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Influence of Superplasticizer Dosage on the Workability and Compressive Strength of Tenera Oil Palm Shell Concrete

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ABSTRACT

This paper investigates the effects of superplasticizers (SP) on Tenera oil palm shell concrete (Tenera OSPC) in comparison to normal weight concrete (NWC) with similar strengths. Two types of Tenera OSPCs were examined: one with coarse-sized aggregates (coarse OPSC) and the other with fine-sized aggregates (fine OPSC). Two methods were employed in this study: in the first method, SP was added while maintaining a constant water-to-cement (w/c) ratio, and in the second method, the water content was reduced by adding SP while keeping the slump similar to the original mix without SP. The results of the first method indicate that a maximum SP dosage of 0.3% is optimal for both types of Tenera OSPC, although it is recommended to use a lower dosage for fine OPSC to prevent segregation. For the second method, it was found that SP dosages of ≤1% are not as effective as observed for NWC when the w/c ratio is reduced, indicating that higher dosages are required. The study identified that SP does not function as intended with Tenera OSPC most probably due to the chemical processes involved.

1. Introduction

The demand for cost-effective and high-strength concrete in contemporary civil structures is on the rise. Superplasticizers (SPs) are commonly employed to enhance concrete workability, as a low water-to-cement (w/c) ratio is often used to attain high strength and low permeability [1-3]. Research indicates that the use of a polycarboxylate ether (PCE)-based plasticizer or SP can enable concrete to maintain good flowability at a w/c ratio as low as 0.16 and achieve a compressive strength exceeding 150 MPa [4]. Typically, long-chain polymers or co-polymers with negative charges serve as superplasticizers. When mixed with water, they are adsorbed on the cement particles' surfaces, causing the cement particles to become negatively charged. Consequently, negatively charged cement particles repel each other, releasing water trapped in agglomerated cement particles. The addition of SP not only improves the flowability of the concrete but also significantly homogenizes the concrete mix by dispersing (or de-agglomerating) the particles. According to some research, SP can further increase the packing density of solid particles in a cement paste [5].

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Numerous investigations have been conducted on the use of oil palm shell (OPS) waste as a coarse aggregate in concrete over the past four decades [6]. However, no research has examined the impact of superplasticizers (SPs) on oil palm shell concrete (OPSC) using Tenera OPS, with the exception of a study conducted by Okafor [7], which employed Dura OPS as coarse aggregate and a second-generation SP made of sulphonated naphthalene formaldehyde. The third generation polycarboxylate SP is the most widely used type of SP in the industry, known for its greater efficiency and lower cost than the first- and second-generation SPs [8]. In Malaysia, it has already been demonstrated that over 90% of all palm oil producers have shifted to Tenera-shell-producing palm trees, and as a result, the number of Dura-producing trees is anticipated to decrease significantly in the future [9]. There is very little research on the use of Tenera OPS in concrete; thus, it is essential to re-examine the utilization of Tenera OPS as an aggregate in concrete, incorporating third generation polycarboxylate SPs.

The objective of this study is to investigate the influence of SP dosage on Tenera OPSC and compare it to normal weight concrete (NWC) with a similar grade strength of 20 MPa. The investigation focuses on two types of OPSC concrete, namely coarse OPSC made with Tenera OPS as coarse aggregate (C-OPS), and fine OPSC made with Tenera OPS as fine aggregate (F-OPS). Two methods have been adopted in this study to investigate the effect of SP dosage on the strengths of the concrete. In the first method, SP dosages of 0.1%, 0.3%, and 0.5% are added to the concrete mixes while keeping the water-to-cement (w/c) ratio constant. The aim is to study the impact on workability, compressive strength, and water absorption. In the second method, SP dosages of 0.4% and 1% are added while reducing the w/c ratio and maintaining the slump similar to the original mix without SP. The objective is to investigate the effect on the compressive strength of the concrete.

2. Methodology

2.1 Materials

Portland cement (MS EN 197-1-CEM II / B-L 32.5N) was used as a binder in this study also known as CASTLE. A commercially available polycarboxylate-based SP from Sika and specific density of 1.08 kg/l was used as a water reducer. The recommended dosage of 0.25 – 1.0% by weight of cement is advised in the product data sheet from Sika Malaysia [10]. Similar dosage is also advised by BS EN 934-2 [11]. Potable water was used for all mixes.

Two types of aggregates were used in this study, natural and organic waste aggregates, i.e., OPS. The natural aggregates were river sand for fine aggregate and granite for coarse aggregate. Tenera OPS was used as fine (F-OPS) and coarse (C-OPS) sized aggregates. The F-OPS was produced by grinded the material using a Retch SM100 with a filter size opening of 5 mm. Both types of fine aggregates were used with sizes <5 mm and coarse aggregates with sizes >5 mm. The properties and grading of the materials are presented in Table 1 and Figure 1, respectively. Both F-OPS and C-OPS were washed with a detergent and used in an SSD state prior to mixing done in a similar manner as previous authors [6].

