STRENGTH ASSESSMENT OF YOYO SAND CONCRETE PAVING STONES

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ABSTRACT

This paper reports the results of an investigation of strength assessment of interlocking paving stones using Yoyo sand either wholly or as a partial replacement of river sand in concrete. 270 Nos of "double T" shaped concrete paving stones, (Thickness = 60mm; Area=29587m^2) with varying mix ratio of Yoyo/ Natural river sand were tested. The mix ratios used were 1:2:4 and 1:3:6 with corresponding ratio of 0.65 and 0.75 respectively. The percentage content of Yoyo sand in the fine aggregate was varied from 0 to 100% in steps of 25%.

The results of the investigation showed that the presence of Yoyo sand in the concrete increased the strength characteristics compared to natural river sand. However, 50% replacement of river sand by Yoyo sand should be avoided as there was abnormal behaviour in this grade. Also, early development of compressive strength by Yoyo sand makes it a better choice over river sand in the production of paving stones. The compressive strength result shows that 1:2:4 mix ratio with = 0.65 can be used for light traffic pavers while 1:3:6 mix ratio with = 0.75 can only be suitable for walkway pavers. Yoyo sand can therefore be considered as a better total or partial substitute for river sand in paving stones production.

Keywards: *Yoyo sand, concrete paving stone, double T-shaped, strength, mode of failure.*

INTRODUCTION

Interlocking concrete paving stones have been in existence for many years. In Nigeria, Guffanti Construction Company started the production of rough interlocking paving stones mainly for road constructions about 30 years ago. HFP Engineering Company later started the same rough interlocking paving stones used. Capimpex Nigeria Limited started the production of smooth interlocking paving stones few years ago and the stones are widely used for walkways, parking lots, driveways, petrol stations, access roads, estate roads, etc.
In recent time, the use of concrete interlocking pavement has increased. This can be witnessed on some major streets and roads in Lagos State metropolitan areas, such as Adeola Odeku, Engineering Close, Idowu Taylor street Ademola Adetokunbo and Adeogun Streets.

Several symposia held by UNESCO's Advisory Committee for Humid Tropics Research, the United Nation's General Assembly and the International Symposium for the Industrial Development in 1969, resolved that "Developing countries should take all necessary measures to develop their sources of construction material to the maximum".

This has motivated the various research institutions and researchers to embark on the task of finding and developing possible local building and construction materials within the localities.

Parikh (1) showed that replacement of 35% of regular sand with crushed core sand.

Ghafoori et al(8) also discovered that concrete containing 50% bottom ash of the total dry volume of natural fine aggregate exhibited compressive strength and depth of wear identical to that of PCC as given by American Coal Ash Association(9) and, Tyson and Blackstock(5).

Recent researches showed the possibility of a new type of fine aggregate, different from lateritic material, generally referred to as "Yoyo" sand. Yoyo sand occurs in commercial quantity in the South-Western States of Nigeria. It may also occur abundantly in other parts of tropical regions of the world with the same geological formations as the South-Western States. It is mined from the ground and normally very close to locations where laterite is mined. It differs from the conventional river sand by its colour which could be pink or yellowish and it is most likely of lateritic origin, though containing less than 10% clay.

According to Wroth and Houlsby (10), it was observed that real soil rarely consists exclusively of either sand or clay fraction and it only requires a relatively small fraction, say 10-15%, of clay to make behaviour of sandy soil like that of a clay. It is therefore, necessary to determine the clay content of any fine aggregate for its suitability in concrete production

Series of researches have commenced on the use of Yoyo sand either for partially or wholly replacement of normal river sand in concrete, block wall or brick wall making.

Sadiq et al. (11) investigated the suitability of "Yoyo" sand concrete for structural use. They concluded that:

- Yoyo sand has a density more than 2400kg/m^3, moisture content of about 4%, silt content of less than 10%.
- There exists a consistent pattern of strength-age curves for concrete with normal and Yoyo sand content, though Yoyo sand concrete exhibited higher strength at 28 days compared to the corresponding river sand concrete. There was early strength development; about 60% of 28 days strength was observed at 7 days in all mixes.
- For a given mix proportion the

compressive strength does not increase appreciably with increase in Yoyo sand content. However, the highest strength was exhibited by mix proportion of 2:3:6 by weight with water/cement ratio of 0.55 for 100% Yoyo sand fine aggregate.

