Effects of Manufactured Sand on the Properties of Normal and High Strength Concrete

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ABSTRACT

Manufactured Sand (MS) has been introduced as a very effective fine aggregate and is being widely used in various construction activities. Large amounts of Manufactured Sand Fines (MSF) that are less than 75 µm in particle size, are produced during the production process. Costs are incurred in separating these fines from the crushed stone and are then dumped in landfills, thus causing serious environmental issues. Studies on MSF are not well established and a handful has been done on High Strength Concrete (HSC). The key objectives of this study were to study and compare the effects that MSF have on the properties of Normal Strength Concrete (NSC) and HSC and to propose effective fines percentages that could be incorporated in them. Tests were carried out by partial replacement of MS with fines in proportions of 10%, 15% and 20% for C30 and C60 concrete and were compared with the control mixes that contained 3.36% MSF. It was identified that a 15% replacement of MSF produced effective results with the highest compressive, splitting tensile and flexural strength results and minimum water absorption in both NSC and HSC. At 15% fines content, a strength of 35.3 MPa and 63.3 MPa was achieved by the C30 and C60 concretes respectively. However, the increment of fines decreased the workability significantly. The microstructure analysis proved the densification of the microstructure at 15% MSF content. The cost analysis showed that the availability of high fines content can deduct the cost of NSC by 1.8% and HSC by 1.6%. The 10% - 15% range was identified as the most effective fines content range that can be incorporated in NSC and HSC. Results of this study can contribute to develop concrete with better performance while addressing several environmental and cost issues related to the concrete industry.

KEYWORDS: *Manufactured sand, fines, partial replacement, normal strength concrete, high strength concrete.*

1 INTRODUCTION

Concrete is considered to be the most widely used construction material all over the world. Depending on the compressive strength of concrete, concrete can be categorized into NSC and HSC. Concrete compressive strength of 60 MPa is considered as the lower limit for HSC (Al-Oraimi et al., 2016). Among the various materials used as fine aggregates in the industry, River Sand (RS) is considered to be the most prominent material that has been used in concrete over many decades. With the scarcity of RS and the restrictions towards mining, the prices of RS have vastly increased, bringing RS to be unaffordable and not economical. Thus, there arose a need for the use of alternative materials for RS for the use as fine aggregates.

In the search for alternatives, MS has been introduced as a very effective alternative for RS. Unlike RS which is naturally occurring, MS is artificially produced by the mechanical crushing of the parent rock under controlled processes. Therefore, due to this reason, MS appears to have different compositions, shapes, gradation and fines content (particles smaller than 75µm) when compared to RS. One of the components of MS that has extensive effects on the properties of concrete is the amount of fines content incorporated in MS. The percentage of MSF that can be incorporated in concrete is usually limited to specific ranges due to several reasons. One of the reasons is due to the decrement of workability of the fresh concrete due to the large surface area that has to be wetted. This as a result will

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lead to the increment of the water content in order to maintain the workability, and as a result, the concrete being more susceptible to shrinkage and cracking. These fine particles have a high tendency of attaching to the surfaces of the larger particles thus preventing proper bonding among the cement paste and aggregate. Another reason is due to the availability of clay particles among the MSF which are less than a few micrometers. The hardened concrete is more susceptible to have more sensitivity to cracking due to the volume changes that occur in the clay particles by water absorption and drying out. This will result in a decrease in the strength of the concrete. As a result of the above-mentioned restrictions, various methods such as washing are used to separate MSF and are discarded to landfills. Since the entire number of fines will not be removed from these processes and due to the above-mentioned restrictions, several standards have been put up to limit the quantity of fines that can be used in concrete.

However, studies done on NSC have proved that the use of high levels of MSF in concrete have both favorable and adverse effects on the mechanical and durability properties of concrete.

