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Combined Effect of Natural Zeolite and Limestone Powder on the Rheological and Mechanical Behavior Self-Compacting Concrete (SCC) and Mortars (SCM)

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ABSTRACT

New generation concretes have specific properties, often obtained by using additives, and these properties are strongly affected by the rheological characteristics of the fresh cement paste. In this study, the effects of synthetic zeolite, and limestone on the rheological and mechanical properties of fresh concrete and mortars were investigated. Using self-compacting concrete (SCC) which is mainly known by high flow ability, good cohesiveness, and high segregation resistance has been increasing worldwide in concrete structures in recent years. Because of the extensive use of mineral admixtures in SCC the effect of these admixtures on the flow ability of cementitious mixtures should be studied. For this reason, in the preliminary investigation of this study six mortar mixtures with different W/C ratios were prepared and the optimum W/C for self-compacting was reported. Then W/C was selected at 0.45 and the effect of natural zeolite (NZ) and limestone powder (LP) on the fluidity, viscosity and stability of SCCs was investigated. The 28-day compressive and tensile strength of all the mixtures is also determined herein. The results indicate that NZ and LP improve the fluidity of the mixtures. NZ increases the viscosity while LP does not have a significant effect on the viscosity of SCCs. Furthermore, use of LP may improve the compressive strength of cementitious mixtures to some extent.

Keywords:

Self-compacting concrete, Rheology, Compressive strength, Natural zeolite, Limestone powder

1. Introduction

Self-compacting concrete (SCC) is an innovative, non-segregating concrete that is able to flow under its own weight, completely filling formwork and achieving full compaction even in the presence of congested reinforcement [1]. Since the 1980s when SCC was first introduced by Okamura in Japan, there has been a growing interest on SCC technology among constructors and construction industry and this technology has been transferred from laboratory research to practical application. Nowadays, SCC has a worldwide application for precast, prestressed or cast-in-place concrete construction [1-3]. The principal reasons for this interest are concerned with its extraordinary workability and superior flowability which tends to a significant reduction of the construction period and reduced effort in accomplishing some of the casting tasks and enables a considerable reduction of the acoustic noise levels [1, 2]. Blends of supplementary cementitious materials (SCMs) perform better than a single SCM in cementitious systems. The motivations for the present study include the introduction of novel blends of SCMs like limestone and zeolite powders to provide efficient SCC. A major issue associated with SCC is that it has two plastic state properties: flowability (ability to flow into and within intended enclosure) and stability or static segregation resistance (the ability to withstand undue separation of aggregate and sand-cement) [1,4]. Flowability is generally attained using superplasticizers (SPs). For enhancing stability of SCC increasing the fine aggregate content; limiting the maximum aggregate size; increasing the powder content; or utilizing viscosity modifying admixtures (VMAs) is suggested [5]. Mineral admixtures such as natural zeolite, blast furnace slag or limestone powder have been extensively used in SCC for several years. As these mineral additives replace part of the Portland cement, the cost of SCC will be reduced especially if the mineral additive is an industrial by-product or waste. It is also known that some mineral additives, such as natural zeolite, may increase the workability, durability and long-term properties of concrete [6]. Because of the wide use of mineral admixtures in SCC mix design, their effect on the properties of SCC should be investigated. The main objective of this study is to evaluate the rheological behavior and also stability of SCC mixtures incorporating Natural zeolite (NZ) and Limestone Powder (LP). As W/C ratio is the most significant parameter influencing the fresh properties of SCC finding the optimum W/C is considered as the first step of achieving a stable highly flowable mortar. Therefore, mortar mixtures with different W/C ratios were prepared and the optimum W/C ratio to assess self-compatibility was reported. Then the fluidity, viscosity and also stability of cementitious mixtures with NZ and LP were evaluated by mini-slump flow test and mini- V- funnel test. The 28-day compressive strength of all the mixtures is also determined herein. All these tests are conducted on self-compacting mortars (SCCs) originated from SCC because the investigation of mortars rheology provides a basis for the workability properties of the corresponding SCC [7]. In fact, assessing the properties of mortars is an integral part of SCC design [8].

