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Effect of Coarse Aggregate Type on the Modulus of Elasticity of Concrete

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A B S T R A C T

In this study, effect of coarse aggregate type on the modulus of eladticity of concrete was investigated.Three different coarse aggregate samples were used namely: granite, sandstone and unwashed gravel. Amongst other tests carried out, the two principal tests performed include compressive strength test and modulus of elasticity test.The different coarse aggregates were used to make 18 concrete specimens each. Granite based concrete specimens gave a mean modulus of elasticity of 57.3 N/mm2, 84.9 N/mm2, and 86.6 N/mm2 on the 7th, 14th and 28th day of testing. Sandstone based concrete specimens gave a mean modulus of elasticity of 44.0 N/mm2, 68.3 N/mm2and 77.3 N/mm2on the 7th, 14th and 28th day of testing. Gravel based concrete specimens gave a mean modulus of elasticity of 38.5 N/mm2, 48.2N/mm2and 70.1 N/mm2on the 7th, 14th and 28th day of testing. From the results, granite based concrete gave the highest mean modulus of elasticity followed by that of sandstone, then that of gravel was the least. And this indicates that the granite based concrete gave the highest compressive strength than the others thus making it the most preferred coarse material amongst them.

1. Introduction

Concrete is a composite material produced by the homogenous mixing of selected proportions of water, cement, and aggregates,fine and coarse (Aginam,*etal*.,2013).The compressive strength of concrete depends on the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate (Roccoand Elices, 2009; Elices and Rocco, 2008). Strength is the most desired quality of a good concrete. It should be strong enough, at hardened state, to resist the various stresses to which it would be subjected. Compressive strength of concrete, therefore, is the value of test strength below which not more than a prescribed percentage of the test results should fall (Kong and Evans, 1987).

The high variation in strength between concrete and mortar of the same cement/aggregate proportion, suggests the quintessence of coarse aggregates in the development of strength in concretes. The coarse aggregates are obtained naturally or artificially and occupies up to 60% by weight or volume of the concrete, depending on the mix proportion adopted which, in turn, depends on the expected compressive strength.

Aggregate is commonly considered inert filler, which accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete.Aggregates are classified as two different types, coarse and fine. Coarse aggregates are those whose diameters are usually greater than 4.75mm retained on a No. 4 ASTMsieve, while fine aggregates are those whose diameters are less than 4.75mm passing the No.4 ASTM sieve (ACI 301, 2005).Although aggregate is considered inert filler, it is a necessary component that defines the concrete's dimensional stability, thermal properties and elastic properties.The physical and mineralogical properties of aggregates include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight. These properties along with the water/cementitous material ratio determine the strength, workability, and durability of concrete.

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates, the cement matrix and their relative proportions.Yilmaz*et al*.(2006) statedthat aggregate influences the elastic modulus of concrete significantly when the w/c ratio of themix is less than 0.40. Thus coarse aggregate type is a very important factor affecting the elastic modulus of hardened concrete since different types of aggregates can have quite distinct effects on elastic modulus.Mang*et al*.(2005) defined modulus of elasticity as the slope of the stress-strain curve within the proportional limit of the material.The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops.It is important that the modulus of

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elasticity of concrete be known because engineers increasingly use this value in the structural design process. For example, modulus of elasticity is needed to analyze the cross-sectional response of a reinforced concrete beam. In recent years building specifications have even required a specific modulus of elasticity of concrete to be met, mostly to limit excessive deformation and sway in tall buildings.

2. Literature Review

In a study by Stock *et al*.,(1979), it was reported that for concrete with fixed water contents w/c of 0.5, as the volume of coarse aggregates varied from 20 to 60%, the compressive strength of concrete remained almost same as shown in Figure 1. This result is very consistent with the "W/C law" established by Duff (1919), which implies that for a given mix proportion, the compressive strength of concrete would be determined by its water to cement ratio. This is especially true for normal concrete with compressive strength less than 60Mpa. However, the elastic modulus of the concrete was substantially influenced by the change in its coarse aggregate content. As shown in Figure 2, we can see that the elastic modulus of concrete is remarkably different from that of hardened cement. Also, Neville(1996) pointed out that for a concrete of a given strength, because normal weight aggregate has a higher elastic modulus than hydrated cement paste, a higher aggregate content results in a higher modulus of elasticity of the concrete.