As investigated in Ahmed and El-Kourd (1989) using both MS and RS in NSC, with the replacement of MSF, an increase in the compressive strength was observed for the concrete with MSF whereas an approximately constant variation was observed for the concrete with natural sand. It was observed that the slump drastically decreased with the increase in fines. In the studies done on Grade 35 concrete in Katz and Baum (2006), it is further confirmed that the fresh concrete properties such as the slump are greatly affected by the increase in fines content. It was observed in the study that with the increase in the MSF content, the amount of High Range Water Reducing Admixture (HRWRA) that was added in order to maintain a constant slump increased. It was further studied that the fineness of the fines, that is, the decrease in the particle size of the MSF had a major impact on the workability of the concrete. It was observed that the demand for the HRWRA was doubled when the median size of the fines in the concrete decreased. In Beixing et al., (2009), it is discussed that the compressive strength of the concrete increases with the addition of limestone fines. It is mentioned that limestone fines act as nucleation sites for the calcium silicate hydrates accelerating the hydration of clinker minerals at the early stages. Carbo-aluminates are formed by the reaction between limestone fines and tricalcium aluminates further improving the strength. Çelik and Marar (1996) have investigated on the effects of crushed rock fines on the mechanical and durability properties of NSC. It is shown in the study that the flexural strength and the impact resistance are at the maximum at 10% and 5% replacement of fines respectively. In the study, a minimum water absorption has been observed at 15% fines replacement as well. The water permeability continuously decreased with the increment of fines, indicating that the addition of fines improved the durability properties of concrete. In the microstructure studies as discussed in Yang et al., (2018), the filler effect of MSF in concrete was justified since it was observed that the limestone fines that were incorporated in the concrete, densified the pore structure and the Interfacial Transition Zone (ITZ) of concrete. The studies clearly indicated the effectiveness of incorporating high content of fines in concrete.

Though there exists several studies that have been done to study the effects of MSF on the properties of NSC, a handful has been done on the effects of the MSF on the properties of HSC. Furthermore, no proper study has been done comparing the effects that MSF have on the properties of both NSC and HSC. Therefore, it is observed that there exists a gap that requires more investigation on the effects that MSF have on the properties of HSC. There also exists a gap that requires a comparison between the effects of MSF on the variation of the properties and determining the most effective fines content that can be used in NSC and HSC.

The objectives of this study were to study and compare the effects of MSF on the properties of normal and high strength concrete by partial replacement of MS by MSF and to determine an effective amount of fines content in manufactured sand to be used in normal and high strength concrete that would have better properties and be cost effective.

2 METHODOLOGY

2.1 Materials

Ordinary Portland Cement (OPC) of the strength class 42.5 N was used for all the experimental tests that were done. Natural coarse aggregates with a maximum aggregate size of 20 mm were adopted. Properly graded MS was used in all experimental aspects. The dry sieving method was adopted for the sieve analysis test. The MSF were obtained by mechanically sieving the MS using the 75 μm British Standard test sieve (BS 812 – 103.1: 1985) with the aid of a sieve shaker. Water used in concreting was potable water (Babu et al., 2018). A Polycarboxylate based super plasticizer with a relative density of 1.11 was used for the HSC and no admixtures were used for the NSC.

Throughout the experimental process, the quality of the materials was ensured to maintain the consistency and accuracy of the results. Aggregate properties are shown in Table 1.

Table 1. Aggregate properties

Aggregate	**Specific Gravity**	**Water Absorption (%)**	**Aggregate Impact Value**
Coarse Aggregate	2.73	1.6	21.2
Manufactured Sand	2.6	2.75	-

2.2 Test Variables

Table 2 indicates the percentages of partial replacement that was done for the total manufactured sand quantity by MSF. The replacement percentages were decided based on the data analysis of past research data. Gaining insight from the analysis, a replacement range of 10% - 20% was used. It should be noted that the control mix contained a fines content of 3.36%. Table 3 and Table 4 indicate the mix proportions that were used for the Grade 30 and Grade 60 concretes respectively.

Table 2. Test variables

Concrete Grade	**Materials**	**Percentage of Use (%)**			
30	MS (Particle size < 75 μm)	3.36	10	15	20
	MS (Particle size > 75 μm)	96.64	90	85	80
60	MS (Particle size < 75 μm)	3.36	10	15	20
	MS (Particle size > 75 μm)	96.64	90	85	80

Table 3. Mix proportions of Grade 30 concrete

Grade 30				
Fines Content	**3.36%**	**10%**	**15%**	**20%**
Cement	409	409	409	409
Water	225	225	225	225
MS (> 75 μm)	708.4	659.7	623.1	586.4
MS (< 75 μm)	24.6	73.3	109.9	146.6
Coarse Aggregate	1013	1013	1013	1013
Superplasticizer	0	0	0	0
w/c	0.55	0.55	0.55	0.55

Table 4. Mix proportions of Grade 60 concrete

Grade 60				
Fines Content	**3.36%**	**10%**	**15%**	**20%**
Cement	490	490	490	490
Water	157	157	157	157
MS (> 75 μm)	730.2	682.2	644.3	606.4
MS (< 75 μm)	27.8	75.8	113.7	151.6
Coarse Aggregate	1091	1091	1091	1091
Superplasticizer	5.98	5.98	5.98	5.98
w/c	0.32	0.32	0.32	0.32

Note: Concrete mix proportions are in kg/m^3

2.3 Test Program

The test program was set up to test the properties of the materials and the concrete. The outcomes of these tests were analyzed and used to discuss the outcomes of the research.

