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Effect of Limestone Powder as an Additive and as Replacement of Self-Consolidating Lightweight Foamed Concrete

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Abstract: Concrete is the absolute most broadly utilized material in the development which must needs to guarantee attractive compressive quality and sturdiness. Mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength. Numerous studies have been conducted for development of self-consolidating lightweight concrete (SCLWC) by investigating especially on their materials component and mix proportion. Commonly, considerations made by the researchers to produce SCLWC is by replacement of aggregates with alternative lightweight materials such as pumice, expanded clay, rubber granules and more or by adding foam agent. Besides, Limestone powder (LP) is one of concrete admixture that widely used as cement replacement. LP is proven can reduce energy consumption and resources from cement process, as well as effects the concrete properties. However, there are very few studies using only LP as main admixture for SCLWC. Therefore, the objectives of this study are to investigate the effect of limestone powder as an additive and as cement replacement in SCLW foamed concrete (SCLWFC) to the flowability and compressive strength. The experiment involves 3 types of SCLWFC which are normal mix; mixes without LP, additive mix; mixes with LP as an additive and replacement mix; mixes with and LP as cement replacement. Based on this study, the results indicated that the utilization of LP has positive effects to the flowability. Maximum value for slump flow was obtained when the LP as cement replacement at 40% and maximum value for compressive strength was obtained when the LP as an additive at 10%.

Keywords: Compressive Strength, Self-Consolidating Lightweight Concrete, Foaming Agent, Limestone Powder

1. Introduction

Self-consolidating concrete (SCC) is often described as the high-performance concrete due to the ability of the fresh concrete to flow under its own weight over the distance while maintaining sufficient resistance to segregation and achieves proper compaction without the need of a vibrator or any mechanical equipment. This workability saves times, overall cost reduction, improve the working environment by minimizing noisemaker from vibrator as well as improving the environment by reducing carbon dioxide (CO_2) emission from mechanical equipment (Elyamany, Abd Elmoaty & Basma Mohamed, 2014). The most important of SCC is that the characteristic of hardened-concrete is dense,

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homogenous and all engineering properties, characteristic and durability are maintained as traditional concrete (Ramamurthy, Kunhanandan Nambiar & Indu Siva Ranjani, 2009) hence, the density of the SCC is in the range 2200 - 2600 kg/m^3 (Aguilar, Diaz & Garcia, 2010). As an alternative, new technology introduced self-consolidating lightweight concrete (SCLWC) which has a lower density compared to normal concrete. Structural SCLWC is defined as structural concrete made with lightweight materials that have an air-dry density range from 400 – 1850 kg/m^3 (Shohana Iffat, 2015). There are few types of SCLC, which are made with different types of materials such as lightweight aggregate and foam agent.

Self-Consolidating Lightweight Foamed Concrete (SCLWFC) is described as aerated concrete with random air-voids created from the mixture of foam agents in concrete, which produce high flow-ability, low bond content, low total utilization and phenomenal warm protection. With the presence of air-voids, the concrete become less in density and classified as a lightweight concrete, which is a range of density is approximately 300 kg/m^3 to 1850 kg/m^3 (Neville, 2002) which is lighter than normal weight concrete.

To ensure that fresh and the harden state of SCLWFC is stable on their homogeneity and achieved their durability's and engineering properties, some modification of its properties needs to be made to the composition of ordinary concrete. Several problems may occur in some formulations including bleeding, settlement and segregation (Jung et al., 2018). Superplasticizer is utilized to enhance the flowability without causing deformation or segregation issues (Antoni, Owen & Djawantoro, 2017). Mixtures containing moderate amounts of cementitious materials and fine fillers decrease the coarse aggregate volume and reduce the risk of blockage while at the same time expanding the segregation resistance and reducing the expenses related with high volumes of Portland cement and superplasticizer (Sua-iam & Makul, 2013). According to Vakhshouri and Nejadi (2016), reported that mineral admixture such as fly ash, blast furnace slag, silica fume, limestone powder, brick powder, kaolinite, rice husk ash has been utilized in attempts to enhance the properties of SCLFC and each admixture extend different level of hydration reaction, micro-pore structure as well as durability of concrete.

In general, the utilization of mineral admixtures in different combinations can give brilliant mechanical properties of SCLWFC which eventually may benefits the development construction industry by decrease dead loads on the structure and foundation. It also brings down work cost during construction, lessen the expense of production and transportation of building segments and adds to vitality preservation, contrasted with ordinary cement and has the capability of being utilized as an auxiliary material (Amran, Nima & Abang Ali, 2015).

