Effect of Elevated temperatures on Tenera Oil Palm Shell Concrete on Compressive Strength and Weight Loss

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ABSTRACT

Many studies have been conducted on the use of Dura type oil palm shells (OPS) as a replacement for the conventional aggregates in concrete. However, insufficient studies have been done on a new hybrid type called Tenera OPS by utilising it as a coarse aggregate in concrete. Likewise, just one study has been done on the effect of elevated temperatures on oil palm shell concrete (OPSC) made with Dura OPS. The study of elevated temperatures on concrete is vital to further understand its mechanical strength capability when a structure undergoes a fire incident for a certain amount of time for safety considerations. This study focuses on the compressive strength and weight reduction effects of Tenera OPS-concrete (Tenera-OPSC) when exposed to elevated temperatures at 150, 250, and 350 ºC. In addition, colour change, crack patterns and ultrasonic pulse velocity (UPV) analysis was also evaluated when concrete samples were exposed to elevated temperatures in this study. The results indicate high strength reduction of Tenera-OPSC compared to NWC when exposed to elevated temperatures with a decrease of 50% at 350 ºC. A weight reduction of 43% was observed in the Tenera-OPSC type compared to NWC at 350 ºC. Further recommendations have been made for future studies.

Keywords: *Lightweight Aggregate; Lightweight Concrete; Tenera Oil Palm Shell; Elevated Temperatures*

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Introduction

Just in Malaysia, there has been reported a total of 50,720 fire incidents in 2019, which increased by 24.1% compared to 2015 [1]. This indicates a need to study concrete structures under elevated temperatures. When compared to other building materials, concrete can perform excellent when exposed to fire. However, because fires can reach extreme temperatures, appropriate structural fire design is vital to understand the behaviour of the material and structure when exposed to elevated temperatures [2]. When concrete is exposed to high temperatures for a time, strength and stiffness of the concrete is known to deteriorate. It will also cause spalling of the concrete, thus exposing the reinforcement to the extreme heats that can cause sudden failures. When concrete is exposed to fire, its performance change and depends on the concrete's changing properties, the distribution of temperature with the members, the reinforcement type and time and severity of temperature exposure [3].

Reviewers have concluded that significant achievements can be attained with the use of Dura OPSC as a coarse aggregate in concrete depending on the mix design and with or without admixtures [4]-[9]. However, no study has been done on the Tenera type shell other than by [10] and [11] which only studied the compressive strengths with different mixes and different treatments methods respectively.

One of the most important factor worth mentioning is that the oil palm tree produces different types of fruit species that effects the shell thickness. In the early ages of the oil palm plantations, there used to be the Dura and the Pisifera type fruits. The Dura type is known to have a thick shell (2-8 mm) while the Pisifera (sterile tree) is known to be shell-les. A breeding hybrid of the types (Dura and Pisifera) produces a type of fruit called Tenera. This produces a fruit with a very thin shell. The thinner shell (0.5-4 mm) of Tenera allows more oil to be in the fruit part called Mesocarp compared to the Dura by 30% [12]. Therefore, the Tenera type tree has the highest yield production and is expected that the Dura type shell to be outsourced in the future [13].

Generally, in the case of LWC, excellent behaviour is also displayed when exposed to fire and can even be better than NWC. Structural LWC is known to be a suitable element for high fire ratings and better than NWC because of lower strength-reduction at high temperatures, LWC are more insulated and low thermal expansion, which in turn cause less spalling [14]. However, since OPS is an organic material, this might just be the opposite. One paper has been found on OPSC exposed to elevated temperatures. A method was proposed by [15] to find out if there would be any effect in the concrete's enhancement if Dura OPS was replaced with palm oil clinker (POC) at elevated temperatures. However, no study has been done on comparing Tenera OPSC to NWC when exposed to elevated temperatures. Therefore, the objective of this study is to investigate Tenera OPSC and NWC exposed to elevated temperatures up to 350 ºC and make comparisons in compressive strength, UPV, colour change in the concrete and weight loss.

Materials and Methodology

This study focuses on the behaviour of Tenera OPSC compared to NWC when exposed to elevated temperatures. The specimens were subjected to temperatures ranging from 150 to 350 ºC. The subsections point out the materials used and the experiment methodology to achieve the objectives of this study.

