Investigating the Appropriateness of the Adoption of Mai Mahiu Fine Aggregate for Use in Concrete

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Abstract

Scarcity of natural resources has broadened the interest in alternatives to conventional materials used in concrete production.

The key aim of studying the various properties of concrete is to allow a choice to be made of the appropriate mix constituents. However, an attempt has to be made to balance the necessity of quality control vis-à-vis the economics and environmental consideration of producing concrete. This has seen in the recent years an attempt to replace the use of river sand as fine aggregate.

In certain parts of Nairobi, especially in Eastlands, and in Nakuru County a more economical material is being used as a substitute for river sand. Locally and commonly called "Mchanga ya Mai Mahiu" which can be referred to as Mai Mahiu fine aggregate.

The study of Mai Mahiu fine aggregate has thereby grown out of the recognition that it is commonly being used in construction in certain parts of Kenya. This requires a diligent inquiry and critical examination of its effects on the strength, workability of concrete and to make inferential comments on the rheology of concrete therein.

Silt and fine dust should not be present in large proportions owing to their fineness and therefore large specific surface (Neville, 1981). They form surface coatings which hinder the bond between cement and aggregate thereby lowering the strength of concrete. Moreover, they increase the amount of water necessary to wet all the ingredients in the mix proportion. In lieu of these effects, a study was conducted on the effects of silt and fine dust in Mai Mahiu fine aggregate using river sand for comparison. The properties of concrete under scrutiny are strength and workability.

This study will serve as a reference in concrete production and quality control of Mai Mahiu fine aggregate and river sand in Kenya with regard to the amounts of silt and fine dust in fine aggregates and their effects thereof on strength and workability.

To cater for various deposits, the silt content was varied in the fine aggregates through sieving on BS sieve number 200.

Key words: Mai Mahiu fine aggregate, Strength, Silt content, Workability

Introduction

Rivers all over the world are under intense pressure due to anthropogenic activities; such indiscriminate extraction of sand puts the river ecosystem at a very high risk of deterioration (Kondolf, 1994).

To address the problem in Kenya, in 2007 NEMA came up with National Sand Harvesting Guidelines. They are to ensure sustainability and proper management of the environment.

Due to environmental degradation and the resulting policy restraints, the price of river sand is becoming more and more competitive. This has led to the need for alternative sources of fine aggregates.

In the suburbs of Nairobi City, Nakuru Town and Naivasha Town a different type of fine aggregate is being used for construction. It is from Naivasha more specifically coming from Mai Mahiu to fill the void in the market.

It is cheaper compared to the price of river sand.

The purpose of this study is to investigate the suitability in terms of strength and workability of the adoption of Mai Mahiu fine aggregate as a constituent of concrete and to provide measures to counter the adverse effects of its high silt content.

River sand will be used as a control to compare the phenomena under scrutiny.

Mai Mahiu fine aggregate is widely being used in parts of Nairobi and Rift Valley province. This study is to investigate its properties in order to enable prediction of its use in concrete.