Table 1
Properties of aggregates

	Unit	Fine Aggregate	Coarse Aggregate	Tenera-OPS	
				C-OPS	F-OPS
Dry Loose Bulk Density	kg/m^3	1350	1567	442	572
SSD particle density		2710	2620	1220	1220
Water absorption	%	0.72	0.60	30.65	34.28
FM	-	2.33	-	-	4.02

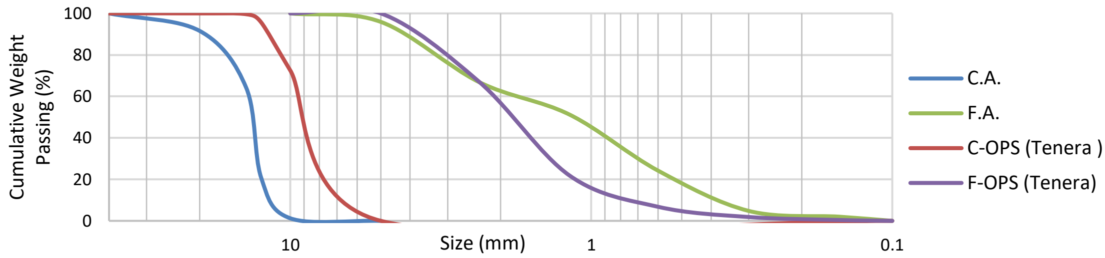


Fig. 1. Grading curves aggregates

2.2 Mix Proportions

The mix designs were produced with target strengths of 20MPa at 28 days (moist cured). The normal weight concrete (NWC) was designed according to Clayton *et al.,* [12] as a reference concrete [13]. As for coarse and fine OPSC, the dry density was targeted to be below 2000 kg/m3 to produce a lightweight concrete (LWC) according to BS EN 206 [14]. The mix proportions used in this study are shown in Table 2.

Evident is that the cement content for the coarse OPSC is much higher than the NWC and fine OPSC. From an external study by the authors, it was found that the coarse OPSC could only reach a 28-day compressive of 20 MPa with this amount of cement content. The main reasoning for such a result was mainly attributable to the weak Tenera OPS aggregate and due to its distinct shape being half-hollow-spherical. It was also found that the OPS as coarse sized did not bond with the cement matrix due to swelling and shrinking of the OPS aggregate when mixed in the concrete changing from saturated to dry state during hardening state, respectively.

Table 2
Mix proportions and strength

ID	Cement Kg/m^3	Fine Aggregate	Coarse Aggregate	Water	w/c	28-day strength MPa	Slump mm	Dry-Density Kg/m^3
NWC	350	605	1175	217	0.62	20.12	15	2141
Coarse OPSC	1050	283	152	315	0.30	20.24	42	1672
Fine OPSC	400	124	1236	140	0.35	20.85	10	1995

2.2 Methods for Testing

The main purpose of this investigation was to evaluate the effect of SP in coarse and fine OPSC and compare them to NWC of similar strengths (20MPa). Details of the two test methods are explained in the following sub-sections.

2.2.1 Addition of superplasticizer with constant w/c

In this method, the influence of SP on the concretes were investigated whilst keeping the w/c constant. The main aim was to observe the change in workability done with a slump test according to BS EN 12350-2 [15]. Though other workability testing methods are available, the slump test is known to be the simplest, cheapest, and most widely used test globally [16]. Also, according to BS EN 934-2 [11], the workability can be observed either by slump or flow test. In addition, the water absorption, and compressive strength at ages 7 and 28 days were also investigated with SP dosages of 0.1%, 0.3%, and 0.5% by weight of cement [17,18]. The concrete samples were also sliced for microscopic inspections.

2.2.2 Addition of superplasticizer with decrease of w/c

SPs are known to improve the workability and also to produce high-strength concretes by reducing the water content [19]. Therefore, in this method, the SP dosage of 0.4% and 1.0% was added whilst the w/c ratio was reduced to investigate the influence on the compressive strength at 28-days. In this setup, all the materials were first dry mixed. Then a small amount of water, with the designated SP dosage, was added and increased gradually until a water amount achieved a similar slump as the original mix without SP by visual inspection. The total amount of water added was then recorded. Finally, the concrete cubes were cured for 7 and 28 days and tested for their compressive strength. In addition, UPV tests were also performed in accordance with BS EN 12504-4 [20] by using a Pundit NDT device.

