggregate

Aggregate Crushing Value (ACV)		Aggregate Impact Value (AIV)		BS 882:1992 Classification (Not exceeding %)
Physical Properties	Timber clinker Aggregate	Physical Properties	Timber clinker Aggregate	
Aggregate Crushing Value (ACV) (%)	29.06	Aggregate Impact Value(AIV) (%)	25.60	< 25 (Heavy duty concrete floor finishes) < 30 (Pavement wearing surfaces) 50 (Others)

These test conducted aims to measure the suitability of aggregate as regards to toughness for use in construction work to resist impact and crushing strength of the aggregate. The experimental result obtained showed that the ACV value for timber clinker aggregate was 29.06% while AIV value was 25.6%. The result also indicated that ACV and AIV percentage were at the range of 25% to 30% and is similar within close limits. Low percentage of aggregate crushing value indicates the aggregate is strong as the crushing fraction is low. The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slow compressive load. The AIV test showed that the aggregate not significant affected by the impact load which is only 25.6% only and can be classified used for concrete for non-wearing surfaces which is less than 30% (British Standard Institution, 1992).

The density of timber clinker aggregate concrete was summarized in Table 6. The result obtained indicated that 7 and 28 days timber clinker aggregate concrete were almost heavier and dense compared with control specimens. The control specimens for concrete mix without Supracoat SP1000 gave the concrete density vary between 2258 kg/m^3 for 7 days and 2320 kg/m^3 for 28 days. While for partial replacement of 10 mm sieve size timber clinker aggregate(10%, 20% and 30%), the concrete density vary between 2350 kg/m^3 to 2376 kg/m^3 for 7 days and 2370 kg/m3 to 2350 kg/m^3 for 28 days. The concrete mix with original 10 mm sieve size coarse aggregate with Supracoat SP1000 gave the concrete density varies between 2175 kg/m^3 for 7 days and 2326 kg/m^3 for 28 days. While for partial replacement of 10 mm sieve size timber clinker aggregate(10%, 20% and 30%), the concrete density vary between 2341 kg/m^3 to 2293 kg/m^3 for 7 days and 2370 kg/m^3 to 2359 kg/m^3 for 28 days. The results also showed that the smaller of the aggregate size, the concrete density is high, good and denser where the void in the concrete itself is less[22]. This will contribute to the concrete strength and durability of the concrete where the water permeability is poor.

Table 6: Density of Timber Clinker Aggregate Concrete

Concrete Mix ID	*7Days Density (kg/m^3)*	*28Days Density (kg/m^3)*
C0/CA0	2175/2258	2326/2320
C10/CA10	2341/2350	2370/2370
C20/CA20	2350/2359	2427/2367
C30/CA30	2293/2376	2359/2350

*C- With Supracoat SP1000 ; CA- Without Supracoat SP1000

The slump tests result for timber clinker aggregate concrete was showed in Table 7.

Table 7: Timber Clinker Aggregate Concrete Slump

Concrete Mix ID	*Slump (mm)*	
	With Supracoat SP1000	*Without Supracoat SP1000*
C0/CA0	20	15
C10/CA10	15	10
C20/CA20	10	5
C30/CA30	10	5

*C- With Supracoat SP1000 ; CA- Without Supracoat SP1000

The results indicated that concrete with Supracoat SP 1000 produced higher slump compared with concrete without Supracoat SP 1000. The results obtained showed the decreased of 5mm with the increment percentage of timber clinker aggregate used in concrete mixes. This scenario maybe due to the pozzolanic reaction for by-products waste will consume more water and Supracoat SP 1000 added will improve the concrete slump where it act as high range water reducing admixture according to ASTM C494 requirements. The lower slump values obtained compared with control specimens also may be due to the timber clinker aggregate was the crushed aggregates with rough in surface texture compared with original uncrushed aggregates with smooth textures [23,24]. Low slump concrete presents the risk to create honeycomb problem.

The compressive strength developments for the timber clinker aggregate concrete with and without Supracoat SP 1000 was showed in Figure 2 and Figure 3 respectively. The results obtained indicated that both series of concrete mixes with 10 mm sieve size timber clinker aggregate of 20% (C20 and CA20) partial replacement gained a highest compressive strength which is 37MPa and 34 MPa respectively at the age of 28 days. The 10% and 30% of timber clinker aggregate use as partial aggregate replacement also produce greater compressive strength compared with control specimens for both series of concrete mixes at the age of 28 days. The compressive strength results for 7 and 14 days for both series of concrete mixes also performed the same increment pattern as concrete mix C20/CA20 at 28 days result.

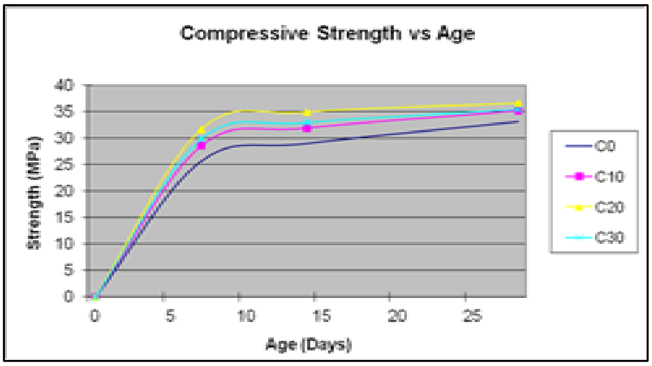

Figure 2 : Compressive Strength of Timber Clinker Aggregate Concrete with Supracoat SP 1000.

