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The Use of Blended Cinder Aggregates for Concrete Mixes

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Abstract

The study to design concrete by using cinder blended aggregates was conducted in Mbeya Region Tanzania. Cinder aggregates were blended with crushed stones aggregates for concrete mixes. In Mbeya Region there are abundant volcanic materials which are pozzolan, cinders and pumices. The study involved characterization of source aggregates and for blended aggregates. The materials used for this study were natural cinder aggregates from Ituha, Crushed stone aggregates from Mbalizi and excavated pit sands from Ituha. The binder used was CEMI 32.5N manufactured by Tembo Lafarge Cement Company Limited. The results from strength and physical properties tests of aggregates indicated that Ituha cinder aggregates have low strength, low specific gravity and high water absorption compared to Mbalizi crushed stone aggregates. The strength results for Ituha cinder aggregates are 75kN for TFV, 38.76% for ACV and 48. 26% for AIV. The results of SG, WA, EI and FI for Ituha cinder aggregates are 1.77, 3.31%, 19.82% and 12.88% respectively. The strength results for Mbalizi crushed stones aggregates are 240kN for TFV, 15.82% for ACV and 18. 30% for AIV. The results of SG, WA, EI and FI for Mbalizi crushed stone aggregates are 2.63, 0.87%, 34.41% and 12.60% respectively. The SG and WA for Ituha pit sand are 2.44 and 3.18% respectively. Sieve analysis for Ituha cinder aggregates, Mbalizi crushed stone aggregates and Ituha pit sands were conducted. The aggregates and sands were blended together to get six blended sample materials targeting the selected aggregate envelopes for concrete mixes. The concrete were prepared for two different cement contents of 350kg/m^3 and 450kg/m^3 mixed at W/C ratio of 0.55. Due to high demand of mixing water the super plasticizer at 2.5% and 3% for cement content of 450kg/m^3 and 350kg/m^3 respectively were added to fresh concrete. The concretes were cured under water for 7days, 14days, 21days and 28days. The results for compressive strength indicated that the compressive strengths increased with increasing curing period and increased amount of Mbalizi crushed aggregates and cement contents.

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The compressive strength of concrete specimens mixed at cement content of 350kg/m^3 cured for 28days are 23.8MPa for 55IPS45MCA00ICA, 22.3MPa for 50IPS36MCA14ICA, 20. 7MPa for 45IPS27MCA28ICA, 18.4MPa for 40IPS18MCA42ICA, 18.0MPa for 35IPS09MCA56ICA and 16.6MPa for 30IPS00MCA70ICA. The compressive strength of concrete mixed at cement content of 450kg/m^3 cured for 28days are 27.8MPa for 55IPS45MCA00ICA, 29.0MPa for 50IPS36MCA14ICA, 26.1MPa for 45IPS27MCA28ICA, 24.6MPa for 40IPS18MCA42ICA, 22.9MPa for 35IPS09MCA56ICA and 22.2MPa for 30IPS00MCA70ICA. But also densities of cured concrete specimens for both cement contents increased with increased curing periods and amount of Mbalizi crushed aggregates. The increase in compressive strength with increased curing period and Mbalizi crushed aggregates is because of development of cementitious compound and high resistance against crushing. For this study for easy blending process of aggregate materials, the blending model have been developed, the model uses median particle size (MS) and grading factor (GF) as variables. To make use of strength of aggregate materials, the prediction model of compressive strength of 28days cured concrete specimens was developed. The model uses TFV, SG and cement content as variables.

Keywords: Aggregates; Ciders, Concretes; Light weight concrete; Prediction model; Blending; Compressive strength; Density; Blending model.

1. Introduction

Concrete is the mixture of sand, aggregates, cement and water at a given proportions and in order to improve workability, the additives such as super-plasticizer is added into fresh concrete. But also admixtures such as natural pozzolan, fly ash, silica fume, and ground granulated blast furnace slag, metakaolin, and rice husk ash are added into fresh concrete to improve heat of hydration, setting time, bleeding, strength and durability [2, 17].

Aggregates are vital components of concrete, they occupy largest volume in concrete and it is estimated to be more than 70% of the concrete volume. The well graded aggregates ensures good workability, reduces segregation, bleeding and loss of entrained air and plastic shrinkage cracking to fresh concrete. The strength and durability of cured concrete specimens are also governed by physical and mechanical properties of aggregates [1, 3]. The self-weight of concrete structures are influenced by type of aggregates used for concrete production which affect structural member sizes and hence cost of construction [4, 8].

In Tanzania, normal and high strength concretes are made from crushed igneous, granite and basalt rocks and stones which are strong and durable. In many Countries, strong and durable aggregates are scarce and depleting with time due to demand of construction of modern buildings and infrastructures resulting into seeking alternative sustainable lightweight aggregate that are environmentally friendly [8]. Cinder aggregates are among of lightweight aggregates and are of volcanic origin on which the deposits can be found around many volcanoes in many parts of the world.

In Tanzania, the cinder aggregates are available in areas where Great Rift Valley have passed through which includes Mbeya, Songwe, Arusha, and Kilimanjaro regions [6, 7]. These areas have scarcity of igneous, granite, basalt rocks and stones for strong and durable aggregates. The abundant materials available in these areas for concrete mixes are volcanic materials which are cinder and pumices [6, 7]. The cinder aggregates are vesicular fines to coarse fragments, very porous, reddish or black in color, lightweight and relatively stronger than pumice [8].

The cinder and pumice materials have been widely used as supplementary cementitious pozzolanic materials when finely grounded and mixed with industrial cement [7, 8, 11]. Several studies have indicated improvement of fresh and hardened concrete when pozzolanic materials are added as supplementary cementitious materials at a proportion less than 30% by weight [7, 11]. Such properties includes workability, setting time, heat of hydration, reduce bleeding and improve strength development and durability [7].