Materials tests, fresh concrete tests, hardened concrete tests and a microstructure study was conducted. Material tests such as sieve analysis test, specific gravity test, water absorption test and aggregate impact value test were conducted for the aggregates.

The fresh concrete was tested for initial slump and wet density.

Hardened concrete tests namely compressive strength test, splitting tensile test, flexural strength test and water absorption test was conducted. 150 x 150 x 150 mm cubes, cylinders with a 150 mm diameter and a depth of 300 mm and 100 x 100 x 400 beams were used for the compressive, splitting tensile and flexural tests respectively. The samples for the hardened concrete tests were tested after 28 days of curing. The compressive strength was tested at both 7 and 28 days of curing.

2.4 Microstructure Study

To study the microstructure, a Scanning Electron Microscope (SEM) analysis was done. A ZEISS EVO18 SEM was used for this purpose. Concrete samples from mechanically tested concrete specimens after 7 days of curing was used for the analysis. The samples were properly washed and oven dried at 60°C prior to the analysis.

3 RESULTS AND DISCUSSION

3.1 Initial Slump

Figure 1 demonstrates the variation of initial slump with fines content in the C30 and C60 mixes.

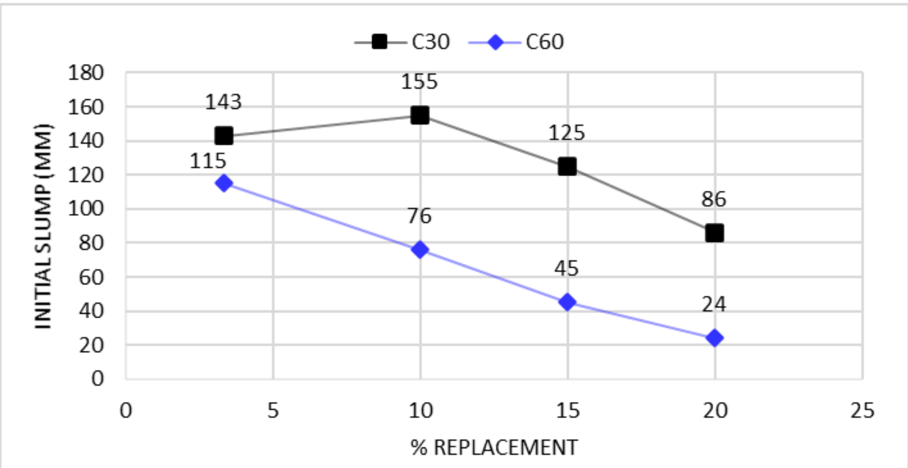

Figure 1. Variation of initial slump with fines content

As illustrated in Figure 1, slump decreases in both the concretes indicating that the increment of fines had a similar effect on the workability. Though there was an increment in the slump at 10% fines in the C30 concrete, no such observation was observed in the C60 concrete. All in all, increment of fines had negative effects on the workability of both, C30 and C60 concretes.

In the C30 concrete, an increase in the slump could be observed at 10% replacement. According to Shen et al., (2018), this behavior could be due to the contribution of the fines in filling the gaps in the packed aggregate and improving the fluidity of the mortar, thus improving the workability. This decrease in workability beyond the 10% replacement can be explained in relation to the specific surface area of the fine aggregates. As discussed in Katz and Baum (2007), with the increase of fines in mixtures, the fineness of the fine aggregates increases, thus increasing the specific surface area. The increase in specific surface area increases the demand for water to wet the increased surface area, thus decreasing the workability of concrete.

3.2 Concrete Densities

Figure 2 shows the variation of wet and dry densities of the C30 and C60 mixes with MSF.

