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The effect of superplasticizer dosage on fresh properties of self-compacting lightweight concrete produced with coarse pumice aggregate

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Abstract:

The use of superplasticizer in the manufacture of self-compacting concrete is gradually more common. Each type of superplasticizer available in the market has different compositions, causing differences in dosage requirement. Also, superplasticizer affect the fresh and hardened properties of concrete. In this experimental study the effect of different dosage of superplasticizer (SP) on fresh properties of self-compacting lightweight concrete (SCLC) containing coarse aggregate pumice were studied by using five different percentages for (SP) (1%, 1.3%, 1.5%, 1.7% and 2%) of the binder weight. (SCLCs) were produced with constant binder content of 550 kg/m^3 and at a water-to-binder ratio of 0.26. 20% of portland cement was replaced with fly ash by weight. The workability of SCLCs was quantitatively evaluated by slump flow time and diameter, V-funnel flow time, and L-box height ratio. Moreover, compressive strength of hardened SCLCs was measured at 28 days by using compression machine and Rebound hammer test. The results show that with the increase of (SP) dosage in the concrete mixture, the flowability increased. However, there is an optimum value of (SP). The increase of (SP) dosage is accompanied by decreasing of T_{500} slump flow and V-funnel time until it reaches the optimum level. Nevertheless, excessive use of (SP) lead to increase of slump flow diameter.

Keywords: Self-compacting lightweight concrete, superplasticizer dosage, pumice aggregate, fresh properties, Compressive strength.

1. Introduction:

Self compacting concrete (SCC) is another type of high performance concrete that was invented by the Japanese researchers in the late of the 1980's which has good segregation resistance, deformability and can consolidate into the congested reinforcement, narrow and deep sections by its self-mass to completely fill the formwork without demanding external mechanical vibration and can be pumped through long distances (Okamura & Ouchi, 2003; Ozawa, 1989). Actually, the combination of SCC with lightweight aggregate (LWA) to produce self compacting lightweight concrete (SCLC) can maximize the applications and benefits of SCC (Kim et al, 2010; Hwang & Hung, 2005). Well-designed SCLC mixtures can fill the formwork and surround the reinforcement without any bleeding or segregation (Wu, Z., Zhang et al., 2009). Furthermore, using lightweight concrete (LWC) leads to the reduction of the dead weight in a building that related to the reduction in the size of structural reinforced concrete such as foundation, beams, columns, and slabs (Topcu, 1997). Furthermore, LWC has some advantages such as; increasing the strength-to-weight ratio, reducing the modulus of elasticity, enhancing the thermal and sound insulation and fire resistance properties (Dhir et al., 1984). Pumice is available in the nature from volcanic origin produced by the release of gases during the solidification of lava, and it has been used as lightweight aggregate in the production of lightweight concrete in many countries around the world. So far, the use of pumice was dependent on the availability and limited to the countries where it is locally available or easily imported. Approximately, 7.4 billion m^3 (40%) of the total 18 billion m3 of pumice reserve is located in Turkey (Mor, A. 1993).

Lightweight aggregates were primarily used to reduce the weight of concrete structures. However, these aggregates were usually saturated prior to use in concrete to ensure adequate workability, since it was recognized that dry porous aggregates could absorb some of the mix water in fresh concrete (Cusson & Hoogeveen, 2008). The workable concrete mixtures become stiff within a few minutes of mixing Because of high water absorption. So, it’s a standard practice to pre-soak lightweight aggregates before batching (Craig & Wolfe, 2012). Actually, the aggregates will be soaked in water for 24 h prior to mixing is commonly used. So, it’s a standard practice to pre-soak lightweight aggregates before batching (Craig & Wolfe, 2012).

In self compacting concrete and high strength concrete, superplasticizers are used as an essential ingredient for achieving higher workability at a very low water-to-powder (w/p) ratio (Matsumoto et al., 2009). The effect of superplasticizer in 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. Yamada et al., (2001) remark that there are critical dosage and saturation dosage of SP in the concrete mixture. Critical dosage is defined as minimal dosage needed to cause overall effect of SP in the mixture.

Many studies (Brencich et al., 2013; Pucinotti, 2015) have investigated the reliability of the compressive strength estimates from the rebound hammer test. Lower W/C ratio provides higher rebound value. However, variation of the rebound value with the W/C ratio is similar to the general variation of concrete compressive strength with the W/C ratio, but less pronounced (Katalin, S., 2013). Moisture in the concrete can decrease the rebound by up to 20 percent (A. Samarin, 2004).

The purpose of this study was to examine the superplasticizer dosage on SCLCs produced by pumice lightweight coarse aggregates by using five different percentages for (SP) (1%, 1.3%, 1.5%, 1.7% and 2%) of the binder weight. Consequently, a total of five SCLC mixes were designed at a constant w/b ratio of 0.26 and the total binder content of 550 kg/m^3. For fresh properties (Slump flow time and diameter, V-funnel and L-box height ratio) and Rebound Number, compressive strengths were measured at the age of 28 days.

2 Experimental study:

2.1 Materials:

In this study, CEM I 42.5 R type portland cement (PC) with Blaine fineness of 326 m^2/kg and specific gravity of 3.15 and class F fly ash (FA) with Blaine fineness of 379 m^2/kg and specific gravity of 2.05 were used for manufacturing both the artificial lightweight aggregates and the concrete mixtures. The chemical compositions and physical properties of the Portland cement and fly ash are presented in Table 2.1. A polycarboxylic ether based superplasticizer with a specific gravity of 1.10 g/cm^3 was used in all mixtures as shown in (Fig. 2.1).

The mixture grading curve illustrated in (Fig. 2.2) of crushed stone and river sand with a maximum particle size of 4 mm was used as normal fine aggregate and pumice lightweight gravel with a maximum particle size of 16 mm was used as normal lightweight coarse aggregate as illustrated in (Fig. 2.3). The sieve analyses as well as the physical properties of the normal and lightweight aggregates are given in Table 2.2.