- The introduction of reinforcements improved the flexural strength, ductility and post cracking behaviour of beams with different percentage of Yoyo sand content. However, the effect of increase in strength is more pronounced in Yoyo sand than in normal sand beams.

In general, they concluded that the presence of Yoyo sand in concrete increased the strength characteristics compared to normal river sand. Hence, it can be considered as a total or partial substitute for river sand in concrete for load bearing structural members.

However, very little or nothing is known yet about the use of Yoyo sand in interlocking concrete paving stones..

1.1 Principal Components of Inter Locking Concrete Pavement System and Uses

The principal components of interlocking concrete pavements are shown in Figure 1. They include base materials, pavers (paving stones), bedding sand, jointing sand, sealer, geotechnical fabric and edge restraints. The pavers come in many sizes, shapes, and colours to enhance the architectural flavour of the pavement. The pavers are generally bedded on 25 to 40 mm of high quality bedding sand, with a high quality sand used for infilling of the joints between the pavers. The jointing sand allows the pavers to interlock and structurally function as one durable layer.

Paving stone systems can be used for light, medium and heavy-duty pavements in residential, commercial, industrial or municipal applications. In Nigeria, the present predominant use of interlocking pavements is in the residential and architectural segments, but as of recent, it is used for road paving (see Plates 1-3).

The acceptance of pavers in this area has contributed to the growing use of pavers as an alternative to asphalt and cast in place of concrete in other applications. Although, aesthetic appeal has a great influence on their use, they are recognized load-carrying pavements with a ride quality and favorable safety characteristics.

1.2 Advantages of Using Interlocking Concrete Paving Stones

The architectural advantages of interlocking concrete paving stones are readily apparent. With their small size, colour and shape varieties, they offer a warmth and human scale that is difficult to achieve with conventional concrete and asphalt. They are a perfect complement to almost any architectural style. Concrete pavers can be installed in a variety of patterns including curves, straight lines, intricate designs, and this thereby add vitality to almost any environment.

Being manufactured from high strength, low absorption concrete, the pavers are very resistant to freeze-thaw cycles and de-icing chemicals. High temperatures, moisture, petrochemicals or point loads do not damage them. They offer high frictional resistance. They arrive on the job as a finished product, and require no curing, allowing traffic immediately after installation. Year round construction is possible using pavers. If paving stones must be removed in order to correct pavement distress, or to allow utility repair, the units are completely reusable and recyclable.

Paving stones have a proven record of long-term performance under heavy loads in industrial and port applications. They provide high resistance to abrasion and point loads that are common to these applications. Often industrial and port pavements are built on sites that have poor soil conditions. These soils often settle and consolidate unevenly under load resulting in serious damage to pavements. This deformation is more easily handled by interlocking pavers as they can withstand greater deformation than conventional pavements while remaining in service. Where areas have settled, or require access to utilities, the pavers are easily removed, the necessary repairs made, and the pavers reinstalled.

The method used in the design of interlocking concrete pavements is the same as that used for the design of flexible (asphalt) pavements. The designer has the ability to assess all the factors that impact the pavement structure. These include the sub-grade soils, the available roadbed construction materials and the imposed loads which all are assessed in a fashion similar to the methods used to design asphalt streets, parking lots and industrial pavements.

There is sufficient data to allow the designer to assess the life-cycle costs of interlocking concrete pavements and compare them to alternative pavement structures. Concrete Paving stone can easily provide long-life, low-maintenance pavements for all applications.

According to Shetty (12), more owners and designers are evaluating the life-cycle costs of pavement design alternatives in order to obtain the most benefits from the pavement investment.

2.0 EXPERIMENTAL PROCEDURE

Various constituent materials for the production of cast concrete pavers used in this research include Ordinary Portland cement (OPC), fine and coarse aggregates and water. The OPC brand used is locally produced at Ewekoro, Ogun State, Nigeria The fine aggregate consists of the natural river sand and Yoyo sand. The natural river sand used was gotten from Oworonsoki, Lagos State while the Yoyo sand used was gotten from Ikorodu, Lagos State. The coarse aggregate used is crushed granite chippings from Ibadan quarry, Oyo State. The size ranges from 5-12mm. portable water was used for the mix.

