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Basic Study on Effective Utilization of Newly Volcanic Ash from Mt. Shinmoedake into Concrete

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ABSTRACT

Mt. Shinmoedake erupted on January 26th, 2011 is still active, so establishing effective utilization of volcanic ash (VA) is required. VA particle size distribution was wide from fine to coarse in the sampling site, and blending fine and coarse VA can make better distribution. VA pH-value ranged from 4.9 (acidity) to 6.0-6.7 (near neutrality). Comparing with the standard sand (SS), the ratio of flexural strengh to compressive strength of VA mortar, was 1/4.8~1/6.0 and a little larger than that of concrete. The strengths of VA mortar were larger or smaller than SS mortar, depend on the difference of VA-absorption and the flow-value and unit-weight of mortar. The difference in strength values between SS mortar using saturated surface dry sand and oven-dry sand recommends the use of the former. The basicity of tephra of Mt. Shinmoedake was 0.49-0.51 as compared to basicity values of 0.41-0.44 usually found in volcanic areas from other countries.

Keywords: Volcanic ash, Property, Fine aggregate, Effective utilization, Concrete

INTRODUCTION

Location of Volcanos in the Southern Kyusyu Island of Japan.

The country of Japan is usually called “Volcanic Island”, and many volcanos are located widely in Japan. For example, Mt. Fuji, famous of beuatihful figure with a highest altitude of

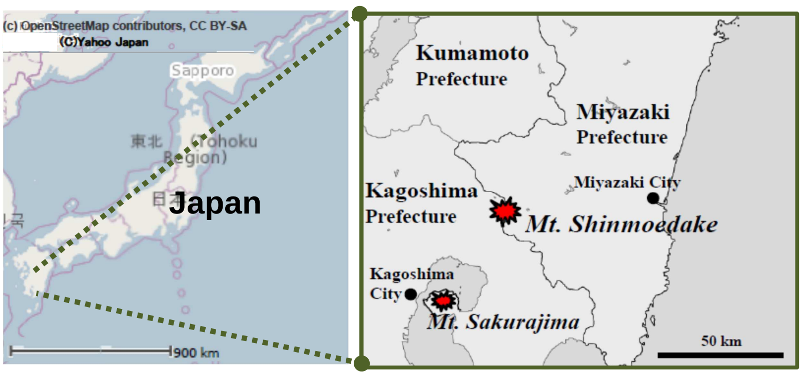


Figure 1. Location of two active volcanos in the southern Kyusyu Island of Japan

3,776 m in Japan, is one of the dormant volcanoes. Since there are many active and rested volcanos, we Japanese and many foreign visitors can spent pleasure time in many hot springs. However, the sudden volcano eruption led a large damage to the nature, industry, civic life and so on.

There are two active volcanos in the southern Kyusyu Island, as shown in Figure 1. Mt. Sakurajima (Altitude: 1,117 m) in Kagoshima Prefecture has been erupted sometimes. On the other hand, Mt. Shinmoedake (Altitude: 1,421 m) in the border of Miyazaki and Kagoshima Prefectures erupted largely in the end of January, 2011, after a half century from a former eruption. These two volcanos belong to different volcanic belts. Mt. Sakurajima is still active and sometimes smoking with tephra, whereas Mt. Shinmoedake, albeit its currently small volcanic activity, still needs to be monitored.

Distribution of Volcanic Ash (VA) of Mt. Shinmoedake and Crop Damage

Mt. Shinmoedake erupted largely on January 26th, 2011. The amount of the ejection during first 2 days of eruption was estimated at about 72 million tons (National Institute of Advanced Industrial Science and Technology (NIAI), 2011), and the falling ash (tephra, or volcanic ash: VA) caused destruction to the wild life, crops and disrupted daily life activities in all neighboring areas. Almost VA was spread to southeast depend on the wind direction when volcano's smoking on Jan. 27, 2011, as shown in Figure 2.

VA-weight per square meter were also indicated in Figure 2. VA-weight became light as the distance from the crater of Mt. Shinmoedake became far. Bigger-size volcanic rocks were found near the crater, and the damage of upland crop in Miyakonojo area located 10~30 km far from the crater was very serious because of covering by about 5 cm thickness of VA in wide agricultural area. There was no countermeasure against the VA's acidity during the first stage of growing crop. The safety of civilians' lives was also seriously threatened by VA fallout, so an immediate treatment of VA was required.

