Eurasian Journal of Science & Engineering
ISSN 2414-5629 (Print), ISSN 2414-5602 (Online)

Fresh Properties of Lightweight Concrete and Lightweight Self Compacting Concrete Produced with Pumice Aggregate

Baban Jamal Hamasalh[1] & Bahman Omar Taha[2] & Ganjeena Jalal Khoshnaw[3]

[1]Civil Engineering Department, Tishk International University, Erbil, Iraq
[2]Civil Engineering Department, Technical College, Erbil Polytechnic University, Erbil, Iraq
[3]Road Construction Department, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq
[3]Civil Engineering Department, Tishk International University, Erbil, Iraq
Correspondence: Baban Jamal Hamasalh, Tishk International University, Erbil, Iraq.
Email: baban.jamal@tiu.edu.iq

Doi: 10.23918/eajse.v6i2p11

Abstract: Lightweight aggregates have long been used widely in construction worldwide. One of the most widely used lightweight aggregate in concrete construction is Pumice. This paper investigates the lightweight concrete (LWC) and lightweight self-compacting concrete's (LWSCC) fresh properties produced by using pumice aggregates. Two groups of concrete were made, first lightweight concrete, and the second group was lightweight self-compacting concrete by using lightweight coarse and fine aggregate (Pumice) (50% - 60% by volume) with fine natural aggregates (50% - 40% by volume). 10% of silica fume was used as cement replacement with a constant (0.40) water-to-binder ratio by mass. Both groups of concrete's rheological properties were studied by conducting a comprehensive series test (slump, slump flow, J–Ring, L-Box, and V-Funnel). The fresh densities and workability tests showed that this lightweight concrete meets the lightweight structural concrete requirements. Developing LWC and LWSCC with acceptable rheological characteristics and density, which are more environmentally friendly, and low-cost, will support the sustainable construction and reconstruction of volcanic disaster regions worldwide.

Keywords: Lightweight Concrete (LWC), Lightweight Self-Compacting Concrete (LWSCC), Aggregate, Pumice, Fresh Property

1. Introduction

Structural lightweight concrete made with lightweight aggregate; the air-dried unit weight at 28 days is usually in the range of (1440 to 1850 kg/m), and the compressive strength is more than (17.2 MPa) (Akers et al., 2003). Production of lightweight aggregate concrete has received greater attention in the recent decades (Cui, Lo, Memon, & Xu, 2012). Over the years, lightweight aggregates have been commonly used to build concrete (Cui et al., 2012). Natural lightweight aggregates like Pumice, volcanic scoria, oil palm shell, diatomite, sawdust, bottom ash, etc., can be used easily in the production of lightweight concrete (LWC) instead of artificial aggregates like expanded shale, sintered fly ash, perlite, bonded fly ash, slate (Hossain & Lachemi, 2007). Several experiments have been performed to manufacture lightweight concrete with good fresh and mechanical properties (Ünal, Uygunoğlu, & Yildiz, 2007). The concrete structure's self-weight is significant in structural applications and it constitutes a large part of the total load.

Received: October 15, 2020
Accepted: November 27, 2020
Hamasalh, B.J., Taha, B.O., & Khoshnaw, G.J. (2020). Fresh Properties of Lightweight Concrete and Lightweight Self Compacting Concrete Produced with Pumice Aggregate. *Eurasian Journal of Science & Engineering*, 6(2), 11-20.

The gravity load and seismic inertia mass will be decreased due to the reduced self-weight of lightweight concrete, resulting in the lower foundation and member sizes. Lightweight concrete can significantly lower construction costs, simplify design, ease development, and benefit from being green building material (Cui et al., 2012). Self-compacting concrete (SCC) can easily flow and fill into the framework and pass through the reinforcements due to its being highly flowable, not needing mechanical compaction, and its high resistant to the segregation of the materials (Maghsoudi, Mohamadpour, & Maghsoudi, 2011). There are some excellent characteristics of SCC which cannot be found in normal concrete as reducing construction time, labor cost, eliminating the need for vibration, strengthening the bonds between transitional zone with the aggregate, cement paste and the reinforcement, noise pollution control, enhancing the durability, lowering the permeability of the concrete, and higher structural performance (Maghsoudi et al., 2011).