2. Experimental Program

2.1. Materials

ASTM type 2 ordinary Portland cement was used in all the mixtures which is shown in Table1. The fine aggregate was well-graded river sand with a specific gravity of 2.65 and water absorption of 2.7%. The maximum size of aggregates was 12.5mm and its fineness modulus was 2.67. The superplasticizer was polycarboxylic acid-based with specific gravity and solid content of 1.07gr/cm^3 and 36%, respectively. There was also one type of NZ and LP used in this investigation.

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Table 1. The chemical makeup and physical characteristics of powdered cementations material.

Chemical composition (%)								Physical properties	
Materials	SiO_2	Al_2O_3	Cao	Fe_2O_3	MgO	SO_3	$CaCo_3$	Density g/cm^3	Specific Surface m^2/g
Cement	21.25	4.95	64.09	3.19	1.2	2.04	-	3.15	0.31
Natural Zeolite	69.5	12.6	0.4	1.33	0.8	0.5	1.53	2.20	20.2
Limestone powder	0.3	0.1	-	0.02	0.02	-	99.3	2.70	0.48

2.2. Mixture Proportions and Testing Methods

The preliminary investigation consisted of six mortar mixtures with a fixed SP dosage of 1% by cement mass and W/C varying in the range of 0.35 to 0.5 by a 0.5% increscent. Then the W/C was kept fixed at 0.45 and two mixture series was prepared were consisting of three mixtures with 10%, 30% and 50% (by cement mass) of NZ or LP. The SP dosage was 1% by cement mass in all these series. The fluidity and viscosity of cementitious mortars was evaluated by measuring the mini-slump mini-V-funnel V-funnel flow time in conformity with the standard procedures given by EFNARC [8]. The test apparatus are shown in Figs.1. EFNARC suggests a spread diameter of 24-26cm and a flow time of 7-11sec for a mortar mixture with satisfactory self-compatibility. In this study, a visual assessment of stability was also made in the slump flow test and the visual stability index (VSI) was evaluated. The VSI ranged from 0 for excellent; 1 acceptable; 2 needs improvement; to 3 unacceptable [9].

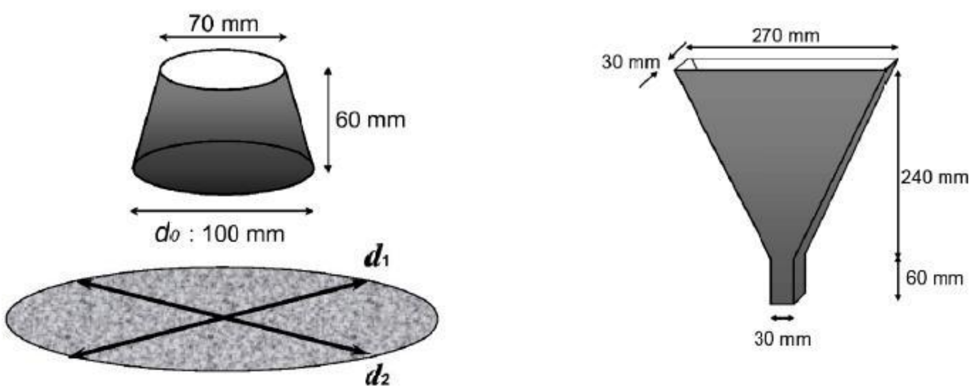

Figure 1. a) Mini-slump flow cone b) Mini-V-funnel apparatus

The prepared fresh concrete was cast in 50×50×50mm trio molds. All concrete specimens were first cured 24hr in air conditions, then, immersed in the water at a temperature of 25 °C. Compressive strength test was performed on the specimens aged for 28 days and the average of test results were reported.

