Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 125 (2015) 773 – 779
Procedia Engineering
www.elsevier.com/locate/procedia

The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

The impact of using fly ash, silica fume and calcium carbonate on the workability and compressive strength of mortar

Antoni[a,*], Lucky Chandra[a], Djwantoro Hardjito[a]

[a]*Petra Christian University, Jalan Siwalankerto 121-131, Surabaya 60236, Indonesia*

Abstract

Pozzolanic materials and calcium carbonate can be used to partially replace the use of cement in making mortar or concrete without altering the rheological properties of the fresh mixture. This study focuses on the use of fly ash in the range of 0-30%, silica fume 0-10% and calcium carbonate 0-15% of the cement content, by mass. The workability of the fresh mortar was evaluated and the compressive strength of hardened mortar were measured at the ages of 7, 14, 28 and 56 days. Test results show that increasing partial replacement of cement with fly ash increased the workability and compressive strength of mortar. The use of silica fume reduces the workability of the fresh mortar, and thus requires the addition of superplasticizer to improve the workability. Finer particle size of calcium carbonate also increase workability. The addition of calcium carbonate resulted in higher early strength, whereas the Strength Activity Index (SAI) values slightly reduced with age.

Peer-review under responsibility of organizing committee of The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

Keywords: fly ash; silica fume; calcium carbonate; compressive strength; workability;

1. Introduction

Producing high quality and high performance concrete may require partial replacement or addition from the conventional materials, such as cement and aggregates. The use of replacement materials may end up with increasing homogeneity and density of concrete or mortar produced, while maintaining the workability of the fresh mixture.

With appropriate replacement materials, it is possible to increasing the density and compressive strength of the hardened products. The use of high amount of cement in concrete mixture to produce high compressive strength may

* Corresponding author. Tel.:+62-819-3107-3728
E-mail address: antoni@petra.ac.id

Peer-review under responsibility of organizing committee of The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)
doi:10.1016/j.proeng.2015.11.132

cause side effects such as high heat of hydration, shrinkage and cracks. The presence of supplementary cementing materials, such as fly ash and/or silica fume (both of them are pozzolanic materials), may overcome this undesirable situation. Study on the use of fly ash and silica fume to replace cement up to 30%, by mass, resulted in more workable and denser mixture [1]. Fine-sized pozzolanic materials can also have a role as a filler that fills the cavities in the mixture.

The use of other additional materials, such as calcium carbonate, may replace part of cement and at the same time increase the density, the compressive strength and the cohesiveness of concrete mixture [2]. Calcium carbonate with particle size less than 8 μm is commonly used as filler with the aim of filling the gaps between particles, producing mixture with high density and other technical advantages, such as control of bleeding, increased early compressive strength, reduced concrete sensitivity due to lack of curing [3].

Research on the use of replacement materials have been conducted extensively [4-9]. In most cases, the study has been performed separately, i.e either using pozzolanic materials only or calcium carbonate only. Study on involving both pozzolanic materials and calcium carbonate at the same time, to enhance the quality and the performance of concrete or mortar is still lacking. This study focuses on the use of pozzolan; i.e. fly ash and silica fume; and calcium carbonate with the aim to improve the quality and performance of mortar while maintaining the good workability of the fresh mixture.

2. Experimental Details

Fly ash was obtained from Paiton Power Plant unit 5 and 6, Situbondo, East Java, Indonesia, as a by-product of burning sub-bituminous coal to generate electrical energy. The chemical composition can be seen in Table 1. Silica fume used in this study was Rheomac SF100, produced by BASF. Pozzolanic Portland cement (PPC) produced by Semen Gresik was used throughout the study. Polycarboxylate-based superplasticizer (SP), Glenium ACE8590 produced by BASF, was added to ensure the desired workability was achieved. Calcium carbonate was obtained from Masachemitra Solar Industry, Gresik. Silica sand with fineness modulus of 2.624 was used.