2.2 Mix proportions:

After materials preparation, the self-compacting lightweight concretes (SCLC) with a total binder content of 550 kg/m^3 and at a water-to-binder ratio of 0.26 were produced by replacing superplasticizer (SP) dosage to investigate the influence of superplasticizer on the fresh properties of SCLC (slump flow time and diameter, V-funnel, L-box) as well as on compressive strengths and rebound hammer number. In all mixtures, the class F fly ash was used by 20% of the total binder content. In the mix design, the total aggregate volume was designated as 50% fine and 50% coarse aggregates by volume. Five different self-compacting lightweight concrete were designed in this study by using five different percentages for (SP) (1%, 1.3%, 1.5%, 1.7% and 2%) of the binder weight. However, all mixes made with lightweight pumice aggregates as coarse aggregates. Totally 5 self-compacting concrete mixtures were designed and produced. The detailed mix proportions of the mixtures are tabulated in Table 2.3. In the Mix ID; SP is the abbreviation of superplasticizer. For example, $SP_{1.5\%}$ means that the SCLC mixture containing superplasticizer dosage as 1.5% of the binder weight.

2.3. Specimens preparation and curing:

All concrete mixtures were mixed in power-driven revolving pan mixer with capacity of 30 liter. Mixing and batching procedure suggested by (Khayat et al., 2000) was followed in this study to achieve the same homogeneity and uniformity in all SCLCs due to the fact that the mixing sequence and duration are very important in the SCC production. However, for the concrete mixture produced with pumice lightweight aggregates, before each mixing, sufficient amount of coarse pumice lightweight aggregates were immersed in water for 24 hr for saturation. Then, coarse pumice aggregates lightweight were taken out of water and put on the mesh for the outflow of excessive surface water for about 30 s. The extra water on the surface of pumice aggregate was rubbed out manually by a dry towel as shown in (Fig. 2.4). This is an effective way to obtain SSD condition for the lightweight pores aggregates (Gesoğlu, 2004). Regarding to this procedure, the fine and coarse aggregates were poured in a power-driven revolving pan mixer and allowed to mix homogeneously for 30 seconds. After that about one-third of the mixing water was added into the mixer and it was allowed to proceed the mixing for one more minute. The aggregates, then, were left to absorb the water for 1 minute. Afterwards, the powder materials (cement and fly ash) were added to the wetted aggregate mixture for mixing another minute. After that SP with remaining water was poured into the mixer, the concrete was mixed for 3 min and then left to rest for a 2 min. Finally, the concrete was mixed for additional 2 min to complete the production. The quantity of superplasticizer was arranged for all mixtures to obtain the desired workability. To determine the fluidity and workability properties of SCC, V-funnel tests were performed to gather information about flowing ability and viscosity with flow diameter and time of fresh concrete.

Besides, the L-box tests were performed to determine the passing ability from narrow sections of fresh concrete. These fresh concrete tests were conducted according to the standards of (EFNARC, 2005), prepared by the European Working Group on Self-Compacting Concrete. For each mixture, the flow diameter, time to flow a diameter of 500 mm (T_{500} time), V-funnel flow time and L-box ratio were measured. As well as, the concrete mixtures were poured in the plastic moulds and kept in the casting room at

20±2 ºC for 24 hours. After the demoulding, 28-day water curing was applied to the compressive strength and rebound hammer test specimens of the SCLCs.

2.4. Test procedure:

Slump flow diameter, T_{500mm} slump flow time, V-funnel flow time, and L-box height ratio tests were done according to the procedure recommended by (EFNARC, 2005). Slump flow value describes the flowability of a fresh mix. It is an important test for self compacting concretes as the primary check that the fresh concrete meets the specification in terms of flow. T_{500mm} is the time measured that shows the concrete has flowed to a diameter of 500 mm (EFNARC, 2005). According to EFNARC, there are three typical slump flow classes for the range of applications according to their flow diameter as shown in (Fig. 2.5). Their typical application fields as well as the upper and lower limits are illustrated in Table 2.4.

Viscosity of the produced SCLCs can be characterized with the T_{500mm} slump flow time and V-funnel flow time. These values do not measure the viscosity directly but they are related to the rate of flow. In the case of V-funnel test, a V shaped funnel is filled with fresh concrete (Fig. 2.6) and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time. According to (EFNARC, 2005) there are two viscosity classes to measure V-funnel and T_{500mm} slump flow times. Viscosity classification was given in Table 2.4. For checking passing ability of the fresh mixes by using L-box test (Fig. 2.7) to show the flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation. Another important test for SCC is L-box test, a limited volume of fresh concrete is allowed to flow horizontally through the gaps between vertical, smooth reinforcing bars and the height of the concrete beyond the reinforcement is measured. Table 2.4 presents the passing ability types on the basis of L-box height ratio.

Testing for compressive strengths and rebound number (Figs. 2.8 and 2.9) were done at 28 days of age. According to (ASTM C 39, 2012) the test was conducted on three 150 * 150 * 150 mm cubes by means of a 4000 kN capacity testing machine (ASTM C 39, 2012). Also, according to (ASTM C805, 2013) the three cubs were tested for rebound hammer.The average of three test specimens was computed.

3. Experimental results:

3.1. Fresh properties:

The concretes produced in this study, approximately had similar fresh and dry densities for all mixes of 1930 kg/m^3 and 1815 kg/m^3, respectively.

According to (EFNARC, 2005) standard, the flow diameter, time to flow a diameter of 500 mm (T_{500mm}), V-funnel flow time and L-box ratio were measured.

The flow diameters of SCLC containing 5 l/m^3 of superplasticizer (SP) for the first mix ($SP_{1\%}$) was measured as 700 mm and gradually increased with increasing SP dosage while for using 10 l/m^3 of SP the flow diameter reach 750 mm (Halim et al., 2017). However, flow diameter for the other mixes $SP_{1.3\%}$, $SP_{1.5\%}$ and $SP_{1.7\%}$ were increased by 2.86%, 4.29% and 5%, respectively compared with the first mix. Figure 3.1 illustrated the relationships between flow diameter and SP dosages. The mixtures have satisfied 660 – 750 mm value of flow diameter is the second class SF2, proposed by (EFNARC, 2005).

The time required to reach 500 mm slump-flow and the time required to flow through the V-funnel apparatus of produced SCLCs were presented in (Figs. 3.2 and 3.3), respectively. These parameters can be used to evaluate the segregation resistance of SCLCs (Kim et al., 2010). It was observed that both the time required to reach 500 mm slump-flow and the time required to flow through the V-funnel apparatus decreased as the dosage of SP was increased up to 1.5% of the binder weight after this point the time required to reach 500 mm slump flow and V-funnel were increased . T_{500mm} slump flow for $SP_{1\%}$, $SP_{1.3\%}$, $SP_{1.5\%}$, $SP_{1.7\%}$ and $SP_{2\%}$ was recorded as 3.2, 2.9, 2.7, 3.3 and 3.5 s respectively. However, the time obtained from V-funnel for all mixes were out of recommended by EFNARC (20) except $SP_{1.5\%}$ was 25 s. Furthermore, the other mixes ($SP_{1.3\%}$ and $SP_{1.7\%}$) and ($SP_{1\%}$ and $SP_{2\%}$) their time extend from $SP_{1.5\%}$ time by 50% and 100%, respectively.