Cement

The cement type used is MS EN 197-1-CEM II / B-L 32.5N, also known as CASTLE [16], was used for all the specimens.

Fine and coarse aggregates

River sand of size below 4.75 mm was used with a fineness modulus of 2.33, specific gravity of 2.6, water absorption of 0.7% and a bulk density of 1350 kg/m3.

Tenera type OPS was used as a coarse aggregate replacement in the OPSC specimens while conventional crushed aggregates were used in NWC. The sizes of the Tenera OPS were between 3.35-12.5 mm. The properties of OPS and conventional coarse aggregates are presented in Table 1. The thickness of the shells was between 0.5-1.5 mm which is much thinner compared to Dura OPS seen in Figure 1.

Figure 1: Tenera OPS and Dura OPS

Table 1: Properties of Tenera OPS and coarse aggregate for NWC

Material	Coarse Aggregate	Tenera OPS
Fineness Modulus	8.22	3.08
Bulk Density (kg/m3)	1567	550
Specific Gravity	2.62	1.22
Absorption rate (%)	0.6%	30.7

Mix proportions

The guideline used for choosing the mix ratio for NWC is from [17]. The concrete was prepared using river sand, coarse aggregate, cement, and water. Table 2 shows the mix ratios chosen for NWC and OPSC. The mix ratio chosen for the OPSC is based on the report by [18]. The OPS was filtered for unwanted waste such as dirt and fibres and cleaned with a detergent to remove any oil residue. Then the OPS was placed into water for 24 hours and then kept under the sun to achieve an SSD state prior to mixing.

Table 2: Mix ratio for NWC and OPSC

Type	Cement	Sand	Coarse Aggregate	Water	Wet Density	w/c
			(kg/m^3)			
NWC	350	605	1175	210	2340	0.60
OPSC	450	688	446	270	1787	0.45

Specimen preparation

For both NWC and OPSC the compressive strength, UPV, weight loss, colour change was studied. All concrete samples were batched according to their mix design and batched conform to [19]. The mould sizes used were 100x100x100 mm. All moulds were cleaned and applied with oil before casting. The moulds were put on a shaker to prevent air being entrapped. All specimens were cast together for 24 hours. The specimens were then demoulded and put into a curing tank (28 ºC ± 4) for 28 days. Specimens were tested just after heating and after 7 days of cooling.

Heating and cooling of specimens

After 28 days of curing, the cubes were air cured for 24 hours and then the cubes were exposed to elevated temperatures in the furnace for 1 hour at designated temperatures of ambient temperature (29 ºC±3), 150 ºC, 250 ºC and 350 ºC. For each set of temperature, 6 cubes were tested as seen in Table 3. The cubes were put in a Carbolite furnace as seen in Figure 2. For each set of temperature, three cubes were tested right after removing them from the furnace at hot temperature and the other three were tested 7 days later when cooled down.

Figure 2**:** Furnace used for cubes

Table 3: Cubes exposed to elevated temperatures

Type	Condition	No. Cubes	Type	Condition	No. Cubes
NWC - Control	(Room temperature)	6	OPSC - Control	(Room temperature)	6
NWC	150 °C	6	OPSC	150 °C	6
	250 °C	6		250 °C	6
	350 °C	6		350 °C	6
	Total =	24			24

The temperature increase rate was set at 4 ºC/min. for all specimens as seen in Figure 3 which was similar to the study done by [15]. This is also advised by [20] to use a constant rate between 0.5-10 ºC/min. when increasing the temperature. Furthermore, they also mentioned to keep peak temperatures maintained between 1-2 hours to ensure the integrity of samples or structures [20].