Table 1. Chemical Composition of Fly Ash as Measured by XRF

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Cr_2O_3	K_2O	Na_2O	SO_3	Mn_3O_4
39.78	17.87	15.00	0.73	15.47	6.45	0.02	1.32	1.51	1.32	0.18

The mixture composition of mortar was taken as follows: the mass ratio of silica sand (s) to cementitious materials (cm) was taken as 2.5: 1, with water-to-cementitious ratio (w/cm) of 0.35. Study was carried out by replacing part of the cement content with pozzolanic materials, which is a combination of fly ash and silica fume.

First stage of research, fly ash content was varied from 0 to 30%, while silica fume from 0 to 10%, of the total mass of cementitious material. At first, w/cm was set constant at 0.35, with SP content was taken as 0.5% of the cementitious material, by mass. Later, with w/cm remained unchanged, SP was varied to achieve a constant flow diameter of 13±1 cm.

At the following stage, calcium carbonate was added to the mortar mixture at various levels. In this case, fly ash and silica fume content were taken as 10% and 2.5%, respectively, of the cementitious material. The addition of calcium carbonate powder was varied from 5 to 15% of the cementitious material, by mass. The particle size of the powder was also varied, i.e. passed #800 mesh (15 μm), #1200 mesh (12 µm) and #2000 mesh (8 µm). A mixture without any pozzolanic material content was also prepared as a control mixture.

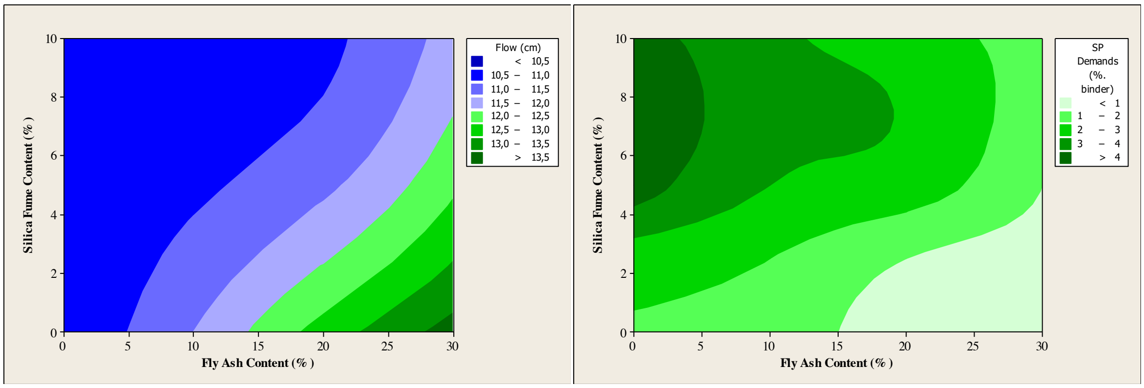
Mixing process was started with all the dry materials, mixed for about 5 minutes. Next, water was added gradually. The fresh mortar mixture was then vibrated on a vibrating table approximately for 3 minutes, to make it more workable. Workability was measured by performing flow table test, whereby in each test the flow diameter was determined. The fresh mixture was then casted on 5×5×5cm cubes, cured in the water until one day before testing. Testing for compressive strength was carried out at the age of 7, 14, 28 and 56 days. Each data represents the average compressive strength of three mortar cubes.

3. Results and Discussion

3.1 The Influence of Fly Ash and Silica Fume Content on the Workability of Mortar

The workability of fresh mortar was measured in terms of flow diameter in a flow table test in accordance to ASTM C230 [10]. The tests were aimed to determine the influence of using fly ash and silica fume on the workability of the mortar. Figure 1(a) shows the contour graph, showing relationship among the fly ash content and silica fume content on the flow diameter of fresh mortar, while Figure 1(b) shows the relationship among the fly ash content and silica fume content with the SP demand to achieve a target flow diameter of 13 ± 1 cm.