The percentage of Yoyo sand by weight of the total fine aggregate was varied in steps of 25% up to a maximum of 100%, corresponding to

Yoyo concrete while the 0% corresponding to normal concrete. Varying concrete mixes of 1:2:4 and 1:3: 6 (cement: Yoyo river sand: granite) with corresponding water/cement ratio of 0.65 and 0.75 to obtain normal consistency were employed. In all, 270 Nos of "double-T shape" concrete paving stones 60mm thick, were tested after curing at different periods of 1,2,4,6,8,12,16,20, and 24 weeks for strength properties. Figure 2 shows the plan of the concrete paving stone.

The moulds with the specimens were stored for 24 hours before transferring the specimens into the curing tank up to the specified age for crushing. Prior to crushing for compressive strength, the specimen were air-dried for a minimum of 24 hours and weighed 100kN Avery Denison testing machine, with a load rate of 0.5kN per second, were used for the compressive test.

A preliminary study carried out for impact load test for different series of interlocking concrete paving stones produced by manufacturers within Nigeria, showed that one to two blows of 4.5Kg - hammer cracked the stones. Hence, the research only limited itself to the study of compressive strength and density of replacing river sand either partially or wholly with normal river sand in concrete paving stone.

3.0 RESULTS AND DISCUSSIONS

3.1 Physical Properties

The results of the sieve analysis of the aggregates are presented in Figure 3. From this figure, it shows that the Yoyo sand and the natural river sand are similar in grading. The obtained fineness modulus of the Yoyo sand is 3.43 while that of the river sand is 3.38. These values are relatively close; thus their combination led to the production of an easily compatible concrete mix. The grading curves obtained (see Figure 3) showed that the sands (Yoyo and River) are well graded and their particles range from 0.4mm to 1.18mm in size. However, the river sand has more gravel content (3.42%) than the Yoyo sand (2.29%) Hence, the concrete produced from 100% Yoyo Sand fine aggregate is expected to be lower in strength compared to the one from 100% river sand.

3.2 Crack Pattern and Mode of Failure

The crack formation during the loading of a paving stone depends on the shape and method of loading and the first crack load corresponds to the load at which micro cracks commenced on the paving stone. the ultimate failure is the load at which the paving stone refused to take more load due to the failure of the composite materials.

In the tested paving stones, 'double T' shape, the first cracks started from the top, and in some cases from the bottom extreme edges of the paving stones. This is the critical sections of the paving stone shape due to the symmetry.

Furthermore, as the load was increased from the first crack load, the inclined cracks extended further to the middle portion of the paving stones and there was subsequently the ultimate (final) failure of the whole surface area of the paving stone.

3.3 Density

The average density of all the mixes did not change appreciably with age for different mix proportions, as shown in Table 1. For the same mix proportion and ratio, the density of 1 week old 100% river sand paving stone 2574kg/m^3 while that of corresponding 24 week old is 2560kg/m^2. In the case of 100% Yoyo sand paving stone, the density is 2563kg/m^3 and 2538kg/m^3 for 1 week and 24 weeks old However, the density of concrete for mix proportion 1:2:4 with = 0.65 is higher than the corresponding concrete with mix proportion of 1:3:6 and = 0.75.

None of the densities for different mixes and varying Yoyo sand contents is less than 24 50kg/m,. showing that these concrete can be classified as heavy weight. The varying proportions of substitute of fine aggregate with Yoyo sand has no effect on the density of the paving concrete produced.

3.4 Compressive Strength

The values of the average compressive strength for various mix proportions and percentage contents of Yoyo sand are presented in Table 2. As in normal concrete, the compressive strength of the Yoyo /river sand concrete increased with age for all mixes. Initial substitute of normal river sand with Yoyo sand up to 50% reduced the compressive strength of the paving stone. However, with higher amount of Yoyo sand content, there was increase in the compressive strength compared with the control specimen (0% Yoyo Sand). Total substitute of normal river sand with Yoyo sand (100% Yoyo sand concrete) showed an increase of up to 21% for early age of one week and about 8% after six weeks.