However cinder and pumice aggregates have been used to make light weight concretes by replacing with conventional aggregates [8, 11]. The adverse properties of cinder aggregates to be used for concrete mixes includes high void contents which absorbs high amount of water, relatively high demand of binder to fill the voids, low specific gravity, relatively soft grains and relatively low strength of hardened concrete. Several studies conducted on light weight concrete made from cinder aggregates have been found to be suitable for low to medium strength concretes [11]. The concrete produced using cinder aggregates can insulate heat five to seven times better than the concrete produced using conventional aggregates [8]. Therefore, cinder materials can be used to make heat-insulating concrete and blocks having strength and durability characteristics comparable to other lightweight aggregates [8, 11]

The use of light weight concretes in structures offers many advantages over the conventional normal weight concretes, including an increased strength weight ratio and improved thermal and sound insulation and fire resistance properties, less dead load and resistance to freezing and thawing [8, 11, 12]. For reinforced concrete structures, the use of light weight concrete reduces sizes of structural elements and minimize steel reinforcement, offers design flexibility and substantial cost savings by providing less dead load, improved seismic structural response and longer spans [8, 11, 12]. However, several studies on cinder gravel materials for construction of unbound pavement layers for low volume roads have been conducted and the results have been found to be suitable materials for construction when blended with other conventional materials [9, 10].

For this study, the physical and mechanical properties of cinder blended aggregates were investigated under laboratory condition. The mixing of concretes and determination of compressive strength of crushed hardened concrete of blended aggregates were also conducted.

2.1 Investigation Procedure

The investigation for this study involved identification of source materials for concrete mixes. The source materials were, Mbalizi crushed stone aggregates abbreviated as “MCA”, Ituha natural cinder aggregates abbreviated as “ICA” and Ituha pit sand abbreviated as “IPS”. However, CEMI 32.5N from Mbeya Tembo Lafarge cement industry and tape water were used to make concretes.

Characterization of aggregates to determine particle size gradations, water absorptions (WA), specific densities (SG), Ten percent fine values (TFV), Aggregate crushing values (ACV), Aggregate impact values (AIV), Elongation index (EI) and Flakiness index (FI) for source aggregates and for blended aggregates were conducted. Table 1 shows physical and mechanical properties of source aggregates used for this study.

Table 1: Physical and mechanical properties of aggregates.

Parameters	**Abbreviation**	**Source Materials**		
		Mbalizi Crushed Aggregates (MCA)	**Ituha Cinder Aggregates (ICA)**	**Ituha Pit Sand (IPS)**
Specific density	SG	2.63	1.77	2.44
Water absorption	WA (%)	0.87	3.31	3.18
Ten percent fine values	TFV (kN)	240.0	79	n.a
Aggregate crushing value	ACV (%)	15.82	38.76	n.a
Aggregate impact value	AIV (%)	18.30	48.26	n.a
Elongation index	EI (%)	34.41	19.82	n.a
Flakiness index	FI (%)	12.60	12.88	n.a

2.2 Investigation Approach

The laboratory tests for source materials conducted are particle size analysis, physical properties and mechanical properties. Studies have indicated that compressive strengths of cured concrete specimens are affected by several factors including mixing and blending proportions of material ingredients, additives and admixtures, curing processes and curing periods [1, 3, 7]. Properties of aggregates such as ACV, flakiness and elongation indices have been investigated to affect strength of cured concrete specimens significantly [5].

The aggregates and sands from different sources were blended together at different proportions to meet the gradation envelopes for concrete mixes as explained in DIN1045:2008-08, 2009 [13]. The selection of aggregate envelope is based on the nominal maximum sizes of aggregates to be used for concrete mixes. The envelope used for this study is of nominal maximum size of 37mm. The blended aggregates were investigated to determine particle size analysis, aggregate strengths, and flakiness and elongation indices. The blending process was conducted in order the particle size curves at different proportions of aggregates lay within the proposed envelope. The grading envelope is used to enhance packing and interlocking properties of granular materials and hence increased compressive strength and durability [7, 8].

Six different concrete mixes were prepared and cured for 7days, 14days, 21days and 28days. Two different cement contents were used for each mix which are 350kg/m^3 and 450kg/m^3. Three specimens for each curing period and for each concrete mix were casted in cubic molds of 15cmx15cmx15cm. The super-plasticizer (SP) to reduce amount of mixing water in fresh concrete were added. The SP improves workability which eventually improves compressive strength of cured concrete specimens [14, 15].

The demand of mixing water is also increased due to high specific surface areas of concrete ingredients which are binder, sand and aggregates. Water film thickness (WFT) is the additional mixing water requirements which acts as lubricants to granular materials [14]. The amount of water film thickness is substantial when the surface area of the granular materials is high. Therefore the amount of mixing water to maintain workability of fresh concrete is the sum of water to cement ratio, water absorbed by the materials and water film thickness. For this study, the effects of water film thickness to the water demand and workability of concrete was not investigated.

Table 2 shows physical and mechanical properties of blended aggregates.

Table 2: Physical and mechanical properties of six blended aggregates materials.

Blended aggregate materials	Properties of aggregates						
	SG	**WA (%)**	**TFV (kN)**	**ACV (%)**	**AIV (%)**	**EI (%)**	**FI (%)**
55IPS45MCA00ICA	2.526	2.14	240.50	15.62	18.30	34.41	12.60
50IPS36MCA14ICA	2.415	2.37	194.92	22.24	26.69	30.32	12.68
45IPS27MCA28ICA	2.304	2.59	158.04	27.50	33.55	26.98	12.74
40IPS18MCA42ICA	2.193	2.82	127.30	31.88	39.27	24.20	12.80
35IPS09MCA56ICA	2.082	3.04	101.29	35.58	44.11	21.84	12.84
30IPS00MCA70ICA	1.971	3.27	79.20	38.36	48.26	19.82	12.88

3. Results and Discussion

The analysis of the results were based mainly on the aggregates properties and strength performance of cured concretes. The properties of aggregates tested includes sieve analysis for source materials and for blended aggregates to determine particle size gradation, aggregates strength parameters which are TFV, ACV and AIV and physical properties which are SG, WA, EI and FI. In order to obtain the compressive strengths of cured concrete specimens, characterization and analysis of tested data were performed.