As stated earlier, SCC is high in workability, strength and density, but quite heavy; meanwhile SCLFC is high in workability, light in weight but has low strength. It is much better if the combination of both, by producing Self-Consolidating Light Weight Foamed Concrete (SCLWFC), workability, compressive strength and density are improved at the same time. Therefore, to ensure the SCLWFC can be widely used in construction development, many researchers have conducted various studies to create highly innovative solutions by improving SCLWFC properties, in terms of strength especially.

Commonly, investigation to increase the strength of SCLWFC is by additional of mineral admixtures either introduced as an additive or as replacement of cement content with others substance such as fly ash, silica fume, metakaolin, granite dust, marble dust and risk husk in the concrete mixes (Elyamany, Abd Elmoaty &, Basma Mohamed, 2014; Jung et al., 2018; Vakhshouri & Nejadi, 2016; Amran, Nima & Abang Ali, 20160. Mineral admixture is one of important substance in concrete mix proportions. Mineral admixture is added to change the properties of concrete to make it function as required by modifying properties of both fresh and hardened concrete such as to increase workability, to accelerate the rate of strength development, to increase the strength of concrete or mortar, to increase the durability or resistance to severe conditions of exposure and so on (Kumar & Dhinakaran, 2012). According to Elyamany, Abd Elmoaty and Basma Mohamed (2014), the SCC mixes often use a large quantity of powder materials that required maintaining sufficient stability or cohesion of the mixture, hence reducing bleeding, segregation and settlement.

High volumes of mineral admixtures to concrete mixtures is constrained because of their negative impacts on water demand and quality of the hardened concrete. However, according to Jung et al. (2018), these minerals admixtures not only can be efficiently utilized as viscosity enhancers particularly in powder-type SCC but also significantly improve the workability and durability of SCC. At the point when utilized at SCC, mineral admixtures can diminish the measure of superplasticizer important to accomplish a given property (Antoni, Owen & Djawantoro, 2017). Besides, it ought to be noticed that the impact of mineral admixtures on admixture prerequisites is altogether subject to their molecule estimate conveyance and in addition molecule shape and surface characteristics (Jung et al., 2018).

For example, limestone powder is one of mineral admixture that widely used as cement replacement. Limestone is the most common form of calcium carbonate, which is used extensively for the manufacture of cement. The used of limestone powder as a portion of ordinary Portland cement (OPC) can reduce energy consumption and resources from the cement manufacturing process as well as reduce adverse impact to the environment (Gudissa & Dinku, 2010). Limestone powder has been utilized to produce concrete in a few nations. In the recent BS EN 197-1:2000 specification, up to 35% of limestone powder can be added to create Portland limestone cement and Portland composite cement. The addition of fine limestone powder has appeared to upgrade the rate of cement hydration and quality advancement (Heikal, El Didamony & Morsy, 2000), and also to enhance the deformability and stability of fresh SCC (Leeuwen, Kim & Sriraman, 2016).

Although limestone powder has distinctive benefits that are superior to that others substance as a cement replacement, however, very few studies conducted using limestone powder as a main admixture for producing SCLWFC. Normally, limestone powder used only as a partial replacement for cement content together with others substance like silica fume, fly ash, metakaolin and others. From those limited studies, there are some discrepancies from test results either the used of limestone as an additive or replacement of cement content in the concrete mix that would improve the flowability and concrete strength. Hence, this paper presents the investigation on the effect of limestone powder as an additive and as cement replacement to the flowability and compressive strength of self-consolidating lightweight foamed concrete.

2. Materials and Method

2.1 Materials Selection

Fine and coarse aggregate, cement, Superplasticizer (SP), foaming agent, limestone powder and water were used in this research to produce the Self-Consolidating Lightweight Foamed Concrete (SCLWFC).

River sand is used as fine aggregate. Fine aggregate which in properly graded is essential to successful execution of the work. Fine aggregate that used in this research were the maximum size of 5mm. With finer sand it will greatly affect the workability and flow ability of the concrete.

Coarse aggregates used in this research are crushed mining aggregates with a maximum size of 10mm. The coarse aggregate occupied 40% of the total aggregate (EFNARC, 2005).