2.2.3 Preparation and casting of specimens

All concrete samples were batched as per BS EN 1881-125 [21] and BS EN 934-2 [11] for samples with SP according to their mix design. The mould sizes used were 100 mm x100 mm x100 mm for concrete cube samples. All moulds were cleaned and applied with oil before casting. The moulds were kept on a mechanical shaker to prevent air being entrapped (5 – 10 seconds/layer) and poured in three layers. All specimens were cast together and demoulded after 24 hours ± 1h. After demoulding, the specimens were put into a curing tank (29 ^{o}C ± 4) for their designated curing duration in accordance with BS EN 12390-2 [22].

3. Results and Discussions

3.1 Influence on Workability with Constant W/C

The results for this investigation are presented in Figure 2 – Figure 7 and Table 2. From Figure 2, all three types of concrete displayed a comparable slump value at 0.1% SP dosage and showed little change by 2.6, 1.2, and 6.3% for NWC, coarse and fine OPSC respectively, all ranging in a slump value between 40 – 50 mm. Therefore, falling in the range of SLWC slump values of 40 – 70 mm [23]. However, a noticeable difference between 0.1 – 0.3% is seen where both OPSCs performing similarly in terms of slump increment but no discernible change was seen for NWC. At a dosage of 0.3% of SP, the slump values were found to be 74, 233, and 195 mm for NWC, course and fine OPSC, respectively. However, at 0.5% of SP dosage, all three types collapsed in slump test (showing 300 mm). As for the NWC, similar values for slump changes, with a similar mix design from this study was shown by Paktiawal and Alam [24] who used SP dosages from 0.15 – 0.55%. Similar trends have also been observed for Dura OPSC by Okafor [7], Mannan and Ganapathy [25], and Alengaram *et al.,* [26]. Also, the effect of using OPS as coarse or fine sized does not results in different slump effects as was concluded by Alengaram, *et al.,* [27]. It can therefore be concluded that coarse and fine OPSC demand smaller amounts of SP dosage as compared to NWC regarding increasing slump values. This might be due to the fact that OPS, either used as coarse or fine aggregate, has a smoother surface compared to the that of conventional aggregates (coarse and fine) identified by Shafigh *et al.,* [28].

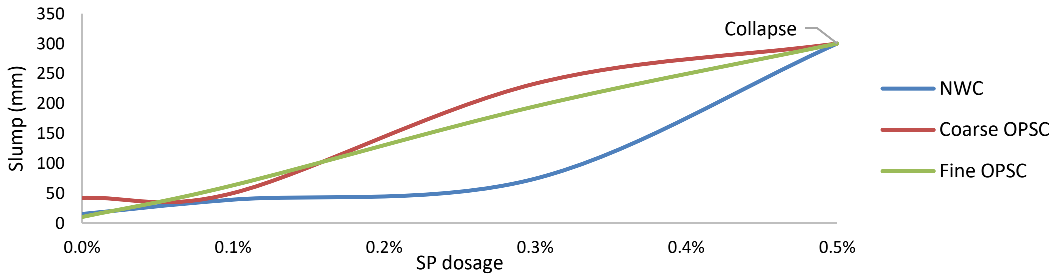


Fig. 2. Influence on slump with increase of SP dosage (constant w/c)

For all three concrete types, a reduction in the compressive strength (compared to 0% SP dosage) was seen at ages 7 and 28 days with the increment of SP dosage seen in Figure 3 and Figure 4 respectively. Therefore, the addition of the type of SP used in this study seemed to have an adverse effect on the compressive strength. This might be caused by the effect of segregation as explained later referring to images taken from the sliced sample in Table 3. The compressive strength at age 7 days for fine OPSC was observed to have the least decrease in strength with the increment of SP dosage compared to NWC and coarse OPSC with a maximum of 5% decrease at 0.3% of SP dosage. The NWC compressive strength decreased in a linear manner up to a maximum of 14% at 0.5% SP dosage, while the coarse OPSC showed the highest decline in compressive strength by 28% at 0.3% of SP dosage. In contrast to NWC decreasing further at 0.5% SP dosage, both coarse and fine OPSC showed a smaller decrease in compressive strength at SP dosage of 0.5% compared to 0.3%. This might be due to the segregation of the OPS at the higher dosage of 0.5% as seen from the figures in Table 3. Though no notable segregation was found in NWC, and little segregation seen for coarse OPSC, fine OPSC showed high segregation of F-OPS aggregates mainly floated to the top. However, it is not possible to tell whether the fine aggregates in NWC and coarse OPSC have also segregated, see Table 3.