Generally, for proportion of 1:2:4: and water/cement ratio of 0.65, 75% substitute of the river sand with Yoyo sand showed approximately the same strength after 4 weeks. This is shown in Figure 4(a). For the same Yoyo content concrete but with mix proportion of 1:3:6 and = 0.75, the stabilization of the compressive strength of paving concrete is achieved after 6 weeks, as shown in figure 4(b).

Figure 4 shows compressive strength/curves fir varying percentages of yoyo sand content for different mix proportion. As it can be observed, samples with 75% and 100% Yoyo sand contents have compressive strengths more than the one with 0% Yoyo sand (control specimen) while 25% and 50% of Yoyo sand contents have lower compressive strength than the control specimen irrespective of the age and the mix proportion. From the graphs in Figure 4, it can be seen that the pattern of the cures are similar for all ages and mix proportions. It is however curious to observe that the 50% Yoyo Sand content has the least compressive strength in all cases.

The compressive strength of concrete paving stones with varying content of Yoyo Sand of more than 20 N/mm^2 after 8 weeks for a mix proportion of 1:2:4 and = 0.65 showed that this can be recommended for light traffic pavement while the mix proportion of 1:3:6 with = 0.75 which showed a minimum compressive strength of 15N/mm^2, for any content of Yoyo sand can be use as walkway pavement

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the experimental investigation carried out showed the following:

The finess moduli of river and Yoyo sand are close and therefore the compatibility of the two fine aggregates in the concrete mix.

The average density of all the mixes did not change appreciably with age for different mix proportions. However, the density of the paving concrete for mix proportion 1:2:4 with = 0.65 is higher than the corresponding mix proportion of 1:3:6 and = 0.75 None of the densities is less than 2450 kg/m^3 for difference mixes and varying Yoyo sand content. Thus, they can be classified as heavy weight concrete.

The first crack in the "Double T" paving stone appeared at the bottom or top extreme ends (due to the symmetry) and later the inclined crack extended to the middle portion up to the ultimate failure of the paving stone.

The compressive strength of the paving concrete increased with age. However, initial substitute of normal River Sand with Yoyo Sand up to 50% reduced the compressive strength. The pattern of compressive strength/Yoyo sand content are the same for all age mix proportions.

Generally, the mix proportion of 1:2:4 and = 0.65 which showed minimum and compressive strength or 20 N/mm^2 can be recommended for light traffic pavement while for walkway paving stones, a mix proportion of 1:3:6 with = 0.75 (with minimum compressive strength of 15 N/mm^2) can be used.

It is recommended that future work should concentrate on why 50% replacement of river sand by Yoyo sand brings about such deviation. Also, thicker pavers (the one for heavy traffic) should be investigated; this may have a relationship with the behaviour of the 50% Yoyo sand content. However, if thicker pavers are to be investigated, impact tests should not be ignored.