Ordinary Portland Cement (OPC) was used as binder material in this experiment and it is complied with BS EN 197-1:2000 and it has a medium rate of hardening and suitable for most a type of work.

Limestone Powder (LP) used in this research was the finest natural calcium carbonate manufactured by Omya Kalsium Sdn. Bhd. The limestone was utilized by added to the concrete mix and replaced the cement content in various percentages which are 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of the cement content by mass.

Superplasticizer (SP) that used in this research is Polycarboxylic Ether (PCE); brand Master Glenium 8589, from BASF. The amount of PCE used is 1L for every 100kg of cement. Effect of superplasticizer on concrete fresh mixture depends on its dosage and distribution in the mixture. Very low dosage will not affect the rheological behavior of the fresh mixture and on the other hand very high dosage may cause detrimental effect such as bleeding and segregation (Antoni, Owen & Djawantoro, 2017).

Tap water was used to mix the concrete as it is considered being cleaned and free from dirt and organic matter. Tap water will also be used for curing the concrete specimens. The quality of water is according to the Public Work Department of Malaysia, adopted from BS EN 1008:2002, for concrete work specifications.

Synthetic foaming agent used in this research was brand Meyco SLF 30 supplied by CT Technology Enterprise. The foam was produced by mixing the foam agent with water at a 1:20 ratio, to create an air bubble that can resist the physical and chemical forces imposed on them during mixing, placing and hardening of concrete.

2.2 Experimental Methods

This research was carried out to identify the slump flowability and compressive strength properties of SCLWFC containing different percentages of the LP as an additive and cement replacement, which are 0%, 5%, 10%, 15%, 20%, 25% of cement content by mass. Water cement ratio is 0.53 of concrete. SCLWFC properties shrouded in this research incorporate properties of flowability at new state and compressive quality at solidified state. For this research, the dimension size of the specimen was 100mm x 100mm x 100mm. Compressive strength test on of SCLWFC was conducted at the age 3, 7, and 28 days. Microstructure analysis is to determine the physical characteristic of the concrete surface that observed by using microscope methods. The chemical composition of LP is determined using X-Ray Florescence (XRF) test.

2.3 Mix Proportion

As reported by Amran, Nima & Abang Ali (2015), there are no particular mix proportion techniques to get focused on properties in foamed concrete. Therefore, an adequate alternative calculation technique to propose the desired strength of foamed concrete are using some trial and error methods by using appropriate mix design methods and fixed the value of water/cement content or water/binder content (Bing, Zhen & Ning, 2012).

Hence, for this study, designing of concrete mix is divided into two stages. First stage is the basic component of mix compositions of SCLWFC are the same as used in normal weight concrete, which is based on the British method Department of Environment revised in 1988 to determine the indicated quantity by weight of the cement content, free water and total aggregates (Fine aggregate and Coarse Aggregate).

Then, in the second stage, in-house developed spreadsheet is to determine the amount of foaming agent lead to a new modified mix proportioning for SLWFC with a target density of 1800kg/m^3. Mix proportion for 1m^3 is determined and shown in Table 1.

2.4 Casting and Curing

To ensure the way toward batching is done successfully to give the concrete better quality; the mixing procedure was executed in a concrete mixer machine. Method for mixing is carried out in accordance with BS 1881-125:2013. The material used in the concrete mixtures was measured to its specific weight as calculated in the design mix.

After 24 hours casting, the specimens were demoulded and cured in water until the testing date. Method of curing was according to BS EN 12390-2:2009. The purpose of the curing process is to promote the hydration of cement, thus develop the strength and durability of concrete. It likewise controls the temperature and dampness development from and into the concrete.

2.5 Test Procedures

There are two categories of testing involved in these research which are slump flow test for the fresh concrete state while concrete compressive strength need to be carried out in the hardened concrete state.

Slump flow test is conducted to measure the horizontal free flow of SCLWFC in the absence of obstructions. Test method is based on the conventional slump test as in accordance to BS EN 206- 9:2010. Filling ability of the concrete is measured by the diameter of the concrete circle. It gives no indication of the ability of the concrete to pass between reinforcement without blocking; however, it gives some indication of resistance to segregation. The ability to fill formwork under its own weight can be determined by the slump flow value. The higher slump flow value shows greater capacity to fill formwork under its own weight.