Lightweight self-compacting concrete (LWSCC) incorporating desirable characteristics of lightweight concrete (LWC) and (SCC) is one of the latest developments in SCC technology (Ünal et al., 2007). LWSCC is the combination of desirable properties of SCC as self-compacting. The ability to pass and fill the framework, a high flowability with the LWC, and low weight with good strength are its features (Hossain & Lachemi, 2007). In general, the use of lightweight aggregates in SCC manufacture is an easy way to reduce the SCC unit weight. Accordingly, reducing the weight of the structures or buildings made with SCC is important as it lowers the earthquake's risk (Chia, Chen-Chung, & Min-Hong, 2005). Commonly, natural aggregates and mortar have more densities than lightweight aggregates. During the vibration process in the plain concrete, coarse aggregates move toward the upper part of the mix which results in segregation of the concrete during the transportation and the placement of the fresh concrete (Topçu & Uygunoğlu, 2010). The upward movement of the coarse aggregates as vibration can be stopped by self-compacting concrete's unique characteristics (Caiza, Gonzalez, Toulkeridis, & Bonifaz, 2018).

In several places around the world, volcanic materials can be found as Pumice and volcanic ash. Efforts to find new and better ways of building upon these natural resources become more common, and their use as building materials leads to low cost, sustainable and safe development (Hossain & Lachemi, 2007). Pumice is a natural material widely recognized for having a high porosity and low density, cream-white or occasionally gray color, glassy igneous rock of volcanic origin produced by release of gasses during the firming of lava. It was used in several countries worldwide as aggregates to manufacture lightweight concrete (Parhizkar, Najimi, & Pourkhorshidi, 2012). To date, the usage of Pumice relied on supply and can be seen only in places where it is available locally or simple to import. One of the factors that directly influence the cost of concrete production is the aggregate and additives minerals. Pumice can be used in the production of LWC and LWSCC, which is easy, workable, and economic (Hossain & Lachemi, 2007). The implementation of civil works is another reason to employ Pumice, given that the weight of the structures is an influencing factor in the design and dimensioning of structural elements, as well as noticeable cost savings in the foundation due to the effect of reducing its weight (Hossain & Lachemi, 2007).

Many recent studies have been conducted on lightweight concrete using Pumice due to its potential to use in building construction. In places where volcanic activities are available and plentiful, local sources of pumice aggregates exist (Hossain, 2004). Yeginobali (2002) studied on the locally available Pumice in Turkey using normal river sand as fine aggregate, pumice aggregate in the corporation of superplasticizer and silica fume to manufacture structural lightweight concrete and satisfactory results were gained. Using lightweight concrete produced from Pumice in Germany reaches 70%. The usage of Pumice and perlite as additives have been found to be outstanding to the thawing and freezing resistance of concrete and cement mortar (Litvan, 1985). Natural Pumice can be used in manufacturing LWSCC, as illustrated by (Topçu & Uygunoğlu, 2010) and (Papanicolaou & Kaffetzakis, 2009). The role of aggregate on the coefficient of thermal expansion in self-compacting concrete and LWSCC was investigated by (Topçu & Uygunoğlu, 2010). Due to the Pumice aggregates' and porous system aggregates, the LWSCC showed more durability with a higher thermal expansion coefficient (Topçu & Uygunoğlu, 2010).

The LWSCC production was described in the strength class LC20/22 and density class D1.4 (as per EN206-1), based on the impact of the coarse-to-fine ratio of aggregates on the rheological and mechanical properties of the material (Papanicolaou & Kaffetzakis, 2009). In a study by Topçu and Uygunoğlu (2010) the difference in the impact value of the natural LWA types (Pumice, diatomite, and volcanic tuff) was discussed and evaluated on the fresh and hard characteristics of LWSCC. The highest Slump-Flow was recorded by using diatomite among all the aggregates. On the other side, pumice LWSCC mixtures, showed the strongest unique strengths owing to the excellent contact between these aggregates and the cement paste, as shown by the microscopic of the interfacial transition region. In this investigation, LWC and SCLWC are produced using Pumice as lightweight aggregate incorporating silica fume to reach the structural concrete's fresh properties. This paper presents the test results of LWC and LWSCC, such as; values of density, slump, slump flow, L-box, V-funnel, J-ring, and L-Box.

2. Experimental Details

2.1 Materials

The properties of the materials used for producing the LWC and LWSCC are presented in the following:

2.1.1 Cement, Silica Fume

Ordinary Portland cement was used for the mixes (OPC) type CEM I 42.5 R. Silica fume is used to replace cement for reducing cement consumption and get high early compressive and tensile flexural strength. The chemical and physical properties of cement and silica fumed are presented in Table 1and Table 2.