In a study by Persson (2001), it was reported that the elastic modulus of self-compacting concrete was the same that of normal concrete as long as their compressive strengths were the same. However in the study of Schlumpf (2004), the elastic modulus of self-compacting concrete was reported to be 20% lower than that of a normal concrete with similar strength. In addition the findings from the study by Chi (2003) also indicated that the aggregate fraction in concrete had a considerable effect on the elastic modulus of concrete.The reported findings by Zhou *et al*.,(1995) show that the coarse aggregate type has a considerable influence on the elastic modulus of concrete. In their study the effects of expanded clay, sintered fly ash, limestone, gravel, glass

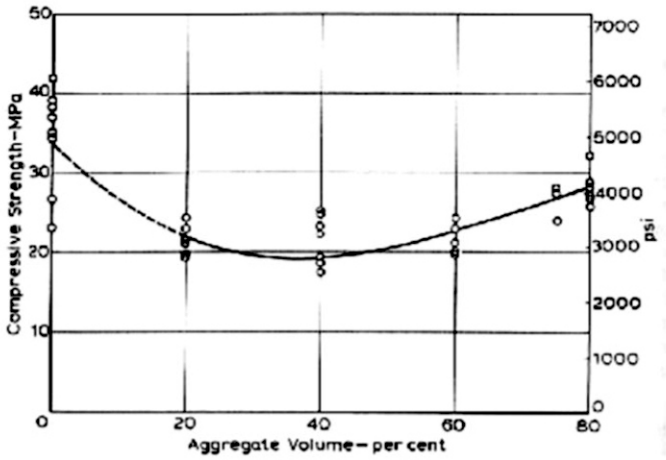

Figure 1: Relationship Between Compressive Strength And Volume Of Aggregate at W/C=0.5 (Shock, et al.,1979)

and steel aggregate on the elastic modulus of concrete were investigated. Figure 3 shows the plot of elastic modulus versus compressive strength of concrete made with different aggregate types. In addition, the study results reported by Shideler (1957) on concrete mixtures using gravel and expanded clay as aggregate also indicate the same conclusion as reported by Zhou *et al*.,(1995).

1. Materials and Methods

This study was limited to investigating the effects of only three types of coarse aggregates on the elastic modulus of concrete.Thecoarseaggregates used wereunwashedgravel, granite and sand-stone. Other materials used include: sand as fine aggregates, Portland cement as binder and portable water. A 1:2:4 mix ratio was maintained throughout the study for the three different types of coarse aggregate and the materials were batched by weight. Each aggregate type was used to produce 18 concrete cylinder specimens of 150mm x 300mm dimension. A total of 54 concrete cylinder specimens were utilized for this study.

3.1 Determination of compressive strength

This was done to determine the compressive strength of concrete cylinder specimens as per BS1881-116. The mean value of the compressive strength, f_c, determines the stress applied in the determination of static modulus of elasticity. It utilized a compression testing machine conforming to BS1881-115.

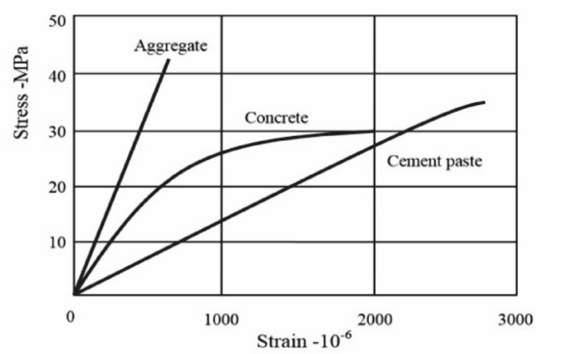

Figure 2: Stress-Strain Relations For Cement Paste, Aggregate And Concrete (Neville, 1996).

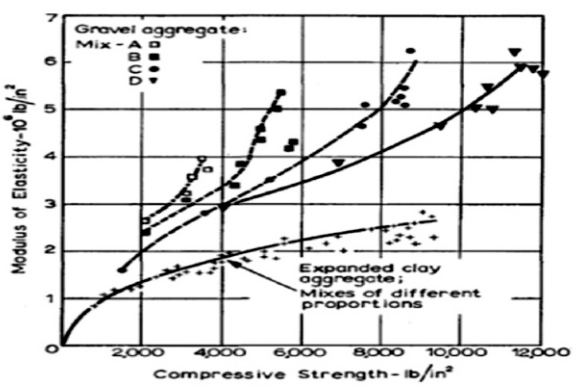

Figure 3:Static Modulus Of Elasticity of Concrete made with Gravel Aggregate and Expanded Clat, and tested at different ages up to One Year (Shideler, 1957)

3.2 Age of Test

Test was done on the 7th, 14th and 28th day of curing in moist condition. The age was calculated from the time of the addition of water to the drying of ingredients.