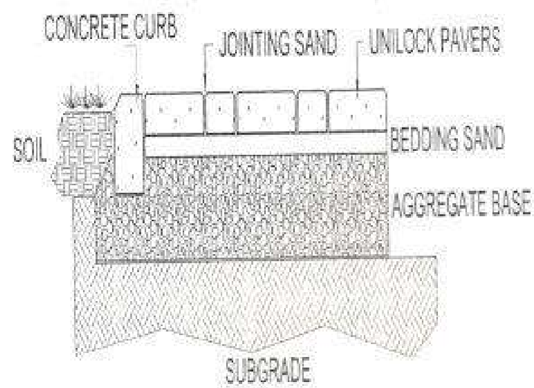


Figure 1: Typical Cross Section of Interlocking Concrete Pavement

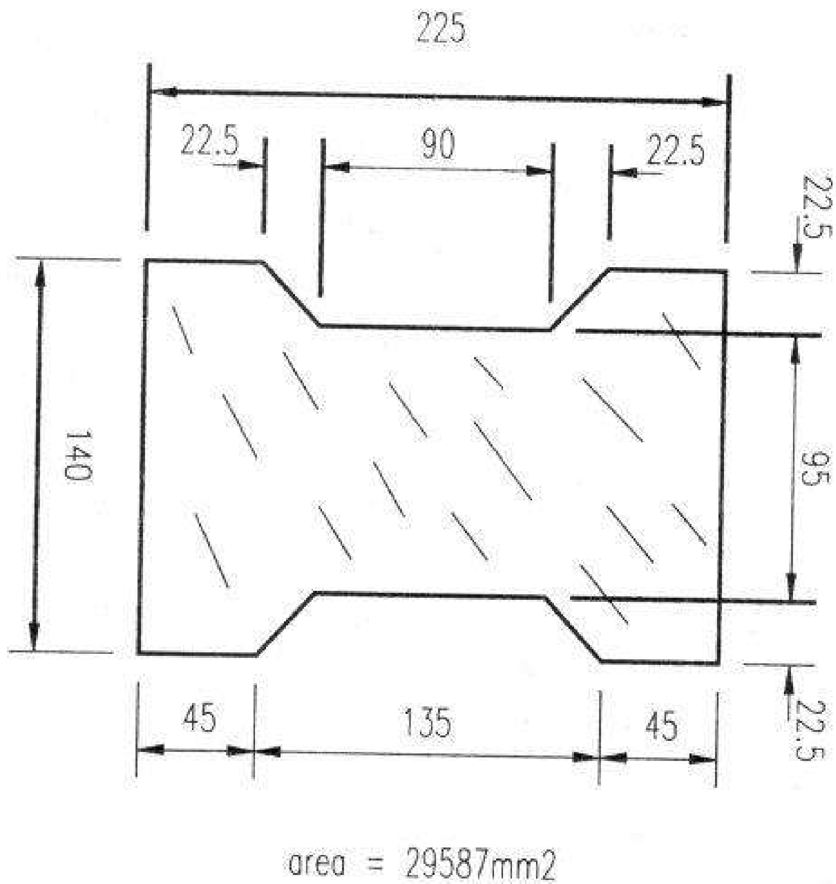


Figure 2: Dimension of the "Double Shaped" Concrete Paving Stone

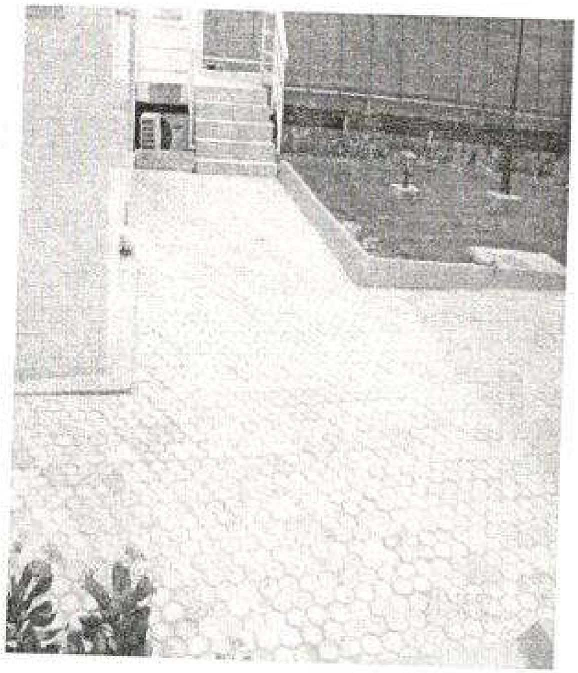


Plate 1: The Use of Concrete Paving Stone for Residential External Floor

Plate 2: The Use of Concrete Paving Stone for Road Construction

Plate 3: The Use of Concrete Paving Stone for Road Maintenance

Table 1: Average Density of Concrete Paving Stone with Different Percentage of Yoyo/Normal and Mix Proportion

