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Performance of silane water repellent and flexible PCM coating applied on ASR deteriorated structures after over 20 years

Mikio Wakasugi[1*], Makoto Yamamoto[1], Hiroyuki Sakakibara[1] and Toyo Miyagawa[2**]

[1]*Sumitomo Osaka Cement Co., Ltd, Japan*
[2]*Kyoto University,Japan*
[*]*6-28, Rokubancho, Chiyoda-ku, Tokyo 102-8465 Japan,*
mwakasugi@soc.co.jp,
myamamoto@soc.co.jp, hsakakibara@soc.co.jp
[**]*Kyoto-daigaku-katsura, Nishikyo-ku, Kyoto 615-8540 Japan,*
miyagawa@sme.kuciv.kyoto-u.ac.jp

ABSTRACT

Concrete structures deteriorated due to Alkali-Silica Reaction (ASR) were repaired with silane water repellent and flexible polymer modified cementitious (PCM) coating over 20 years ago. Concrete core specimens are drilled from the structures to investigate the performance of the repair materials. Remaining depth of the silane water repellent is examined by differential thermal analysis (DTA) and water and vapor permeability are measured at the appropriate depth of silane impregnated concrete. Furthermore water and vapor permeability, adhesive strength and elongation of the flexible PCM coating are measured. Energy dispersive x-ray spectroscopy, scanning electron microscope and DTA are conducted to observe the condition of cement particles hydration and polymer film formation. As a result of the investigations, silane water repellent still maintains waterproof and vapor permeable performance after over 20 years at the impregnated depth of 2-10 mm. The flexible PCM coating which is exposed to the outdoor during over 20 years is also more waterproof and vapor permeable than initial. Adhesive strength increased to twice the initial after 5 years, and maintains the performance after over 20 years. Crack elongation performance increased after over 20 years although it decreased after 2 years. Hydration of cement particle was remarkably inhibited and the polymer film had almost no damages after over 20 years.

Keywords. Silane water repellent, flexible polymer-modified cementitious coating, repair of concrete, water permeability, vapor permeability.

INTRODUCTION

Concrete structures deteriorated due to ASR were treated with silane water repellent and flexible PCM coating over 20 years ago. This treatment is characterized by moderate waterproof, vapor permeable and crack elongation performance. We had reported the performance of this treatment after 2-3 years. Furthermore, we have investigated the performance of the treatment after over 20 years. Concrete core specimens were drilled from the concrete structures. DTA was conducted to investigate the remaining depth of the silane. Water and vapor permeability were measured at the appropriate depth of the silane impregnated concrete core. Furthermore water and vapor permeability, adhesive strength and elongation of the flexible PCM were measured. Energy dispersive x-ray spectroscopy (EDXS), scanning electron microscope (SEM) and DTA were conducted to observe the condition of cement particle hydration and polymer film formation.

EXPERIMENTAL METHOD

Investigated Structure and Repair Materials. Externals of investigated structures are shown in **Photo.1**, and elapsed years from the repair are shown in **Table1**. Silane water repellent, flexible PCM coating and topcoat were applied. Specifications of the repair materials are shown in **Table2**.

(Concrete wall) (Cement silo) (Pillar of sewage structure)

Photo1. Externals of the investigated structures

Table1. Elapsed year of the investigated structures

Structure	Date of repair	Date of inspection	Years after repair
Concrete wall	1984.09	2006.10	22.1
Cement silo	1985.08	2006.10	21.2
Pillar of sewage structure	1989.03	2008.06	19.3
	1991.03		17.3
	1992.03		16.3
	1993.03		15.3

Table2. Nature of the repair materials and specifications

Material & Specification	items	result
Silane water repellent (0.2kg/m^2, 1 time)	Principal ingredient	Alkyl alkoxy siloxane
	External	Colorless transparent liquid
	Viscosity, Density	4mPa･s, 0.8
Flexible PCM (2.3kg/m^2, 2 times)	Mix proportion	W/C=0.61, S/C=1.5, P/C=0.52
	Viscosity, Density	4000～9000mPa･s, 1.45
Top coat (0.4kg/m^2, 2 times)	Principal ingredient	Acrylic emulsion paint
	Content	40%
	Viscosity, Density	2000～5000mPa･s, 1.05

Impregnated depth of silane. It was reported that the quantitative analysis of silane was conducted by the DTA heat peak area because it burns at 300-400°C. DTA was conducted at the depth of 0, 1, 2, 5. 7, 10 and 20mm, using concrete core specimens drilled from the structures.