3.3 Number of Specimens

Three cylinder specimens was used to determine the compressive strength of the concrete from the same batch as those to be used for the determination of the static modulus of elasticity, made and cured under similar conditionsat each selected age.

3.4 Procedure

The specimens, prepared according to BS 1881-3:1970 and stored in water, was tested immediately after removal from the water and while still in wet condition. The weight of the specimenswas noted before testing. The bearing surfaces of the compression testing machine was wiped clean and any loose sand or other material was removed from the surfaces of the specimen, which would be in contact with the compression platens. The axis of the specimen was carefully aligned with the centre of thrust of the spherically seated platen. No packing was used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block is brought to rest on the specimen, the movable portion was rotated gently by hand so as to obtain uniform seating. The load was applied without shock and increased continuously at a rate of approximately 140kg/sq.cm/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen was recorded.\

The measured compressive strength of the specimen was calculated by dividing the maximum load applied to the specimen during the test by the cross - sectional area, calculated from the mean dimensions of the section and should be expressed to the nearest N/mm^2. An average of three values was taken as the representative of the batch.

3.5 Determination of Static Modulus of Elasticity

This experiment was performed on the concrete cylinder specimens and it utilized a compression testing machine conforming to BS1881-115 for compression testing machines, strain measuring apparatus: dial gauge having an accuracy of ± 5 micro strain and a retort stand .The test specimen was placed, with the measuring instruments or fixing points attached axially, centrally in the machine.

The basic stress of $0.5N/mm^2$ σ_b) was applied, and the strain gauge readings taken at each measurement line was recorded. The stress was increased steadily at a constant rate within the range 0.6± $0.4N/(mm^2{\cdot}s)$ until the stress equal to one-third of the compressive strength of the concrete ($f_{cu}/3$) is reached.The stress was maintained for 60s and the strain readings taken during the succeeding 30s at each measurement line was recorded. When the centering was sufficiently accurate the load was reduced, at the same rate as during loading, to the level of the basic stress. Two additional preloading cycles were carried out, using the same loading and unloading rate, and maintaining the stress($\sigma_\alpha$andσ_β) constant for a period of 60s. After completion of the last preloading cycle and a waiting period of 60s under the stress σ_b =0.5 N/mm^2, at the various measurement lines the strain reading ϵ_b takenduring the succeeding 30s was recorded. The specimen is reloaded to stress σ_a at the specified rate, and at the various measurement lines the strain reading $\epsilon_a$taken within 30s were recorded. When all elasticity measurements have been completed, the load on the test specimen is increased, at the specified rate, until failure of the specimen occurs to know the value of the compressive strength.

The mean strain ϵ_a and ϵ_b was calculated respectively. The static modulus of elasticity in compression E_c (in N/mm^2) is given by the formula

$$\frac{\Delta\sigma}{\Delta\epsilon} = \frac{\sigma_a-\sigma_b}{\epsilon_a-\epsilon_b}$$

Where

σ_a= is the upper loading stress (in N/mm^2) (σ_a= $f_{cu}/3$),σ_b= is the basic stress (i.e. 0.5 N/mm^2), ϵ_a is the mean strain under the upper loading stress and ϵ_a= is the mean strain under the basic stress.

4 Results

The results presented below include aggregate impact value test, compressive strength test and modulus of elasticity test results for the three types of aggregate material: Granite, Gravel and Sandstone.The compressive strength test was relevant to determine the one-third value of the mean compressive strength ($f_{cu}/3$)required for estimatingmodulus of elasticity.

The results obtained from aggregate impact value test are summarized in Table 1, 2 and 3 below. The aggregate impact value for the granite used was 32.50 %, that for sandstone was 69.55% and that for gravel was found to be 44.24%. A comparison of these results clearly identifies sandstone as the weakest aggregate.

Table1: Aggregate Impact Value Test for Granite

S/No	Net Weight of aggregates in the measure in g (A)	The fraction passing through 2.36mm IS sieve in g (B)	The fraction retained on 2.36mm sieve in g (C)	Aggregate impact value =B/A x 100(%)
1	317.50	99.20	217.75	31.24
2	301.00	99.60	200.62	33.09
3	310.10	102.83	206.60	33.16
			Average	32.50

Table2: Aggregate Impact Value Test for Sandstone

S/No	Net Weight of aggregates in the measure in g (A)	The fraction passing through 2.36mm IS sieve in g (B)	The fraction retained on 2.36mm sieve in g (C)	Aggregate impact value =B/A x 100 (%)
1	286.50	195.40	90.30	68.20
2	275.00	190.00	85.00	69.09
3	281.4	200.84	79.78	71.37
			Average	69.55

Table3: Aggregate Impact Value Test for Gravel

S/No	Net Weight of aggregates in the measure in g (A)	The fraction passing through 2.36mm IS sieve in g (B)	The fraction retained on 2.36mm sieve in g (C)	Aggregate impact value =B/A x 100 (%)
1	300.90	135.23	164.90	44.94
2	308.80	137.74	170.29	44.60
3	309.00	133.40	174.90	43.17
			Average	44.24

Granite

Table 4 and 5 below show the results of compressive strength and modulus of elasticity tests carried out on granite concrete specimens at age 7, 14 and 28 days.