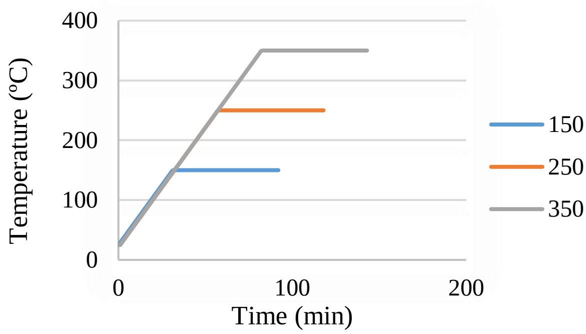


Figure 3: Temperature profile

Ultrasonic pulse velocity (UPV)

UPV tests were also conducted prior to compressive strength testing by using a Pundit testing device. The device was calibrated, and the probes were moisturized with gel prior to each test.

Results and Discussions

For both NWC and OPSC the compressive strength, UPV, weight loss, colour change is investigated and discussed. Also, the effect of testing the specimens when hot and cold were investigated. The subsections show the results and discussions on the investigations conducted.

Colour and cracking pattern at elevated temperature

Table 4 lists and shows the cubes of NWC and OPSC after being exposed to 150, 250 and 350 ºC for 1 hour. The NWC did not significantly change in colour as the temperature increased. Though it only changed to a slightly darker colour. However, in the case of the OPSC, a significant colour change was observed. An orange-reddish colour was seen on the surface at 350 ºC. This might be the extrusion of the oil from the shells to the surface. Palm oil is known to boil at between 200-300 ºC [21]. This colour change was only observed at the bottom of the cubes, which were placed on a ceramic plate in the furnace. It can be concluded that the oil fluid did not evaporate but became less viscous and caused it to flow to the bottom of the cube by gravitation. Also, the higher the temperature, a stronger smell of OPS burning was observed. Similar observations were found by Jumaat et al. [15].

Besides colour change, no visual cracks or spalling was noticed on the surfaces of the cubes. However, under a microscope cracks, de-bonding and exclusion of OPS could be seen. At 150 ºC, some small cracks and slightly burned OPS could be seen on the surface as seen in Figure 4. When increased to 250 ºC, see Figure 5, the cracks seem to be wider compared to 150 ºC. Also, the shells seemed to not only be burned, but also started to de-bond with the cement matrix. When the specimens reached to 350 ºC, the OPS on the surface seemed to have fallen out totally and at other places greater de-bonding was observed with wider cracks compared to lower temperature exposures, see Figure 6. Such observations were not noticed with the NWC specimens. This might be obvious since the OPS shells were at SSD state (30.7% was moisture). The high amount of water inside the shells with the remaining palm boiling point of palm oil causes a higher stress inside the concrete matrix compared to NWC is evident. These factors are known to happen since a development of stress occurs in concrete at elevated temperatures withing the aggregates and the mortar as the water vapour pressure increases. Also, the development of thermal stresses occurs due to the difference in temperature between the inner core of the specimen and the surface which lead to the initial progress of cracking [22].

Table 4: Colour change after heating

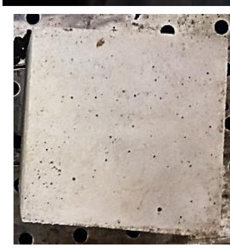
Temperature Exposed (1 Hour)	Colour of Specimen	
	NWC	OPSC
150 °C		
250 °C		
350 °C		

Figure 4: Burned OPS (left) and crack (right) at 150 ºC (10x)

Figure 5: Burned OPS (left) and crack (right) at 250 ºC (10x)

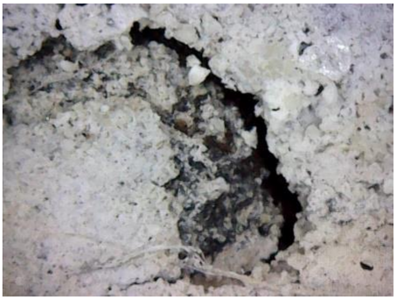
 

Figure 6: Total burned OPS (left) and crack (right) at 350 ºC (10x)

Effect of temperature on weight loss

The weight of each specimen was taken just before exposing it to elevated temperatures and just after removing them from the furnace. The weight loss for each specimen is shown in Figure 7. The NWC in this study exhibited a normal loss compared to a review study by [23]. However, the OPSC had a significant higher weight loss compared to NWC. The weight loss of OPSC seemed to increase by 18, 37.5 and 43% at 150, 250 and 350 ºC respectively compared to NWC. This indicates that the trend is increasing with increase of temperature. This is most probably because of the moisture loss in the OPS aggregates itself since OPS was used in an SSD state prior to batching. From Table 1, Tenera OPS has a much higher water absorption compared to the conventional coarse aggregate used in NWC (0.6% vs 30.7%). Also, since OPS is an organic material, it burns easier compared to crushed aggregates [24]. This is also evident from the Figures 4-6 where the OPS shells are decomposed due to the high temperatures.