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3. Results and Discussions

3.1. Effect of W/C on the Rheological Behavior and Compressive Strength of SCC

The most significant parameter influencing the properties of SCCs in the fresh state is W/C ratio. In spite of very effective role of W/C in providing high fluidity of self-compacting mixtures, it may cause the mixture susceptible to any kind of heterogeneity and instability. Therefore, finding the optimum W/C ratio is considered as the first step of achieving a stable highly flowable mortar. The effect of W/C ratio on the fluidity of mortar mixtures is summarized in Figure 2.a. As shown in the figure, W/C ratio directly influences the fluidity of cementitious mixtures. The relationship between fluidity and W/C ratio of the mixtures seems to be linear and an increase of W/C by 10% tends to a 15% increase in fluidity. The obtained results also indicate that all the mixtures with W/C ratio greater than 0.4 have the minimum fluidity requirement given by EFNARC. Figure 2.b shows the effect of W/C ratio on the viscosity of cementitious mixtures. The obtained results indicate that the effect of W/C ratio on the viscosity of mortar mixtures is much more pronounced than the fluidity and there seems to be an exponential trend between the viscosity of mortar mixtures and W/C ratio. The reduced viscosity of the mixtures enables the ease of self-flowing. On the other hand, cementitious mixtures with low viscosities may exhibit heterogeneity and segregation during and after the casting process.

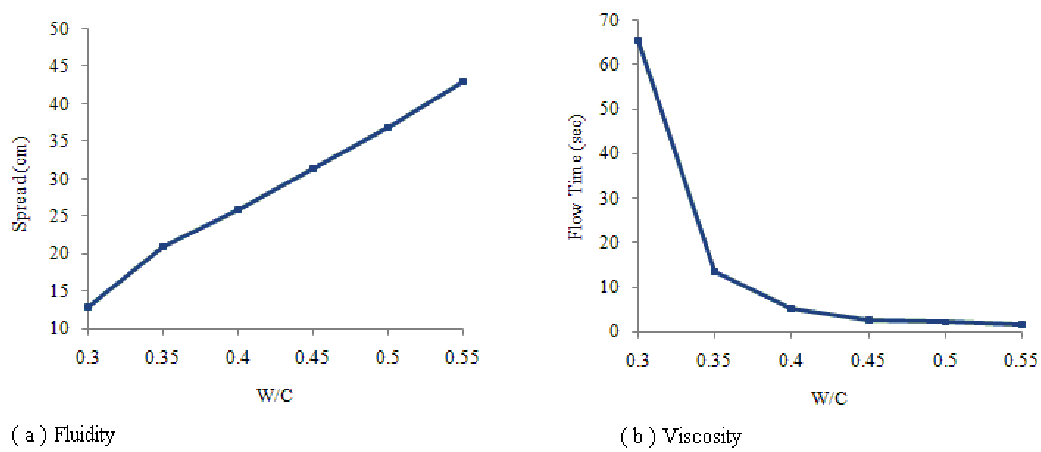

Figure 2. Rheological properties of SCCs with different W/C ratios.

Table1 summarizes the VSI of mortar mixtures. The results show all the mixtures with W/C ratio greater than 0.45 exhibit some nonuniform texture and bleeding. As shown in the table, W/C ratio has a great effect on the stability of the mixtures and cementitious mixtures with higher W/C ratios may exhibit severe bleeding and segregation. Spread of mortar mixtures with W/C ratio of 0.4 and 0.5 are shown in Figures 3a, 3b, respectively. As shown in the figure, mortar mixture with W/C of 0.4 is completely stable after conducting mini-slump flow test while mortar mixture with W/C of 0.5 exhibits sever heterogeneity.

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Table 2. VSI of SCCs with different W/C ratio.