Table 4: Compressive Strength of Granite at 7, 14 and 28days

Specimen number	Compressive strength (N/mm²)		
	7 days	**14 days**	**28 days**
CMPR 01-GN	15.56	18.12	22.64
CMPR 02-GN	14.71	19.24	20.65
CMPR 03-GN	15.84	18.12	22.07
Average	15.37	18.49	21.79

$f_{cu}/3 = 5.12 N/mm^2$, $f_{cu}/3 = 6.16 N/mm^2$ and $f_{cu}/3 = 7.26 N/mm^2$

Table5: Modulus of Elasticity test for Granite at 7, 14 and 28days

Force (kN)	Stress?? (N/mm²)	Strain								
		ELM 701-GN	ELM 702-GN	ELM 703-GN	ELM 1401-GN	ELM 1402-GN	ELM 1403-GN	ELM 2801-GN	ELM 2802-GN	ELM 2803-GN
0	0	0	0	0	0	0	0	0	0	0
10	**0.56( )**	0.002	0.035	0.042	0.025	0.042	0.030	0.005	0.008	**0.004( )**
20	1.12	0.010	0.049	0.055	0.037	0.050	0.045	0.011	0.014	0.008
30	1.68	0.020	0.055	0.062	0.040	0.054	0.052	0.017	0.018	0.012
40	2.24	0.032	0.061	0.070	0.045	0.058	0.060	0.024	0.023	0.017
50	2.80	0.043	0.068	0.080	0.050	0.064	0.064	0.030	0.027	0.022
60	3.36	0.055	0.076	0.090	0.053	0.070	0.068	0.035	0.035	0.029
70	3.92	0.076	0.088	0.104	0.060	0.074	0.078	0.043	0.040	0.037
80	4.48	0.088	0.094	0.110	0.065	0.078	0.084	0.049	0.040	0.051
90	5.04	0.092	0.106	0.118	0.075	0.084	0.088	0.057	0.056	0.063
100	5.60	-	-	-	0.080	0.095	0.093	0.063	0.070	0.066
110	6.16	-	-	-	0.091	0.105	0.099	0.065	0.077	0.071
120	6.72	-	-	-	-	-	-	0.077	0.083	0.075
130	**7.28( )**	-	-	-	-	-	-	0.083	0.087	**0.080( )**
Modulus of Elasticity (N/mm²)		49.8	63.1	58.9	84.8	88.9	81.2	86.2	85.1	88.4
Average (N/mm²)			57.3			84.9			86.6	