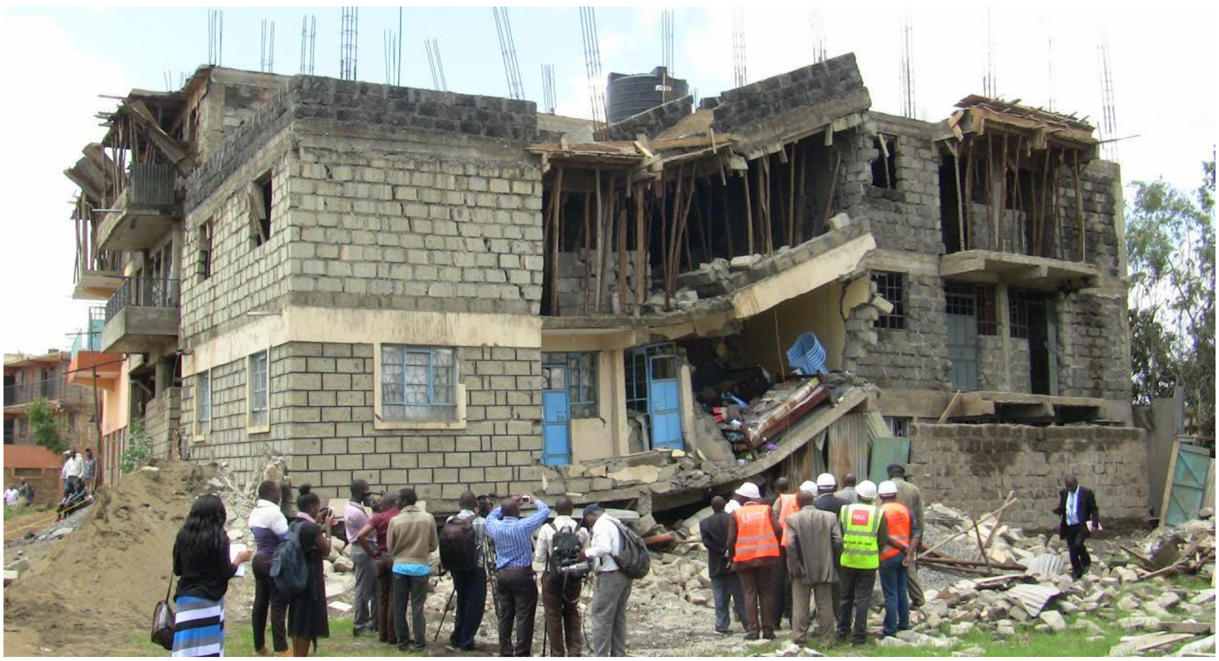

Plate 1: the debris of the building that collapsed in Kimbo area Juja Sub-County on 25th November 2016

Speaking in Kimbo, Moses Nyakiongora, the secretary of the National Buildings Inspectorate claimed that Mai Mahiu fine aggregate did not bond well to form concrete leading to the collapse in Plate 1(www.thikatown.co.ke/2016/11/). It can be seen that people had already moved into the building. This is extremely dangerous. The fine aggregate can be seen heaped on the bottom left side of the photograph.

This study will enable understanding of the fine aggregate to avoid such conditions as illustrated in Plate 1.

By visual inspection and physical touch, Mai Mahiu fine aggregate has a lot of silt content compared to river sand.

The high silt content would most likely affect the strength as they will result in formation of surface coatings which will hinder the bond between cement and aggregates thereby lowering strength.

Furthermore, the higher specific surface will increase the water requirement of the concrete resulting in a significant decrease in workability. If this is the case, then an attempt to increase the workability on site may compromise strength as a result of increased water to cement ratio.

Both Mai Mahiu fine aggregate and river sand will be studied at different silt contents.

Methodology

Variation of the silt content was achieved by complete removal of silt through sieving over BS sieve No.200 with an aperture size of 75microns. BS sieve No.16 with an aperture size of 1.19mm was used as a nesting guard to protect the sieve No.200 from damage.

Plate 2 : River Sand without Silt and Fine Dust

Plate 3 : Silt and Fine Dust Extracted from River Sand

Plate 4 : Mai Mahiu Fine Aggregate without Silt and Fine Dust

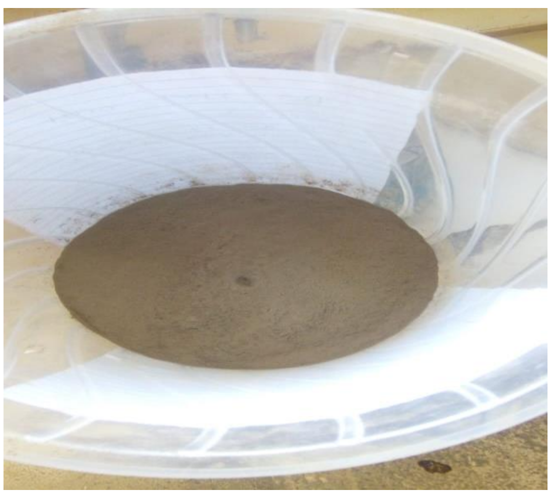

Plate 5 : Silt and Fine Dust Extracted from Mai Mahiu Fine Aggregate

Afterwards, the silt content was reintroduced at controlled quantities as percentages of the mass of fine aggregates to be used in the respective mix proportions.

The percentages were 0, the field silt content of the sampled Mai Mahiu fine aggregate and at 20% of the total weight of fine aggregates.