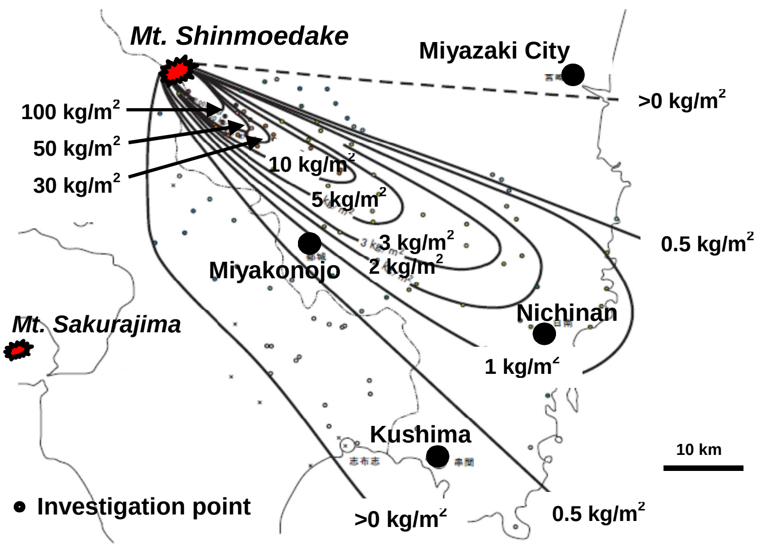


Figure 2. Distribution of tephra (VA) during Jan. 26-27, 2011

(National Institute of Advanced Industrial Science and Technology, 2011)

VA-Treatment in Miyakonojo City

Miyakonojo City as one of VA-falling areas decided immediately to accumulate VA by citizen and then to carry them to the specified disposal sites by trucks, and also other work was to cram VA into many 1 m^3-plastick bags to fix to places to prevent disaster like VA-debris-flood, as shown in Figure 3. To reduce the quantity of VA, some factories tried to make roofing tiles and bricks as one of effective utilizasion but without a scientific analysis on VA property. The volcano become small but is still active, so establishing the effective utilization of VA is required for the recovery of remaining landfill capacity and the mitigation against sediment disaster.

Figure 3. Disposal site carrying accumulated VA (left), work of craming VA into 1 m^3-plastick bags (middile), and fixing the bags on sites to prevent VA-debris-flood (right)

MATERIAL AND METHOD

Sampling and Microscope Observation of VA

VA for some tests were sampled in several VA-accumulated sites of Miyakonojo area while driving a car. The distance from the volcano to the sampling site was measured using the map of Geographical Survey Institute with 1/50,000 scale. Some information of tephra like volcanic rock and ash were gotten from the website of volcano hazards by National Institute of Advanced Industrial Science and Technology (NIAI) of Japan. The shape and grade of VA were observed by an extended substance microscope and then taken photographs with a scale.

Tests of Physical Properties and pH-value of VA

There is no test method for VA, and therefore the phisyal properties of VA were tested by the aggregate test method (Japanese Industrial Standard: JIS) as shown in Table 1. Furthermore, pH-value of VA as one chemical property was measured by the test method for pH of suspended soils (JGS 0211-200), using a glass electrode pH meter put into the water mixed VA and a clean water by the weight ratio of one to five.

Table 1. Test methods for fine aggregates

Method of test for sieve analysis of aggregates	JIS A 1102
Methods of test for density and water absorption of fine aggregates	JIS A 1109
Methods of test for bulk density of aggregates and solid content in aggregates	JIS A 1104
Method of test for amount of material passing test sieve 75 μm in aggregates	JIS A 1103

Strength Test of Mortar mixed with some VA to compare with Standard Sand (SS)