Figure 1 shows that the use of fly ash increases the workability of fresh mortar, on the contrary the use of silica fume tends to reduce it. With the increase of fly ash content of up to 30%, the flow diameter was also increased. The increase use of silica fume increases the SP demand to achieve the desired flow diameter.

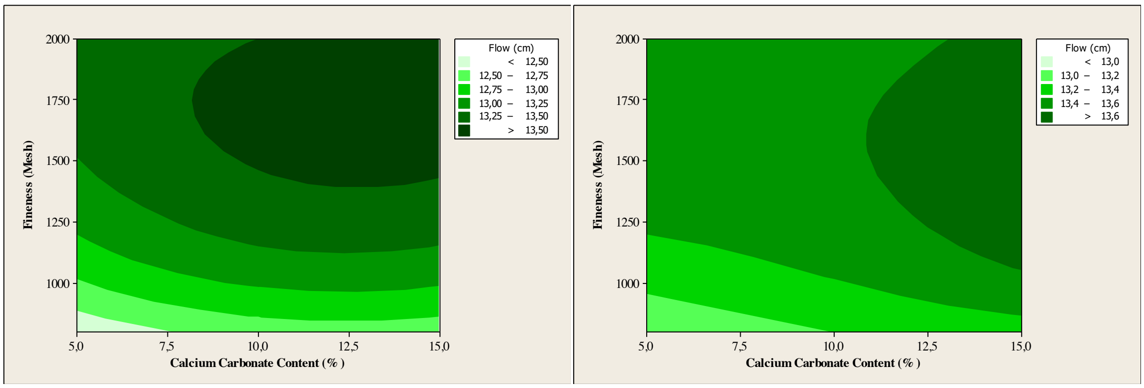


(a) (b)

Fig. 1. Relationships among (a) Fly Ash-Silica Fume-Flow Diameter, (b) Fly Ash-Silica Fume-Superplasticizer Demand

3.2. The Influence of Calcium Carbonate Content and Fineness on the Workability of Mortar

Figure 2(a) shows the impact of calcium carbonate content and fineness on the workability of fresh cement mortar without any pozzolanic material content, while Figure 2(b) exhibits the one on the workability of fresh mortar incorporating pozzolanic materials. Both figures show that with the increase in the calcium carbonate content of up to 15%, by mass, and with the increase in its fineness, the workability of the fresh mortar was also increased.



(a) (b)

Fig. 2. The Impact of Calcium Carbonate Content and Fineness on Mortar Workability: (a) Without Pozzolan, (b) With Pozzolan

3.3. The Influence of Fly Ash and Silica Fume Content on the Compressive Strength of Mortar

The compressive strength and its activity index of mixture with variation pozzolanic replacement is shown in Table 2. From the superplasticizer (SP) dosage to achieve flow of 13±1 cm, it can be seen that more fly ash replacement, reduces the use of SP while more silica fume increases the SP demand. Compressive strength of 7, 14, 28 and 56 days shows that the mortar have similar strength due to the constant w/b ratio use throughout the experiment. Strength activity index for the mixture was showing lower value for early age specimen because of lower rate of pozzolanic reaction and could achieve SAI, up to 111% for later age.

Table 2. Compressive strength and strength activity index for the pozzolanic replacement mixture