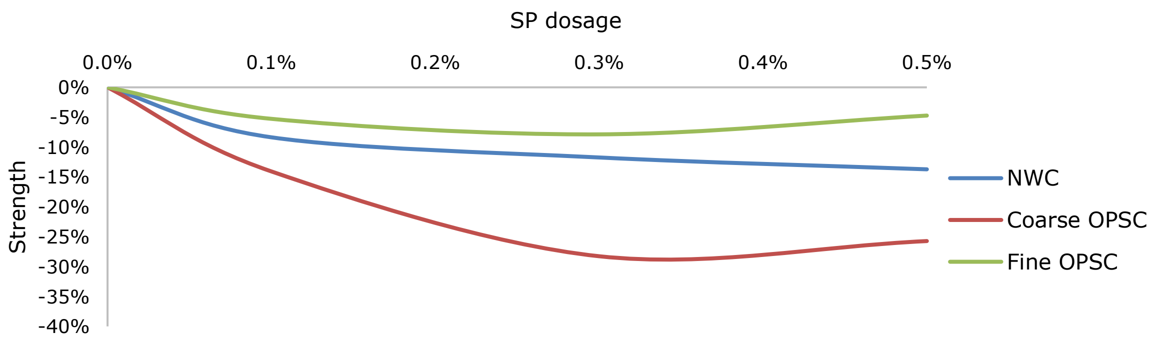


Fig. 3. Influence on 7 days compressive strength with increase of SP dosage

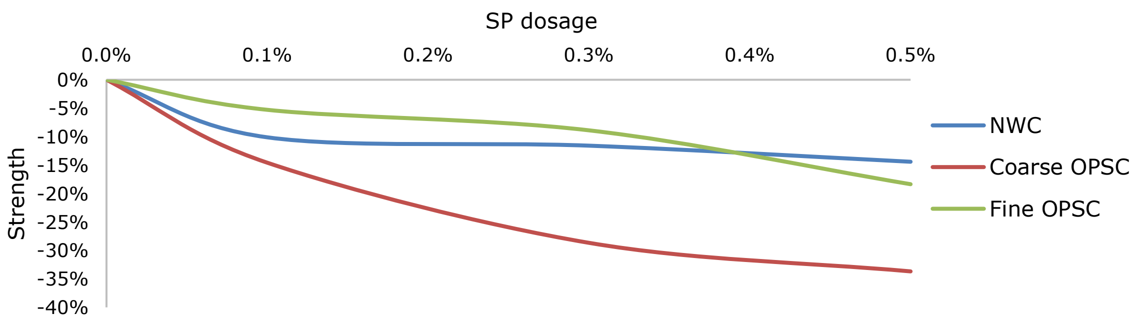


Fig. 4. Influence on 28 days compressive strength with increase of SP dosage

A similar reduction pattern in compressive strength was observed at 28 days compared to 7 days for all three concrete types. However, both coarse and fine OPSC decreased further in compressive strength by 34% and 18% respectively at a dosage of 0.5% compared to 14% for NWC. NWC had a similar decrease rate at 7 days of 8%, 12%, 14% and at 28 days 10%, 12%, and 14% at SP dosages of 0.1%, 0.3%, and 0.5% respectively showing that the hydration continued in a linear manner. This can be better observed from Figure 5, showing that NWC has a similar increase rate of 27 – 30% between 7 and 28 days with all dosages. Both coarse and fine OPSC demonstrated a similar trend as NWC up to 0.3% SP dosage but then at a higher dosage of 0.5%, the hydration seems to halt after 7 days for fine OPSC while only a 10% increase from 7 to 28 days compressive strength is seen for coarse OSPC (compared to 29% for NWC). Accordingly, it can be concluded that 0.3% of SP was the optimum dosage for both coarse and fine OPSC, producing slump values of 233 mm and 195 mm and reducing the compressive strength at 28 days by 28% and 8% for coarse and fine OPSC, respectively, while having no effect on the hydration process up to 28 days. But perhaps a lower dose than 0.3% is recommended for fine OPSC to prevent segregation.