The smallest size visible to the human eye is 50microns (www.nilfiskcfm.com). Silt and fine dust are particles less than 75microns in size. Accepting the human limitation in identifying these particles, a method had to be employed to check the efficiency of silt removal.

A sample weighing 200g from the fine aggregate that had been retained on BS sieve No.200 was taken. The sample was then washed through BS sieve 200 to get rid of any remaining silt and fine dust. The washed sample was then oven dried for 24hours at a temperature of 105℃ and weighed.

The accuracy of removal of silt and fine dust as a percentage was calculated as:

$$\frac{\text{Washed fine aggregate that had previously been retained on sieve No. 200}}{\text{Original unwashed fine aggregate retained on sieve No. 200}} \times 100\%$$

The values were as follows:

1. River sand :

$$\frac{197.8}{200} \times 100\% = 98.9\%$$

2. Mai Mahiu Fine Aggregate

$$\frac{196.9}{200} \times 100 = 98.5\%$$

Since the amount of silt left after agitating the sample over BS sieve number 200 is small compared to the sample size, it was assumed that silt was completely removed before being reintroduced in the desired controlled percentages.

For the test samples, concrete class 30 was selected according to the Code of Practice CP 110: 1972 where the margin between the characteristic strength and mean strength is at least 7.5Mpa. Therefore, the target mean strength for the control mix proportions with the fine aggregates having zero percent silt and fine dust content is 37.5Mpa.

Results and Discussions

Table I: Sieve Analysis for the sample of River Sand used

River Sand 500g

	Retained		**Cumulative**		
Sieve (mm)	Retained Weight (g)	Percentage Retained (%)	Cumulative Weight(g)	Cumulative Percentage Retained (%)	Percentage Passing (%)
9.51	0.00	0.00	0.00	0.00	100.00
4.76	5.42	1.08	5.42	1.08	98.92
2.36	21.97	4.39	27.39	5.48	94.52
1.19	80.12	16.02	107.51	21.50	78.50
0.55	155.62	31.12	263.13	52.63	47.37
0.295	164.44	32.89	427.57	85.51	14.49
0.149	51.12	10.22	478.69	95.74	4.26
0.075	11.58	2.32	490.27	98.05	1.95