Cement	Fly ash	Silica Fume	SP (%) required	Compressive Strength (MPa)				Strength Activity Index (SAI) (%)			
				7 days	14 days	28 days	56 days	7 days	14 days	28 days	56 days
100	0	0	2	48,80	50,13	52,93	64,00	100,00	100,00	100,00	100,00
90	10	0	1,5	47,07	49,07	53,73	64,67	96,45	97,87	101,51	101,04
80	20	0	0,5	41,33	46,40	54,53	61,47	84,70	92,55	103,02	96,04
70	30	0	0,2	40,27	44,00	55,33	65,20	82,51	87,77	104,53	101,88
87,5	10	2,5	2	48,93	50,67	54,13	68,67	100,27	101,06	102,27	107,29
77,5	20	2,5	1	46,67	49,47	54,80	71,07	95,63	98,67	103,53	111,04
67,5	30	2,5	0,5	43,47	48,00	56,13	59,07	89,07	95,74	106,05	92,29
85	10	5	3	46,67	49,33	50,27	65,20	95,63	98,40	94,96	101,88
75	20	5	2,5	44,00	47,20	52,00	67,07	90,16	94,15	98,24	104,79
65	30	5	1	42,67	46,67	53,47	60,00	87,43	93,09	101,01	93,75
80	10	10	3,2	43,87	48,93	55,47	64,67	89,89	97,61	104,79	101,04
70	20	10	2,5	43,33	47,33	56,27	62,93	88,80	94,41	106,30	98,33
60	30	10	1,5	40,67	43,20	50,80	62,93	83,33	86,17	95,97	98,33
97,5	0	2,5	2,5	49,20	50,67	53,73	64,67	100,82	101,06	101,51	101,04
95	0	5	4,5	44,00	47,33	50,40	56,67	90,16	94,41	95,21	88,54
90	0	10	4,5	42,67	46,53	51,73	61,87	87,43	92,82	97,73	96,67

Figure 3 shows the influence of fly ash and silica fume content on the compressive strength of mortar at 28 and 56 days of age. The w/cm value was set constant at 0.35, and SP content was taken as 0.5% of the cementitious material.

The increase content of fly ash in the mixture of up to 30% of the cementitious material increases the compressive strength of mortar at 28 and 56 days. On the contrary, however, the addition of silica fume of up to 10% to the mixture containing fly ash tends to decrease the compressive strength of mortar. This is related to the flow diameter of the fresh mixture, which shows the reduction with the increase use of silica fume (Figure 1). To maintain the same flow diameter or workability, the SP content should be altered. The reduction of compressive strength of harden mortar due to the use of silica fume can be caused by the reduction in the workability of the fresh mixture.

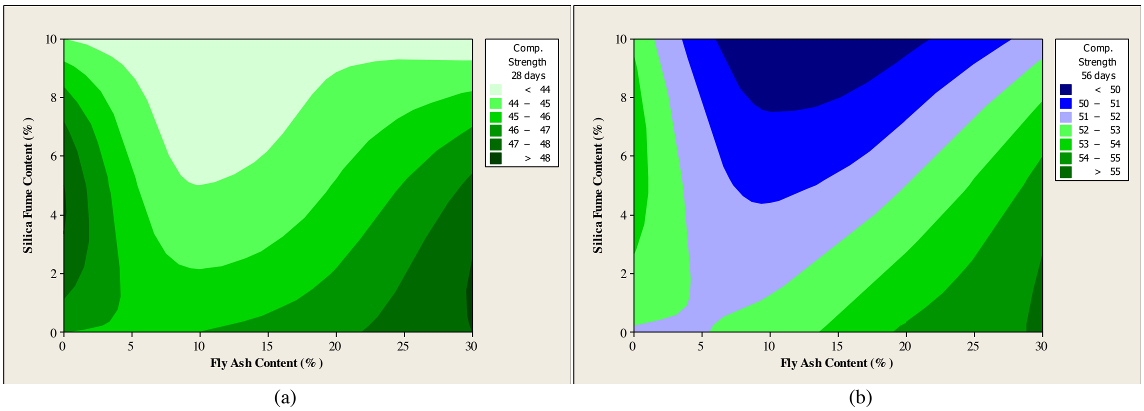
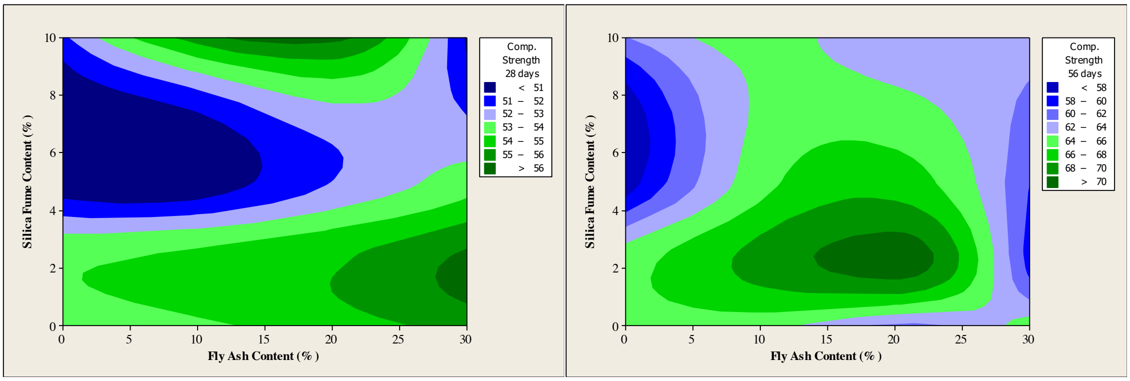