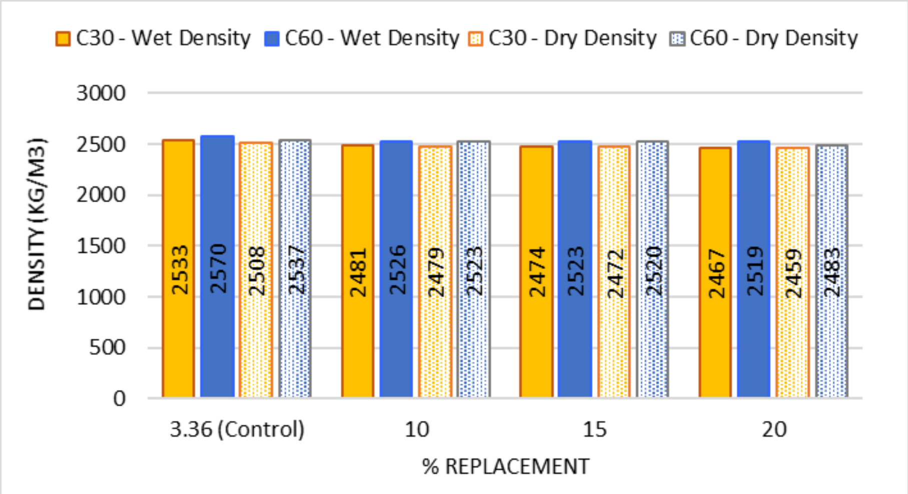

Figure 2. Variation of densities with fines content

As shown in Figure 2, though there appears to be a negative trend in the densities, the percentage reduction doesn't appear to be significant indicating that the increment of fines doesn't have a significant effect on the wet and dry densities of C30 and C60 concretes and that the above trends are not much notable. It was also observed that the difference between the wet and dry densities at the 10% - 15% MSF replacement range were less when compared to the other mixes. This could be due to the minimum water desertion from the concrete.

3.3 Compressive Strength

Figure 3 given below is an illustration of the variation of compressive strength at 7 and 28 days with the fines content in the C30 and C60 mixes.

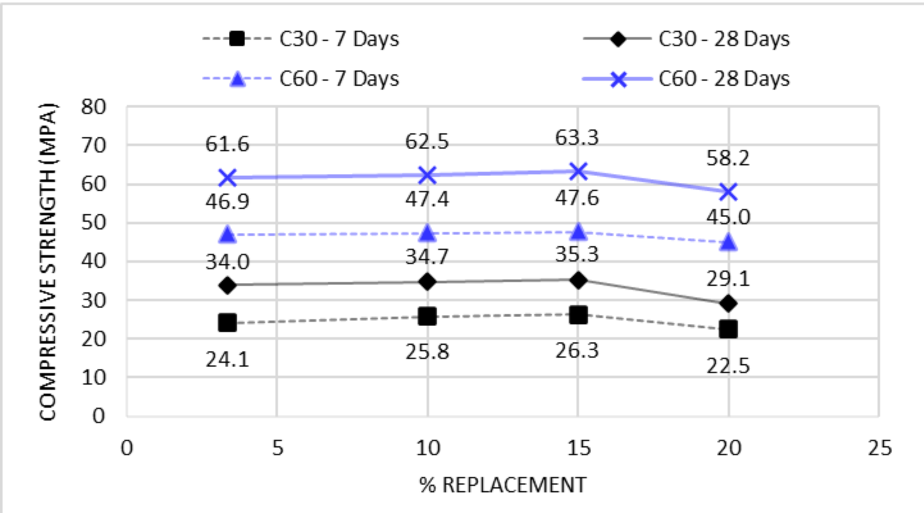

Figure 3. Variation of compressive strength with fines content

As shown in the above figure, the maximum compressive strength of both the grades have been achieved at 15% MSF replacement. Replacement of 20% fines showed negative effects on the compressive strengths of both the grades indicating that a 20% fines content is not an effective amount to be incorporated in both normal and high strength concrete. No sign of early strength gain at 7 days was observed in both the concrete grades. Increment of MSF had a similar effect on the compressive strength of both the C30 and C60 mixes, Since the 10% - 15% fines content produced effective compressive strength results, it could be considered as an effective fines percentage range for both normal and high strength concrete.

The reason for the increase in the compressive strength with the increase in MSF could be due to the filler effect of the fines. As discussed in Goldman and Bentur (1992), the addition of micro-fillers to the concrete significantly enhances the strength of the paste – matrix and also densifies the interfacial transition zone, thus improving the strength of the concrete.