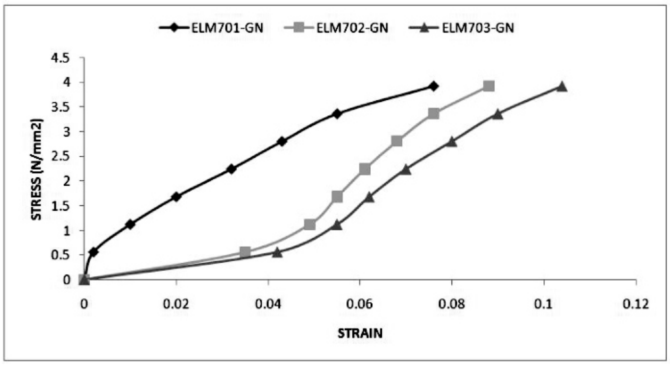

Figure 4: Modulus of Elasticity curve for Graniteat 7 days

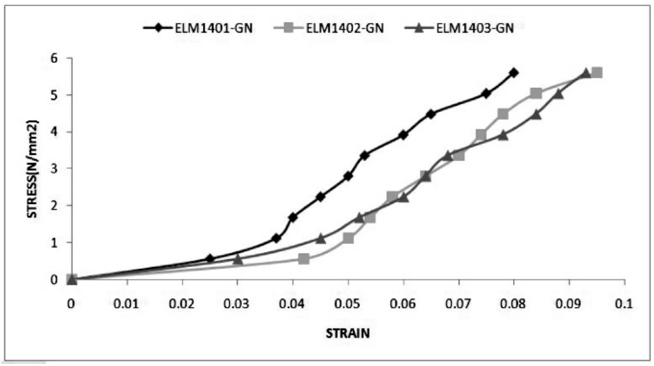

Figure 5: Modulus of Elasticity curve for Granite at 14 days

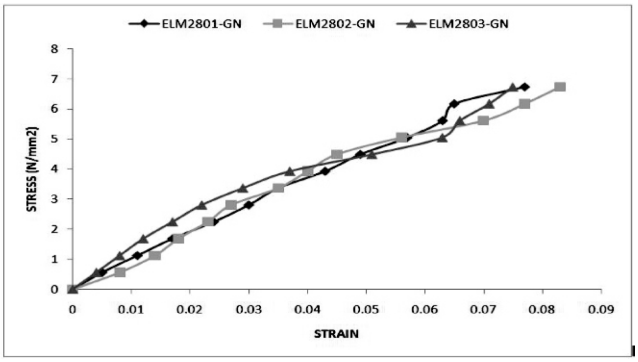

Figure 6: Modulus of Elasticity curve for Graniteat 28 days

Gravel

Table 6 and 7 below showthe results of compressive strength and modulus of elasticity tests carried out on gravel concrete specimens at age 7, 14 and 28 days

Table6: Compressive Strength of Gravel at 7, 14 and 28 days

Specimen number	Compressive strength (N/mm^2)		
	7 days	**14 days**	**28 days**
CMPR 01-GV	10.19	11.03	11.88
CMPR 02-GV	10.75	11.88	11.32
CMPR 03-GV	7.92	11.32	14.15
Average	9.62	11.41	12.45

$f_{cu}/3$ = 3.21N/mm^2, $f_{cu}/3$ = 3.80N/mm^2 and $f_{cu}/3$ = 4.15N/mm^2

Table7: Modulus of Elasticity test for Gravel at 7, 14 and 28 days

Force (kN)	Stress ?? (N/mm^2)	Strain								
		ELM 701-GV	ELM 702-GV	ELM 703-GV	ELM 1401-GV	ELM 1402-GV	ELM 1403-GV	ELM 2801-GV	ELM 2802-GV	ELM 2803-GV
0	0	0	0	0	0	0	0	0	0	0
10	0.56( )	0.003	0.004	0.006	0.003	0.007	0.005	0.003	0.011	0.004( )
20	1.12	0.020	0.013	0.026	0.013	0.037	0.019	0.010	0.020	0.013
30	1.68	0.038	0.019	0.050	0.031	0.048	0.027	0.016	0.025	0.020
40	2.24	0.048	0.031	0.069	0.043	0.057	0.037	0.021	0.030	0.026
50	2.80	0.058	0.048	0.082	0.058	0.067	0.047	0.030	0.050	0.038
60	3.36	0.073	0.067	0.096	0.065	0.077	0.052	0.034	0.060	0.045
70	3.92	-	-	-	-	-	-	0.038	0.070	0.055
80	4.48( )	-	-	-	-	-	-	0.047	0.084	0.062( )
Modulus of elasticity (N/mm^2)		40.0	44.4	31.1	45.2	40.0	59.5	89.1	53.7	67.6
Average (N/mm^2)			38.5			48.2			70.1	