According to Table 2.4, the viscosity classes of the produced SCLCs are shown in Figure 3.4. EFNARC (2005) recommended that viscosity should be indicated only in special cases such as best surface finish and in limiting the formwork pressure or improving the segregation resistance. As obviously seen in (Fig. 3.4), all SCLCs mixtures were classified as VS2/VF2.

The L-box test can be used to measure the passing ability of SCLC mixes such that the ratio of H2/H1 represents a measure of the passing ability among the reinforcing bars. The variation in the three bar L-box height ratio with superplasticizer dosage is presented in (Fig. 3.5) for the SCLCs. To confirm that SCLC has the passing ability, L-box height ratio must be equal to or greater than 0.8. According to (Fig. 3.5), H2/H1 ratio met the (EFNARC, 2005) limitation for all mixes. As clearly seen, the first mixture $SP_{1\%}$ has the lowest H2/H1 ratio of 0.92. Especially, a perfect fluid behavior was observed in $SP_{1.5\%}$ due to having H2/H1 ratio being 0.97. However, for the mixes $SP_{1.3\%}$ and $SP_{1.7\%}$ were calculated as 0.96 and for $SP_{2\%}$ was 0.95.

3.2. Compressive strength and rebound number:

The effect of SP dosage on the 28-day compressive strength for SCLCs were presented in (Fig. 3.6). It is shown that the presence of SP certainly has positive influence in increasing the compressive strength of concrete with the increase of workability and it is agreement with (Halim et al., 2017). There is an optimum dosage of 8.25 kg/m^3 to achieve higher strength. Further dosage increment reduces the strength. The 28- day compressive strength of the $SP_{1.5\%}$ was 45.67 MPa while that of $SP_{1\%}$ being 37.1 MPa. In particular, the 28-days compressive strength of SCLC containing 7.15 kg/m^3 of SP was 16.1% lower than that of the $SP_{1.5\%}$ mix, while the 28-days compressive strength of $SP_{1.7\%}$ and $SP_{2\%}$ mixes were measured as 44.62 and 43.95 MPa, respectively.

According to RELEM/CEB (Clarke, 1993) the compressive strengths recorded in this SCLC experiments were satisfy the minimum value for structural lightweight concrete is 15 MPa and the density was as (1805 kg/m^3) is in the range (1600 – 2000) kg/m^3 that illustrated in Table 3.1.

On the other hand, the influence of SP dosage on the rebound number on cubes of SCLCs at 28-day were shown in (Fig. 3.7). The rebound number of SCLCs were recoded as 38.5, 39.6, 43.3, 42.1 and 41.3 for the mixes $SP_{1\%}$, $SP_{1.3\%}$, $SP_{1.5\%}$, $SP_{1.7\%}$ and $SP_{2\%,}$ respectively. Furthermore, the estimated compressive strengths that obtained from the chart that delivered with the rebound hammer instrument were presented in (Fig. 3.8). The maximum estimated compressive strength was measured as 52.1 MPa for $SP_{1.5\%}$ mixture.

Correlating the experimental data is an important practice for the researchers to evaluate of the determined results. Theoretically, the major parameter controlling the mechanical characteristics of concrete is its quality and the increasing the compressive strength lead to improve other mechanical behavior. Therefore, the relationship between rebound number and estimated compressive strength from the chart depending on the rebound number as well as compressive strength measured from the cubes of SCLCs at 28 days were illustrated in (Fig. 3.9). The iteration between test results was evaluated in terms of R-square values. It was noticed that there are strong relationship between the compressive and estimated compressive strengths with the rebound number of the SCLC mixtures.

4. Conclusions

From this study, the following conclusions can be summarized:

- Slump flow diameter increased with increasing of superplasticizer dosage.
- Both the time required to reach 500 mm slump-flow and the time required to flow through the V-funnel apparatus decreased as the SP dosage increased up to 8.25 kg/m^3 dosage then both of them increased with increasing SP dosage.

- It was observed that increasing the SP amount resulted in a gradual increase in the L-box height ratio of SCLCs mixes up to an amount 8.25 kg/m^3 which recorded 0.97 after that decreased by increasing SP amount.
- The increased dosage of SP caused an increment in the compressive strength of SCLCs up to the third dosage in the $SP_{1.5\%}$ mixture then slightly decreased.
- The rebound number consequently the estimated compressive strength were increased by increasing SP amount till to 8.25 kg/m^3 then decreased.
- The analysis of the iteration of the compressive and estimated compressive strength with rebound number indicated that there is a strong relationship between these tests in terms of R-square value of 0.95 and 0.97 respectively.
- It is very clear from the test results that the mix $SP_{1.5\%}$ of SCLCs produced by coarse pumice lightweight aggregate satisfy the requirements of SCC with respect to (EFNARC, 2005) and its compressive strength was 45.67 MPa greater than the minimum value indicated in RELEM/CEB.