3.1 Characterization and Results Discussion of Source Materials

The characterization of aggregate materials to determine physical and mechanical properties were conducted. The materials tested are Ituha pit sand (IPS), Ituha cinder aggregates (ICA) and Mbalizi crushed stone aggregates (MCA). The physical properties tested includes sieve analysis, specific gravities (SG), water absorption (WA), and elongation index (EI) and flakiness index (FI). The mechanical properties conducted for course aggregates are TFV, ACV and AIV.

The aggregates crushing value (ACV) and aggregates impact value (AIV) are conducted in order to determine the strength of aggregates in terms of crushing and in terms of shock according to MoW, 2000 [16]. The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load and aggregate impact value gives the idea about how much impact load can be resisted by aggregate. In case the crushing value and impact value of aggregates are greater than 30% then the aggregates are considered to be weak for structural concrete [18]. The ACV and AIV for Mbalizi crushed aggregates are 15.82% and 18.30% and for Ituha cinder aggregates are 38.76% and 48.26% respectively which indicates that the aggregates from Itaha volcanic cinder are weak to resist crushing and impact forces.

The ten per cent fines value (TFV) of coarse aggregates is a relative measure of the resistance of the aggregate to crushing under a gradually application of compressive load. The test is conducted according to MoW, 2000 [16]. The recommended TFV of aggregates for structural concrete should be greater than 100 kN, the values less than 100kN, the aggregates are considered to be weak [20]. The force required to produce 10% fines for Mbalizi crushed aggregates is 240kN which is 3 times that for Ituha cinder aggregates (refer table 1 and 2). The TFV results indicates that, Ituha cinder aggregates are not strong enough to resist crushing load.

The aggregates shape tests were conducted according to MoW, 2000 [16] in order to determine flakiness and elongation indices. The flaky and elongated particles have less strength, less bonding, less interlocking and durability as compared with cubical, angular or rounded particles of the same sizes [19]. The EI and FI should be in the range of 15% to 30% of the total aggregates. It is indicated that EI of crushed aggregates is higher compared to natural aggregates due to crushing process. The FI and EI for Mbalizi crushed aggregates are 12.60% and 34.41% and for Ituha cinder aggregates are 12.88% and 19.82% respectively. The results of shape tests shows that Mbalizi crushed aggregates have exceeded the minimum specified amount of elongated aggregates which is mainly due to crushing process.

The specific gravity (SG) and water absorption (WA) of aggregates and sand were determined according to MoW, 2000 [16]. The specific gravity and water absorption expresses the quality of aggregates in terms of strength and durability. It has been observed that aggregates having low specific gravity and those with high water absorption are considered to be weaker and porous than those with high specific gravity and low water absorption. The SG and WA recommended for aggregates to be used in construction ranges from 2.5 to 3.0 and water absorption ranges from 0.1% to 2.0%. The specific gravity and water absorption for Ituha cinder aggregates are 1.77 and 3.31% and Ituha pit sand are 2.44 and 3.18% respectively which are out of recommended ranges (refer table 1). In order to enhance physical and mechanical properties of cinder aggregates the source materials were blended together into different proportions and the results are indicated in table 2.

The blending process started with sieve analysis of source materials (aggregates and sands) to determine particle size gradation according to MoW, 2000 [16] which were used to compute gradation factors “GF” and median particle sizes “MS”. Figure 1 is the particle size distribution curves of source aggregates (Ituha cinder aggregates, Mbalizi crushed aggregates and Ituha pit sand).

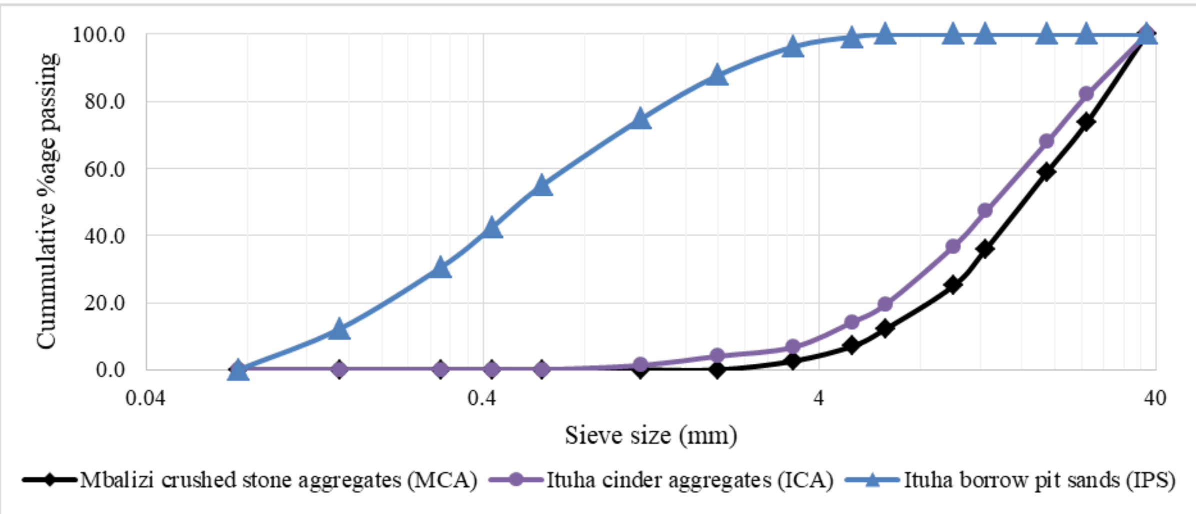

Figure 1: Particle size distribution curves of source aggregates.

The average particle sizes and nominal maximum sizes of three source aggregates are 0.71mm and 6.3mm for Ituha pit sand (IPS), 12.54mm and 37mm for Ituha natural cinder aggregates (ICA) and 14.65mm and 37mm for Mbalizi hand crushed aggregates. The gradation factors (GF) and median particle sizes (MS) were used to obtain blending proportions of aggregates and sand so that the blended aggregates lay within the specified envelope. The GF and MS are computed using equation 1 and 2.

$$\mathrm{GF} = \frac{\sum_{P=0}^{100} \mathrm{PP}_i * \mathrm{SS}_i}{\sum_{P=0}^{100} \mathrm{PP}_i} \qquad 1$$

Where: "PP_i" denotes percentage passing sieve size in mm; "SS_i" denotes sieve size for each percentage passing

$$\mathrm{MS} = \frac{\sum_{i=0}^{n} \mathrm{PR}_i * \mathrm{SS}_i}{100} \qquad 2$$

Where: "PR_i" denotes percentage retained on sieve size in mm; "SS_i" denotes sieve size for each percentage retained.