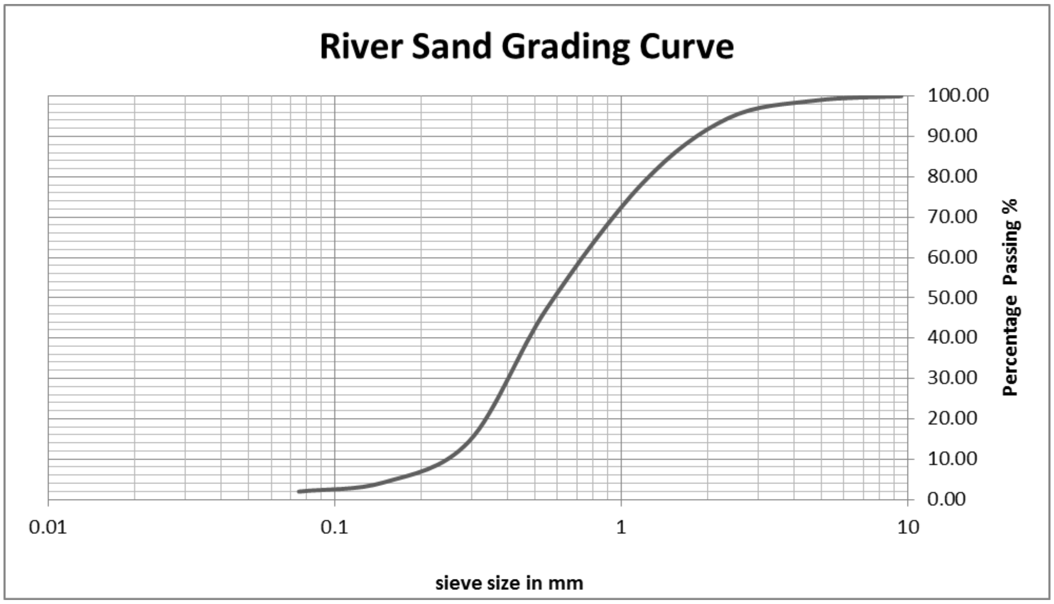

Figure 1: Grading Curve for River Sand

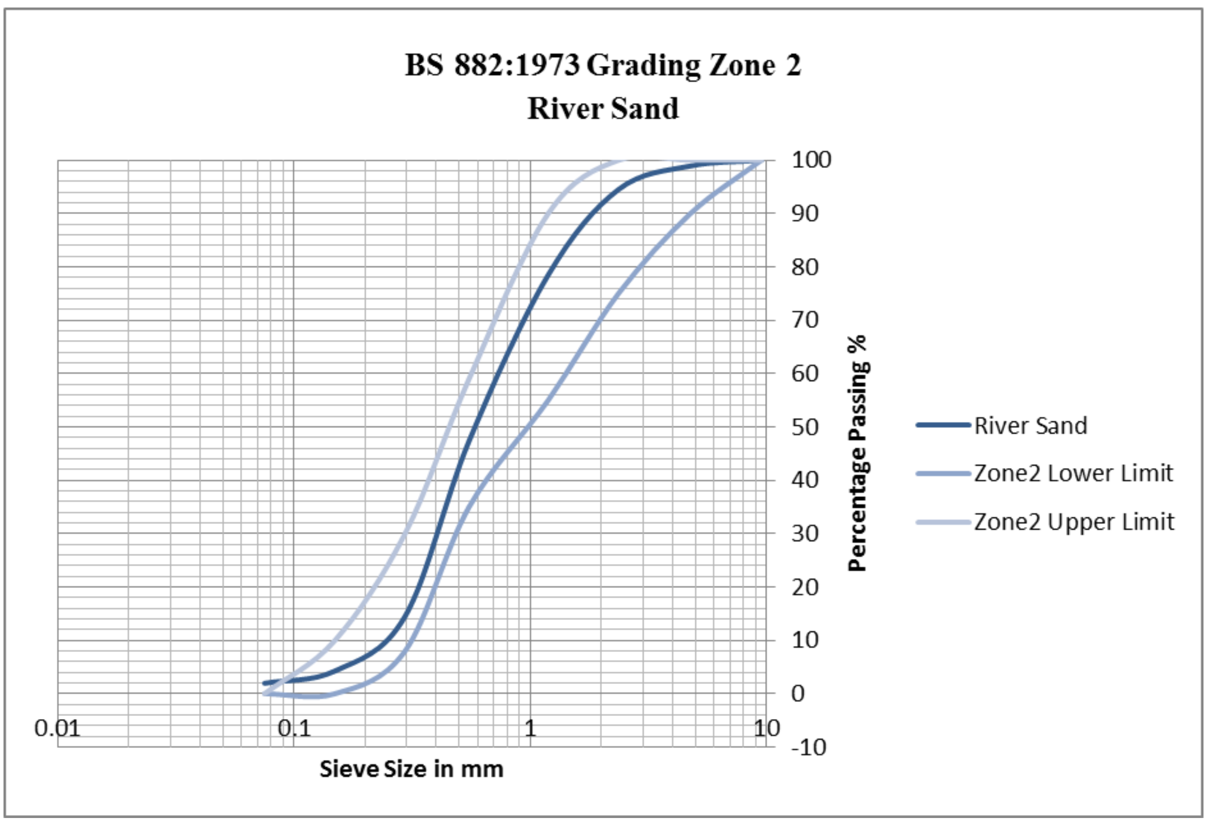

Figure 2 : River Sand Falling within Zone 2 of BS 882:1973

A large number of sand naturally divides itself above and below 600microns, being approximately uniform above and below this size. Moreover, the amount of particles less than 600microns in size have a significant influence on the workability of the mix proportion and provides a fairly reliable index on the specific surface of fine aggregates (Neville, 1981).

This is the case with the sample of river sand used in this study, from the sieve analysis 52.63% is above 600microns while 47.37% is below this value.

The river sand used in the experiment falls within Zone 2; it represents medium sand generally suitable for the standard one to two ratio of fine and coarse aggregate when the maximum size of aggregate is 20mm (Neville, 1981).

The percentage of silt and fine dust in the sample of river sand is 1.95%.