Compressive strength test was conducted on concrete specimens (100mm x 100mm x 100mm) at the age of 3, 7, and 28 days. For each mixture and test age, three specimens were tested, and average values were reported. Test was conducted using Auto Test 3000kN Compression Machine.

Table 1- Mix Proportion of SCLWFC

Type of Mixture		Batch No.	MIX PROPORTION						
			Cement	Water	Fine Agg.	Coarse Agg.	Foam	Limestone Powder	Superplasticizer
			kg/m^3	kg/m^3	kg/m^3	kg/m^3	L/s	kg/m^3	L/m^3
Control Mix		N1	338.46	180.77	769.23	511.54	1.83	-	3.55
Additive Mix	5%	A1	338.46	180.77	769.23	511.54	1.83	16.92	3.55
	10%	A2	338.46	180.77	769.23	511.54	1.83	33.85	3.55
	15%	A3	338.46	180.77	769.23	511.54	1.83	50.77	3.55
	20%	A4	338.46	180.77	769.23	511.54	1.83	67.69	3.55
	25%	A5	338.46	180.77	769.23	511.54	1.83	84.62	3.55
	30%	A6	338.46	180.77	769.23	511.54	1.83	101.54	3.55
	35%	A7	338.46	180.77	769.23	511.54	1.83	118.46	3.55
	40%	A8	338.46	180.77	769.23	511.54	1.83	135.38	3.55
Replacement Mix	5%	R1	321.54	180.77	769.23	511.54	1.83	16.92	3.55
	10%	R2	304.62	180.77	769.23	511.54	1.83	33.85	3.55
	15%	R3	287.69	180.77	769.23	511.54	1.83	50.77	3.55
	20%	R4	270.77	180.77	769.23	511.54	1.83	67.69	3.55
	25%	R5	253.85	180.77	769.23	511.54	1.83	84.62	3.55
	30%	R6	236.92	180.77	769.23	511.54	1.83	101.54	3.55
	35%	R7	220.00	180.77	769.23	511.54	1.83	118.46	3.55
	40%	R8	203.08	180.77	769.23	511.54	1.83	135.38	3.55

3. Results and Discussion

3.1 Chemical Composition of Limestone Powder

Chemical test result obtained on both cement and limestone powder as stipulated on Table 2.

Table 2 - Chemical composition of cement and limestone powder

Compound formula	Concentration of compound (%)	
	Cement	Limestone powder
MgO	1.27	1.149
Al_2O_3	2.56	0.083
SiO_2	15.05	0.166
P_2O_5	0.06	0.013
K_2O	0.41	0.011
CaO	72.17	65.71
Fe_2O_3	4.00	0.057

Magnesium Oxide (MgO) that is contained in cement does not have much different which the percentage of MgO in cement and limestone is 1.27% and 1.149% respectively. Greater difference can be seen is in Silicon Dioxide (SiO_2) which is 14.884%. The concentration of Calcium Oxide (CaO) and Ferric Oxide (Fe_2O_3) in limestone powder also differ about 6.46% and 3.943% from the concentration of CaO in cement. Apart from that, the Aluminium Oxide (Al_2O_3) content in cement is 2.477% more than its content in limestone powder.

3.2 Slump Flow Test of SCLWFC

Results of slump flow test for additive mix and replacement mix of limestone powder are given in Figure 1. Slump flow for control mix batch no. N1 is 725mm. As for concrete batch with limestone powder as an additive up to 5% and 10%, the slump flows are increasing from 738mm and 752mm respectively, and the slump flows were decreased when the additional of limestone powder were increased from 15% up to 40% in value 752, 734, 726, 719, 702, 688 and 670mm respectively.

Meanwhile, slump flow test result of replacement of limestone powder batch increases gradually with the increases of limestone powder replacement. Slump flow for replacement of 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% are 728, 730, 733, 734, 738, 741, 749 and 755mm respectively.

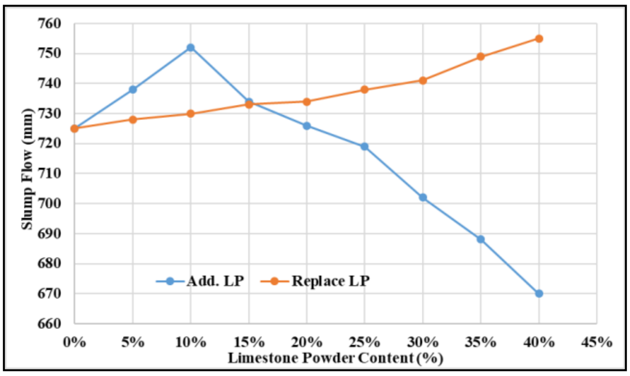

Fig. 1 - Slump flow test of self-consolidated lightweight foamed concrete made with various limestone powder contents.