Table 3 shows computed gradation factors and median particle sizes for each source material and for upper and lower limit of the gradation envelopes.

Table 3: Gradation factors and median particle sizes of source aggregates and for the envelopes.

Source materials	**Ituha pit sand**	**Mbalizi crushed stone aggregates**	**Ituha cinder aggregates**	**Lower limit**	**Upper limit**
Abbreviations	**IPS**	**MCA**	**ICA**	**LL**	**UL**
Gradation factor (GF)	4.0	23.9	21.8	13.0	20.4
Median particle size (MS)	0.7	14.6	12.5	3.7	8.9

The three source aggregate materials were blended together into different proportions and for this study six new mixtures were obtained. The blending process were conducted in order to obtain particle size gradation curves laying within the selected envelope. Equation 3 was used to determine proportions of fine and course aggregates to be blended.

$$\mathrm{P_A} = \frac{(\mathrm{GF_U}+\mathrm{GF_L}-2\mathrm{GF_B})+(\mathrm{MS_U}+\mathrm{MS_L}-2\mathrm{MS_B})}{2[(\mathrm{GF_A}+MS_\mathrm{A})-(\mathrm{GF_B}+\mathrm{MS_B})]} \text{ and } \mathrm{P_B} = 1 - \mathrm{P_A} \qquad 3$$

Where: P_A and P_B are proportions of aggregate type A and B in decimals respectively, GF_A and GF_B are gradation factors of aggregate A and B respectively, MS_A and MS_B are the median particle sizes of aggregate A and B respectively, MS_L and MS_U are the median particle sizes of lower and upper gradation envelopes respectively, GF_L and GF_U are the gradation factors of lower and upper gradation envelopes respectively.

The proportional values obtained from equation 3 ranges between 0 and 1, in case the proportional values are outside the rage then the materials are not suitable to be blended for concrete mixes. In case there are more than two aggregate types to be blended, then the combined parameters (GF and MS) of the first blended aggregate materials are used to blend with other aggregate materials. Gradation curves of the six new mixtures used for concrete mixes and the gradation envelope (lower and upper limits) are shown in figure 2. The proportions of the aggregate materials in percentages are given as numerals in front of the abbreviation of each source aggregate material. The six new aggregate mixtures are 55IPS45MCA00ICA, 50IPS36MCA14ICA, 45IPS27MCA28ICA, 40IPS18MCA42ICA, 35IPS09MCA56ICA and 30IPS00MCA70ICA. Uniformly distributed gradation of aggregate particle sizes enhances packing density and friction resistance of concrete which eventually improves compressive strength performance and durability of hardened concrete [7, 8]. Therefore the gradation curves of the six blended sample aggregate materials used for this study are within the selected envelope.

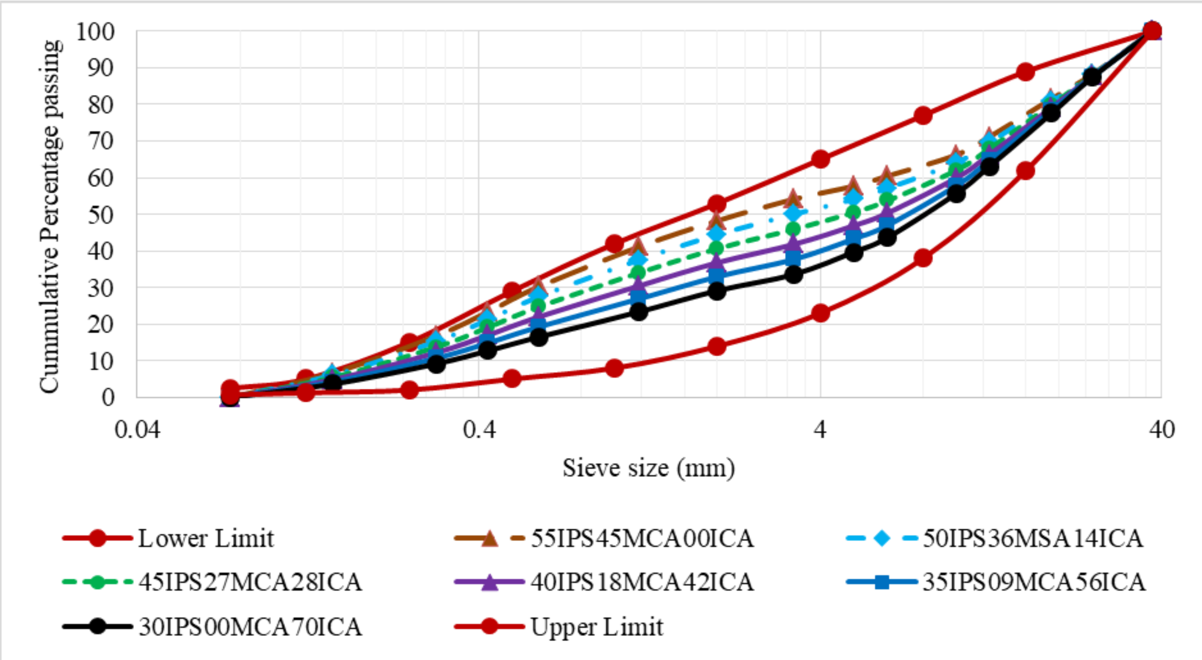

Figure 2: Particle size distribution curves of blended aggregates**.**

The physical and mechanical properties of the six aggregate mixtures were determined. Table 2 shows the physical and mechanical properties of the six mixtures used for preparation of fresh concrete mixes. The results indicates that specific gravities, ten percent fine values and elongation indices increased with increased contents of Mbalizi crushed aggregates. This is because the values of the properties for Mbalizi crushed aggregates are higher than for Ituha cinder aggregates. The values of water absorptions, aggregate crushing values and aggregates impact values were decreased as content of Mbalizi crushed aggregates increased. High water absorption for cinder aggregates is an inherent property which is due to high porosity caused by volcanic action. The decreased ACV and AIV with increased content of Mbalizi crushed aggregates is because, the aggregates are stronger and durable.