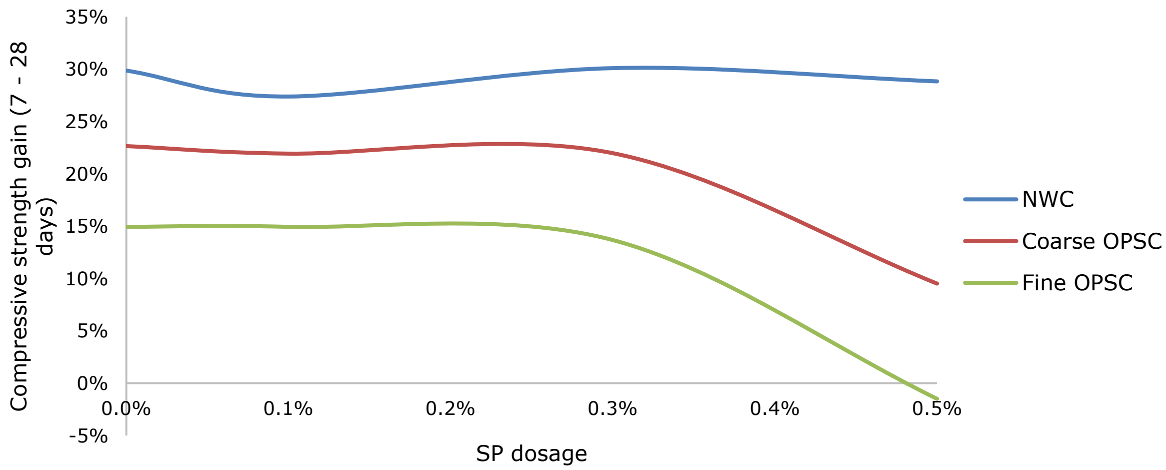
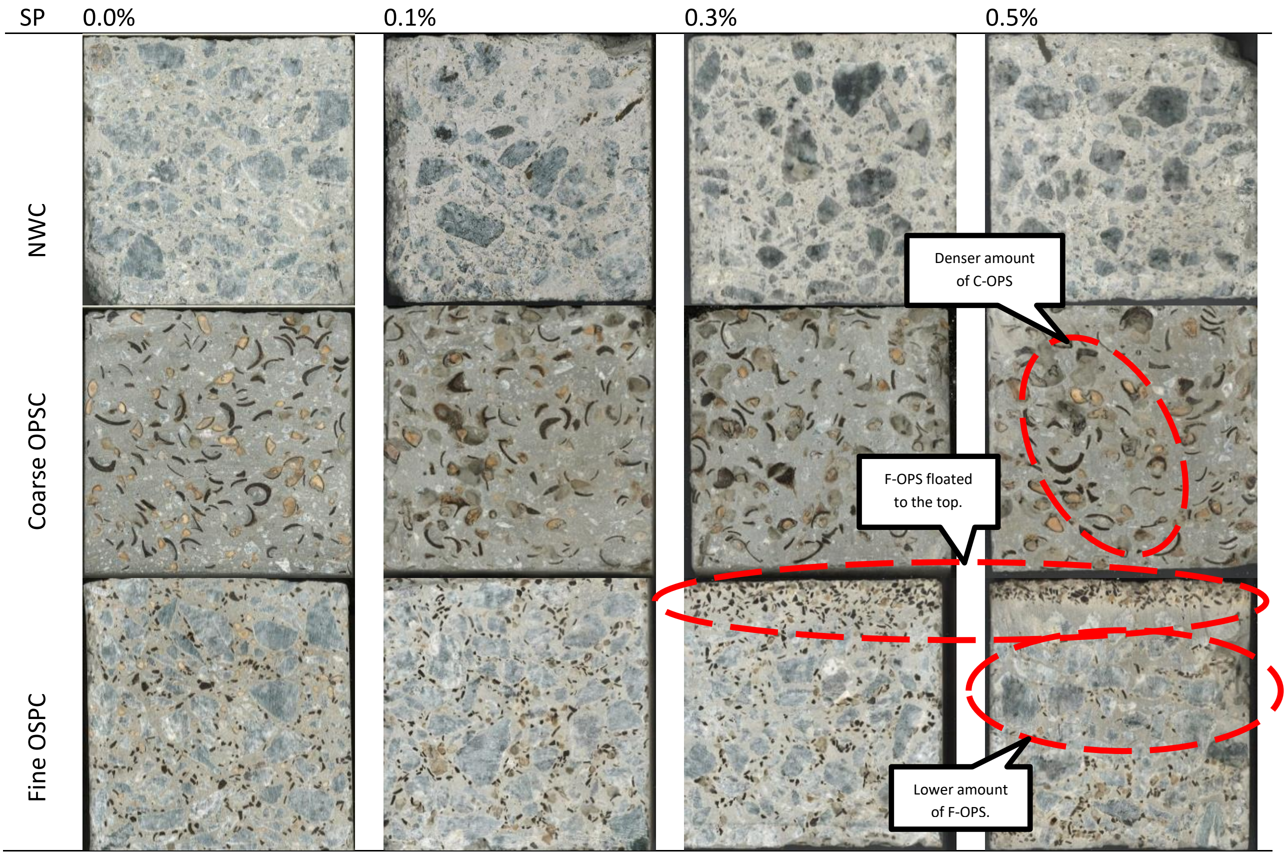


Fig. 5. Increase rate from 7 to 28 days at different SP dosages

The influence on water absorption with increase of SP dosage of all three type concretes is seen in Figure 6. While NWC had the lowest values, coarse OPSC had values that were nearly twice as high as those of NWC and fine OPSC. In contrast to coarse and fine OPSC, NWC exhibits no changes in water absorption with an average value of 7.7% for all SP dosages. Both coarse and fine OPSC showed an increase in water absorption by 0.6% and 24.1% respectively with increase of SP dosage. The segregations found in the OPSCs (see Table 3), especially in fine OPSC, probably explains the reason behind the higher increase in water absorption. Since OPS has a high-water absorption rate, the OPS aggregates segregated to the top surface, allows water to penetrate the concrete at a higher rate. Similar findings were observed by Teo *et al.,* [29], who suggested that the porous OPS's high water absorption may have led to more air being trapped in the concrete paste, which in turn increased the water absorption.