It is necessary to grasp the property of sand (fine aggregate) to use as a concrete material. To compare with the standard sand (SS), the flexural and compressive strength of mortar mixed with some VA was designed to test by the method of test for cement strength (JIS R 5201). The test piece of 40×40×160 mm size to compare sand-effects to the strength were manufactured by the old JIS without vibrating, because of no special table vibrator when testing.
The mortar mix proportion is shown in Table 2. By depending on the old JIS, the water-cement ratio was 65%, and the ratio of cement to sand was one to two in a weight. Cement with an environmental consideration was used a Portland blast-furnace cement class B with 3.04 specific gravity and 3,790 cm^2/g specific surface area by Taiheiyo Cement Corporation.
Before mixing mortar, sand of VA and SS were treated in two dry conditions, i.e. oven-dry condition and saturated surface-dry condition. SS was a supply from Japan Cement Association. Mortar for test pieces was mixed in a 5-litter mortar mixer (Hobart type) with a paddle. Concerning the mortar flow value, maximum diameter of flowed mortar and then its rectangular diameter were measured by using 30-cm vernier caliper after 15-times dropping mortar on the table, and then calculated their average. The mortar was fixed into the three-test piece-mold. After 24 hours under a wet condition, test pieces were removed and the unit weight were calculated by measuring each weight and three dimension size of test pieces in surface-dry condition after removing. The test pieces were cured for 27 days in a water of 20 centigrade degree temperature until measuring their strength.
At 28-day age, the flexual and compressive strength of mortar was measured by a universal tester (Shimadzu, Autograph-5000A, 500 kN) and a compressive tester (Enami, Amsler type, 1,000 kN), respectively.

Pozzolanic property of VA

The pozzolanic property of VA is interesting when using VA into concrete. Some papers and website reporting about the chemical analysis of valcanic ash are studied to gather the information.

Table 2. Mix proportion of mortar*, and their flow value and unit weight

Sand dry condition	Kind of sand (Mark)	W/C (%)	C : S (weight ratio)	Water W (g)	PBF (B) cement: C (g)	Sand S (g)	Flow value (mm)	Unit weight (kg/m^3)**
Oven-dry condition	Standard sand (SS)	65	1 : 2	455	700	1400	227	2056±3
	Mawatari (M)						182	1782±11
	Yamada (Y)						145	1895±5
	Kosen (K)						158	1895±4
Saturated surface-dry condition	Standard sand (SS)	65	1 : 2	455	700	1400	231	2072±6
	Mawatari (M)						224	1864±5
	Yamada (Y)						182	1910±7
	Kosen (K)						172	1910±6

* Mortar mix proportion was by the old JIS R 5201, ** Just after removing mold.

RESULTS AND DISCUSSION

Microscope Observation of VA

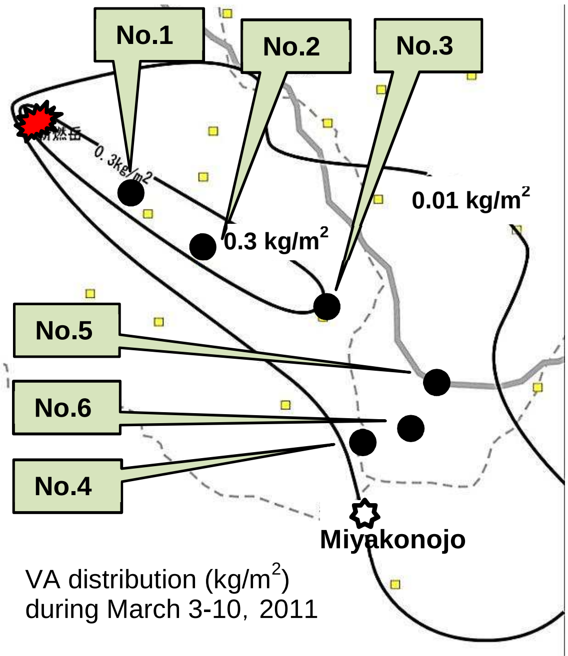
Sampled VA indicates in Table 3, showing the distance from the crater o Mt. Shinmoedake to each sampling site and conditions of VA when sampling. There was in the condition's difference, as some of VA were flushed by rain or by pressure-hose water like No.1 and No6, or were cramed into plastic bag like No.5, and the others were set as sediment. It is, however, possible to contain organic matter, small stone and so on in VA-sediment.

While observing VA of No.1~No.6 by an expanding stereo microscope, some photographs were taken. The sampling sites and photographs are shown in Figure 4. Falling ash during March 3-10, 2011, was distributed from northwest to southeast depending on the wind direction. Bigger size of tephra (VA) was found near the crater.