The decrease in the compressive strength at the 20 % replacement can be explained in relation to the water film thickness and the high water demand that occurs due to the increased surface area with the availability of high fines content. As explained in Kwan and McKinley (2014), there lies an optimum water film thickness that corresponds to good strength properties. Due to the availability of high fines content, there would be a decrease in water film thickness due to the increased water demand as a result of the high surface area, thus leading to insufficient water to fill the voids. This would result in high air entrapment within the paste thus leading to a decrease in strength.

All in all, it could be identified that the effective MSF range to be used in NSC and HSC in relation to the compressive strength is 10% - 15%.

3.4 Splitting Tensile Strength

Figure 4 demonstrates the variation of the splitting tensile strength with the fines content.

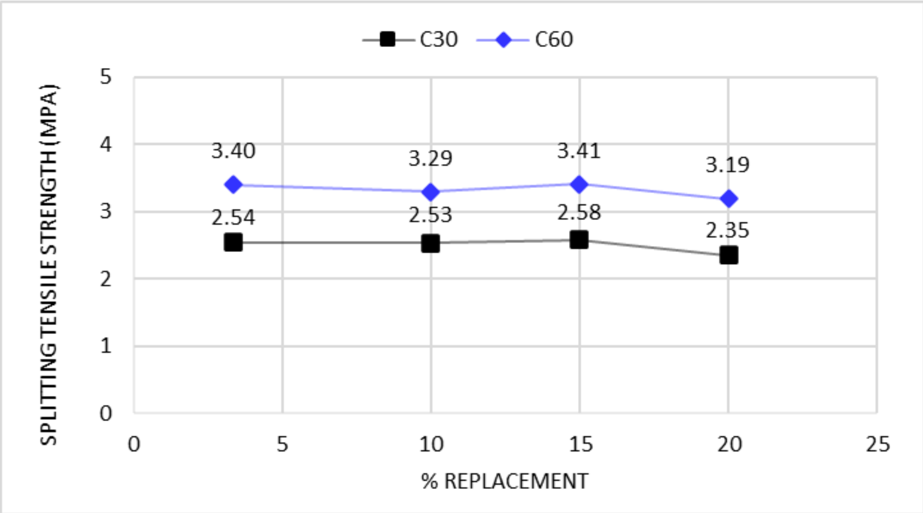

Figure 4. Variation of splitting tensile strength with fines content

The highest splitting tensile strength was observed at 15% fines replacement while the lowest was observed at 20% fines for both the C30 and C60 mixes. Increment of MSF appeared to have a similar effect on both the types of concrete. Though there was a slight drop in splitting tensile strength at 10% fines replacement in the C60 concrete, the drop did not appear to be significant and the 10% - 15% fines percentage could be considered as an effective range in terms of the splitting tensile strength for both the normal and high strength concrete.

3.5 Flexural Strength

Figure 5 illustrates the variation of the flexural strength with the fines content in C30 and C60 concretes.

The highest flexural strength was observed at 15% fines replacement for both the C30 and C60 mixes. Increment of MSF appeared to have a similar effect on both the types of concrete. However, the samples with 20% MSF had higher flexural strengths than the control mix. Availability of up to 20% fines content could be considered as an effective percentage in relation to the flexural strength of concrete.

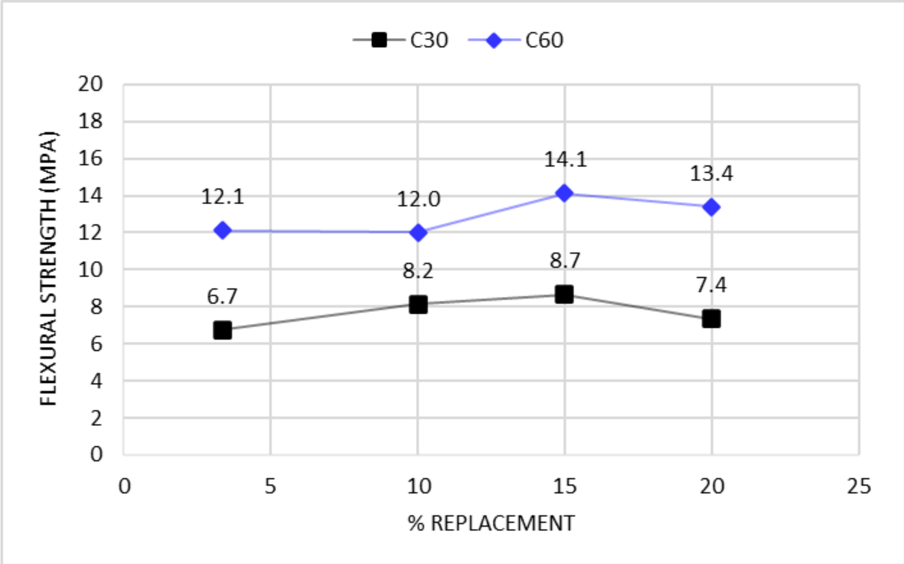

Figure 5. Variation of flexural strength with fines content

3.6 Water Absorption

Figure 6 shows the variation of water absorption with fines content in C30 and C60 concretes.