Table 1: Chemical composition of Cement and Silica fume

Chemical composition %	Cement	Silica Fume
CaO	67.46	1.65
SiO_2	13.48	91.25
Al_2O_3	3.69	1.32
Fe_2O_3	7.78	0.98
MgO	1.29	0.91
Na_2O	0.36	0.24
K_2O	0.98	0.78
SO_3	4.82	0.12

Table 2: Physical properties of Cement and Silica fume

Physical Composition	Cement	Silica Fume
Specific Weight(g/cm^3)	3.15	2.2
Specific Surface area(cm^2/g)	3352	20
Loss on ignition	1.98	1.53

2.1.2 Pumice

Pumice, which was obtained from Iran's volcanic areas, were brought from the mines near the mountains in the southwest of Iran, near the Iraq border. It is used as lightweight aggregate for producing LWC and LWSCC mixtures. Table 3 displays the chemical and physical properties of the pumice. Pumice's particle-size distribution was calculated according to the ASTM C136. The gradations met the ASTM C330 lightweight aggregate criteria for structural concrete.

Table 3: Chemical and physical composition of Pumice

Chemical Composition %	Pumice
CaO	6.8
SiO_2	55.2
Al_2O_3	20.57
Fe_2O_3	1.26
MgO	2.3
Na_2O	1.8
K_2O	1.73
SO_3	0.44
Physical Composition %	Pumice
Specific Wight(g/Cm^3)	2.3
Specific Surface Area (cm^2/g)	440
Loss On ignition (%)	1.95

2.1.3 Fine Aggregates

River natural fine aggregate having a specific gravity of 2.67, Fines Modulus of 2.55, and water absorption of 0.25 is used.

2.1.4 Superplasticizer

For increasing the workability, water reduction, increasing strength, and suitable for hot climate, (Sika ViscoCrete-227) concrete superplasticizer is used for the LWC mixes. (Sika ViscoCrete-5930-L) superplasticizer is used to gain high self-compacting properties, reducing water, flowability increasing, and improved water impermeability for the LWSCC mixes.

2.2 Mix Proportions

This paper's main objective is to study the influence of incorporating Pumice as lightweight aggregate particles on the fresh properties of LWC and LWSCC. Two groups of mixes were presented. In the first group, mix LWC1 was cast with the ratio of pumice aggregates (coarse and fine) of 50% by volume. Natural river sand was 50% by volume. Mix 2 was cast with the same ratio while adding silica fume 10% as cement replacement. LWC3 mix was prepared with the proportion of pumice aggregates of 60% by volume, and the natural river sand was 40% by volume. Mix 4 was cast with the same ratio while adding silica fume 10% as cement replacement. The w/c ratio kept same for all the mixes and 1.5% of superplasticizer was used.

The second group, LWSCC1, was cast with the ratio of pumice aggregates (coarse and fine) of 50% by volume. The natural river sand was 50% by volume. Mix 2 was made with the same ratio while adding silica fume 10% as cement replacement. LWSCC3 was cast with the rate of pumice aggregates of 60% by volume, and the natural river sand was 40% by volume. Mix 4 was casted with the same ratio while adding silica fume 10% as cement replacement. The w/c ratio kept same for all the mixes and 5% of superplasticizer was used. Moreover, the Pumice cannot be used directly for the preparation of a concrete batch unless immersed in water for 24 hours or prewetted before casting because of its high porosity and the content of the mixes presented in Table 4.

Table 4: Mixture proportions

Mix No.	Cement (Kg/m^3)	Silica fume (Kg/m^3)	Water (Kg/m^3)	w/b	Pumice Aggregate (coarse and fine) (Kg)	Pumice Aggregate (coarse and fine) (Vol.)	Fine Aggregate Sand (Kg)	Fine Aggregate Sand (Vol.)	Superplasticizer (%)
LWC 1	450	0	180	40	355.54	50	888.855	50	1.5
LWC 2	405	45	180	40	352.27	50	880.681	50	1.5
LWC 3	450	0	180	40	426.65	60	711.085	40	1.5
LWC 4	405	45	180	40	422.72	60	704.545	40	1.5
LWSCC 1	450	0	180	40	349.96	50	874.925	50	5
LWSCC 2	405	45	180	40	346.70	50	866.75	50	5
LWSCC 3	450	0	180	40	419.96	60	889.15	40	5
LWSCC 4	405	45	180	40	416.04	60	882.61	40	5