Table 3. Distance from the crater to sampling site and condition of VA

No.	Distance (km)	Sampling site	Condition when sampling VA
1	5.8	Miike	VA sediment on road side after flushing by rain
2	10.9	Mawatari	VA sediment gathered by people on road side
3	16.3	Yamada	VA sediment carried in the site specified by City
4	23.1	Kosen	VA sediment gathered in ground of Kosen
5	24.5	Takaki	VA bag sampled in a car park near Miyakonojo I. C.
6	25.2	Tokita	VA gathered from roof of Sumitomo Rubber Factory

No.6 was sampled on March 3, 2011, and other were on April 16, 2011.



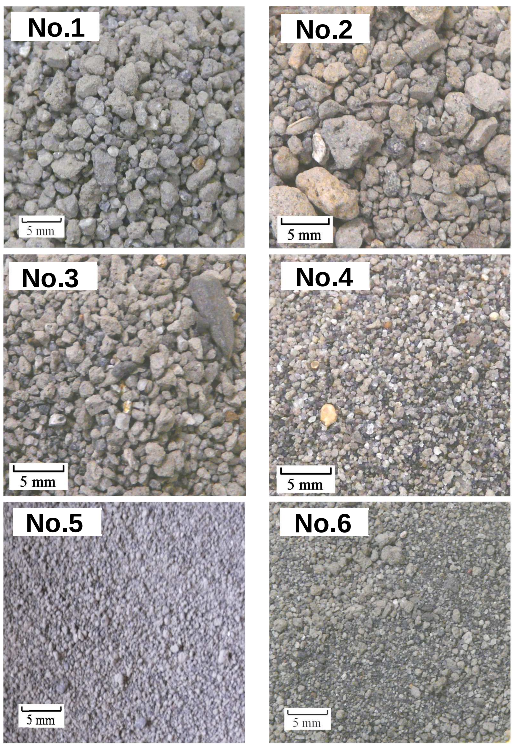


Figure 4. Sampling sites (above) and photographs (right) of tephra (VA)

Physical Properties of VA

The physical properties of VA are shown in Table 4. Fineness modulus of VA was ranged from 2.03 to 3.17. Figure 5 shows the relationship between the distance from the crater and fineness modulus, and this relationship is in a high negative correlation ($P<0.01$). The size of VA became coarse as the distance from the crater close. In Figure 6, VA of No.1 and No.2 distributed outside of the standard grade range of JIS A 5005, as being large grade (coarse), and VA of No.4~No.6 distributed almost in the standard grade range but the quantity of 0.3 and 0.6 mm grade of them was short. Thus the grade of VA ranged widely from fine to coarse.

Table 4. Physical properties and pH of VA

No.	Sampling site	Fineness modulus	Density (g/cm^3)		Absorption (%)	Unit weight (kg/ℓ)	Solid volume (%)	Materials finer than 75 μm sieve (%)	pH
			Saturated surface-dry	Oven-dry					
1	Miike	3.17	2.16	2.08	3.78	1.36	65.7	11.5	6.0
2	Mawatari	2.90	2.08	1.95	6.97	1.32	68.2	1.7	6.6
3	Yamada	2.91	2.15	2.01	6.75	1.15	57.4	1.0	4.9
4	Kosen	2.03	2.27	2.19	3.84	1.23	56.1	3.0	4.9
5	Takaki	2.10	2.32	2.21	5.07	1.27	57.6	8.1	6.7
6	Tokita	2.03	2.29	2.20	3.97	1.33	60.3	6.7	5.6

No.6 was sampled on March 3, 2011, and other were on April 16, 2011.