Fig. 3. The Influence of Fly Ash and Silica Fume Content on Mortar Compressive Strength (Constant SP): (a) 28 days, (b) 56 days

Figure 4 shows compressive strength contour of mortar containing fly ash and silica fume with a constant flow diameter. SP was added in various content to ensure a constant consistency of the fresh mixtures. Noticeable differences can be identified compared to those with constant SP. With a constant flow diameter, the addition of silica fume of up to 3%, by mass, increases the compressive strength of the mortar. At the age of 56 days, the highest compressive strength was achieved by mortar with mixture composition of 20% fly ash and 2.5% SF. This shows that the use of combined fly ash and silica fume, accompanied with the addition of SP, give positive effect on the compressive strength of mortar.



(a) (b)

Fig. 4. The Influence of Fly Ash and Silica Fume Content on Mortar Compressive Strength (Constant Flow Diameter): (a) 28 days, (b) 56 days

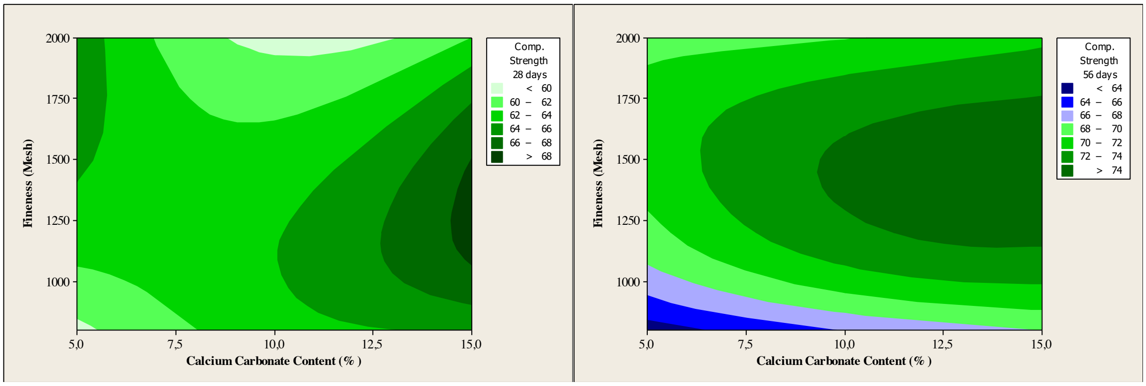
3.4. The Influence of Calcium Carbonate Content and Fineness on Compressive Strength of Mortar with/without Pozzolan

The compressive and strength activity index of the mixture with addition of fine particle of calcium carbonate is shown in Table 3. All mixture was made with the same mixture proportion, only with addition of calcium carbonate to increase the cohesiveness of the mixture. It was found that the addition of calcium carbonate increases the compressive strength compared to the control mixture. Finer particle of calcium carbonate have higher strength increment.