Mix Proportion	Age of paving Concrete (Weeks)	Average density of paving stones (kg/m²) Average Percentage of Yoyo Sand Content in Fine Agregate				
		0%	25%	50%	75%	100%
	1	2574	2557	2524	2546	2563
	2	2546	2563	2552	2557	2546
	4	2563	2535	2546	2524	2535
	6	2569	2479	2563	2535	2524
1:2:4	8	2524	2535	2557	2535	2569
	12	2546	2552	2535	2552	2552
$\frac{w}{c}=0.65$	16	2535	2546	2548	2560	2565
	20	2528	2524	2532	2538	2546
	24	2560	2532	2546	2535	2538
	1	2450	2450	2467	2479	2467
	2	2479	2467	2434	2490	2479
	4	2467	2456	2456	2490	2490
	6	2490	2467	2473	2467	2473
1:3:6	8	2467	2479	2479	2501	2479
	12	2479	2490	2473	2490	2507
$\frac{w}{c}=0.75$	16	2448	2462	2458	2494	2490
	20	2462	2456	2460	2494	2472
	24	2464	2458	2456	2465	2480

Table 2: Compressive Strength of Concrete Paving Stone with Varying Percentage of Yoyo/Normal and Mix Proportion

Mix Proportion	Age of concrete paving stone (Weeks)	Average Compressive Stress concrete (N/mm^2) Percentage of Yoyo sand content in Fine Aggregate				
		0%	25%	50%	75%	100%
	1	15.92	15.65	14.16	16.35	18.89
	2	19.00	17.47	15.99	18.89	21.26
	4	20.38	20.08	17.71	22.34	23.20
	6	22.78	20.89	20.08	23.42	24.50
1:2:4;	8	23.50	21.73	20.38	23.82	25.42
	12	24.06	22.37	20.65	24.44	25.95
$\frac{w}{c} = 0.65$	16	24.50	22.81	21.06	24.88	26.30
	20	24.94	23.22	21.33	25.32	26.67
	24	25.35	23.59	21.56	25.62	27.17
	1	10.24	9.73	7.94	11.80	13.00
	2	12.64	12.44	9.09	13.49	14.87
	4	14.74	13.72	12.30	16.39	17.27
	6	16.16	15.65	13.93	17.17	18.18
1:3:6	8	16.70	15.95	14.80	18.25	20.55
	12	17.00	16.16	15.28	19.10	20.85
$\frac{w}{c} = 0.75$	16	17.37	16.39	15.65	19.37	21.26
	20	17.68	16.66	15.92	19.70	21.63
	24	17.91	16.97	16.19	20.04	22.00