2.3 Tests Procedures

The rheological properties of LWC and LWSCC were studied by measuring the mixes' fresh densities and workability. Density in the proportion of lightweight concrete mixtures is one of the critical factors. The density of the aggregate, the proportions of the normal aggregate, and lightweight aggregate are the main elements influencing the density of the mixture. W/C ratio, additives, and air content will also influence it (Akers et al., 2003). The essential property of freshly mixed lightweight concrete is workability. The slump test is commonly used as an indication to know the consistency of the fresh concrete due to its simplicity, and ASTM C143 prescribes it. Guide for Structural Lightweight-Aggregate Concrete. This test is performed for the first group of the mixes of LWC.

The workability of the LWSCC was examined by testing the flowability, passing ability, and viscosity. Relying on the standard measurements recommended by EFNARC committee (Concrete, 2005), slump flow, J-Ring, V- funnel, and L-box tests were performed for the second group of mixes (LWSCC). Slump flow measures the flowability of the concrete in the absence of obstacles. There are usually three classes for measuring the flowability according to the European guidelines (Concrete, 2005), and it is mentioned in the graph as SF1, SF2, and SF3. The passing ability of LWSCC is measured by the J-Ring and L-box tests by flowing the concrete through reinforced bars. The measurements were according to the (Concrete, 2005) and the results are presented in the graphs. Besides, the V-Funnel test can be performed to detect the viscosity of the LWSCC. There are two viscosity classes, (Concrete, 2005) and the results were in the recommendation limits as shown.

3. Results and Discussion

3.1 The Density of LWC and LWSCC

The structural guide for lightweight concrete mentioned in ACI 213R-87 highlights that the density of structural concrete made with lightweight aggregate; air-dried density ranges varies from (1440 to 1850 kg/m). The fresh density of both groups of the concretes (LWC & LWSCC) was found to be in ranges of lightweight aggregate concrete. Same acceptable density ranges were obtained by (Green, Brooke, McSaveney, & Ingham, 2011). Nine specimens of concrete cube 100 mm were cast for each mix. The density in LWC1 has the highest value, and it decreased LWC2 since %10 of the cement was replaced with silica fume, where its specific gravity less than the cement. The density decreased respectively in LWC3 and LWC4 because of the increased amount of the mixes' lightweight aggregate. We can observe the same changes in the LWSCC mixes. LWSCC1 has the highest value of density, and it was reduced in LWSCC2 as %10 of the cement was substituted with silica fume. The LWSCC3 and LWSCC4 showed the least density, respectively, because the lightweight aggregate amount is highest according to the other mixes. Table 5 shows the fresh density of LWC and LWSCC.

Table 5: Fresh density of LWC and LWSCC

Mix No.	Fresh Density (Kg / m^3)
LWC 1	1810
LWC 2	1770
LWC 3	1740
LWC 4	1680
LWSCC 1	1790
LWSCC 2	1760
LWSCC 3	1680
LWSCC 4	1655

3.2 Workability of LWC

3.2.1 Slump

The workability of the LWC can be determined by performing a slump test for the freshly mixed concrete. More than ten trial mixes were conducted before setting the mix proportions for casting the lightweight concrete. The results of the test by using the constant amount of water and superplasticizer, all mixes' slumps are similar and close in ranges. Slump tests were performed for the first group conducted according to ASTM C143, as shown in Table 6. All the results were satisfactory, and the degree of workability is medium. Nearly the same results were obtained by Lightweight (Hossain, Ahmed, & Lachemi, 2011).

The lower slump shown in LWC4 and LWC3 is due to the increased amount of the coarse and fine aggregate. The lightweight aggregate has a porous surface texture, so a higher amount of water absorption can be observed and lead to a lower slump in respect to LWC1 and LWC2. Addition of the silica fume to the mixes also reduce the workability.