The six aggregate mixtures were used to make concrete at two different cement contents which are 350kg/m^3 and 450kg/m^3. Constant water to cement ratio of 0.55 was used during concrete mixing for all aggregate samples and cement contents. In order to improve workability due to high water demand of cinder aggregates, super plasticizer were added into fresh concrete. The amount of SP used for concrete mixes with 450kg/m^3 cement content is 2.5% and with 350kg/m^3 cement content is 3%. Figure 3 gives slump of fresh concrete for six different mixes for two different cement contents. The results indicated that for both cement contents the slump values increased with increased Mbalizi crushed aggregates. This is because the mixing water which would make the concrete plastic is absorbed by Ituha cinder aggregates and then the concrete becomes stiff (refer table 2). The water absorbed by the aggregate mixtures 30IPS00MCA70ICA is 3.27% while for 55IPS45MCA00ICA is 2.14% since the same water to cement ratio have been used to mix the concrete therefore the mix with zero Mbalizi crushed aggregates (MCA) will be stiff resulting into low slump.

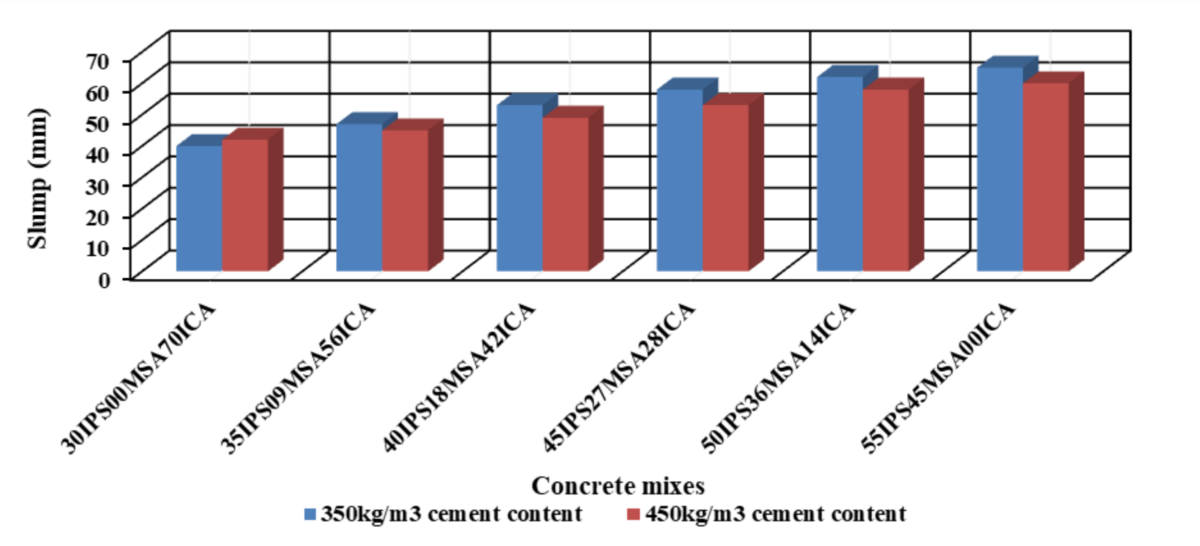

Figure 3: Slump values for fresh concrete mixes.

The concrete mixes were casted into 15cmx15cmx15cm cubes and cured under water after 7days, 14days, 21days and 28days. The cured specimens were crushed to determine compressive strengths and densities of specimens.

3.2 Compressive Strengths and Densities of Hardened Concrete Specimens

The mixing process of fresh concretes and crushing of cured concrete specimens to determine compressive strengths and densities were conducted according to MoW, 2000 [16]. The amount of aggregates for each concrete mix were determined using equation 4, and the amount of air content after compaction process of fresh concretes for this study were assumed to be 1.5% of the concrete volume.

$$W_{ag} = \rho_{ag}\left(985 - \frac{1.55W_C}{\rho_C}\right) \qquad 4$$

Where: W_{ag} is the weight of aggregates, W_C is the weight of cement, ρ_{ag} is the specific density of aggregates and, ρ_c is the specific density of cement

The specific densities (SG) of combined aggregates for each mix were determined as indicated in table 2 and the specific density of cement was taken to be 3.15. The amount of aggregate type were computed from blending ratios of each mix after getting total quantity of aggregate required for 1m^3 of concrete. Table 4 shows the amount of material ingredients for each mix for both quantities of cement.

Table 4: Contents of material ingredients for concrete mixes using 350kg/m^3 and 450kg/m^{3}cement contents.

Blended aggregates	Aggregates (kg/m^3)	Ag/C (ratio)	IPS (kg/m^3)	MSA (kg/m^3)	ICA (kg/m^3)
Contents of material ingredients for cement content of 350kg/m^3					
30IPS00MSA70ICA	1592	4.55	478	0	1114
35IPS09MSA56ICA	1682	4.81	589	151	942
40IPS18MSA42ICA	1771	5.06	709	319	744
45IPS27MSA28ICA	1861	5.32	838	503	521
50IPS36MSA14ICA	1951	5.57	975	702	273
55IPS45MSA00ICA	2040	5.83	1122	918	0
Contents of material ingredients for cement content of 450kg/m^3					
30IPS00MSA70ICA	1495	3.32	449	0	1047
35IPS09MSA56ICA	1579	3.51	553	142	884
40IPS18MSA42ICA	1664	3.70	665	299	699
45IPS27MSA28ICA	1748	3.88	786	472	489
50IPS36MSA14ICA	1832	4.07	916	660	256
55IPS45MSA00ICA	1916	4.26	1054	862	0

The amount of aggregates in kilogram increases with increasing Mbalizi crushed aggregates. This is because the density of MCA is high compared to ICA. However the volume of aggregates increased with increasing ICA due to its low density. The high the volume of materials the high the surface area, which eventually demands more cement for paste and mortar to cover the surface and to fill the voids between and within the aggregates. For the same cement content, the workability of fresh concrete with high amount of ICA was reduced. This is because the extra cement to make plastic consistency to concrete is taken up by voids and surface of the aggregates. Figure 4 is the graphs showing variation of compressive strengths of cured specimens with time and content of MCA mixed at cement content of 350kg/m^3. The results of compressive strengths indicates that the strength of concrete is improved with curing periods but also increased with increasing content of MCA. The situation is similar for concrete mixed at cement content of 450kg/m^3 (refer figure 5). The increased compressive strength with increased curing period is because of the formation and hardening of cementitious compound (CSH and CAH) with time [7, 17].