Table 3
Sliced samples with different SP dosages



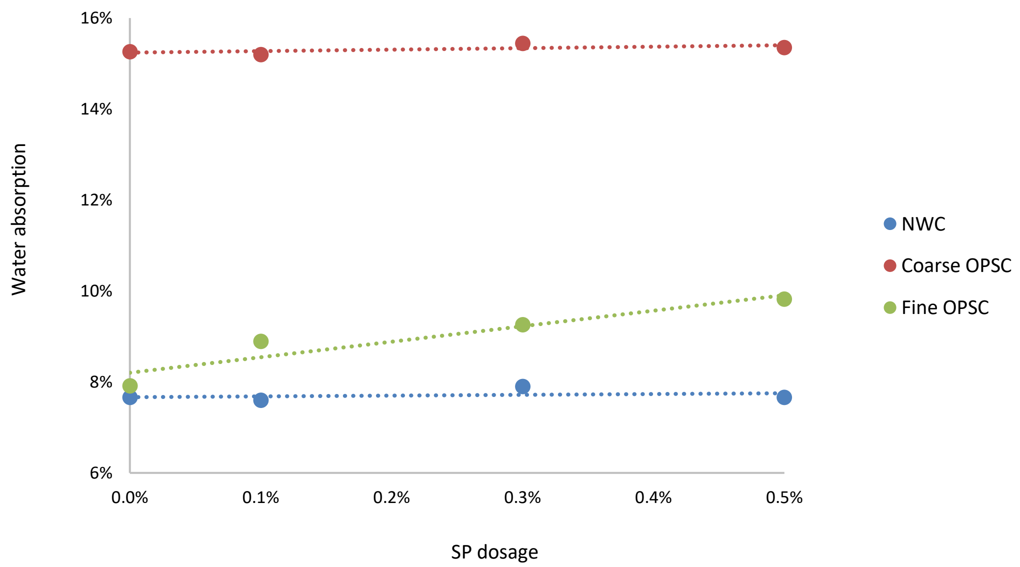


Fig. 6. Influence on water absorption with increase of SP dosage

3.2 Influence on Compressive Strength by Reducing W/C

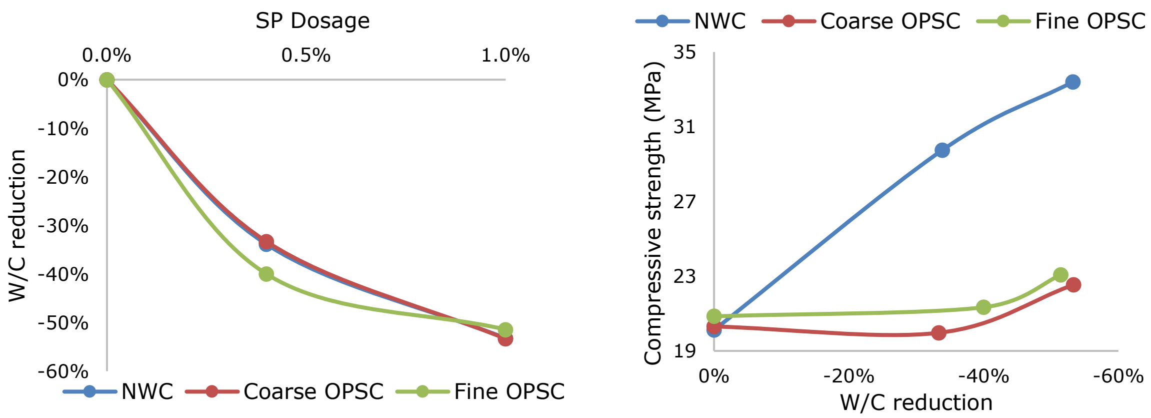
In this method, SP dosages of 0.4% and 1.0% was added whilst the w/c ratio was lowered concurrently to investigate the influence on the compressive strength at 28 days. In addition, the

UPV test was also conducted on the samples. The results for this investigation are presented in Figure 7 – Figure 10. The change in w/c with the addition of SP dosage is shown in Table 4.