W/C	VSI
0.35	0
0.4	0
0.45	2
0.5	2

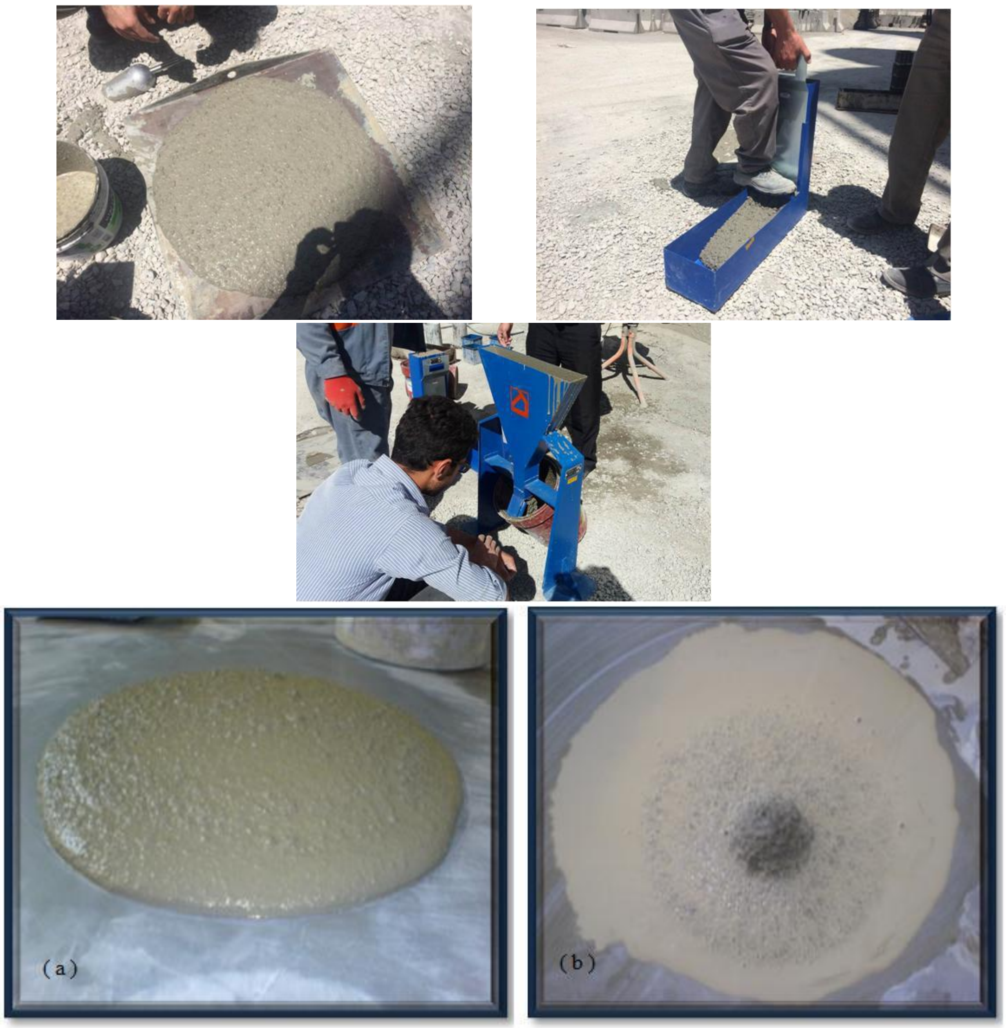

Figure 3. Mortar and Concrete mixtures with a) W/C=0.4 and b) W/C=0.5.

Based on the obtained results, the mortar mixture with W/C ratio about 0.4 may be regarded as self-compacting mortar. Mortar mixtures with less W/C ratios suffer from poor flowablity and mixtures with higher W/C ratios are prone to segregation and instability. In addition to fresh properties of SCCs, compressive strength of SCCs after 28 days is also evaluated in this investigation. Fig. 4 shows the compresive strength of SCCs with different W/C ratios. As expected, the obtaied results indicate that increasing W/C ratio has a significant effect on the compressive stregnth of SCCs, for example, increasing W/C from 0.4 to 0.45 decrease the compressive strength of SCCs from 55MPa to 45MPa. However, all the mixtures in this series have a compressive strength greater than 35MPa.