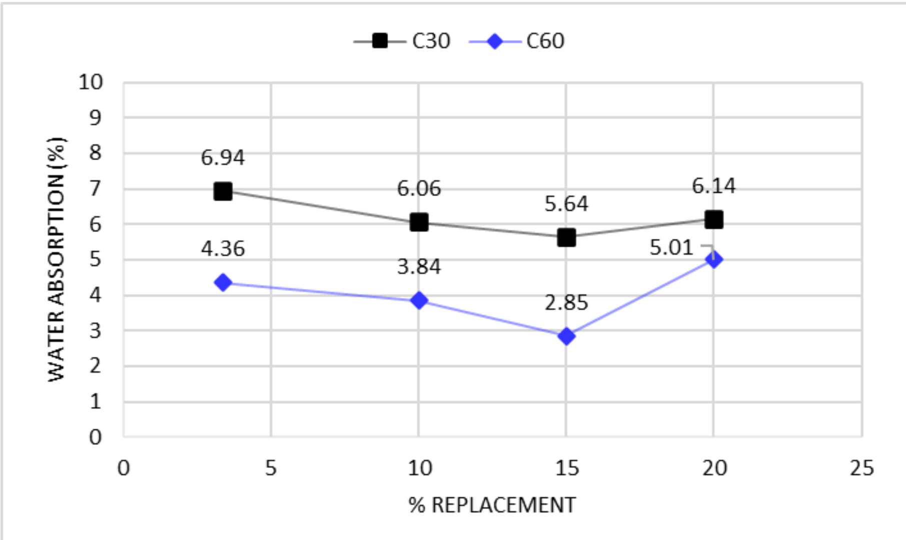

Figure 6. Variation of water absorption with fines content

As shown in Figure 6, both the concrete grades showed low water absorption at 15% fines content. Though there wasn't a significant difference in the water absorption in the C30 concrete at 10%, 15% and 20% fines content, there appeared to be a significant difference between the 10% - 15% range and 20% fines content in the C60 concrete. Therefore, 10% - 20% fines content for C30 concrete and 10% - 15% fines content for C60 can be considered as the effective ranges in terms of water absorption.

The decrease in water absorption could be due to the filler effect of MSF. The fines have decreased the porosity in the concrete, thus reducing the voids that can be filled with water which ultimately has reduced the water absorption of the concrete. Yang et al., (2018) has explained by microstructure studies that the fines fill the micro cracks and pores in concrete and thus reducing the porosity and densifying the microstructure. The increase in water absorption at 20% MSF replacement could be due to the domination of the high water demand over the filler effect which ultimately would increase the water absorption of the concrete. However, even with 20% MSF, the water absorption was less than the control mix.

3.7 Microstructure Study (Scanning Electron Microscope Analysis)

Concrete samples from the control mixes and the mixes with 15% MSF of the C30 and C60 concretes were used for this purpose.