Table II: Sieve Analysis for Mai Mahiu Fine Aggregate

Mai Mahiu Fine Aggregate 500g

	Retained		**Cumulative**		
Sieve (mm)	Retained weight (g)	Retained Percentage (%)	Cumulative weight(g)	Cumulative Percentage Retained (%)	Percentage Passing (%)
9.51	0	0	0	0	100
4.76	1.4	0.28	1.4	0.28	99.72
2.36	18.3	3.66	19.7	3.94	96.06
1.19	54.2	10.84	73.9	14.78	85.22
0.55	106.55	21.31	180.45	36.09	63.91
0.295	124.22	24.84	304.67	60.93	39.07
0.149	57.34	11.47	362.01	72.4	27.6
0.075	76.2	15.24	438.21	87.64	12.36

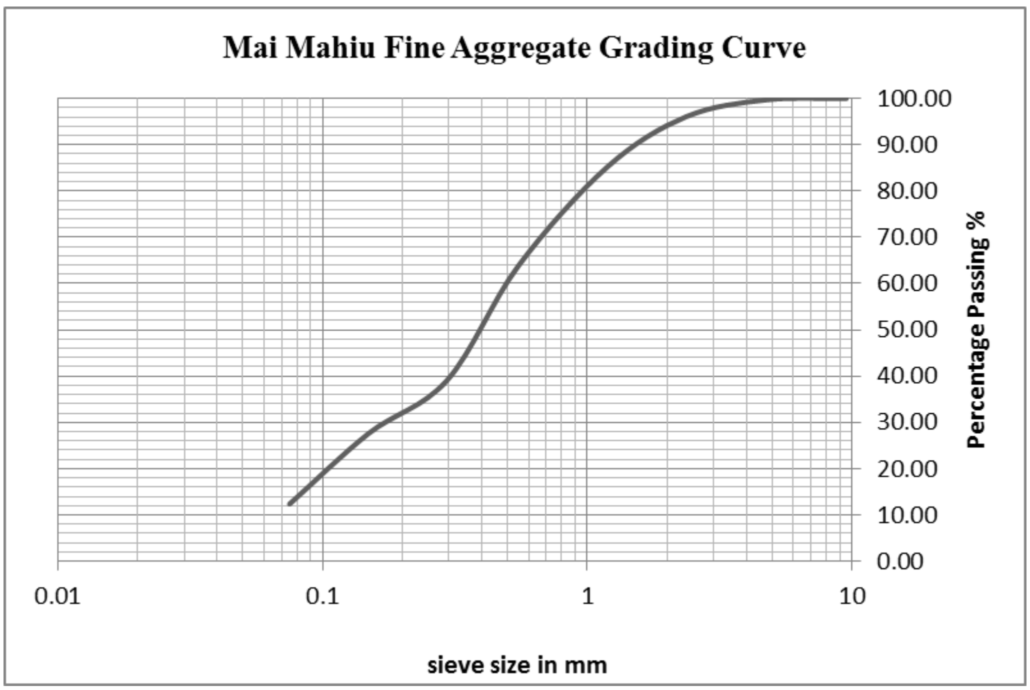

Figure 3 : Grading Curve for Mai Mahiu Fine Aggregate

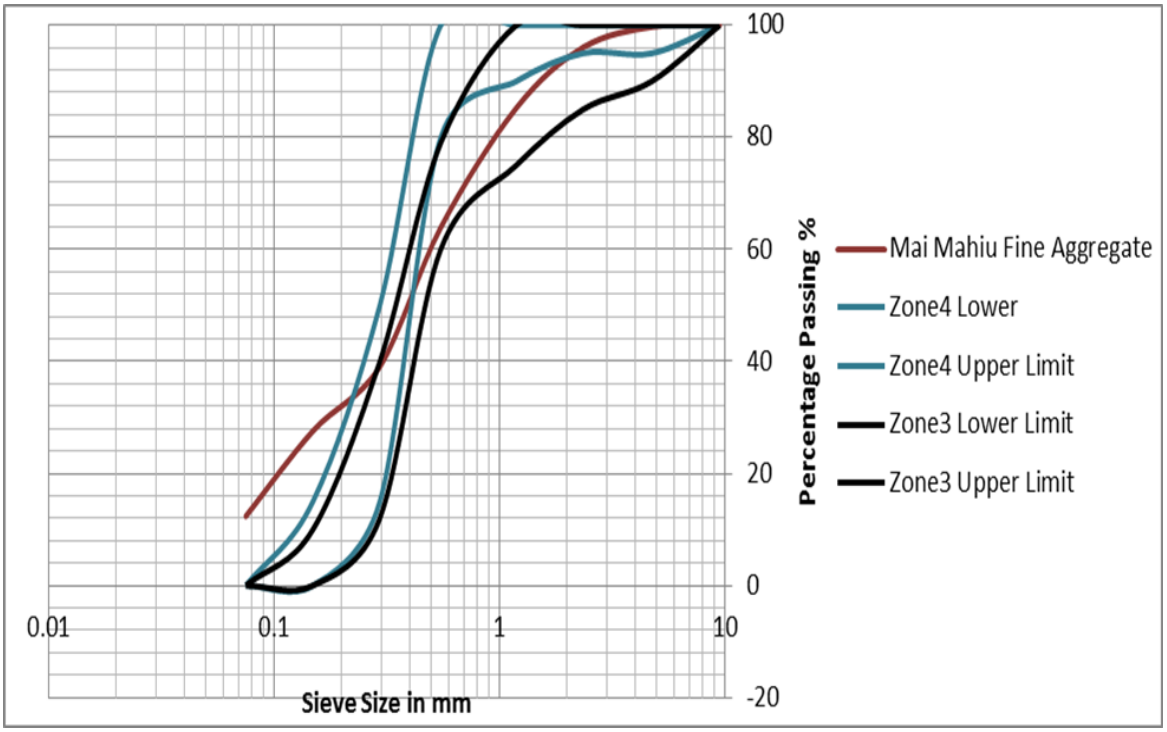

Figure 4 : trying to place Mai Mahiu Fine Aggregate in BS 882: 1973 Zones

It is difficult to place Mai Mahiu fine aggregate in the zones provided in BS882:1973.

This is not surprising since the zones are for river sand which have their particles almost uniformly distributed above and below 600microns.

However, as seen in the sieve analysis 63.91% are below 600microns and 36.09% is above 600microns. This gives an indication that Mai Mahiu fine aggregates consists of finer particles.

Furthermore, suggesting it has a higher specific surface than river sand.

Part of it falls within zone 3, 60%, while some of it, 25%, falls within zone 4 but overlaps into zone3 partially.

The silt and fine dust content is high, 12.36%, when compared to the 1.95% of river sand. It is six times higher in silt and fine dust content.

Fineness Modulus of Mai Mahiu Fine Aggregate

$$\frac{0.28 + 3.94 + 14.78 + 36.09 + 60.93 + 72.40}{100} = 1.88$$