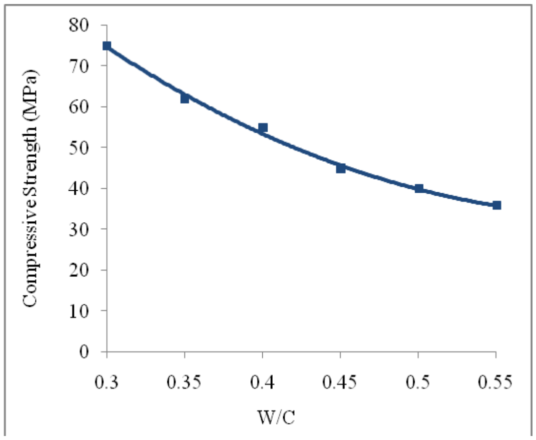

Figure 4. Compressive strength of SCCs with different W/C ratios.

After the preliminary invetigation mixture with W/C ratio of 0.45 which has a superior fluidity but inadequate segregation resistance selected and the effect of addition of NZ and LP in different dosages on the fluidity, viscosity, stability and also compressive strength was investigated.

3.2. Effect of NZ on the Rheological Behavior and Compressive Strength of SCCs

Spread diameter of mortar mixtures with different dosages of NZ is illustrated in Figure 5a The obtained results indicate that increasing NZ improve the fluidity of SCCs to some extent. This may be because of the spherical shape of NZ particles. The spherical shapes reduce the friction at the aggregate-paste interface producing a ball-bearing effect at the point of contact [10, 11]. Figure 5b shows the effect of NZ dosage on the viscosity of mortar mixtures. The obtained results indicate that using NZ significantly increases the viscosity of mortar mixtures and SCCs with 30% and 50% NZ are much more viscous than the control mixtures. Table 2 summarizes the VSI of the mortar mixtures incorporating NZ. The results show that no bleeding is observed in the mixtures incorporating NZ.

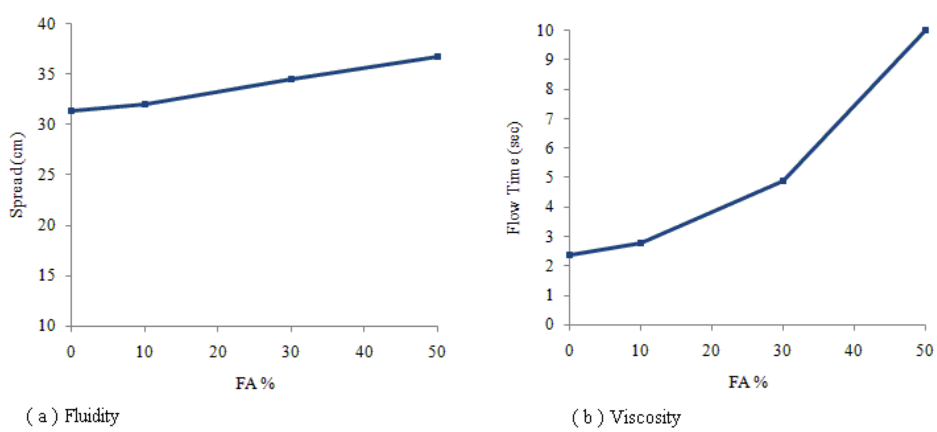

Figure 5. Rheological properties of SCCs incorporating NZ.

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Table 1. VSI of NZ-SCCs.

NZ%	VSI
0	2
10	0
30	0
50	0

The compressive strength of NZ-SCC is shown in Fig. 6. As shown in the figure, use of NZ may increase or decrease the compressive strength of cementitious mixtures. Addition of NZ up to 10% improves the compressive strength. Use of 30% NZ does not influence the compressive strength while use of 50% NZ decreases the compressive strength to some extent. Based on the obtained results, the optimum dosage of NZ in SCCs seems to be in the range of 10% to 30% by cement mass. Furthermore, the visual observation of the mixture incorporating NZ indicates that the SCC with NZ content more than 30% exhibits segregation as it is left undisturbed for about 15min. Also, in terms of tensile splitting tests, there is growth in results respectively 6%, 8%, 5% and 2% by replacing the LP and NZ.