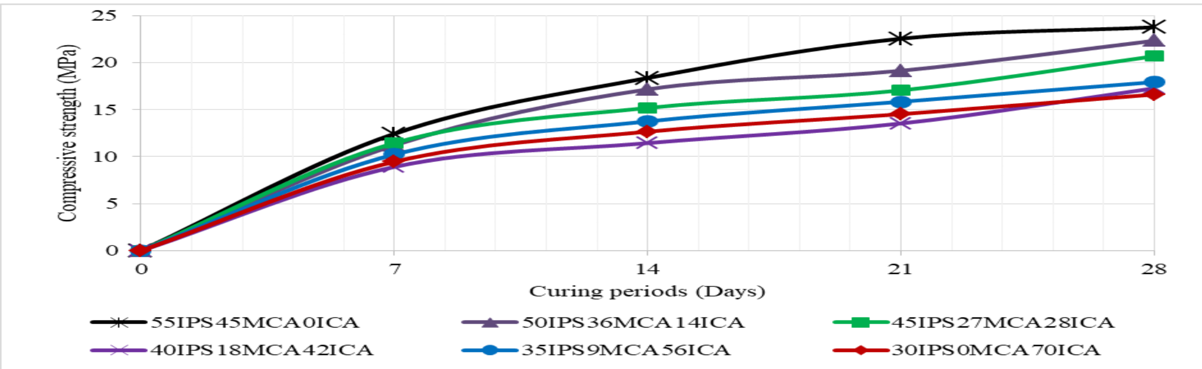

Figure 4: Compressive strength of concrete specimens for 350kg/m^3 cement content.

But also the increased compressive strengths with increased content of MCA is because, the MCA have high resistance against crushing compared to ICA (refer table 1 and 2). The compressive strengths of concrete mixed at cement content of 350kg/m^3 cured for 28days for the six mixes are 23.8MPa for 55IPS45MCA00ICA, 22.3MPa for 50IPS36MCA14ICA, 20.7MPa for 45IPS27MCA28ICA, 18.4MPa for 40IPS18MCA42ICA, 18.0MPa for 35IPS09MCA56ICA and 16.6MPa for 30IPS00MCA70ICA.

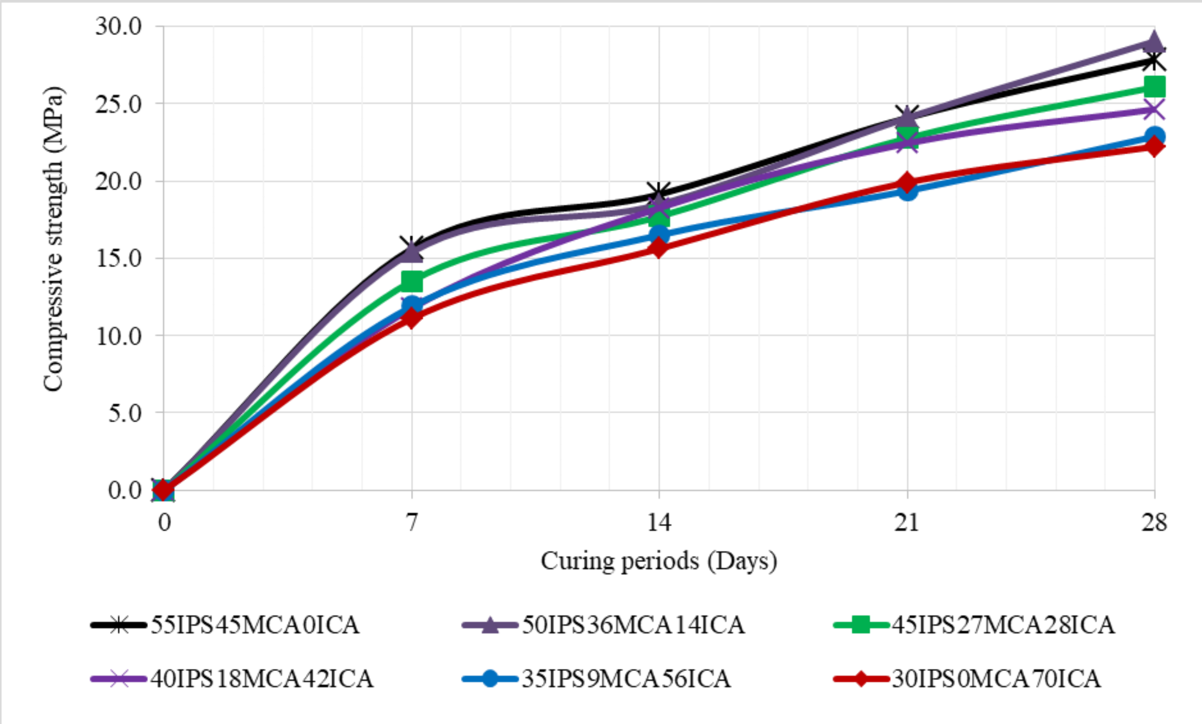

Figure 5: Compressive strength of concrete specimens for 450kg/m^3 cement content**.**

The compressive strength of concrete mixed at cement content of 450kg/m^3 cured for 28days for the six mixes are 27.8MPa for 55IPS45MCA00ICA, 29.0MPa for 50IPS36MCA14ICA, 26.1MPa for 45IPS27MCA28ICA, 24.6MPa for 40IPS18MCA42ICA, 22.9MPa for 35IPS09MCA56ICA and 22.2MPa for 30IPS00MCA70ICA.