The average size of the Mai Mahiu Fine Aggregate is 1.88mm; it does NOT falls within the range of 2.3 and 3.1 recommended for fine aggregates by AASHTO-M6 and adopted by the Ministry of Transport & Infrastructure in Kenya**.**

Specific Gravity of Mai Mahiu Fine Aggregate

$$G_S = \frac{82.36 - 67.03}{(182.83 - 67.03) - (191.41 - 82.36)}$$

$$G_S = 2.27$$

The value is between 2.00 and 2.45 which are characteristic of pyroclastic material of volcanic origin. This is the case of the Rift Valley which is historically known to have been volcanically active. Mai Mahiu fine aggregate is mainly from the Rift Valley Region of Kenya.

For both river sand and Mai Mahiu fine aggregates, a similar mix proportion was adopted and variations made only on the silt content as a percentage of the total weight of the fine aggregates. The variations were:

1. 0% amount of silt and fine dust
2. 12.36% amount of silt and fine dust (which is the percentage of the amount of silt found in the test sample of Mai Mahiu fine aggregate).
3. 20% amount of silt and fine dust.

Summary of Mix Proportions

1. 0% silt and fine dust

Table III: Mix Proportion for 0% Silt Content

Water to cement ratio :0.45		Tested at: UON Laboratory		Description of Concrete : Class 30	Additive	Cement			
Design Mix	Total Water	20mm maximum size coarse agrregate	10mm maximum size coarse agrregate	Total Fine Aggregate	Sikament NNG	Nguvu 32.5N	Fine Aggregate without Silt	0% Silt and Fine Dust	Total
Design Batch Weight kg/m^3	202.5	600	500	450	5	450	450	0	2207.5
Design Batch Weight for a volume 0.025m^3	5.06	15.00	12.50	11.25	0.13	11.25	11.25	0.00	55.19