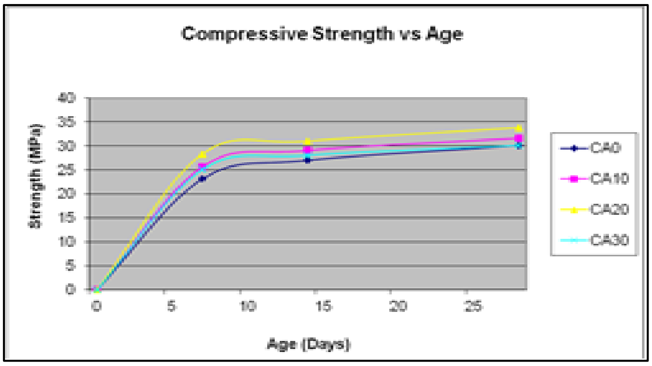

Figure 3 : Compressive Strength of Timber Clinker Aggregate Concrete without Supracoat SP 1000.

This scenario occurred maybe due to the surface texture of the timber clinker aggregate have a rough surface compared with natural aggregate which is smoother and create a higher bonded matrix between the aggregate particles which tend to increase the concrete strength [22]. The higher compressive strength of timber clinker aggregate concrete also may be due to high silica glass (SiO2) content which was 65.3% will be the good contribution to the pozzolanic reaction with the calcium hydroxide(Ca(OH)2) in portland cement[25]. The hydration products produced will fill the interstitial pores tend to reduce the permeability of the matrix. The pozzolanic reaction matrix will help to increase the concrete strength where the pores between the aggregate was being filled. It can be proved by the series of concrete contain 10 % (C10 and CA10), 20%(C20 and CA20) and 30%(C30 and CA30) timber clinker aggregate produced higher compressive strength compared with control specimens(C0 and CA0). Besides, the smaller aggregate size used also contribute to the compressive strength increment compared with coarsest aggregate where the void in the concrete itself less and produce more dense and durable concrete [22].

The comparison between timber clinker aggregate concrete with and without Supracoat SP1000 was showed in Figure 4. The results showed that the compressive strength of timber clinker aggregate concrete with Supracoat SP1000 produced higher compressive strength compared with without Supracoat SP1000.

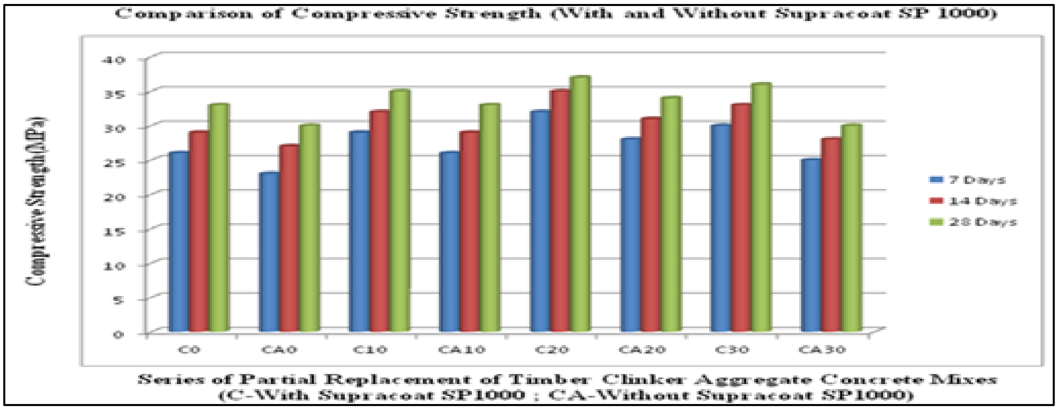

Figure 4: Comparison of timber clinker aggregate concrete compressive strength with Supracoat SP1000 and without Supracoat SP1000

The experimental result showed that the compressive strength increment for 7, 14 and 28 days almost consistent where C20 gained highest compressive strength at the age of 28 days by 37MPa with Supracoat SP1000 while 34MPa for CA20 without Supracoat SP1000. This indicated that timber clinker aggregate concrete with Supracoat SP1000 produced 8.8% higher compressive strength compared with timber clinker aggregate concrete without Supracoat SP1000 where Supracoat SP1000 act as high range water reducing admixture which contribute to the concrete slump and compressive strength. Besides, the optimum percentage used for timber clinker aggregate as partial replacement in producing concrete was 20% (C20 and CA20) where exceed will decreased the compressive strength. This scenario maybe due to the bonded matrix between timber clinker aggregate with natural aggregate and cement paste cannot take effect after achieved their maximum bonded matrix capability. This study also showed that the optimum percentage of partial replacement of recycled materials and pozzolanic materials in producing concrete vary between 0% to 30% only according to previous researchers findings [10, 11, 21]

4.0 Conclusion

The study on the use of timber clinker aggregate as partial aggregate replacement in producing concrete can be drawn and summarized as follows:

1. Timber clinker aggregate concrete produced highest compressive strength due to pozzolanic reaction take place, rough aggregate surface texture and 10 mm smaller size aggregate used tend to produce less void, poor water permeability, heavier, dense and durable concrete.
2. The principle mechanical properties of timber clinker aggregates for ACV and AIV values were at the range of 25% to 30% which comply with BS882. This indicated the suitability for use in construction work to resist impact and crushing strength of the aggregate itself.
3. The higher timber clinker aggregate used tend to decrease the concrete slump due to by-product waste create pozzolanic reaction which consume more water. The rough surface texture of timber clinker aggregate itself also contributed to low slump concrete. The use of Supracoat SP1000 has improved the concrete workability.
4. The10 mm timber clinker aggregate with 20% (C20) partial replacement as optimum percentage use to gain highest compressive strength which was 37MPa at the age of 28 days where exceed will decreased the concrete compressive strength.
5. The use of Supracoat SP1000 tends to increase the compressive strength of timber clinker aggregate concrete compared with concrete without Supracoat SP1000.

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