Table 3. Compressive strength and strength activity index for mixture with addition of calcium carbonate

Calcium Carbonate		**Compressive Strength (MPa)**				**Strength Activity Index (SAI) (%)**			
Mesh #	**% addition**	**7 days**	**14 days**	**28 days**	**56 days**	**7 days**	**14 days**	**28 days**	**56 days**
Cement 100%									
	0	45,60	52,00	56,27	61,33	100,00	100,00	100,00	100,00
800	5	47,07	53,87	59,47	62,93	103,22	103,59	105,69	102,61
	10	48,40	54,13	63,07	66,00	106,14	104,10	112,09	107,61
	15	50,40	55,47	64,00	68,00	110,53	106,67	113,74	110,87
1200	5	47,33	56,80	62,93	69,33	103,80	109,23	111,85	113,04
	10	49,07	58,40	63,87	73,47	107,60	112,31	113,51	119,78
	15	51,87	61,07	68,67	74,40	113,74	117,44	122,04	121,30
2000	5	48,53	56,80	65,33	69,20	106,43	109,23	116,11	112,83
	10	49,73	57,33	59,33	69,87	109,06	110,26	105,45	113,91
	15	52,27	58,67	62,00	71,47	114,62	112,82	110,19	116,52
Cement 87.5%, fly ash 10% and silica fume 2.5%									
	0	46,13	48,93	57,73	67,73	100,00	100,00	100,00	100,00
800	5	44,00	51,47	54,53	70,40	95,38	105,18	94,46	103,94
	10	46,67	52,00	64,53	69,73	101,16	106,27	111,78	102,95
	15	48,67	54,67	67,47	70,53	105,49	111,72	116,86	104,13
1200	5	42,00	50,67	64,27	76,80	91,04	103,54	111,32	113,39
	10	41,60	50,53	65,60	77,60	90,17	103,27	113,63	114,57
	15	42,67	53,33	66,53	72,00	92,49	108,99	115,24	106,30
2000	5	36,67	45,20	59,47	73,20	79,48	92,37	103,00	108,07
	10	40,93	52,53	58,67	70,93	88,73	107,36	101,62	104,72
	15	42,80	53,47	61,73	69,60	92,77	109,26	106,93	102,76

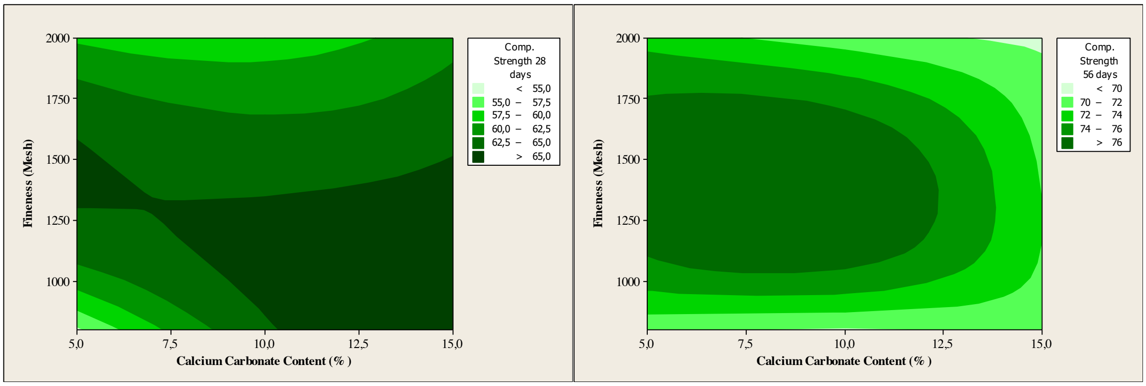
Figure 5 shows graphs of compressive strength contour of mortar without any pozzolanic materials with the various contents and fineness of calcium carbonate. Results show that with the increase of calcium carbonate content to up to 15%, the compressive strength of mortar is further increased with the use of finer particle size of calcium carbonate. Calcium carbonate is also contributing on early strength development of mortar.