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Appendices

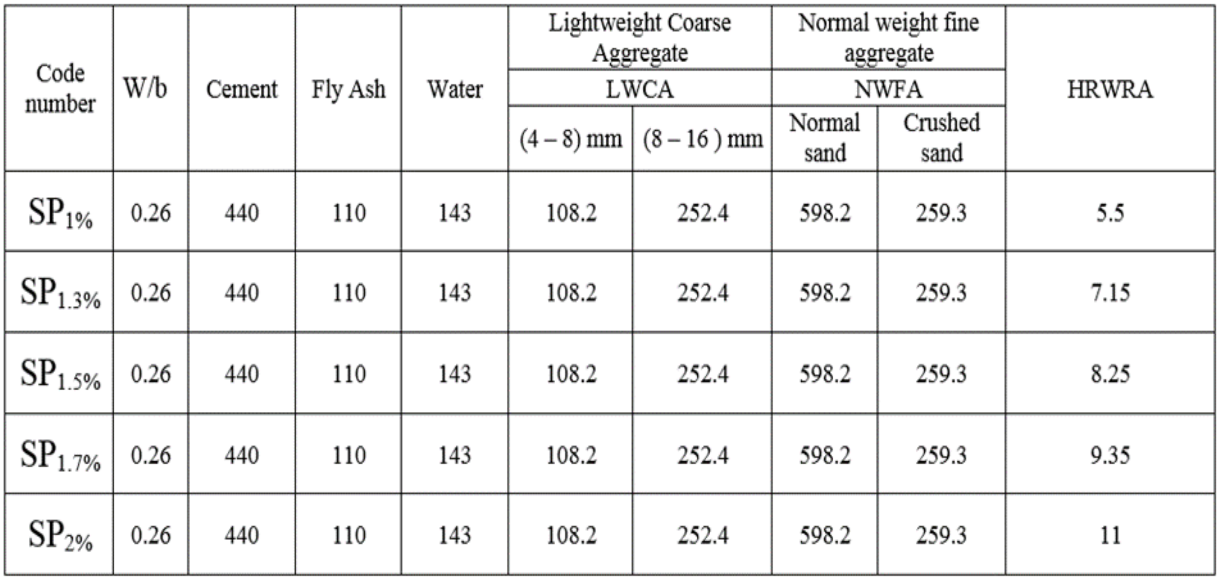
Table 2.1 Chemical compositions and physical properties of Portland cement and fly ash

Analysis report (%)	Cement	Fly ash
CaO	62.58	2.24
SiO2	20.25	57.2
Al2O3	5.31	24.4
Fe2O3	4.04	7.1
MgO	2.82	2.4
SO3	2.73	0.29
K2O	0.92	3.37
Na2O	0.22	0.38
Loss on ignition	2.96	1.52
Specific gravity	3.15	2.05
Blaine fineness (m^2/kg)	**326**	**379**

Table 2.2 Physical properties and Sieve analysis of lightweight and normal weight aggregates

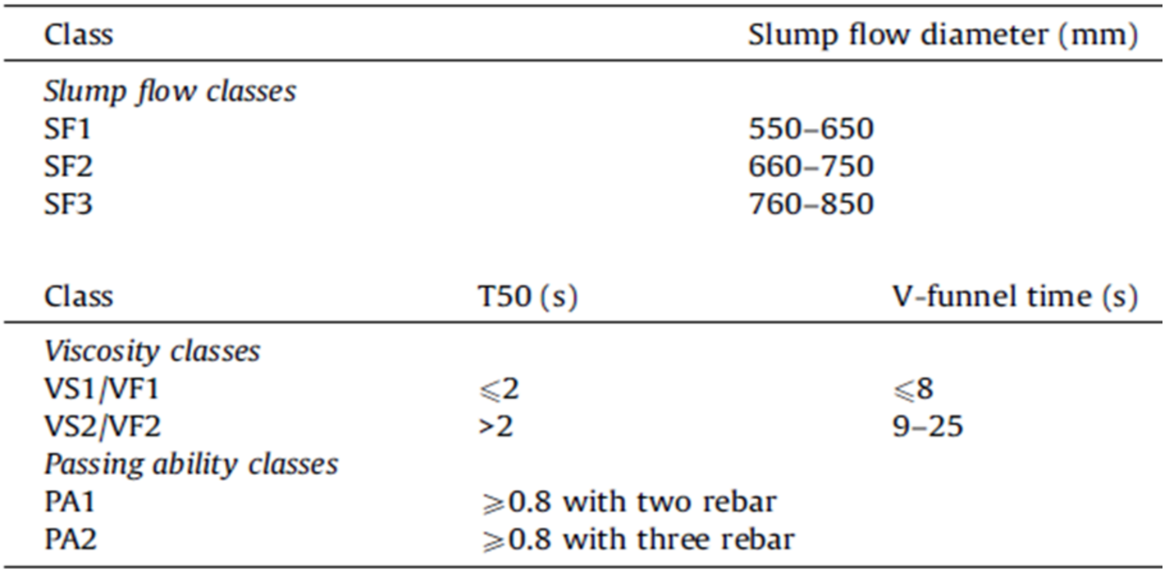
Sieve size (mm)	**Natural weight aggregate**		**Lightweight aggregate**
	River sand	Crushed sand	Coarse 4-16mm
16	100	100	100
8	99.7	100	79.9
4	94.5	99.2	0
2	58.7	62.9	0
1	38.2	43.7	0
0.5	24.9	33.9	0
0.25	5.4	22.6	0
Specific gravity (g/cm^3)	**2.60**	**2.63**	**1.10**

Table 2.3 Concrete mix proportions in kg/m^3



Code number	W/b	Cement	Fly Ash	Water	Lightweight Coarse Aggregate		Normal weight fine aggregate		HRWRA
					LWCA		NWFA		
					(4 – 8) mm	(8 – 16) mm	Normal sand	Crushed sand	
$SP_{1\%}$	0.26	440	110	143	108.2	252.4	598.2	259.3	5.5
$SP_{1.3\%}$	0.26	440	110	143	108.2	252.4	598.2	259.3	7.15
$SP_{1.5\%}$	0.26	440	110	143	108.2	252.4	598.2	259.3	8.25
$SP_{1.7\%}$	0.26	440	110	143	108.2	252.4	598.2	259.3	9.35
$SP_{2\%}$	0.26	440	110	143	108.2	252.4	598.2	259.3	11

Table 2.4: Slump flow, viscosity, and passing ability classes with respect to EFNARC (2005).



Class	Slump flow diameter (mm)
Slump flow classes	
SF1	550–650
SF2	660–750
SF3	760–850

Class	T50 (s)	V-funnel time (s)
Viscosity classes		
VS1/VF1	⩽2	⩽8
VS2/VF2	>2	9–25
Passing ability classes		
PA1	⩾0.8 with two rebar	
PA2	⩾0.8 with three rebar	

Table 3.1 Classification of lightweight concretes according to compressive strength-density relationship (Clarke, 1993)

Property	Class and Type		
	Structural	Structural/Insulating	Insulating
Compressive strength (MPa)	>15	>3.5	>0.5
Density range (kg/m^3)	1600-2000	<1600	$\ll$ 1450