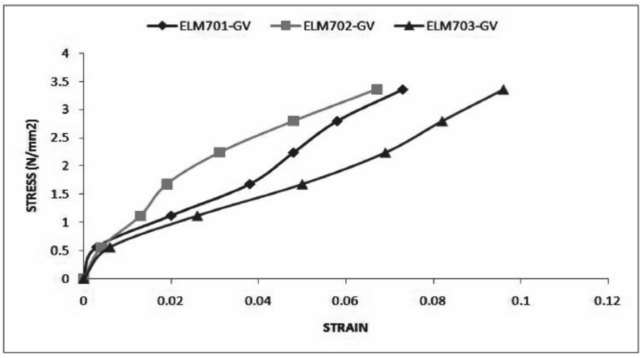

Figure 7: Modulus of Elasticity curve for Gravel at 7 days

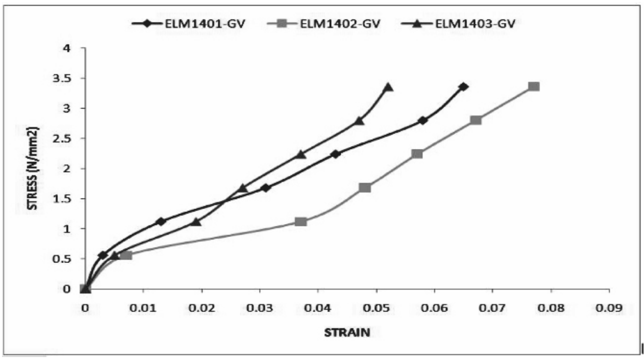

Figure 8: Modulus of Elasticity curve for Gravel at 14 days

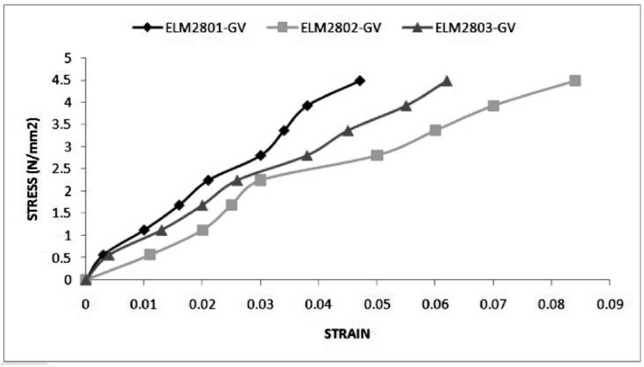

Figure 9: Modulus of Elasticity curve for Gravel at 28 days

Sandstone

able 8 and 9 below show the results of compressive strength and modulus of elasticity tests carried out on sandstone concrete specimens at age 7, 14 and 28 days.

Table 8: Compressive Strength of Sandstone at 7, 14 and 28 days

Specimen name	Compressive strength (N/mm^2)		
	7 days	**14 days**	**28 days**
CMPR 01-SS	14.15	15.28	17.26
CMPR 02-SS	14.43	16.13	17.54
CMPR 03-SS	13.02	16.98	18.39
Average	13.86	16.13	17.73

$f_{cu}/3$ (7 days) = 4.62N/mm^2 $f_{cu}/3$(14 days) = 5.38N/mm^2 and $f_{cu}/3$ (28 days)= 5.91N/mm^2

Table9: Modulus of Elasticity test for Sandstone at 7, 14 and 28days

Force (kN)	Stress ?? (N/mm^2)	Strain								
		ELM 701-SS	ELM 702-SS	ELM 703-SS	ELM 1401-SS	ELM 1402-SS	ELM 1403-SS	ELM 2801-SS	ELM 2802-SS	ELM 2803-SS
0	0	0	0	0	0	0	0	0	0	0
10	0.56( )	0.001	0.002	0.006	0.005	0.001	0.015	0.003	0.004	0.008( )
20	1.12	0.021	0.008	0.026	0.019	0.010	0.027	0.010	0.014	0.015
30	1.68	0.032	0.017	0.036	0.023	0.015	0.040	0.015	0.020	0.023
40	2.24	0.044	0.027	0.051	0.025	0.025	0.045	0.019	0.030	0.031
50	2.80	0.056	0.034	0.066	0.030	0.036	0.050	0.025	0.036	0.038
60	3.36	0.074	0.044	0.081	0.035	0.041	0.060	0.035	0.040	0.043
70	3.92	0.093	0.056	0.096	0.043	0.046	0.065	0.043	0.048	0.049
80	4.48	0.105	0.072	0.108	0.051	0.051	0.070	0.049	0.052	0.053
90	5.04	-	-	-	0.063	0.061	0.082	0.059	0.060	0.058
100	5.60	-	-	-	0.074	0.076	0.093	0.067	0.070	0.063
110	6.16( )	-	-	-	-	-	-	0.080	0.082	0.072( )
Modulus of elasticity (N/mm^2)		37.7	56.0	38.4	73.0	67.2	64.6	72.7	71.8	87.5
Average (N/mm^2)			44.0			68.3			77.3	