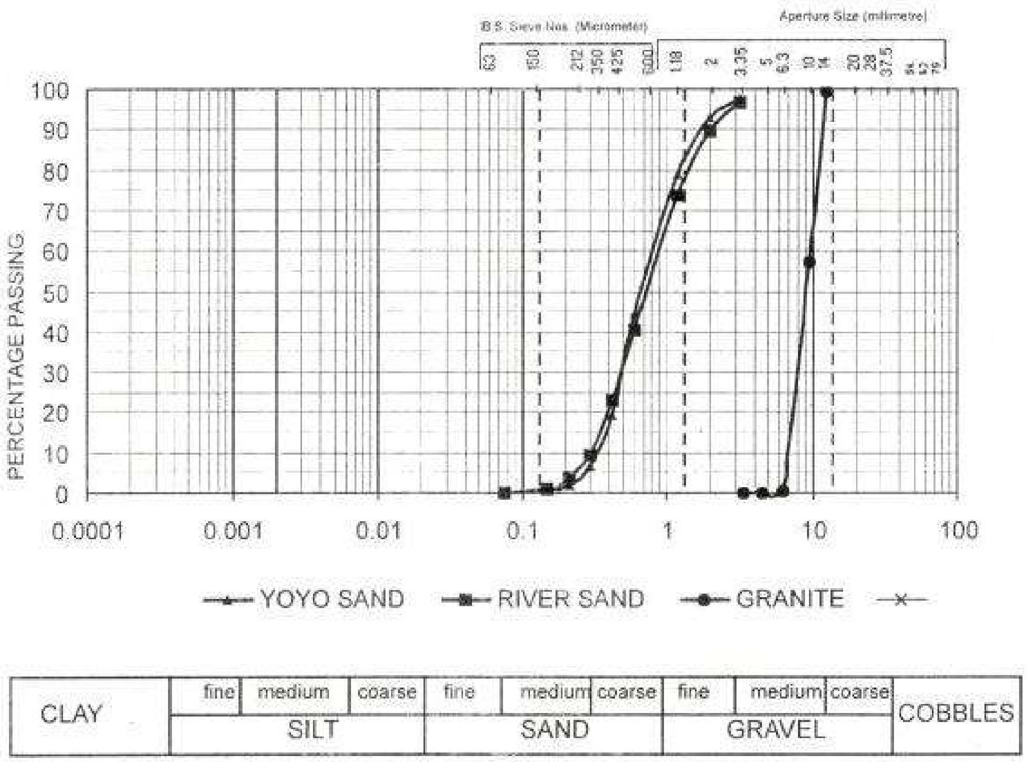
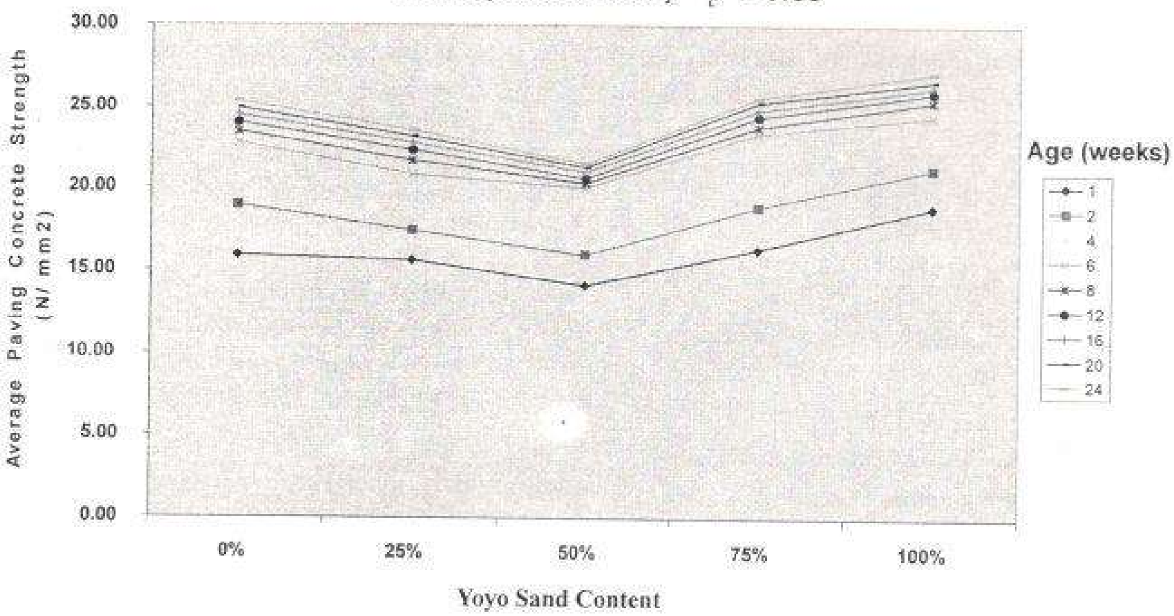


Figure 3: Particle Size Distribution Curve for the Yoyo, Natural River Sand and Granite

a)



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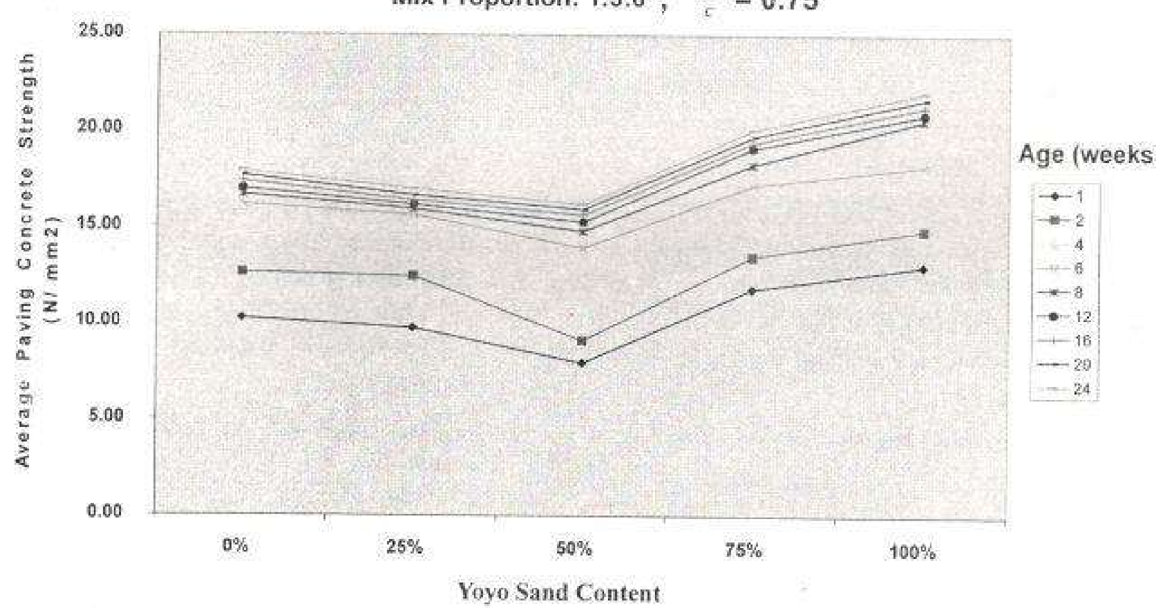