2. 12.36% silt and fine dust

Table IV: Mix Proportion for 12.36% Silt Content

Water to cement ratio :0.45		Tested at: UON Laboratory		Description of Concrete : Class 30	Additive	Cement			
Design Mix	Total Water	20mm maximum size coarse agrregate	10mm maximum size coarse agrregate	Total Fine Aggregate	Sikament NNG	Nguvu 32.5N	Fine Aggregate without Silt	12.36% Silt and Fine Dust	Total
Design Batch Weight kg/m^3	202.5	600	500	450	5	450	394.38	55.62	2202.5
Design Batch Weight for a volume 0.025m^3	5.06	15.00	12.50	11.25	0.13	11.25	9.86	1.39	55.06

3. 20% silt and fine dust

Table V: Mix Proportion for 20% Silt Content

Water to cement ratio :0.45		Tested at: UON Laboratory		Description of Concrete : Class 30	Additive	Cement			
Design Mix	Total Water	20mm maximum size coarse agrregate	10mm maximum size coarse agrregate	Total Fine Aggregate	Sikament NNG	Nguvu 32.5N	Fine Aggregate without Silt	20% Silt and Fine Dust	Total
Design Batch Weight kg/m^3	202.5	600	500	450	5	450	360	90	2202.5
Design Batch Weight for a volume 0.025m^3	5.06	15.00	12.50	11.25	0.13	11.25	9.00	2.25	55.06

Compressive Strength and Slump Test

Six cubes of 150mm were prepared whereby three were crushed for 7-day strength and the remaining three for 28-day strength. The slump test of each mix proportion was done.

0% Silt and Fine Dust Content

The results of compressive strength and slump tests were as follows:

1. River Sand

Mean 7-Day Strength=24.30Mpa

Mean 28-Day Strength=35.26Mpa

Slump=170mm

2. Mai Mahiu Fine Aggregate

Mean 7-Day Strength=25.19Mpa

Mean 28-Day Strength=41.93Mpa

Slump=160mm

At 0% silt content, the 28-day compressive strength of Mai Mahiu fine aggregate (41.93Mpa) is higher than that of river sand (35.26Mpa). The targeted mean strength according to the Code of Practice CP 110: 1972 was 37.5Mpa.

This is mainly attributed to the larger specific surface of the particles of Mai Mahiu fine aggregate which result in an increase in water requirement resulting to a decrease in the effective water to cement ratio in the concrete.

The 7-Day strengths were 68.92% and 60% of the 28-day strengths for river sand and Mai Mahiu fine aggregate respectively.

The Code of Practice CP114 used to accept 7-day strength equal to not less than 66% (two-thirds) of the required 28-day strength.

12.36% Silt and Fine Dust Content

The results of compressive strength and slump tests were as follows:

1. River Sand

Mean 7-Day Strength=24.30Mpa

Mean 28-Day Strength=24.44Mpa

Slump=0mm

2. Mai Mahiu Fine Aggregate

Mean 7-Day Strength=30.81Mpa

Mean 28-Day Strength=29.78Mpa

Slump=0mm

At 12.36% silt content the 7-day strengths were 24.30Mpa and 30.81Mpa for river sand and Mai Mahiu fine aggregate respectively. These values are almost similar to the 28-day strength values which were 24.44Mpa and 29.78Mpa for river sand and Mai Mahiu fine aggregate respectively.

This can be interpreted to mean that at 7 days the hydration process had stopped and there was no further gain in compressive strength.

There is also a decrease in strength and slump when compared to the values at 0% silt content. This can be attributed to the formation of surface coatings from the increased amount of silt that hinder the bond between cement and aggregates, lowering compressive strength. They also consume more water significantly reducing the slump to zero.

20% Silt and Fine Dust Content

The results of compressive strength and slump tests were as follows:

1. River Sand

Mean 7-Day Strength=21.48Mpa

Mean 28-Day Strength=26.37Mpa

Slump=0mm

2. Mai Mahiu Fine Aggregate

Mean 7-Day Strength=1.93Mpa

Mean 28-Day Strength=2.07Mpa

Slump=0mm

At 20% silt content, taking into consideration that mixing fresh concrete uniformly becomes difficult due to the increased shear strength of the fresh concrete (a rheological parameter) and any other sources of error, it would be prudent to conclude the compressive strength of river sand is close to that at 12.36%.