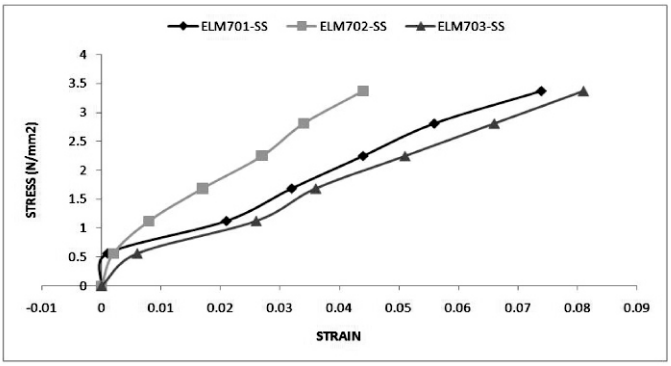

Figure 10: Modulus of Elasticity curve for Sandstone at 7 days

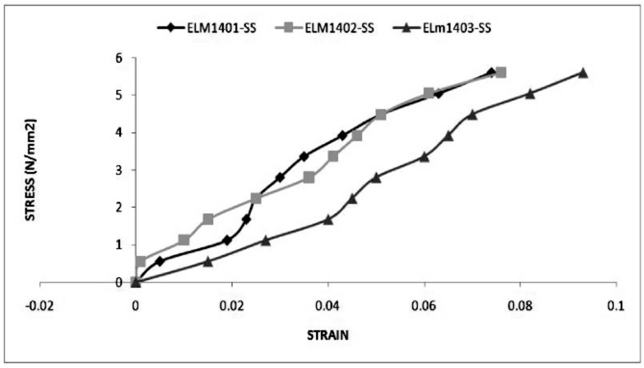

Figure 11: Modulus of Elasticity curve for Sandstone at 14 days

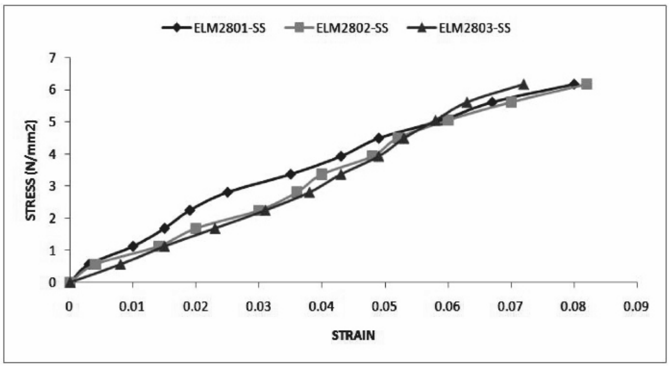

Figure 12: Modulus of Elasticity curve for Sandstone at 14 days

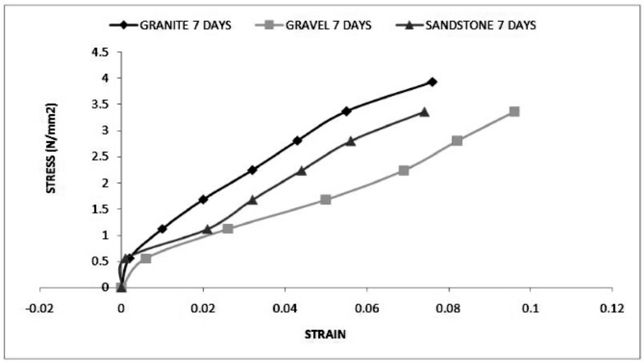

Figure 13: Comparison of 7days Modulus of Elasticity curve for Granite, Gravel and Sandstone

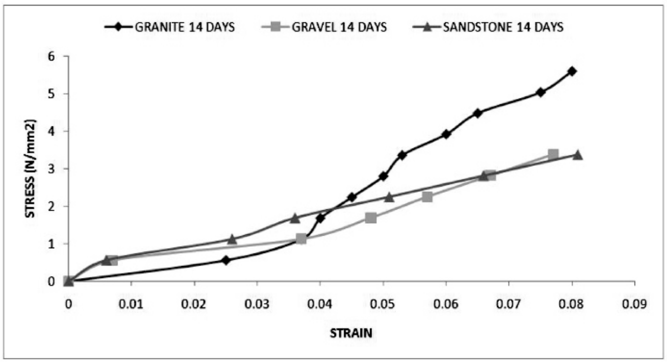

Figure 14: Comparison of 14days Modulus of Elasticity curve for Granite, Gravel and Sandstone

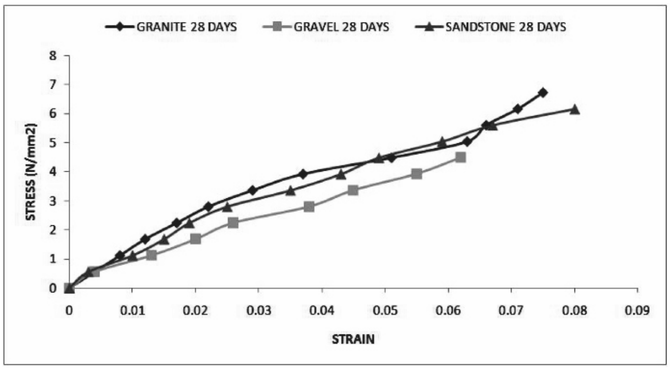

Figure 15: Comparison of 28days Modulus of Elasticity curve for Granite, Gravel and Sandstone.