Figures

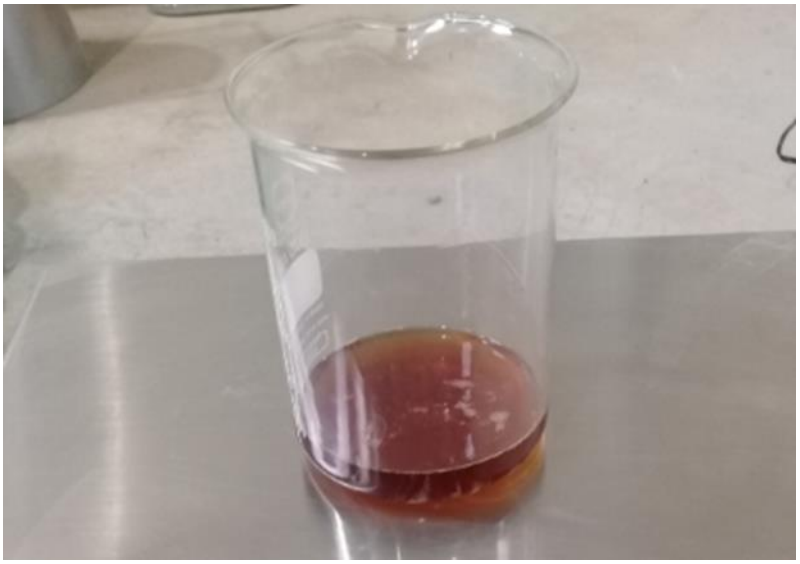


Figure 2.1 Photographic view of HRWRA

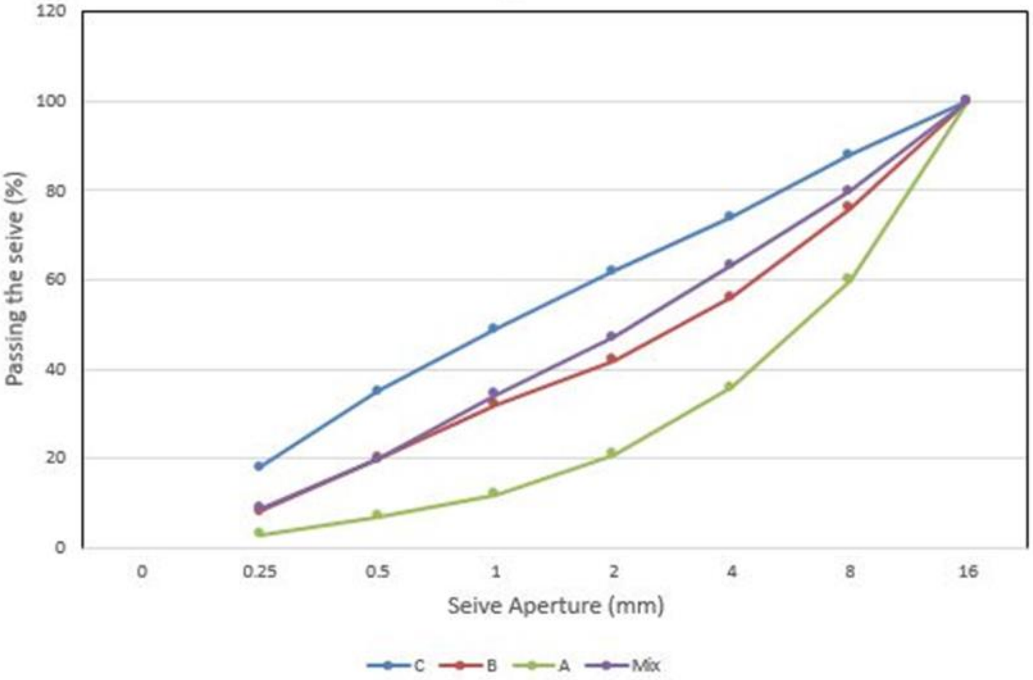


Figure 2.2 Grading curves of coarse pumice lightweight and normal sand aggregates used in experiments.

Figure 2.3 Lightweight coarse pumice

Figure 2.4 LWAs in SSD condition

Figure 2.5 Slump flow test

Figure 2.6 V-funnel test

Figure 2.7 L-box test

Figure 2.8 Compression test

Figure 2.9 Rebound hammer test

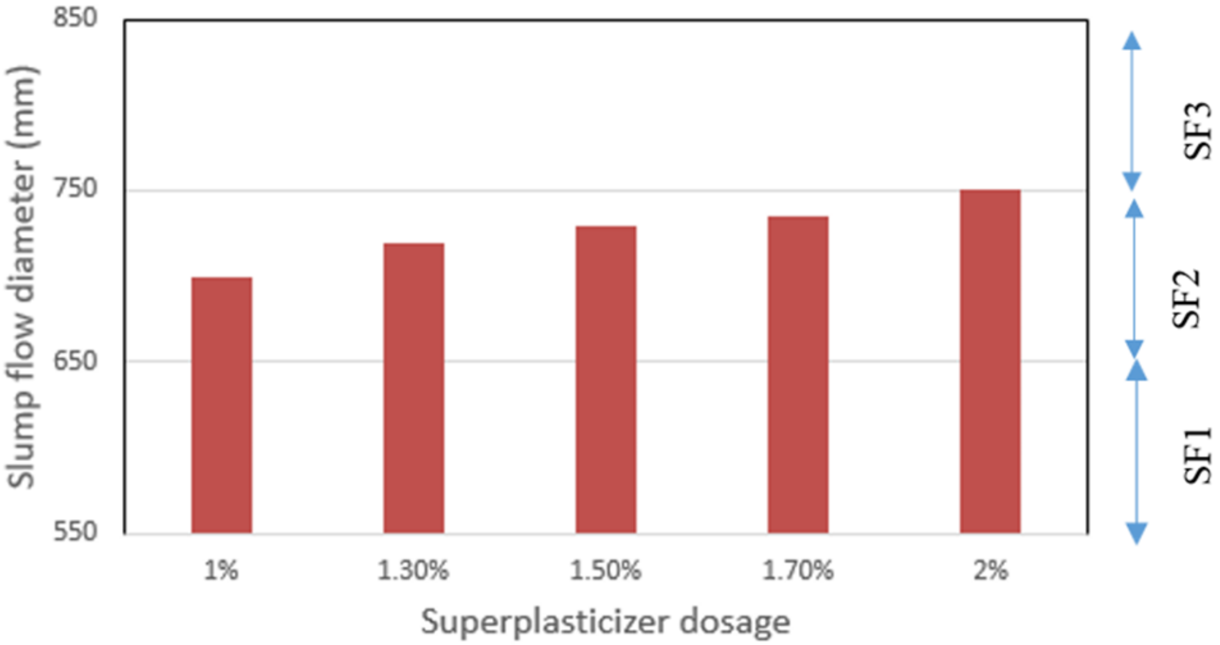


Figure 3.1 Variation of slump flow diameter and slump flow classes for SCLCs.