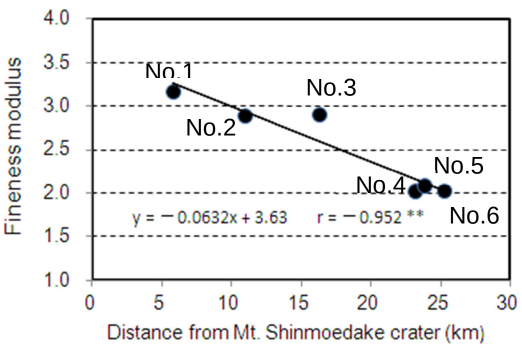


Figure 5. Relationship between distance and fineness modulus of VA

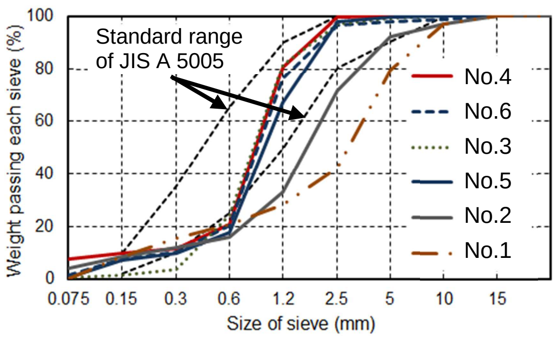


Figure 6. Sieving distributions from No.1 to No.6 of VA

Furthermore, the sieving test was carried on VA sampled in Miyakonojo neiborhood on Feb. 2011 and the test result indicates in Figure 7 (Onoue, 2011). As same above, the distribution is ranged from fine to coarse, indicating outside from the JIS standard grade range. If VA is used into concrete, it is necessary to control of the grade. In one trial, as shown in Figure 8 (Onoue, 2011), the blending with fine VA and coarse one was done in case of 2:1, 3:1, and standard range. Although this trial was to blend with fine and coarse VA, it is required not only the sand grade distribution but the quality of fine aggregate in case of using into mortar and concrete. Consequently, better quality sand is required when mixing with VA and the strength properties of the obtained mortar need to be confirmed.

pH-Value (One Chemical Property) of VA

As soon as eruption, sulfur dioxide (SO_2 gas) contains inside and in surface of tephra is rapidly changed to SO_3 gas because of reacting with oxygen (O_2 gas) in the air. So tephra including SO_2 and SO_3 gas falls on ground. On the other hand, pH-test mixing clean water is

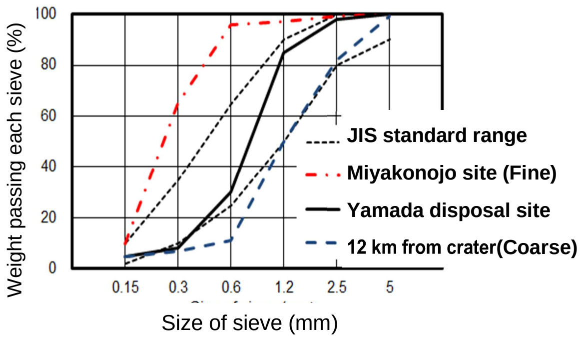


Figure 7. Sieving distributions of VA in Miyakonojo neiborhood (Onoue, 2011)

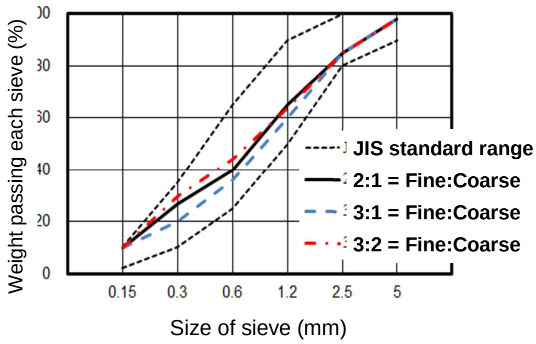


Figure 8. Sieving distributions of blended sand with fine and coarse VA(Onoue, 2011)

carried out on a VA to water ratio of 1:5 and pH-value is measured in that mixing water. There is a simple chemical reaction: $SO_3 + H_2O \rightarrow H_2SO_4$, and $SO_2 + H_2O \rightarrow H_2SO_3$, i.e. sulfuric acid. This acid indicates acidity but is easy to flush away by water like rain. Consequently damages to upland crops by VA are serious, especially in first stage of glowing when planting outside.