5. Discussion

The 7th day test gave a mean compressive strength and modulus of elasticity of 15.37N/mm^2 and 57.3N/mm^2 for granite concrete specimens, 9.62N/mm^2 and 38.5N/mm^2 for gravel concrete specimens and 13.86N/mm^2 and 44.0N/mm^2 for sandstone concrete specimens.

Testing after 14days, granite concrete specimens showed a 20.3% and 48.2% increase in mean compressive strength and modulus of elasticity with values of 18.49N/mm^2 and 84.9N/mm^2. Gravel concrete specimens showed an 18.6% and 25.2% increase in mean compressive strength and modulus of elasticity with values of 11.41N/mm^2 and 48.2N/mm^2. Sandstone concrete specimens showed a 16.4% and 55.2% increase in mean compressive strength and modulus of elasticity with values of 16.13N/mm^2 and 68.3N/mm^2

Testing after 28days, granite concrete specimens showed a 41.8% and 51.1% increase in mean compressive strength and modulus of elasticity with values of 21.79N/mm^2 and 86.6N/mm^2. Gravel concrete specimens showed an 29.4% and 82.1% increase in mean compressive strength and modulus of elasticity with values of 12.45N/mm^2 and 70.1N/mm^2. Sandstone concrete specimens shew a 27.92% and 75.68% increase in mean compressive strength and modulus of elasticity with values of 17.73N/mm^2 and 77.3N/mm^2.

It was generally observed from the three concrete specimens that modulus of elasticity is directly proportional to compressive strength. Each coarse aggregate material has a unique relationship between compressive strength and modulus of elasticity, and for a given compressive strength, the modulus of elasticity of the different coarse aggregate material can vary greatly.

On the basis of the results of compressive strength and modulus of elasticity on the 28th day of testing, the concrete with granite as coarse aggregate can adequately limit excessive deformation if employed in structural construction like reinforced concrete for slabs, columns, beams and foundations as stated in section 3.13 of the Hong Kong Code of Practice (2013). Sandstone concrete could be used for constructing drainage slabs and concrete chairs, while un-washed gravel concrete could be employed in construction activities such as structural fill or trench backfill as prescribed in the "Controlled Low-Strength Material" by the Portland Cement Association.

The aggregate impact value test results shown in tables 1, 2 and 3 suggest that granite is the strongest coarse aggregate followed by gravel and the least sand-stone. According to Marsh (1988) the lower values of compressive strength of the gravel concrete as compared to sandstone concrete could be attributed to the inadequate bonding of the smooth textured gravel aggregates with the concrete matrix.

6. Conclusion

The extent of deformation that concrete can undergo is a function of its modulus of elasticity, the ability of a material to resist an induced amount of stress is a function of its strength. Thus the modulus of elasticity is directly proportional to the compressive strength of concrete. In concluding this study shows the relevance of selection of coarse aggregates (Granite, Gravel and Sandstone) on the modulus of elasticity and corresponding compressive strength of concrete employed in construction. Also the following conclusions were drawn.

i. Concrete specimens made with granite gave the highest meancompressive strength 15.37 N/mm^2, 18.49 N/mm^2 and 21.79 N/mm^2 on the 7th, 14th and 28th day of testing.
ii. Concrete specimens made with sandstone gave the next higher mean compressive strength of 13.86 N/mm^2, 16.13N/mm^2 and 17.73N/mm^2 on the 7th, 14th and 28th day of testing.
iii. Concrete specimens made with gravel gave the least mean compressive strength of 9.62 N/mm^2, 11.41 N/mm^{2}and 12.45 N/mm^{2}on the 7th, 14th and 28th day of testing.
iv. Concrete specimens made with granite gave the highest mean modulus of elasticity of 57.3 N/mm^2, 84.9 N/mm^2, and 86.6 N/mm^2 on the 7th, 14th and 28th day of testing.
v. Concrete specimens made with sandstone gave the next higher mean modulus of elasticity of 44.0 N/mm^2, 68.3 N/mm^{2}and 77.3 N/mm^{2}on the 7th, 14th and 28th day of testing.
vi. Concrete specimens made with gravel gave the least mean modulus of elasticity of 38.5 N/mm^2, 48.2N/mm^{2}and 70.1 N/mm^{2}on the 7th, 14th and 28th day of testing.
vii. The modulus of elasticity of concrete is proportional to its compressive strength
viii. Amongst the three types of coarse aggregates granite has the most suitable modulus of elasticity

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