Slump flow test results of additive of LP showed that the limestone powder as an added substance negatively affects the rheological properties of fresh SCLWFC. The addition of limestone up to 10% indicated increments in slump flow diameter. Be that as it may, increasing the limestone powder content over 10% to 40% decreased in slump flow respectively. This would be clarified by the increase in fineness and surface region adsorbs a more amount of water, accordingly diminishing the amount of free water accessible in the mixture. Therefore, by additional of limestone powder content more that 10% with fixed water/cement ratio, there is insufficient water to wet the surface of particles that makes the mix becomes stiff and consequently flowability.

In spite of that, the degree of flow spreading is likewise reliant on particle qualities, for example, size, shape, surface, area and porosity. As stated by Sua-iam and Makul (2013), limestone powder particles were somewhat littler, smooth surface and circular shape contrasted with the Portland concrete molecule which is the rough surface and precise. Hence, limestone powder has greater surface area than cement, and the characteristic of limestone particles are important in determining the workability characteristic. This is proved by slump flow test results of additive of limestone powder, which is indicating the positive influence of limestone powder in SCLWFC mixtures. This would be clarified by; replacement of limestone powder means reduced in cement content. Therefore, smooth texture and spherical shape are greater than the rough surface and angular shape, thus, reducing inter-particle friction and increase the workability.

Generally, all value of slump flow for the additive and replacement of limestone powder are satisfied the suggested range of values (550 - 850mm) as outlined by EFNARC (2005). However, it is prescribed that the water/cement ratio ought to be limited on the grounds that the excessive volume of water causes segregation of foamed concrete during casting which influences the usefulness execution.

3.3 Compressive Strength and Microstructure of SCLWFC

The summary of values obtained for each characteristic of SCLWFC mixes is presented in Figure 2 (Additive Mix) and Figure 3 (Replacement Mix). Results shown the compressive strength for 3, 7 and 28 days increased to a maximum when limestone powder as an additive were up to 10% and decreased gradually with the increases of limestone content. 28-day compressive strength for batch no A1, A2, A3, A4, A5, A6, A7 and A8 as follows: 14.66, 18.69, 10.26, 7.41, 7.12, 8.00, 7.08 and 6.45 N/mm^2 respectively.

In the meantime, compressive strength of replacement of limestone batches seems to be decreased with the increases of replacement content. The 28-day compressive strength for batch no R1, R2, R3, R4, R5, R6, R7 and R8 as follows: 7.21, 6.35, 6.12, 5.25, 5.00, 4.83, 4.41 and 3.97 N/mm^2 respectively.

Figure 2 and figure 3 show that compressive strength at 3, 7 and 28 days increases to a maximum at the addition of limestone powder content of 10%. The highest strength comes from batch A2 at 28 days with 18.69 N/mm^2. Strength was increased by 35% compared to the control batch, which is 13.80 N/mm^2. The additional of limestone powder for about 10% of the cement content, acts as filler that leads to affect the particle size distribution, decrease the total porosity and accelerate the rate of hydration of the cement paste. Limestone powder is fine particles could improve the compact composition of microstructure of hardened SCLWFC. For specimens N1 and A1, which is with only 0% to 5% limestone powder, there are not enough fine particles to fill all voids between cement pastes hence, lower compressive strength values as compared to specimens A2.

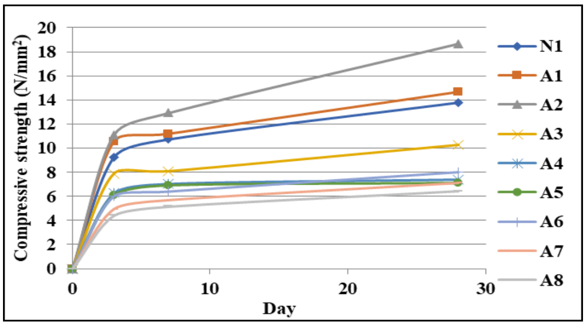

Fig. 2 - Compressive strength development of SCLWFC containing limestone powder as an additive