However, the compressive strengths of cured concrete specimens mixed at cement content of 350kg/m^3 is low for all curing period compared to concrete specimens mixed at cement content of 450kg/m^3. High amount of cementitious gels (CSH and CAH) are developed for concrete with high amount of cement content for the same amount and type of aggregates especially at early days of curing. This is because for concretes with low cement contents, cementitious gels developed in early days are not enough to binder the aggregates together compared to concrete specimens with high cement contents [7].

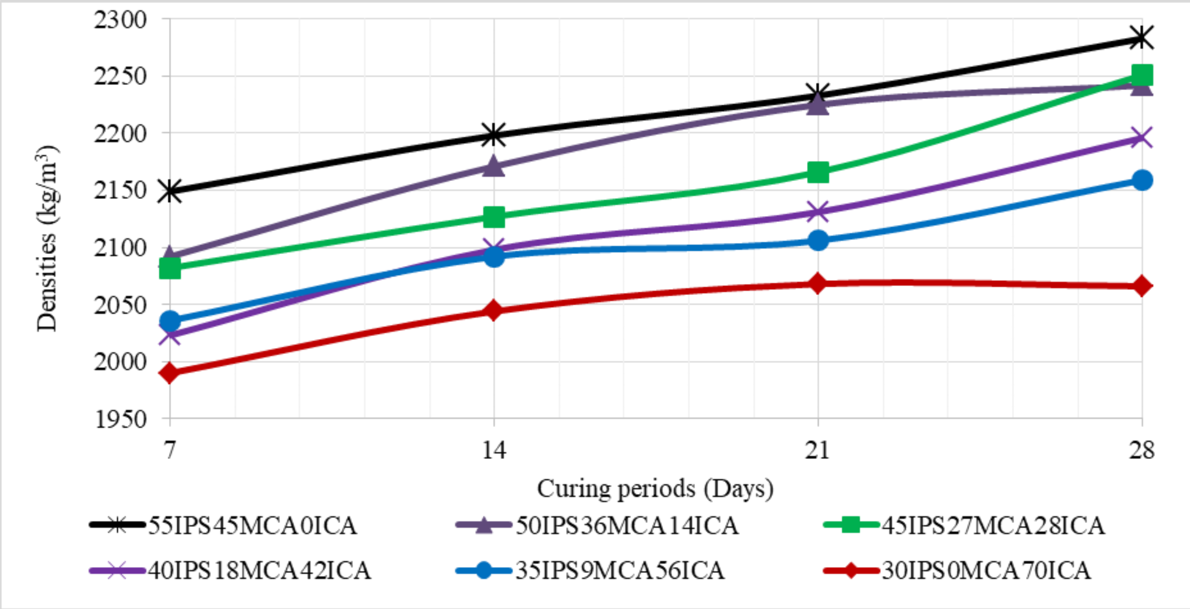

Figure 6: Densities of cured specimens for 350kg/m^3 cement content.

Figure 6 is the graphs showing variation of densities of cured specimens with time and content of MCA mixed at cement content of 350kg/m^3. The results of densities of cured specimens for six mixes indicated that the densities increased with increasing curing periods from 7days to 28days but also densities increased with increasing content of MCA. The situation is similar for concrete mixed at cement content of 450kg/m^3 (refer figure 7). The increased density with increasing curing period is mainly due to development of CSH and CAH of cement during hydration reaction which fills up the voids taken by water [7]. But also densities of cured concrete specimens increased with increasing content of MCA, this is because the MCA materials have higher specific density than ICA and IPS materials used for this study (refer table 1 and 2).

Therefore, it indicates that cinder aggregates due to its low density compared to conventional aggregates can be used to design light weight concrete for massive and suspended structural elements. The densities of concrete mixed at cement content of 350kg/m^3 cured for 28days for the six mixes are 2283kg/m^3 for 55IPS45MCA00ICA, 2242 kg/m^3 for 50IPS36MCA14ICA, 2251kg/m^3 for 45IPS27MCA28ICA, 2196kg/m^3 for 40IPS18MCA42ICA, 2159kg/m^3 for 35IPS09MCA56ICA and 2066kg/m^3 for 30IPS00MCA70ICA. The densities of concrete mixed at cement content of 450kg/m^3 cured for 28days for the six mixes are 2270kg/m^3 for 55IPS45MCA00ICA, 2236kg/m^3 for 50IPS36MCA14ICA, 2204kg/m^3 for 45IPS27MCA28ICA, 2188kg/m^3 for 40IPS18MCA42ICA, 2148 kg/m^3 for 35IPS09MCA56ICA and 2124kg/m^3 for 30IPS00MCA70ICA.