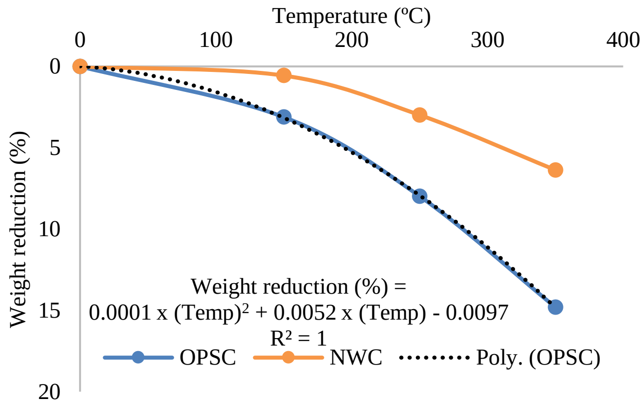


Figure 7: Weight reduction for NWC and OPSC

Effect of temperature on compressive strength

Figure 8 shows the decrease in strength of OPSC and NWC when tested hot and cooled down (after 7 days). Figure 8a shows a normal trend for the NWC as reviewed by [23]. However, the OPSC seemed to reduce its strength in a much higher trend and seemed to change to a more linear change when reaching a temperature of 350 ºC. To validate this, a comparison has been made with the results of [15] in Figure 9. Since the Tenera OPS is much thinner than the Dura OPS type, it is reasonable to remark that the Tenera type would degrade quicker compared to the Dura type. As shown in the Figures 5 and 6, the shells started to de-bond after 250 ºC. This indicates that the shells stop carrying any load capacity afterwards, and therefore a smaller change is seen. This is also evident from the results by [15] in Figure 9, where the Tenera OPSC had a greater loss initially up to 300 ºC and acted similar afterwards in a smaller change.

The other specimens tested after 7 days were cooled down in an outdoor environment of temperatures between 27-31 ºC. It is strange to see that the strength for both NWC and OPSC when tested cooled were higher compared to hot tested specimens as seen in Figure 8a and 8b. Since the concrete matrix is expected to shrink when cooled down, it is normal for the matrix to propagate higher cracks and therefore reduce its strength. Though no conclusion can be extracted for the NWC since 350 ºC is relatively low. However, OPSC seemed to behave in a similar manner up to almost 250 ºC and decreased in strength rapidly afterwards. This is because the degraded OPS aggregates created higher voids inside the matrix.

Though a UPV test would be a good indication for this study, it did not have a good relationship with the compressive strength when comparing Figure 8a and 8b to Figure 8c and 8d, respectively. Though it did show a higher decrease when tested hot compared to cooled, which is similar to the compressive strength decrease.