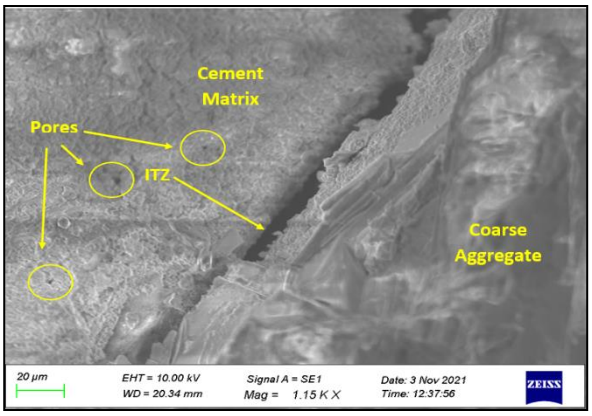

Figure 7. SEM image of C30 concrete with 3.36% fines content

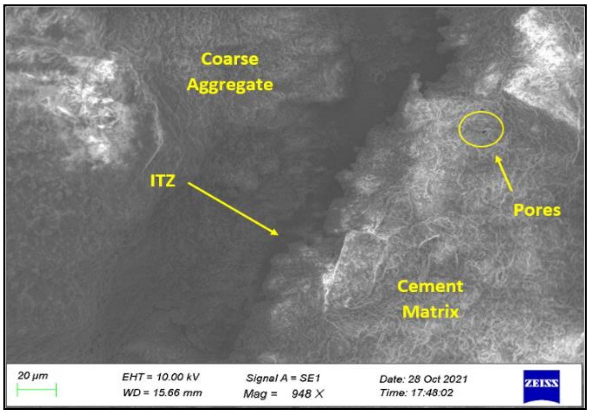

Figure 8. SEM image of C30 concrete with 15% fines content

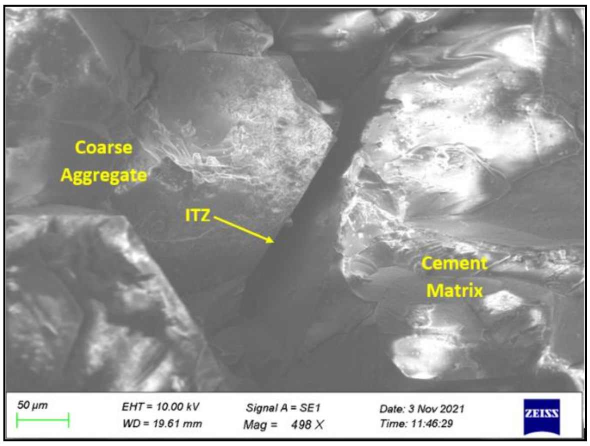

Figure 9. SEM image of C60 concrete with 3.36% fines content

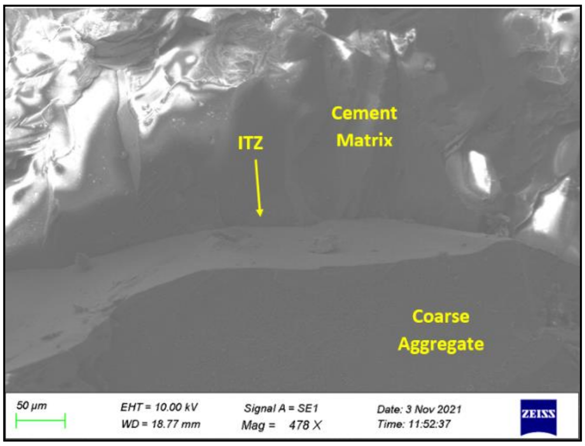

Figure 10. SEM image of C60 concrete with 15% fines content

By observing Figure 7 and Figure 8, it is evident that the concrete with 15% MSF had a dense microstructure. Less number of pores had developed in the mortar in the samples with 15% MSF compared to the control mix. This is likely due to the filler effect of fines that has made it possible to densify the microstructure by filling majority of the pores. No micro cracks had been developed, even close to the ITZ between the coarse aggregate and the cement mortar, which is an indication that the microstructure was dense enough to prevent the development of micro cracks. As observed in Figure 8 and Figure 10, it is evident that the ITZ between the coarse aggregate and the cement mortar of the C30 and C60 concretes had densified compared to the control mixes which showed that the MSF had contributed to densify the ITZ as well. Overall, it could be concluded that the concrete microstructure showed clear signs of densification with the introduction of MSF which justifies the reasons for the improved strength and low water absorption.

3.8 Cost Analysis

A cost analysis was performed in order to determine a cost-effective mix with effective concrete properties. The cost calculations were performed for 1 m^3 of the mixes of the C30 and C60 concretes. The variations in costs were expressed in the form of a ratio in proportion to the cost of the control mix. The main resource rates were obtained using the existing market prices, both locally and overseas. The variable in the cost was considered to be manufactured sand subjected to different washing rounds.

Manufactured sand that is double washed, single washed and non-washed were considered. The fines percentage ranges were as follows:

- Double washed manufactured sand: less than 10% fines
- Single washed manufactured sand: less than 15% fines
- Non - washed manufactured sand: greater than 15% fines

Key points in the cost analysis:

- Labour, tools/machinery and wastage costs were not included.
- The cost reduction depending on the washing trials was determined based on overseas prices and was considered to be 16.67%.

It should be noted the cost analysis was determined based on the cost ratio and the cost ratio is the ratio between the cost of concrete with a particular MSF to the cost of concrete of the control mix

The generated Cost Ratio vs Fines Replacement Percentage graph was the same for both C30 and C60 concretes. Figure 11 given below illustrates the graph.