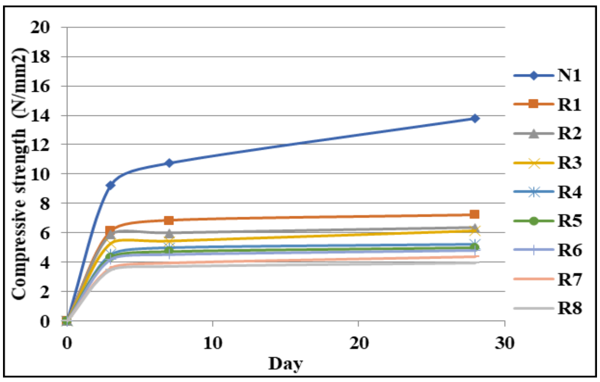

Fig. 3 - Compressive strength development of SCLWFC containing limestone powder as a replacement

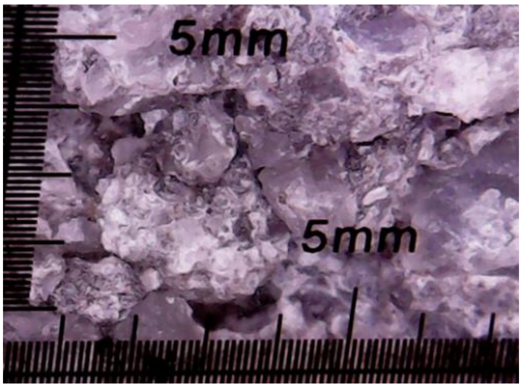

Fig. 4 - (a) Specimen N1 **-** Control Mix (0% of limestone powder)

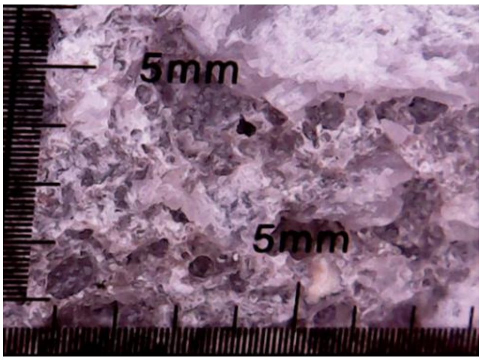

Fig. 4 - (b) Specimen A1 **-** Additive Mix (with 5% add. Of limestone powder)

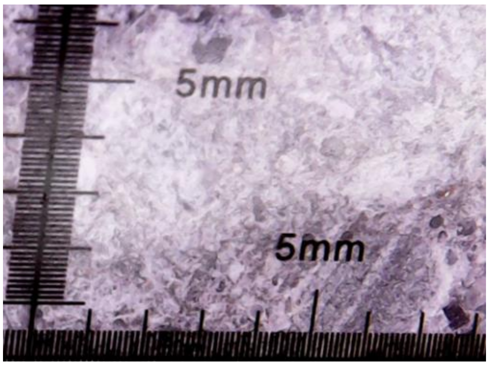

Fig. 4 - (c) Specimen A2 **-** Additive Mix (with 10% add. Of limestone powder)

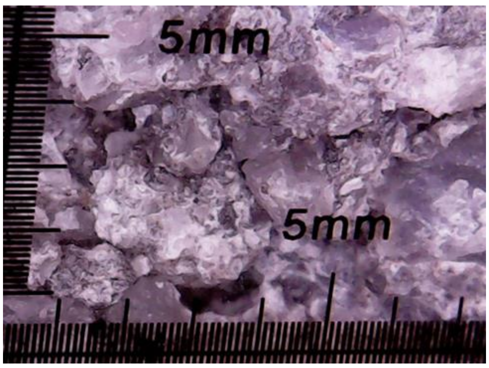

Fig. 4 - (d) Specimen N1 **-** Normal Mix (0% of limestone powder)

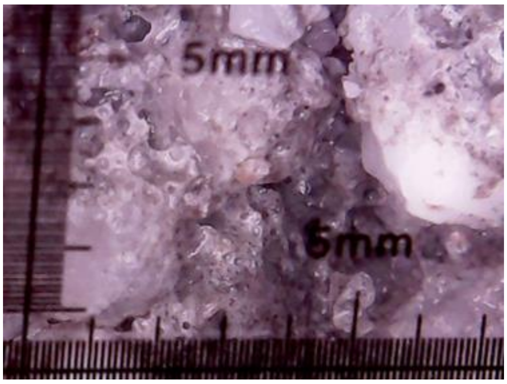

Fig. 4 - (e) Specimen R1 – Replacement Mix (with 5% of limestone powder replacement)

Visual representations of cut sections of the specimens viewed through an optical microscope with magnification factor for 3 types of Control and Additive Mix; Control (N1), 5% additional of limestone powder (A1) and 10% additional of limestone powder (A2), as well as replacement of limestone powder (R1) and 10% replacement of limestone powder (R2) are presented in are presented in Figure 4 (a, b, c, d, e).