Figure 4: Relationship Between Compressive Strength and Verying Yoyo Sand Content for Different Mix Proportions

REFERENCES

1) Parikh, D. M.(1992): "Utilization of Foundry By-Products as Construction Materials,"Master's Degree Thesis, Department of Civil Engineering and Mechanics, College of Engineering and Applied Science, University of Wisconsin-Milwaukee. 129 pages.

2) Javed, S., Lovell, C. W., and Wood, L. E.(1994): "Waste Foundry Sand in Asphalt Concrete," Transportation Research Record, No. 1437, National Research Council, Washington DC. Pp 27-34.

3) Domann, R. A.(1997): "Beneficial Utilization of Used Foundry Sands in Portland Cement Concrete," Master's Degree Thesis. Department of Civil Engineering and Mechanics, College of Engineering and Applied Science, University of Wisconsin-Milwaukee, USA. 126 pages.

4) Bakoshi, T., Kohno, K., Kawasaki, S., and Yamaji, N.(1988): "Strength and Durability of Concrete Using Bottom Ash as Replacement for Fine Aggregate," 1998 Fourth CANMET/ACI/JCI International Symposium on Advances in Concrete Technology, American Concrete Institute, Publication SP 179. pp 159-172.

5) Tyson, S., and Blackstock, T.(1995): "Overview of Coal Combustion Byproduct (CCB) Production and Use in the USA," Proceedings of the 57th Annual American Power Conference, Illinois Institute of Technology, Chicago, IL, Vol. 57, No. 1. pp 292-297.

6) Wei, L.(1992): "Utilization of Coal Combustion By-Products for Masonry Production," Master's Degree Thesis, Department of Civil Engineering and Mechanics, College of Engineering and Applied Science, University of Wisconsin-Milwaukee. 199 pages.

7) American Foundrymen's Society (1991): "Final Report on Alternate Utilization of Foundry Waste Sand," A Report Prepared for Illinois Department of Commerce and Community Affairs, Chicago, IL, pp. 39-41.

8) Ghafoori, N., and Buchole, J.(1996): "Investigation of Lignite-Based Bottom Ash for Structural Concrete," Journal of Materials in Civil Engineering, ASCE, New York, NY, Vol. 8. No. 3. pp 128-137.

9) American Coal Ash Association(1995): "Coal Combustion Byproduct (CCB) Production & Use: 1966-1993: Report for Coal Burning Electric Utilities in the United States", Alexandria, VA. 23 pages.

10) Wroth, C. P and Houlsby, G. T. (1987): "Soil Mechanics Property characterization and Analysis Procedures" Proceedings of the 11th International conference on Soil Mechanics and Foundation Engineering, London Vol. II.

11) Sadiq, O.M., Salau, M.A., Sulymon, N.A (1999): "Yoyo Sand Concrete for Structural Use-Preliminary Investigation". NSE Technical Transactions Vol. 34. No. 2. pp 11-22.

12) Shetty, M.S. (2003): Concrete Technology: Theory and Practice; 3rd edition. S. Chad & Company Ltd., New Delhi. 205 pages.