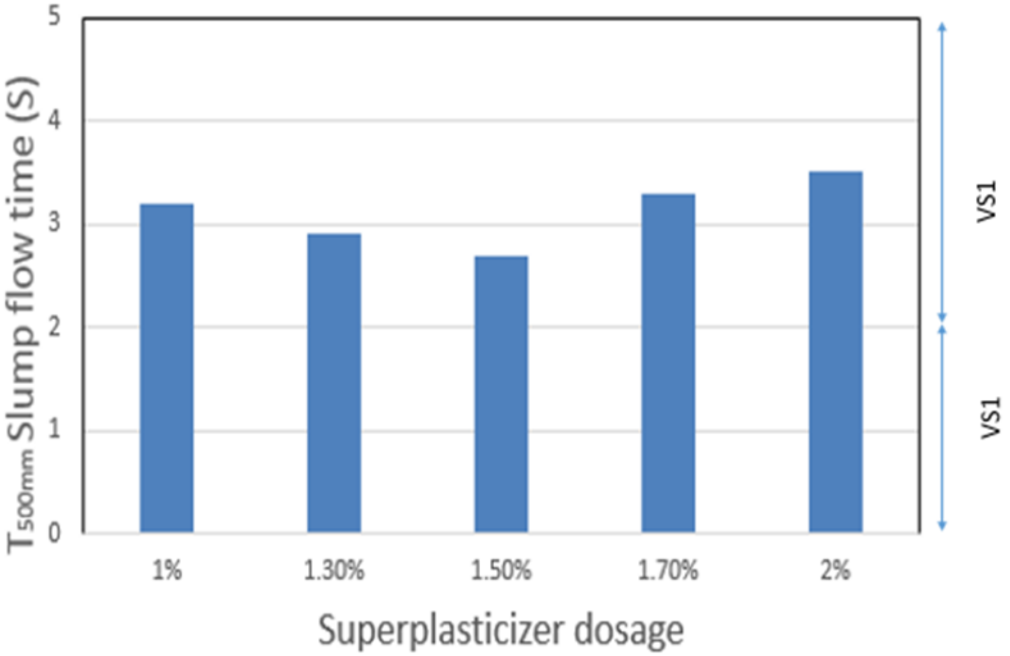


Figure 3.2 Variation of $T_{500\ mm}$ slump flow time and viscosity classes for SCLCs.

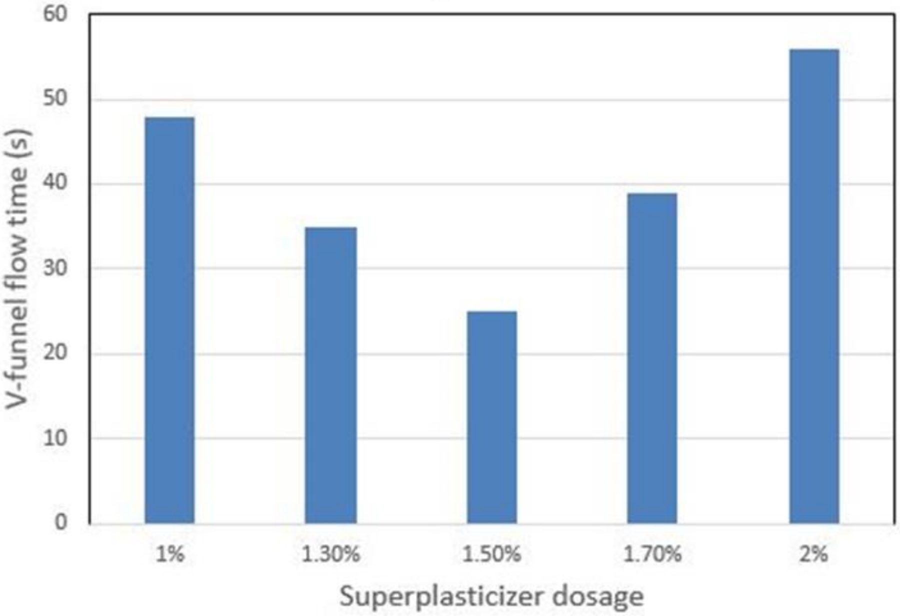


Figure 3.3 Variation of V-funnel flow time for SCLCs.

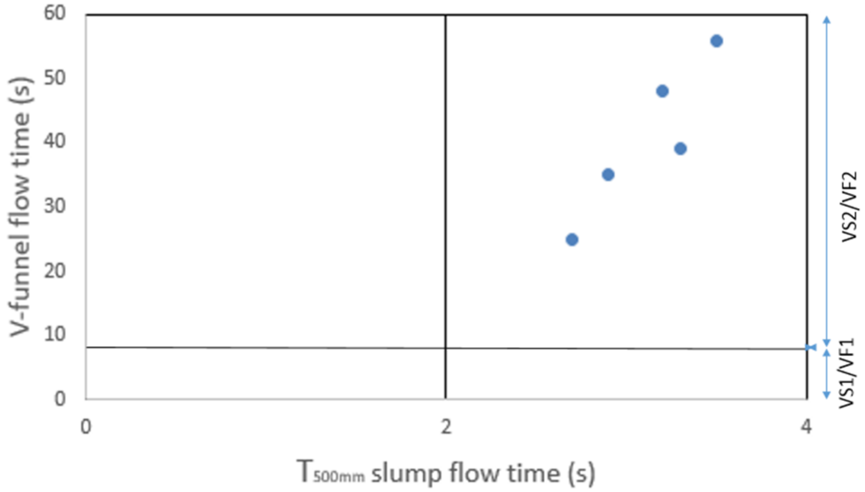


Figure 3.4 Variation of viscosity classes with T500 mm slump flow and V-funnel times for SCLCs.