Figure 4 (a-e) show that the volume, size distribution and spacing between air-voids become narrower and lesser compared from the specimen's number N1, A1 and A2. On the specimen number A2, it's clearly shown that concrete were dense with very minimal of voids, the average size of the pores is less than 1mm in round shape and all pores are not connected with spacing between air-void more than 2mm. For the specimen number A1, the concrete quite dense, the spacing between air-void is closer in the range of 1 - 3mm and size of pore in the range 0.2 – 0.5mm and in round shape. Meanwhile, for the specimen number N1, concrete quite dense with spacing between air-void in the range of 0.5 - 1.5mm, size of pores of 0.3 – 1.2mm and in irregular shape.

This can be described by the limestone particles act as filler helps in achieving more distributions of air void by providing a uniform coating on each bubble and thereby prevents merging the bubbles. As a result, specimen containing 10% of limestone additive becomes denser as well as improving the compressive strength.

Whereas decrease in compressive strength with additional of limestone powder more than 10% probability due to increases in powder or fineness particles, makes reduce of binder/solid ratio. As stated by Nambiar and Ramamurthy (2006), the decrease of binder/solid ratio may affect the concrete unity, since there is insufficient binder to coat all the aggregate particles. As the result, the porosity of specimens is increased, less in density as well as their strength.

On the contrary, decreases of compressive strength for the replacement of limestone powder in the range of 5% - 40%, probably due to the water/cement or water/binder ratio. In this study, water/binder ratio was maintained at 0.53 for all type mixes even though for substituted of limestone powder by cement. According to Gudissa and Dinku (2010), extensive studies reported that limestone powder requires less water; even the finest and surface area is higher compare to cement. Therefore, the water/binder ratio will be increased consequent compressive strength of SCLWFC is decreasing as confirmed by Liu et al. (2016). Alternatively, as suggested by Amarnath and Ramachandrudu (2013), the minimum water/cement or water/binder ratio required for LWFC is 0.35. This is to prevent the cement from taking water from the foam.

For the specimens of limestone powder used as cement replacement, the figures show that with the increases of limestone powder replacement from 5 to 10% of cement content, the porosity of concrete is increased, the spacing between air-void were interconnected with the size of pores more than 1mm in irregular shape, therefore might as well the replacement mix is reducing the density. As stated by Gudissa and Dinku (2010), limestone powder required less water compared to cement. Therefore, water/solid ratio becomes higher. According to Dan-Jumbo (2015), higher water/solids ratio, makes the slurry too thin to hold aggregates resulting in segregation. This statement is in line with the actual physical properties, which is very low in density and strength compared to the control mix.

4. Conclusions

The influence of limestone powders up to 40% as an additive and replacement of cement content of the self-consolidating lightweight foamed concrete fresh and hardened properties was investigated. Based on the results of this investigation, the following conclusion can be drawn:

1. Maximum value of slump flow for Additive Mix is 752mm, which is obtained when the additional of limestone powder is 10%. Slump flows are decreasing with the increase of limestone powder content beyond of 10%.
2. Maximum value of slump flow for Replacement Mix is 755mm, which is obtained when the cement replacement by limestone powder is 40%. Slump flows are increasing with the increase of limestone powder.

3. Maximum value of compressive strength for Additive Mix is 18.69 N/mm^2, which is obtained when the additional of limestone powder is 10%. Compressive strength decreases with the increase of limestone powder content beyond of 10%.
4. Maximum value of compressive strength for Replacement Mix is 7.21N/mm^2, which is obtained when the cement replacement by limestone powder is 5%. Compressive strength decreases with the increase of the limestone powder content.
5. Maximum value of compressive strength was obtained when the limestone powder is used as an additive up to 10% of cement content by mass and the maximum value for slump flow was obtained when the replacement of limestone powder content is 40% of cement content by mass.

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