Table 4
Change in W/C with the addition of SP dosage

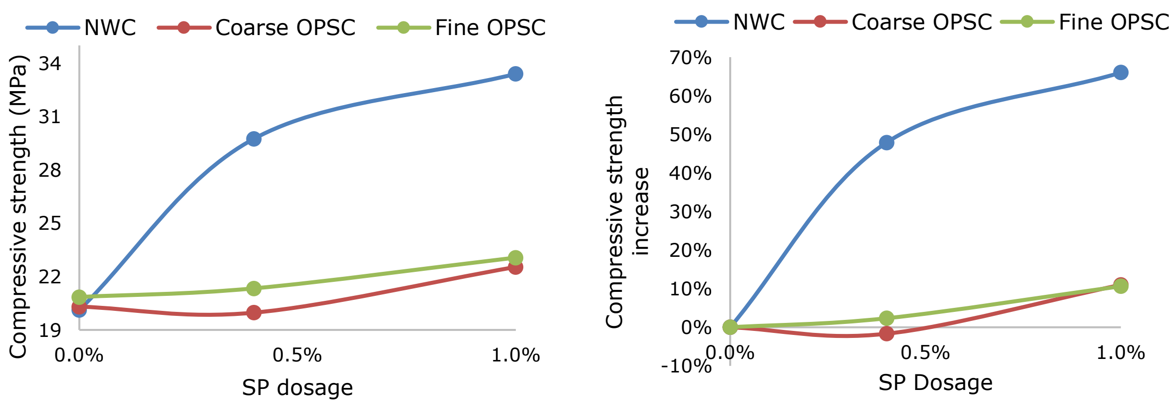
SP dosage	NWC w/c	Coarse OPSC	Fine OSPC
0.0%	0.62	0.30	0.35
0.4%	0.41	0.20	0.21
1.0%	0.29	0.14	0.17

The W/C decreased in a similar manner with the increase of SP dosage for all three concrete types as seen in Figure 7(a). For the NWC, the compressive strength increased with the reduction of w/c (and addition of SP dosage) in a linear manner as seen from Figure 7(b). However, this trend was not observed for coarse and fine OPSC. In fact, from Figure 8(b), it seems that a dosage of 0.4% does not increase the compressive strength for both coarse and fine OPSC, see Figure 8(a). However, only at 1.0% SP dosage a slight increase of 11% for both OPSCs is observed compared to 66% for NWC, as seen in Figure 8(b). It can therefore be concluded that small amounts of SP dosages of ≤1% is not as effective in OPSCs as was observed for the NWC and therefore higher dosages are demanded.



(a) (b)

Fig. 7. Decrease rate of W/C with addition of SP



(a) (b)

Fig. 8. Influence on compressive strength with addition of SP dosage

Another interesting observation was the change in density with the addition of SP for all three concretes as seen in Figure 9. The NWC increased its density by 2.9% and 4.4% with the addition of 0.4% and 1.0% SP dosage, respectively. A similar, yet lower, increase can be seen for coarse OPSC of 1.7% and 2.1% and for fine OPSC of 1.6% and 2.2% with the addition of 0.4% and 1.0% SP dosage, respectively. However, for both OPSCs, it was observed that after an SP dosage of 0.4%, the density increase seems to decline compared to NWC. The reason for no increase in density between 0.4% and 1.0% SP for the OPSCs is quite difficult to rationalize with the limitations of the test conducted in this study. However, certain assumptions could be made, such as variations in the density of the OPS aggregates and/or unusual chemical reactions between the SP and OPS shells, as identified earlier.