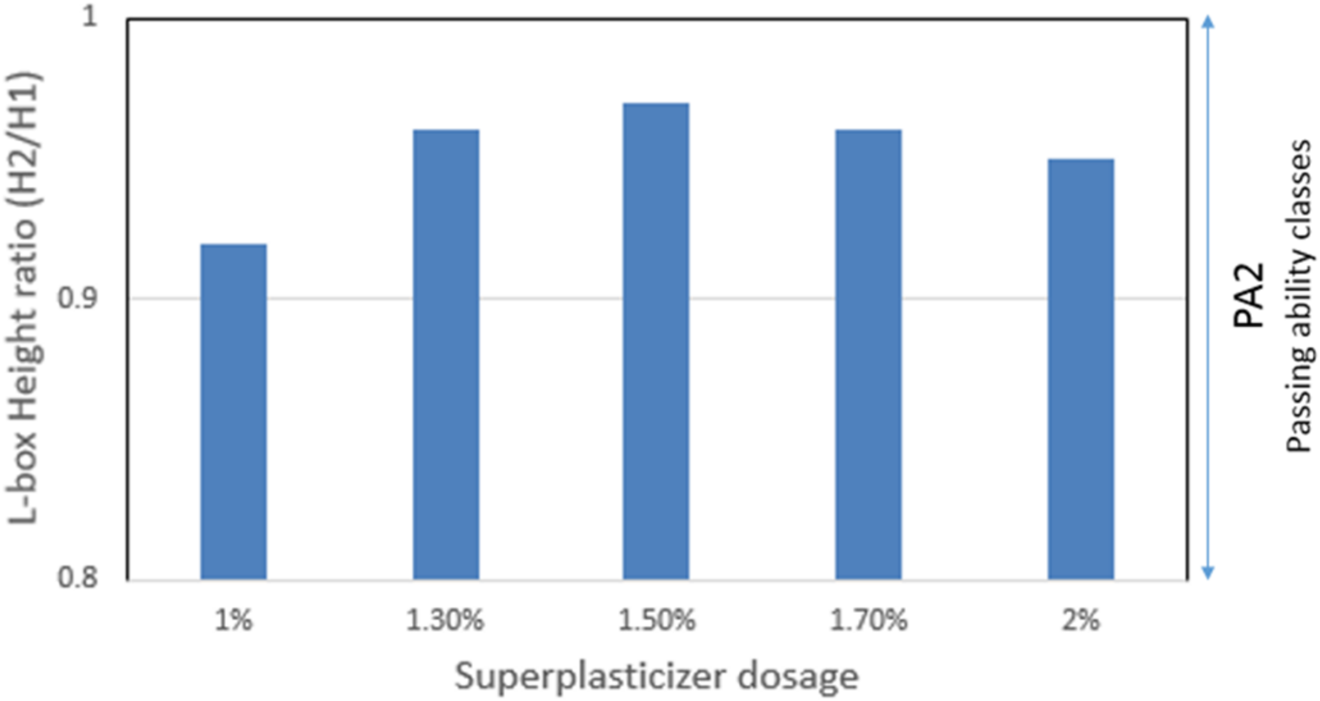


Figure 3.5 Variation of L-box height ratio values for SCLCs.