Table 6: Slump of LWC

Mix No.	Slump (mm)
LWC 1	74
LWC 2	71
LWC 3	67
LWC 4	63

3.3 Workability of LWSCC

3.3.1 Slump Flow

The results of the fresh properties of the lightweight self-compacted concrete produced with Pumice are all shown in Table 7. The rheological tests for LWSCC were performed according to the EFNARC procedure (Concrete, 2005). Generally, the results illustrate that rheological properties are affected by the pumice proportion and silica fume. LWSCC1 showed the highest slump flow (725 mm), and they fall in SF2 categories. LWSCC2 showed fewer results but still managed to be in the SF2 class. The amount of lightweight aggregate increased in LWSCC3 %10 more, causing absorption of more water and reduced the slump flow to (675 mm). LWSCC4 fall in class SF1 with the lowest slump flow to (660 mm) due to the increased lightweight proportion and addition of silica fume. Previously studied work by (Bozkurta & Taşkin, 2017) on LWSCC confirm these results.

3.3.2 J-Ring Flow

The j-ring result for the first mix LWSCC1 was (700 mm), but unlike the first mix, the LWSCC2 showed the slightly lower values (680 mm), and both mixes fall in SF2 categories. Increasing the amount of the lightweight aggregate inversely affects the j-ring test, and the results showed less. The amount of lightweight aggregate improved in LWSCC3 %10 more, causing absorption of more water and reduced the j-ring to (660 mm). This was confirmed by (Ardalan, Joshaghani, & Hooton, 2017). LWSCC4 fall in class SF1 with the lowest j-ring (630 mm).

Table 7: Fresh properties test result of LWSCC

Mix No.	Slump Flow (mm)	J-Ring (mm)	V-Funnel (sec)	L-Box (%)
LWSCC 1	725	700	3.25	0.90
LWSCC 2	700	680	3.73	0.87
LWSCC 3	675	660	4.12	0.85
LWSCC 4	660	630	4.35	0.82

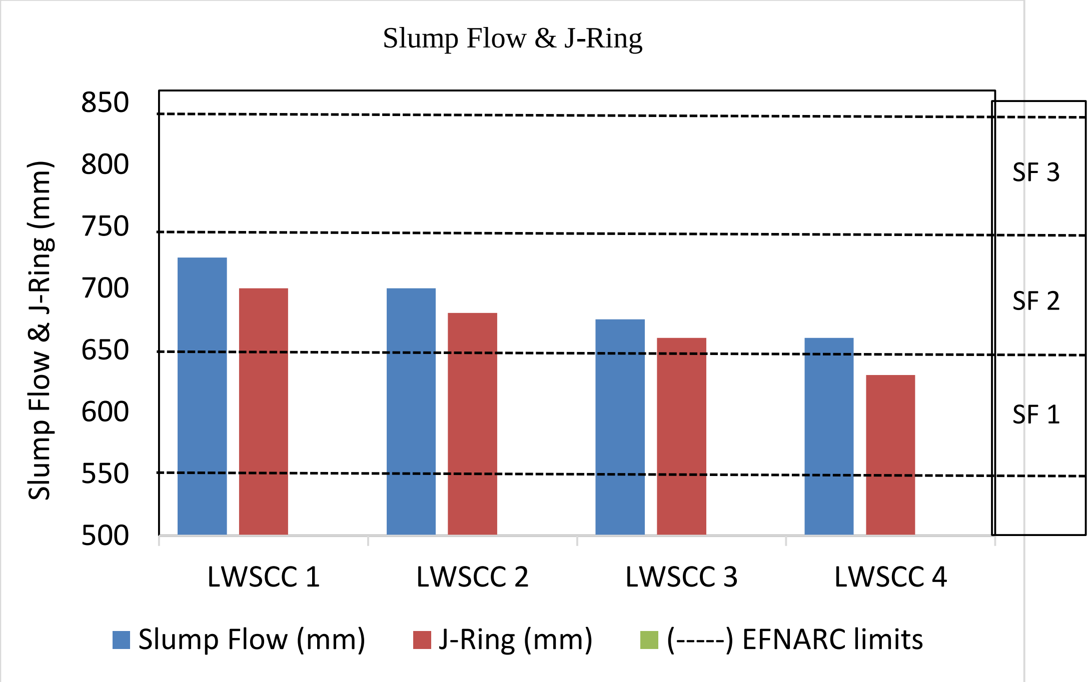


Figure 1: Slump flow and J-Ring results

3.3.3 V-Funnel Test

The filling ability of the LWSCC was tested by performing the V-funnel test. According to the classification EFNARC, there is two class. A) VF1 ≤ 8 sec, Good filling ability, moderate to high flow rate, and B) VF2 9 to 25 sec, Moderate to low filling ability, and low flow rate. As shown in Figure 2, all the LWSCC are smaller than 8 sec and have a high flowing rate with a good filling ability. Previous studies done by (Ardalan et al., 2017) confirm these results.