In the right side of Table 4, pH-value of several VA is indicated. In spite of sampling a few months later from the eruption, pH-value of two sites was both 4.9, showing high acidity, and of No.1-2 and No.5 were 6.0-6.7, close to 7.0 of the chemical neutrality. It was estimated the cause of different pH-value from the condition of VA sediment in Table 3. For example, some of VA sediment have been changed to the neutrality while flushing away by rain, or organic matter was contained in some of VA one. At present, we do not test the organic impurities in VA yet. If containing organic impurities in VA, VA should not be use into concrete depend on the quality. It is necessary to investigate the change of pH-value of VA.

Flexural and Compressive Strength of Mortar Mixed with VA and SS

Figure 9 shows the flexural and compressive strengths of mortar with SS and three VA according to the mix proportions shown in Table 2. The strength change by the mortar proportion between flexural and compressive strengths was similarly, and the flexural strength was about one fifth of the compressive one. The ratio of flexural strenghth to compressive one is generally 1/5~1/8, and in this mortar, the ratio was 1/4.8~1/6.0 and a little larger than a concrete. To compare with SS, both strengths of VA of Yamada and Kosen were strong, but VA of Mawatari was not strong in case of sand under oven-dry condition ($P<0.05$). However, in case of sand under saturated surface-dry condition, only the mortar with VA of Mawatari became smaller than the other ($P<0.05$). To compare with the sand condition of dry or wetting, the mortar using oven-dry sand was slightly stronger than using saturated surface-dry sand. In case of using sand of dry condition, during mixing cement paste with dry sand, the sand could absorb water in the paste and then W/C become smaller.

Although the absorption of Mawatari VA is 6.97% and slightly larger than Yamada VA (6.75%), the flow value and unit weight in VA mortar in Mawatari and Yamada was different, and Yamada VA mortar was smaller in flow value but heavy in unit weight. Thus larger absorption sand does not necessarily make stronger mortar. Consequently, the mortar had better mix with sand (VA) under saturated surface-dry condition when using VA.

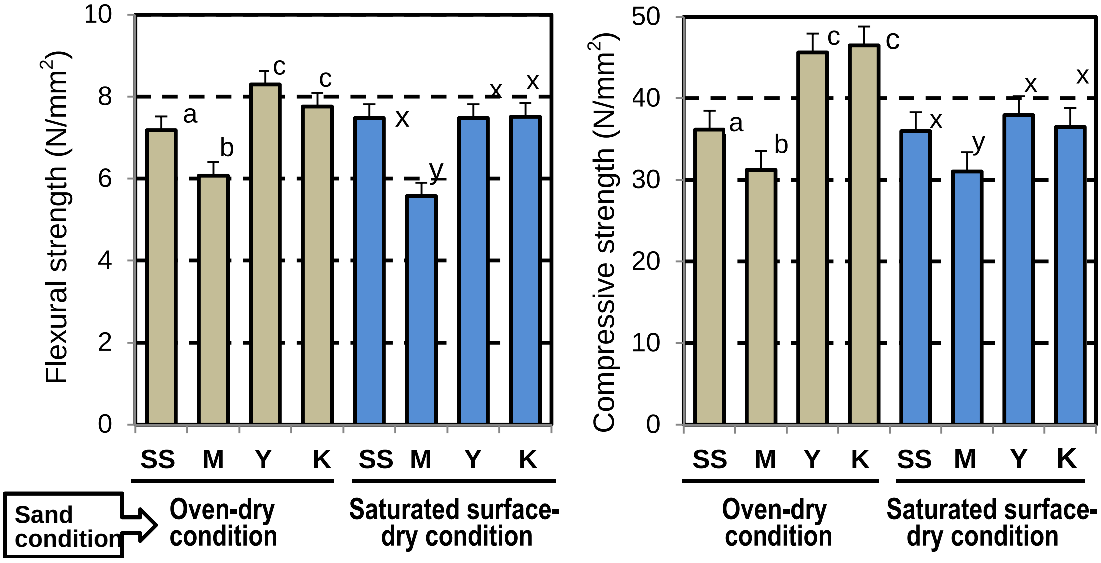


Figure 9. Flexural and compressive strengths of mortar with SS and VA

Mark: there is 5% significant difference between different characters (a~c, and x~y) in this figure.

Pozzolanic property of VA

In Ancient Roman age, volcanic ash with Pozzolanic effects was used to repair old monuments and to construct new ones. Wayman (2011) reported "The Secrets of Ancient Rome's Buildings" in the website, as volcanic ash was used to construct various buildings like the Colosseum.