(a) (b)

Fig. 5. The Influence of Calcium Carbonate Content and Fineness on Mortar Compressive Strength (without Pozzolan): (a) 28 days, (b) 56 days

Figures 6(a) and 6(b) show the compressive strength of mortar with pozzolanic materials content (fly ash and silica fume) with various calcium carbonate contents and fineness. Reducing the fineness of calcium carbonate increases the compressive strength of mortar. At 56 days, the use of calcium carbonate up to 12% does not really alter the compressive strength of mortar, however its use introduces faster strength development at early age and slightly increases the compressive strength of mortar at later age.



(a) (b)

Fig. 6. The Influence of Calcium Carbonate Content and Fineness on Mortar Compressive Strength (with Pozzolan): (a) 28 days, (b) 56 days

4. Conclusions

It can be concluded that:

1. The increase use of fly ash up to 30%, by mass of cementitious material, increases the workability of the fresh mortar mixture and decreases the SP demand. On the contrary, the addition of silica fume up to 10% reduces the workability of the fresh mixture causing the increase in SP demand.
2. Addition of calcium carbonate content of up to 15% improves the workability of fresh mortar, both with or without any pozzolanic material content. The use of finer particle size also increase the workability.

3. Addition of calcium carbonate content of up to 15% in the mortar mixture increases the compressive strength of the mortar, especially at early age. The particle size of calcium carbonate also plays a role in increasing the compressive strength, with finer size tends to increase it more.

References

[1] H. Mohamed, Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions, *Ain Shams Engineering Journal,* 2000, *2*(2), pp. 79–86.
[2] H. Moosberg-Bustnes, B. Lagerblad, E. Forssberg, Function of fillers in concrete, *Materials and Structures*, 2004, *37*(1), pp. 74–81.
[3] T.R. Naik, F. Canpolat, Chun, Y.-M., *Limestone powder use in cement and concrete*, The University of Wisconsin. Milwaukee. 2003.
[4] H. Yazıcı, M.Y. Yardımcı, H. Yiğiter, S. Aydın, S. Türkel, Mechanical properties of reactive powder concrete containing high volumes of ground granulated blast furnace slag. Cement and Concrete Composites, 2010, 32(8), pp. 639–648.
[5] S. Allena, C. Newston, Ultra-high strength concrete mixtures using local materials. In Concrete Sustainability Conference, Dubai, 2010, pp. 1-13.
[6] D. Hardjito, Antoni, L. Chandra, T.H. Widodo, On the development of high volume volcanic mud. In The Thirteenth East Asia Pacific Conference on Structural Engineering and Construction, Sapporo, Japan, 2013, pp. 1-7.
[7] Antoni, R. Geman, R.T. Tjondro, J. Anggono, D. Hardjito, Effects of Calcination Temperature of LUSI Mud on the Compressive Strength of Geopolymer Mortar, *Advanced Materials Research*, 2013, 626(213), pp. 224-228.
[8] Antoni, V. Satrya, D. Hardjito, Simple Mechanical Beneficiation Method of Coarse Fly Ash with High LOI for Making HVFA Mortar, *Civil Engineering Dimension*, 2015, 17(1), pp. 38-43.
[9] D. Hardjito, Antoni, G.M. Wibowo· D.Christianto, Pozzolanic Activity Assessment of LUSI Mud in Semi High Volume Pozzolanic Mortar, *Materials, 2012*, 5, pp. 1654-1660.
[10] ASTM C 230, Standard specification for flow table for use in tests of hydraulic cement. *ASTM International*, 2013.