However, for Mai Mahiu fine aggregate there is a significant drop in strength to 2.07Mpa.

In summary the 28-day strength of river sand began at 35.26Mpa and drop to 26.37Mpa. The slump dropped from 170mm to zero.

The 28-day strength of Mai Mahiu fine aggregate began at 41.93Mpa and dropped to 2.07Mpa. The slump dropped from 160mm to zero.

Conclusions

At zero percent silt content Mai Mahiu fine aggregate had a considerably high value of strength and slump. It had 41.93Mpa which was higher than 35.26Mpa for river sand. The workability of the two mix proportions at zero percent silt content can be concluded to be similar, 170mm and 160mm for river sand and Mai Mahiu fine aggregate.

However, at the silt content at the natural state of Mai Mahiu fine aggregate (12.36%) demonstrates that the hydration process had stopped by the seventh day of crushing the cubes since this strength was similar to that of the 28-day strength.

There was a drop of 11Mpa in strength when compared to the sample at zero percent silt content. Measuring the workability using slump test at this stage was difficult since slump had dropped to zero.

For river sand at 12.36% silt content, the hydration process had also ended by the seventh day when cube crushing was done. Furthermore, the compressive strength had also dropped by 11Mpa when compared to the value at zero percent silt content, from 35.26Mpa to 24.44Mpa.

At twenty percent silt content there was nearly complete loss of compressive strength for Mai Mahiu fine aggregate, the 28-day strength was 2.07Mpa. River sand faired on much better, the 28-strength at 20% silt content was very close to the 28-day strength when the silt content was 12.36%.

Mai Mahiu fine aggregate is suitable for adoption in concrete when it is at zero percent silt content. In actual sense, it even performed better than river sand since it exceeded the target mean strength of 37.5Mpa by 4.4Mpa. River sand fell short of the target by 2.24Mpa.

Both fine aggregates had almost similar workability, 170mm and 160mm, which is very high and easy to pump and compact on site.

However, Mai Mahiu fine aggregate performs very poorly in terms of strength and workability at its field silt content and beyond the field silt content value.

Recommendations

a) Washing of Mai Mahiu Fine Aggregate

Mai Mahiu fine aggregate performs very well in terms of strength and workability at zero percent silt content. In Kenya, quarry dust normally gets washed before being used in concrete. Mai Mahiu fine aggregate should also receive a similar treatment before being used in producing concrete to avoid incidents as the one shown in Plate 1 where a building collapsed.

b) Use of Superplasticizers

In Kenya, adoption of superplasticizers is only done by producers of ready mix concrete who mostly operate within the capital, Nairobi City. In other parts of Kenya where concrete is made in-situ, there is hardly any use of superplasticizers.

Using water-reducing admixtures can prevent occurrence of the situation where too much water is added in an attempt to improve on workability of the concrete.

c) Adding Water

It is seen in the study, at the natural silt content of 12.36% that the hydration process had stopped by the seventh day of crushing the cubes. Table VI (Neville, 1981) guides on how much water needs to be added in the mix proportions prepared in the study.

Table VI: Relative Mixing Water Requirements for Concrete with different Workability

Description	Workability				Relative value of water content per cent
	Slump		Vebe time s	Compacting factor	
	mm	in.			
Extremely dry	—	—	32–18	—	78
Very stiff	—	—	18–10	0.70	83
Stiff	0–25	0–1	10–5	0.75	88
Stiff plastic	25–75	1–3	5–3	0.85	92
Plastic (reference)	75–125	3–5	3–0	0.90	100
Flowing	125–175	5–7	—	0.95	106

Table VI takes values with slump between 75 to 100mm as reference values. It then assigns 100% to those reference values of water requirements. For zero slumps, it can be seen that the amount of water should be increased within the range of 12 to 22% to achieve a slump of 75 to 100mm.

To achieve the slump of 160mm or 170mm found during the test when the silt content was at zero percent, water should be increased in the range of 18 to 28%.

d) Rheological Parameters of Concrete

In all the mix proportions where slump was found to be zero, it is preposterous to assume they had the same workability.

Kenya should begin adopting use of rheometers and viscometer in order to provide a good measure of the workability of concrete.

Acknowledgement

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