Table 5 shows the chemical analysis results of tephra from the website information (NIAI, 2011) and some papers (Onoue *et al*. (2012), Ashraf *et al*. (2005), and Hossain (2003)). The chemical elements with Pozzolanic reactivity and effects are mainly SiO_2, Al_2O_3, Fe_2O_3, CaO, and MgO. These elements are contained in all tephra in Table 5, although some of the components are missing depending on the sources of VA.

Iron-blast-furnace slag is generally used to cement after milling process, and its basicity is over 1.4, being the value with better Pozzolanic reactivity. This basicity is calculated by next equation, using the content (%) of SiO_2, Al_2O_3, CaO and MgO.

$$\text{Basicity} = (CaO + Al_2O_3 + MgO) / (SiO_2)$$

In this connection, the tephra of No.1 and No.2 are same from Mt. Shinmoedake, and its basicity was 0.51 and 0.49 in order. The value of No.3 from Pakistan and No.4 from Papua New Guinea was 0.41 and 0.44 in order. These values of basicity are less than 1.4, being the value with better Pozzolanic reactivity. From these results, it is necessary to confirm the Pozzolanic effects of VA from the strength progress of mortar mixing with VA, comparing with SS.

Table 5. Chemical analysis results of the various tephra (%)

No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	tFeO	Other	Total	Note
1	57.3	17.4	—	7.9	4.1	—	—	7.3	5.4	99.4	NIAI:Tephra on Jan. 27. (2011)
2	58.9	19.4	8.5	7.7	1.7	0.8	2.3	—	0.7	100.0	Onoue *et al*. (2012)
3	60.3	23.4	0.3	1.1 (CaO+MgO)		6.6	5.0 (K_2O+NaO)		—	96.6	Ashraf *et al.* (2005)
4	59.3	17.5	7.1	6.1	2.6	—	2.0	—	4.4	99.0	Hossain K.(2003)

CONCLUSION

Mt. Shinmoedake erupted the end of January, 2011, and spreaded many tephra like volcanic ash (VA) to wide area, especially Miyakonojo City. In this paper, the characterisitic of distribution of VA around the volcano, and the physical and chemical properties of VA to use into concrete as fine aggregate were tested. The strength of mortars mixing with VA from three-sampling-sites was compared with the standard sand (SS), and the pozzolanic reactivity of VA was discussed by using a website information and some papers.
In a future, we will plan some experiments on concrete block mixed with VA for effective utilization while thinking about the volume reduction of VA sediment.

The results are summarized below;

1) Particle size distribution of VA was very wide, especially Miyakonojo area got much tephra (VA) depending on wind direction. Coarse VA with bigger size was found near the crater, but in the site far from the volcano, fine VA was found by a microscop observation.

2) The relationship between the distance from the crater and fineness modulus from a sieving test for VA is obviously in a high negative correlation ($P<0.01$). The grade of VA ranged widely from fine to coarse. Better grade distribution for fine aggregate can make to blend with fine VA and coarse VA in some ratio, as blended VA can range in the standard garde range of JIS.

3) The pH-value, one of the chemical properties of VA, was measured for several VA sampling sites. VA idicated acidity by influence of sulfur dioxide contained in or being on the surface of tephra in first stage. In spite of sampling a few months later from the eruption, one of pH-value of VA indicated 4.9 being strong acid and the other were 6.0-6.7 closing to 7.0 of the chemical neutrality.

4) Although the ratio of flexural strenghth to compressive one is generally 1/5 to 1/8 in a concrete, the ratio of the mortar mixed with VA and SS was 1/4.8~1/6.0, and a little larger than a concrete. To compare with SS, both strengths of Yamada and Kosen VA were strong, but Mawatari VA was not strong in case of sand under oven-dry condition ($P<0.05$). However, in case of sand under saturated surface-dry condition, only Mawatari-VA mortar became smaller than the other ($P<0.05$).

5) The basicity of tephra from Mt. Shinmoedake was 0.51 and 0.49. Also, tephra from Pakistan and Papua New Guinea was 0.41 and 0.44, respectively. These values of basicity are less than 1.4, being the value with better Pozzolanic reactivity.

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