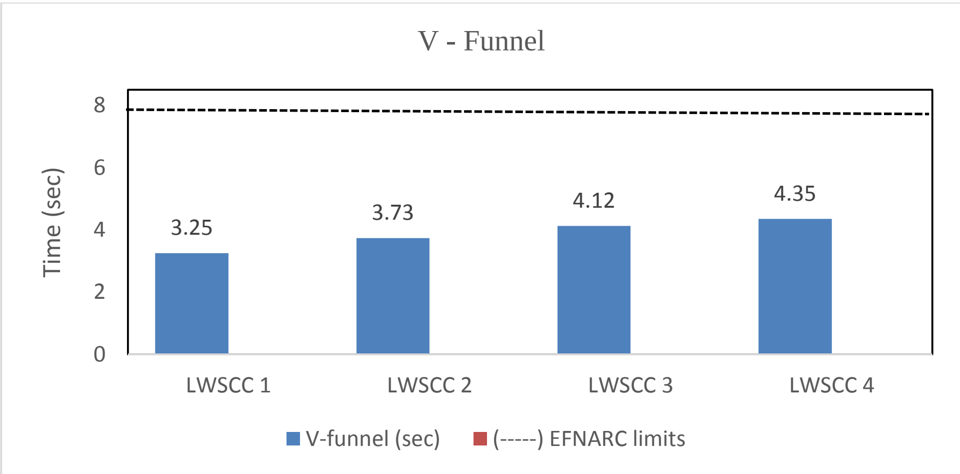
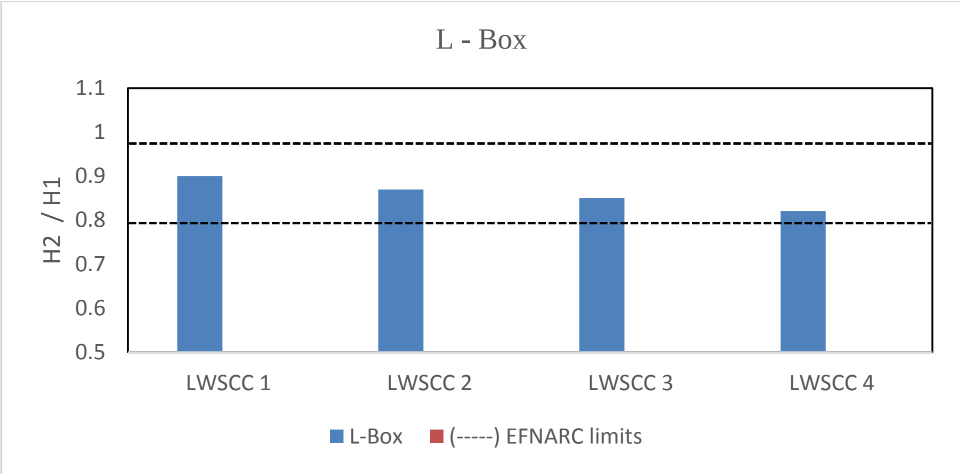


Figure 2: V-Funnel results

3.3.4 L-Box Test

The L-Box test was used to calculate the passing ability of the LWSCC mixes. The results of all mixes are shown in Table 4 and Figure 3. According to the classification EFNARC, there are two classes. A

PA1 ≥ 0.8 with two rebars, and PA2 ≥ 0.8 with three rebars. Overall, all mixes showed great passing ability, which is higher than 0.8, and can be classified as class PA2 as per EFNARC limits. Previous studies done by (Ardalan et al., 2017) confirm these results. As it was observed, the mixes have a good flow, and under their weight, it can pass easily within the reinforced area.