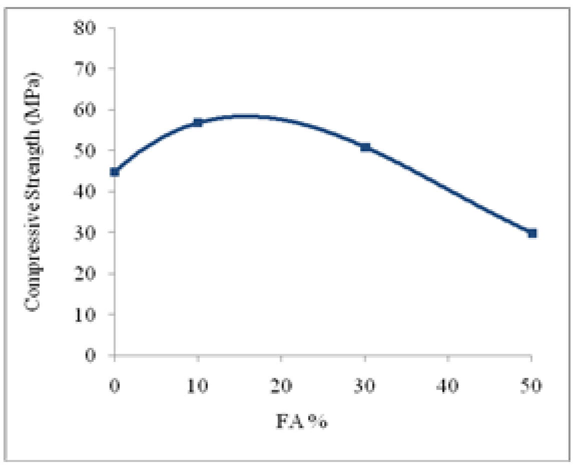

Figure 6. Compressive strength of SCCs incorporating NZ.

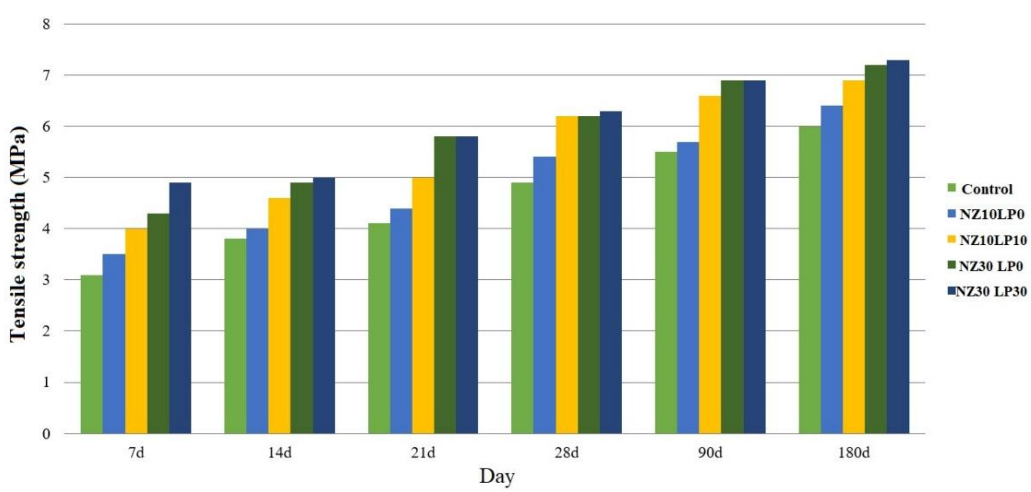

Figure 7. Tensile strength of SCCs incorporating NZ.

3.3. Effect of LP on the Rheological Behavior and Compressive Strength of SCCs

Spread diameter of mortar mixtures with different dosages of LP is plotted in Figure 7a. Based on the obtained results, use of LP is also effective in increasing the fluidity of mortar mixtures. The improving effect of LP on the fluidity of SCCs is also reported by Sahmaran et al. [5]. Figure 7b shows the viscosity of mortar mixtures due to different dosages LP. The results show that LP does not have a great influence on the viscosity of cementitious mixtures.