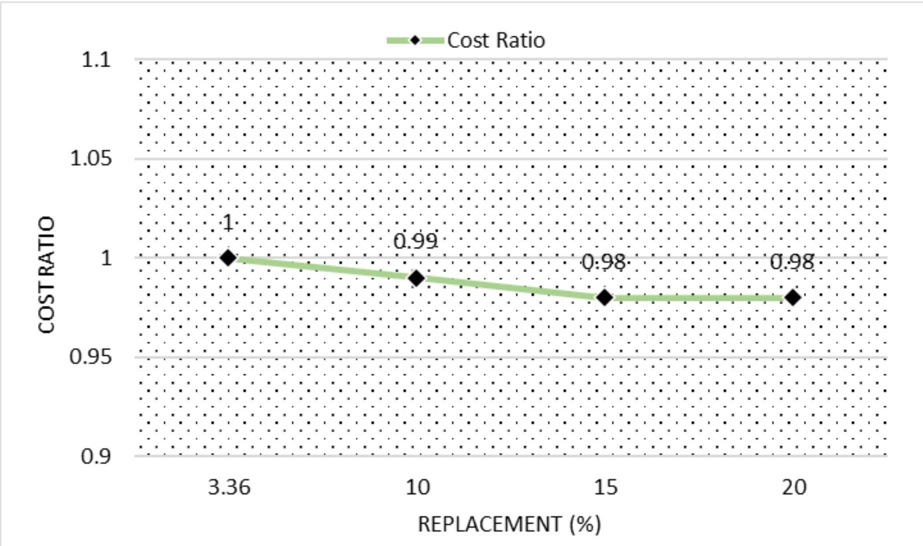

Figure 11. Variation of cost ratio with fines content

The reduction in costs compared to the control mix in C30 concrete was 0.98%, 1.8% and 1.8% at 10%, 15% and 20% replacements respectively. The reduction in costs compared to the control mix in C60 concrete was 0.88%, 1.6% and 1.6% at 10%, 15% and 20% replacements respectively. The least cost can be obtained when the fines replacement is 15% - 20%. Since both normal and strength concretes produced the most effective strength results at 10% - 15% MSF, the 10% - 15% fines content could be considered as the most effective fines percentage in manufactured sand, strength and cost wise.

4 CONCLUSION

The research study was conducted to study the effects of manufactured sand fines on the properties of normal and high strength concrete. Partial replacement of manufactured sand by fines was done at 10%, 15% and 20% and the test results were compared with the control mix that contained 3.36% fines. Grade 30 and Grade 60 concrete were casted to study on the normal and high strength concretes respectively.

Fresh and hardened concrete properties were tested to study the effects of fines. Mixes with 15% fines content produced effective results in both the concrete grades. Mixes with 15% fines content had 3.82%, 1.57% and 15.53% higher compressive, tensile and flexural strength results than the control mix respectively in the C30 concrete. C60 concrete with 15% fines content had 2.76%, 0.29% and 22.99%

higher compressive, tensile and flexural strength results than the control mix respectively. Water absorption of the specimens with 15% fines content was 18.73% and 34.79% lower than the control mixes in the C30 and C60 concretes respectively. The increment of fines showed negative effects on the concrete properties beyond 15% fines content in most of the properties. However, the slump of both the concrete grades decreased with the increment in fines indicating that the fines had detrimental effects on the workability of the concrete.

The microstructure analysis on the concrete with 15% fines showed a dense microstructure with minimal pores and dense interfacial transition zones which confirmed that the fines acted as a filler material and thus contributed to densifying the microstructure.

It was identified from the cost analysis that incorporating about 15% fines can reduce the cost of C30 concrete by 1.8% and C60 concrete by 1.6%. This concluded that cost effective MS concrete can be produced by using high MSF.

All in all, a 10% - 15% fines replacement range appeared to be an effective replacement range in both normal and high strength concrete. Concrete with high fines content can not only generate concrete with better properties, but also reduce the unnecessary costs in washing manufactured sand and reduce the environmental issues that arise due to the dumping of the washed fine sand in landfills. Recommendations for future research would be to study the effect of manufactured sand fines on ultra-high strength concrete, to study the effects of chemical admixtures on MS concrete with high fines content, to study on the effects of MSF on the durability properties of HSC and to research on the effects of blended fines on the properties of manufactured sand concrete.

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