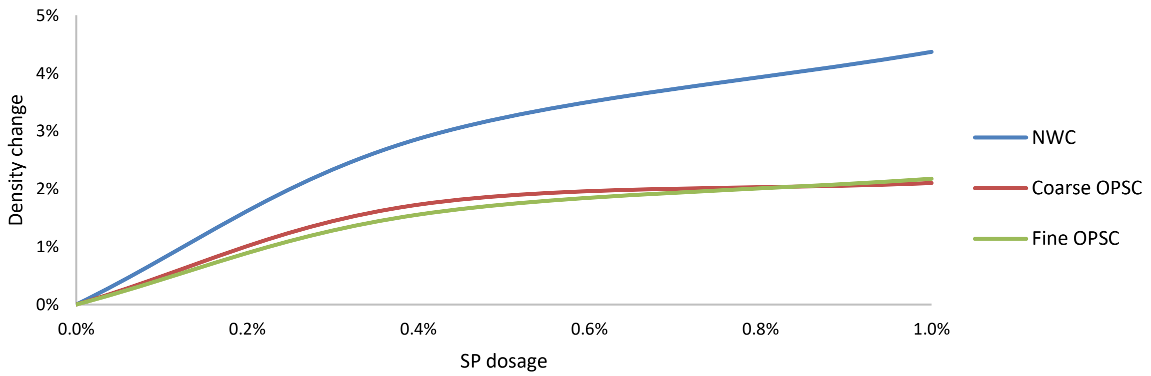


Fig. 9. Influence of SP dosage on density

Nevertheless, a similar increase of 2.3% in density was observed by Cartuxo *et al.,* [30] with the incorporation of 1% SP dosage for concrete made with 100% fine recycled aggregates. Cartuxo, *et al.,* [30] justified this by concluding that by lowering of the w/c of the mixes, the higher density of the other materials replaces the lowered density of water relative to the materials. An additional justification may also be that SP causes the cement grains to proper disperse when w/c is reduced instead of flocculation without SP therefore causing a better packing, consequently increasing its density [31].

Moreover, the change in packing of the concretes can also be observed by the use of the UPV test which measures the time of travel of an ultrasonic pulse. A higher UPV value (km/s) would indicate a better packed concrete [32]. This was confirmed in a study by Guo *et al.,* [33] where they observed the increase in UPV values (km/s) with the decrease of air voids. Certainly, the UPV values for all the three types of concretes increased with the increment of SP dosage (and reduction of w/c), see Figure 10(a). The values for NWC changed from good to excellent by 16% and 22% for SP dosages of 0.4% and 1.0% respectively. However, for coarse OPSC an increase of 9% and 11% and fine OPSC by 1% and 4%, both lower than NWC and fine OPSC being the lowest. As for the relationship between the compressive strength and UPV, strong correlations are found for NWC (R^2=1.00) and fine OPSC (R^2=0.99) and a low correlation for coarse OSPC (R^2=0.31). Therefore, the increase of UPV can be associated with the increase in the density, as was shown in Figure 9, due to the increase of compactness/packing of the materials.

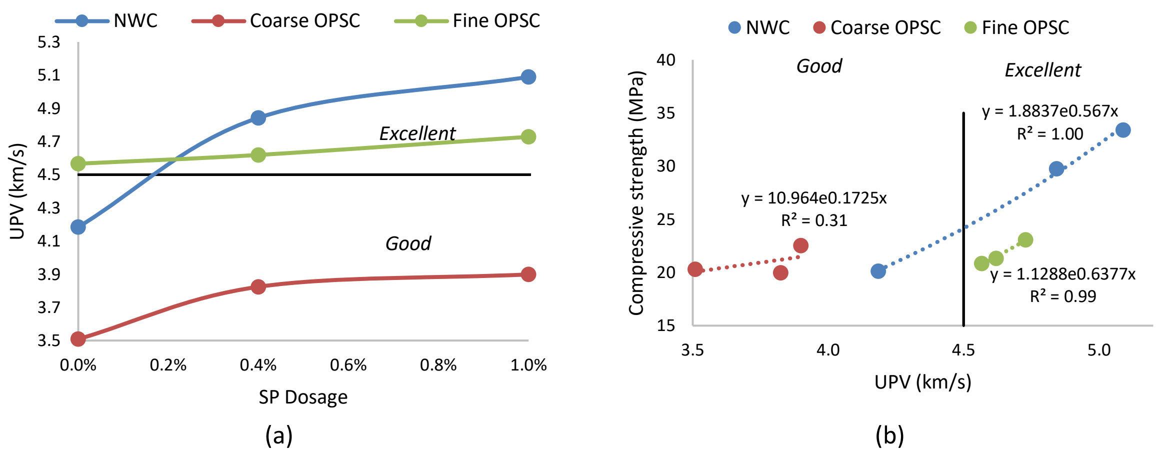


Fig. 10. (a) Influence of SP dosage on UPV (b) Compressive strength vs UPV

4. Conclusions

In this study, the primary objective was to examine the impact of incorporating SP in Tenera OPSC and compare it to NWC of comparable strength grades. Two methods were employed to achieve this objective: investigating the workability changes by adding SP while maintaining the w/c constant and analysing the compressive strength by decreasing the w/c with SP addition. The findings suggest that the optimal dosage of SP for both coarse and fine OPSC is 0.3% when the w/c is constant, but it is recommended to use a smaller amount for fine OPSC to prevent segregation. Moreover, it was observed that both coarse and fine OPSC require less SP than NWC when considering slump demand. However, when the w/c is reduced, it was observed that SP dosages up to 1.0% are not as effective as they are for NWC. As a result, higher dosages may be necessary. The study identified that SP does not function as intended with Tenera OSPC most probably due to the chemical processes involved. The authors of this study therefore recommend further studies on the chemical processes involved between the SP and OPS.

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