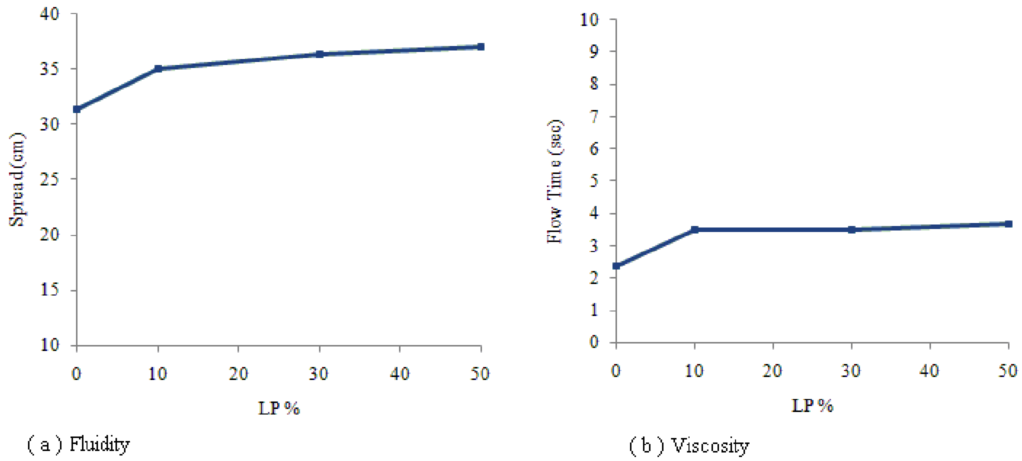

Figure 8. Rheological properties of SCCs incorporating LP.

The VSI of LP-SCCs is summarises in Table 3. Based on the obtained results use of LP is a effecive way for eliminating the bleeding of the mixtures.

Table 3. VSI of SCCs incorporating LP.

LP %	VSI
0	2
10	0
30	0
50	0

Compressive strength of LP-SCCs is plotted in Figure 8. The obtained results indicate that addidtion LP up to 30% does not have a significant effect on the compressive strength while addition of LP beyond 30% slightly increase the compressive strength. The improving effect of LP on the compressive strength may be due to the enhanced packing density and the interaction of LP with cement hydration [12].

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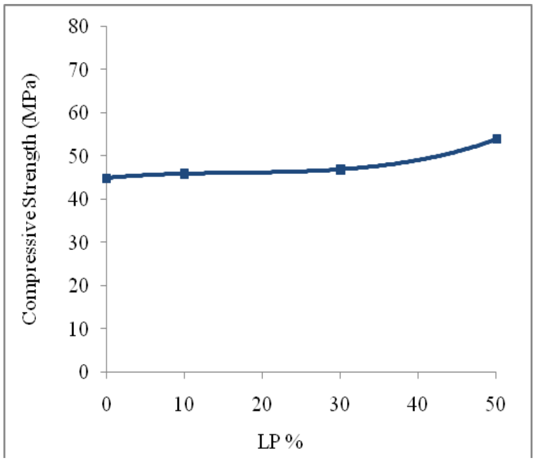

Figure 8. Compressive strength of SCCs incorporating LP.

4. Conclusions

To obtain a proper SCC six mortar mixtures with different W/C ratios were prepared and the optimum W/C was evaluated. Then W/C ratio was selected at 0.45 and the effect of NZ and LP on the rheological properties and also compressive strength of SCCs were investigated. Based on the experimental results, the following conclusions can be made:

- Rheological properties and stability of SCCs are mainly influenced by W/C ratio. W/C ratio affects the fluidity of SCCs linearly while affecting the viscosity and stability exponentially. The optimum W/C ratio for obtaining self-flowing and stability properties of cementitious mortars seems to be about 0.4.
- NZ and LP improve the fluidity of SCCs. Increasing NZ increase the viscosity of SCCs while LP does not influence the viscosity.
- Use of NZ and LP is effective for eliminating bleeding of SCCs. On the other hand, empirical observation indicates that SCCs with NZ or LP content beyond 30% may prone to segregation if they left undisturbed for a while.
- Use of NZ may increase or decrease the compressive strength. Furthermore, use of LP beyond 30% slightly increase the compressive strength of SCCs which is mainly due to the the improved packing density and the interaction of LP with cement hydration.

5. Acknowledgement

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