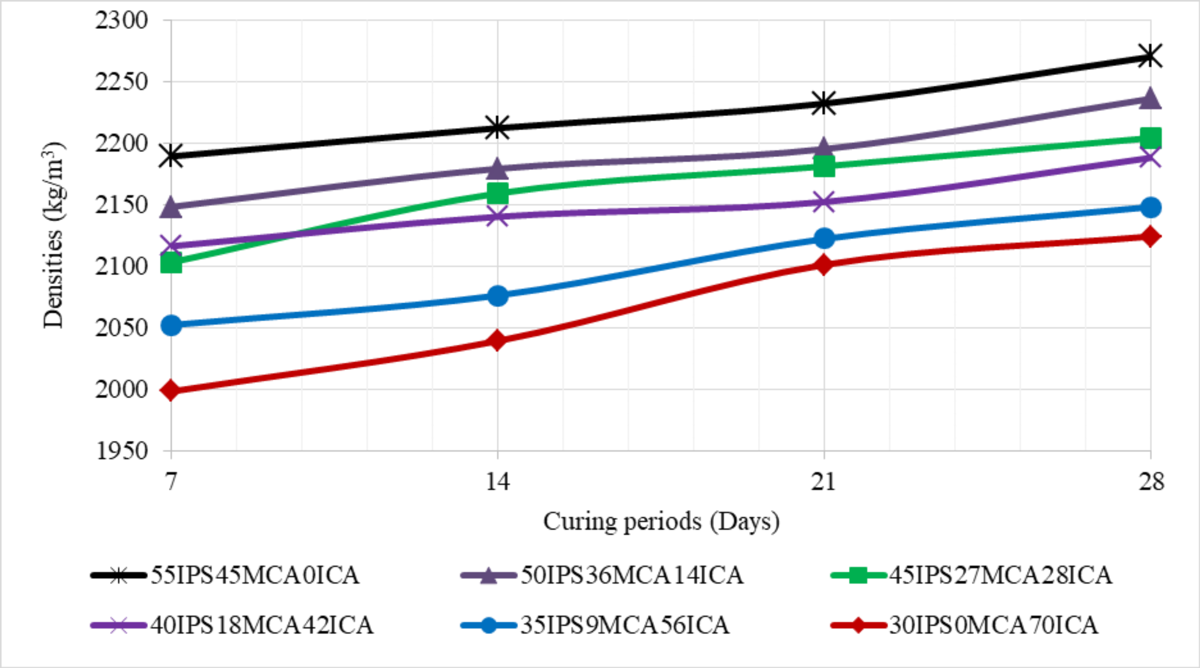

Figure 7: Densities of cured specimens for 450kg/m^3 cement content.

The findings revealed that the strengths of cured concrete specimens increased with increased cement contents, strength of aggregates and curing periods. For this study strength prediction model for normal concrete cured for 28days was developed based on cement content and aggregate parameters which are TFV and SG.

3.3 Prediction model of concrete compressive strength

Compressive strength is the measure of hardened concrete to withstand loads. The prediction of compressive strengths of concrete and mortar is useful because of design requirements, planning and scheduling purposes of construction.

The models/equations are developed from data set of pre-determined criteria/parameters [7]. Several prediction models of compressive strength of cured concrete specimens have been developed. The common strength prediction models includes empirically derived models which utilizing water-to-binder ratio as main parameter of the equations such as Abraham model, Feret model and Balomey model [7]. The maturity functions which utilize hydration temperature and time as major parameters of the equations. Artificial Neural Network (ANN) techniques which are relatively crude connected electronic models which mimic operations of biological neural of human brain [7]. It is clearly known that the compressive strength of concrete is also affected by strength and physical properties of aggregates. However, little/no efforts have been done to predict the compressive strength of cured concrete using strength and physical parameters of aggregates. This research therefore has developed prediction model for compressive strengths of 28days cured concrete specimens using strength and physical parameters of aggregates and content of cement (refer equation 5). The parameters of the equation are ten percent fine value (TFV), specific gravity (SG) of combined aggregates and cement content (C).

$$\sigma_{28D} = 0.0022C[3.375e^{0.575SG} + 9.15e^{0.002TFV}] \qquad 5$$

Where: σ_{28D} is the compressive strength of concrete specimens cured for 28 days, "C" is the cement content in kg/m^3, "SG" is the specific gravity of blended agregates and "TFV" is the ten percent fine value of blended aggregates.

The model is useful for normal concrete without mixtures cured under water at room temperatures.

4. Conclusions and Recommendations

Concrete is the mixture of course aggregates, fine aggregates, cement and water. Some time for the purpose of improving properties of fresh and hardened concrete additives and admixtures are added into concrete. Currently concrete takes large part of building materials for construction of modern buildings and infrastructures. However strong and durable aggregates for concrete mixes are scares and continued depleting with time due to demand of construction projects worldwide. Several studies are conducted to use natural occurring aggregate materials such as cinder aggregates for concrete mixes. In order to improve properties of cinder aggregates and reduce cost of construction of buildings and infrastructures, it is important to blend cinder aggregates with conventional aggregates.

The results from data analysis of aggregates indicated that the strength parameters such as TFV, AIV, ACV and SG are 240kN, 18.3%, 15.8% and 2.63 for Mbalizi crushed aggregates are 79kN, 48.26%, 38.76% and 1.77 for Ituha cinder aggregates. It has been investigated that Ituha cinder aggregates are not suitable to be used for structural concrete because the values of strength parameters of cinder aggregates did not meet the requirements. Therefore blending of cinder aggregates with conventional aggregates to enhance the missing properties from cinder aggregates were necessary. The results for compressive strengths of six cured concrete mixes from blended aggregates indicated that the compressive strengths increased with increasing curing period and amount of Mbalizi crushed aggregates.

The compressive strength of concrete specimens mixed at cement content of 350kg/m^3 cured for 28days for the six mixes are 23.8MPa for 55IPS45MCA00ICA, 22.3MPa for 50IPS36MCA14ICA, 20.7MPa for 45IPS27MCA28ICA, 18.0MPa for 40IPS18MCA42ICA, 18.0MPa for 35IPS09MCA56ICA and 16.6MPa for 30IPS00MCA70ICA. The compressive strength of concrete mixed at cement content of 450kg/m^3 cured for 28days for the six mixes are 27.8MPa for 55IPS45MCA00ICA, 29.0MPa for 50IPS36MCA14ICA, 26.1MPa for 45IPS27MCA28ICA, 24.6MPa for 40IPS18MCA42ICA, 22.9MPa for 35IPS09MCA56ICA and 22.2MPa for 30IPS00MCA70ICA. But also densities of cured concrete specimens for both cement contents increased with increasing curing periods and amount of Mbalizi crushed aggregates.

The increase in compressive strength with increase in curing period is because of development of cementitious gels (CSH and CAH) and the increase in compressive strength with increase in Mbalizi crushed aggregates is because Mbalizi aggregates have high resistance against crushing compared to Ituha cinder aggregates. However the increased in compressive strength of cured concrete is also enhanced by interlocking and friction resistance of aggregates. The interlocking and friction resistance of aggregates are very much enhanced by uniform gradation of aggregate particles which is achieved by blending different aggregate particle groups. For this study for easy blending process of aggregates, the blending model have been developed, the model uses median particle size (MS) and grading factor (GF) as variables. To make use of strength of aggregates, this study has developed prediction model of compressive strength of 28days cured concrete specimens. The model uses TFV, SG and cement content as variables.

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Appendices

Figure 8: Photo of hand crushed aggregates from collected stones at Mbalizi area.

Figure 9: Photo of natural Cinder aggregates excavated at Ituha area.

Figure 10: Photo of sands excavated from borrow pit at Ituha area.