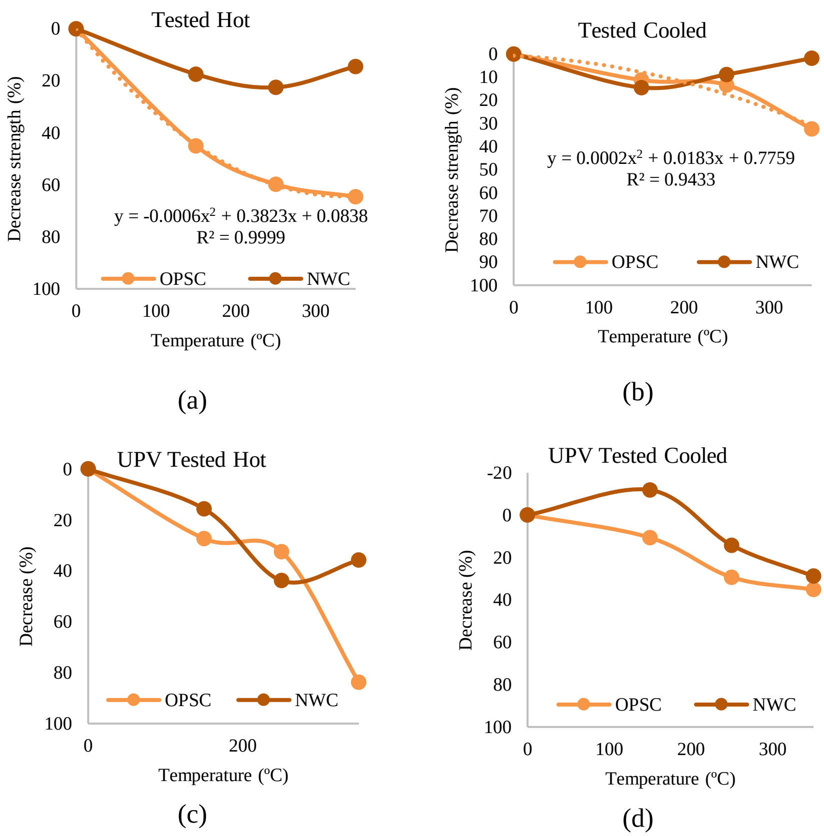


Figure 8: (a) and (b) decrease in strength and (c) & (d) UPV for OPSC and NWC tested when hot and cooled

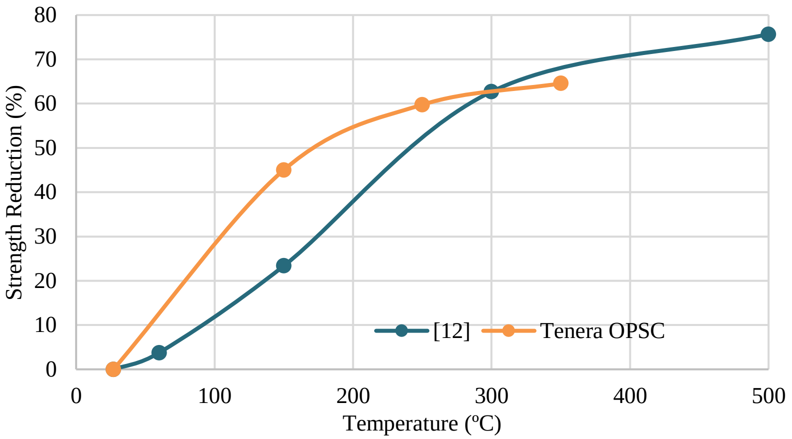


Figure 9: Strength reduction in Tenera OPSC (1 Hour) compared to Dura OPSC from [15]

Conclusions

In this study the reduction in strength and weight effects in Tenera OPSC and NWC were studied exposed to elevated temperatures. Conclusions and analyses are drawn by the following points in this paper:

i. No significant change in colour was observed for the NWC, whereas the OPSC showed orange-reddish colours at 350 ºC signifying to loss of palm oil which is known to have a boiling point between 200-300 ºC. Also, with the increase of temperature, an increase in crack patterns was observed in the OPSC and also in de-bonding between the OPS and the mortar matrix. No such observation was noticed in the NWC. The main reason of this observation is due to the high-water content of OPS in the mix.
ii. When exposed to higher temperatures, higher weight loss was encounter in the OPSC of up to 18.5% at 350 ºC and 43% higher when compared to NWC. This is concluded because of the higher moisture content in the OPS shells.
iii. It can be concluded that OPSC has a higher reduction in strength when compared to NWC by 50% at 350 ºC. Tenera OPSC showed similar results to Dura OPSC at temperatures of 300 ºC and higher.
iv. When tested at cooler temperatures after 7 days, the strength reduction is much lower compared to hot testing. However, more studies should be done at higher temperatures.
v. The UPV results did not indicate lower values because of the shrinkage effect when cooled down.

The authors further recommend doing additional tests with higher temperatures, use fibres to help with bonding and to conduct other tests (RCPT, MIP and BET) to observe the internal crack formation after exposure to heat.

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