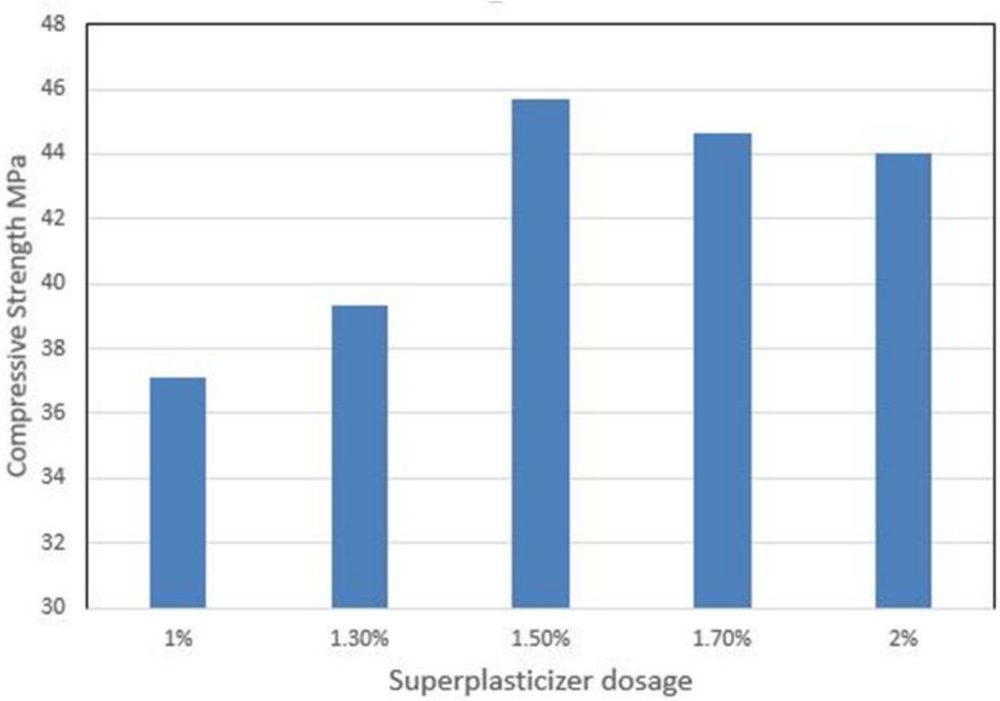


Figure 3.6 Compressive strength of SCLCs at 28 days

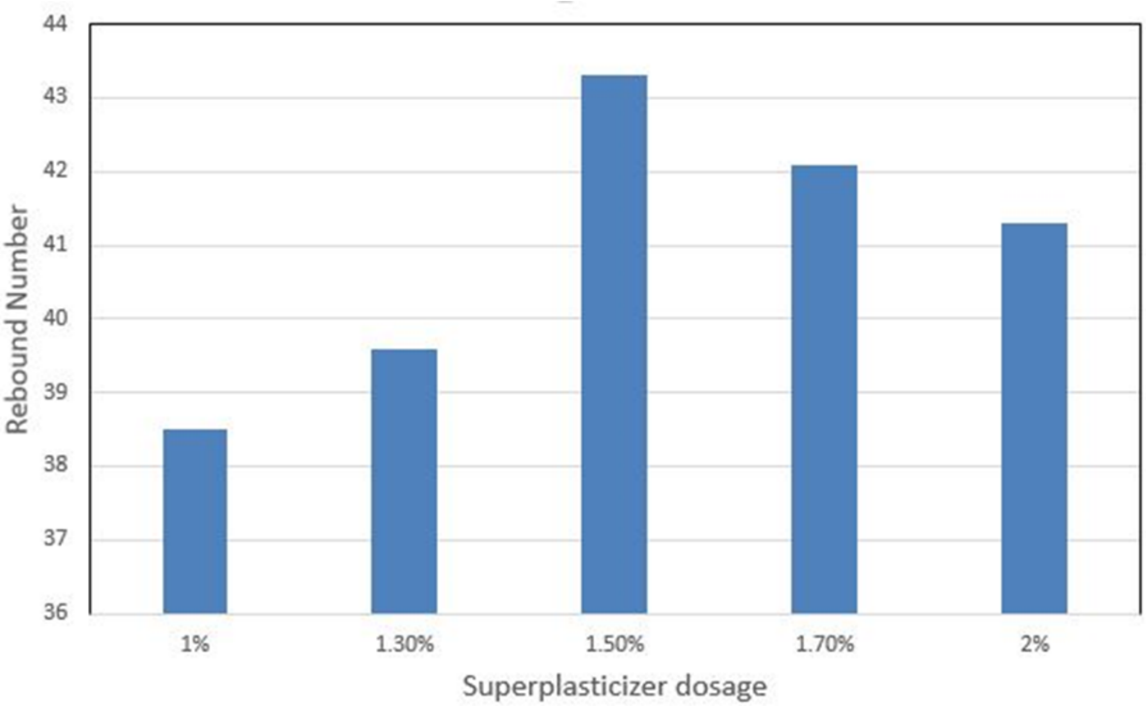


Figure 3.7 Rebound number of SCLCs at 28 days

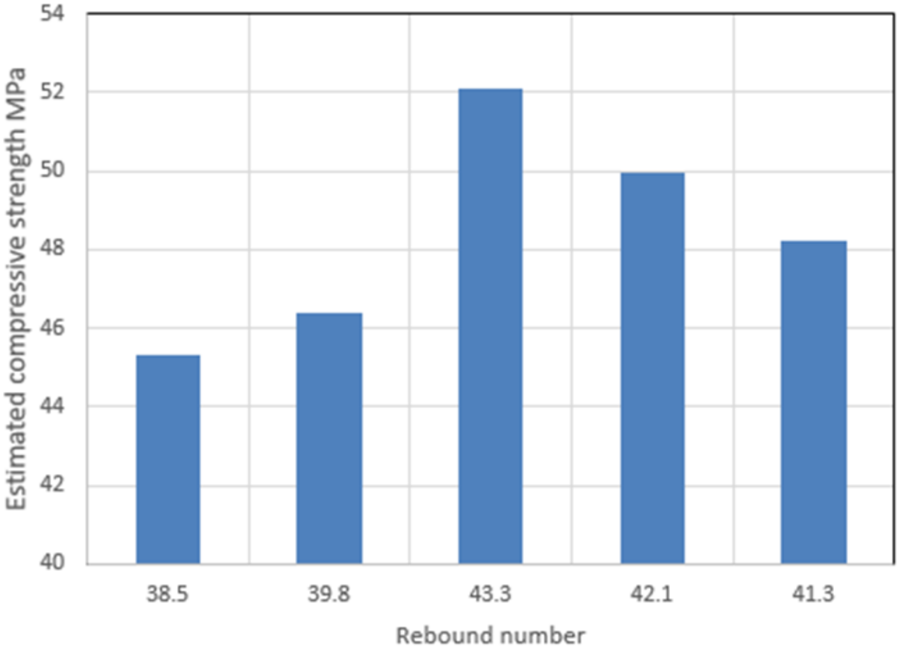


Figure 3.8 Estimated compressive strength of SCLCs

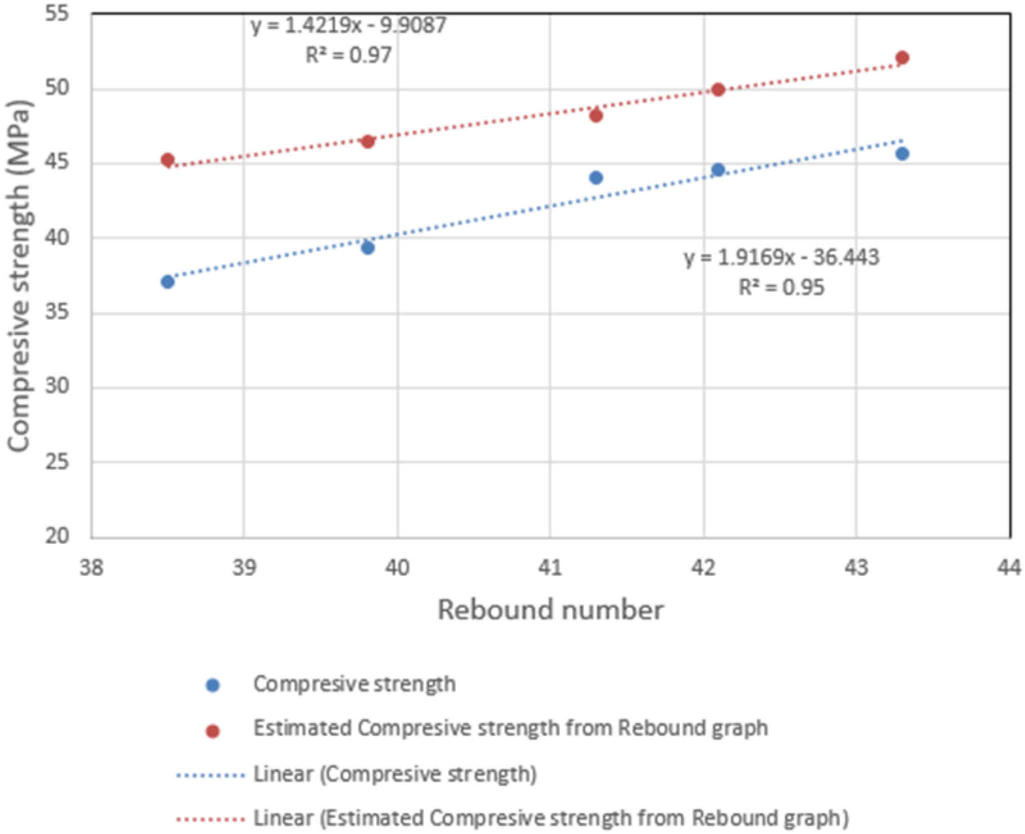


Figure 3.9 Correlation between compressive and estimated compressive strength with rebound number