PA2 ≥ 0.8 with three rebars

Figure 3: V-Funnel results

4. Conclusion

Pumice can be used as lightweight aggregate to manufacture of lightweight concrete (LWC) and lightweight self-compacted concrete (LWSCC). In this study, the density and the workability behavior of these two groups of concrete were tested. The conclusions of this study can be summarized as follows:

1. The average density of LWC and LWSCC was in between (1655 – 1810 Kg/m^3) which is in the range of lightweight structural concrete.
2. LWC obtained the required slump within the medium degree of the workability limits, the results were between (67-73 mm).
3. Increasing the amount of lightweight aggregate %10 by volume will decrease the slump 5 mm.
4. LWSCC achieved to be within the required limits of the EFNARC for the slump flow – SF2 class, good filling ability, J-ring test – SF2 class, good filling ability, V-Funnel - VF1 ≤ 8 sec, having a high flow with a good filling ability, and L-Box test - PA2 ≥ 0.8 with three rebars.
5. Increasing the amount of the lightweight aggregate will decrease the flowability and passing ability as shown in the slump flow test and J-Ring test by the average of (30-50 mm), but still in the recommended limit.
6. Increasing the amount of the lightweight aggregate will slightly decrease the time (sec) in the V-Funnel test by one sec.
7. Increasing the lightweight aggregate amount will slightly increase the (%H2/H1) in the L-Box test.
8. Overall, all mixes obtained the required standard limit of the fresh properties of LWC and LWSCC.

References

Akers, D. J., Gruber, R. D., Ramme, B. W., Boyle, M. J., Grygar, J. G., Rowe, S. K., . . . Burg, R. G. (2003). Guide for structural lightweight-aggregate concrete. *ACI 213R-03. American Concrete Institute (ACI), Michigan*.

Ardalan, R. B., Joshaghani, A., & Hooton, R. D. (2017). Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume. *Construction and Building Materials*, *134*, 116-122.

Bozkurta, N., & Taşkin, V. (2017). Design of Self Compacting Lightweight Concrete Using Acidic Pumice with Different Powder Materials. *Acta Physica Polonica, A.*, *132*(3).

Caiza, M., Gonzalez, C., Toulkeridis, T., & Bonifaz, H. (2018). Physical properties of pumice and its behavior as a coarse aggregate in concrete. *Cem. Wapno Beton*, *6*, 468-478.

Chia, K.-S., Chen-Chung, K., & Min-Hong, Z. (2005). Stability of fresh lightweight aggregate concrete under vibration. *ACI Materials Journal*, *102*(5), 347.

Concrete, S.-C. (2005). The European guidelines for self-compacting concrete. *BIBM, et al*, *22*.

Cui, H., Lo, T. Y., Memon, S. A., & Xu, W. (2012). Effect of lightweight aggregates on the mechanical properties and brittleness of lightweight aggregate concrete. *Construction and Building Materials, 35*, 149-158.

Green, S. M., Brooke, N. J., McSaveney, L. G., & Ingham, J. M. (2011). Mixture design development and performance verification of structural lightweight pumice aggregate concrete. *Journal of Materials in Civil Engineering, 23*(8), 1211-1219.

Hossain. (2004). Properties of volcanic pumice-based cement and lightweight concrete. *Cement and Concrete Research,* 34(32), 283-291.

Hossain, K., Ahmed, S., & Lachemi, M. (2011). Lightweight concrete incorporating pumice based blended cement and aggregate: Mechanical and durability characteristics. *Construction and Building Materials, 25*(3), 1186-1195.

Hossain, K. M. A., & Lachemi, M. (2007). Strength, durability, and micro-structural aspects of high-performance volcanic ash concrete. *Cement and Concrete Research, 37*(5), 759-766.

Litvan, G. G. (1985). *Furthur study of particulate admixtures for enhanced freeze-thaw resistance of concrete.* Paper presented at the Journal Proceedings.

Maghsoudi, A., Mohamadpour, S., & Maghsoudi, M. (2011). Mix design and mechanical properties of self-compacting light weight concrete.

Papanicolaou, C., & Kaffetzakis, M. (2009). *Pumice aggregate self-compacting concrete (PASCC).* Paper presented at the in: 16th Conference on Concrete, Paphos.

Parhizkar, T., Najimi, M., & Pourkhorshidi, A. (2012). Application of pumice aggregate in structural lightweight concrete. *Asian Journal of Civil Engineering (Building and Housing*), 13 (1), 43-54

Topçu, I. B., & Uygunoğlu, T. (2010). Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC). *Construction and Building materials, 24*(7), 1286-1295.

Ünal, O., Uygunoğlu, T., & Yildiz, A. (2007). Investigation of properties of low-strength lightweight concrete for thermal insulation. *Building and Environment*, *42*(2), 584-590.

Yeginobali, A. (2002). Structural lightweight concretes produce with natural lightweight aggregates in Turkey. In *17th International Congress of the Precast Concrete Industry*.