Water permeability. Water permeability was measured by using the above- mentioned concrete core specimens. It was measured to evaluate the waterproof property of flexible PCM and silane impregnated concrete according to the Rohto method of Japanese Industrial Standard (JIS) A 6909. We used 7 kinds of specimens as shown in **Fig.2**.

Vapor permeability. Vapor permeability was measured by using the above- mentioned concrete core specimens. It was measured to evaluate the vapor permeability of flexible PCM and silane impregnated concrete according to the Aluminum cup method of Japan Society of Civil Engineers (JSCE)-K522. We used 4 kinds of specimens as shown in **Fig.3**.

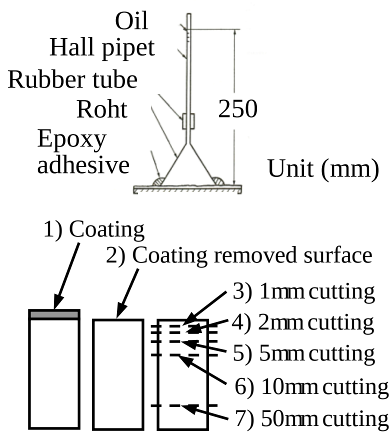


Figure 2. Specimens for water permeability test

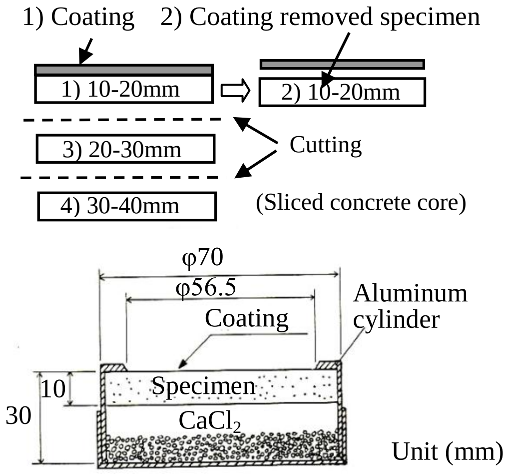


Figure 3. Specimens for vapor permeability test

Adhesive strength of flexible PCM. Adhesive strength of flexible PCM coating was measured by the simple tensile strength test device for incised area of 40×40mm according to "Test method of adhesive strengthof surface coating" of JSCE-K531.

Crack elongation of flexible PCM. Crack elongation of the flexible PCM coating was evaluated by using concrete cores. Specimens of 20mm in thickness were cut from the concrete cores. After making a cutting to the opposite side of the coating surface, two steel plates were bonded as shown in **Fig.4**. Crack elongation was measured by tensile strength test equipment at a speed of 0.1mm/s.

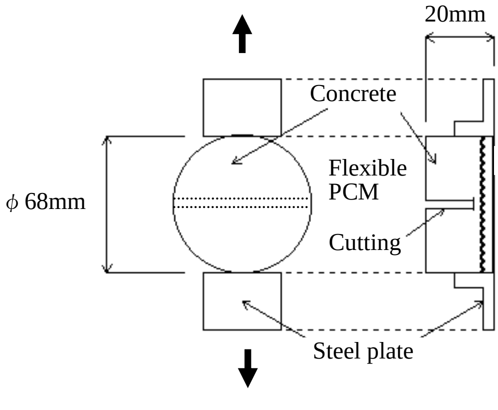
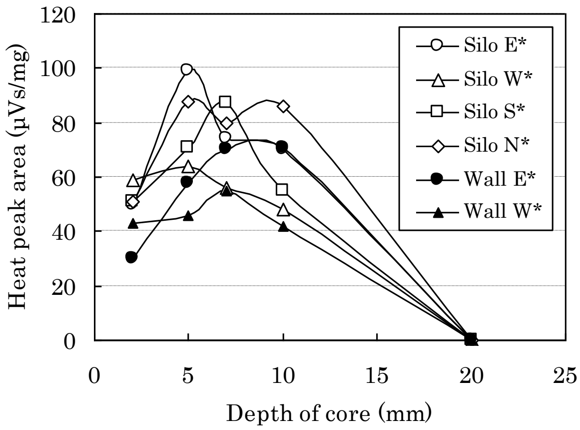


Figure 4. Specimen for crack elongation test

Instrumental analysis on flexible PCM. SEM, TG/DTA and ESXA were conducted to observe the condition of cement particles hydration and polymer film formation.

RESULT AND DISCUSSION

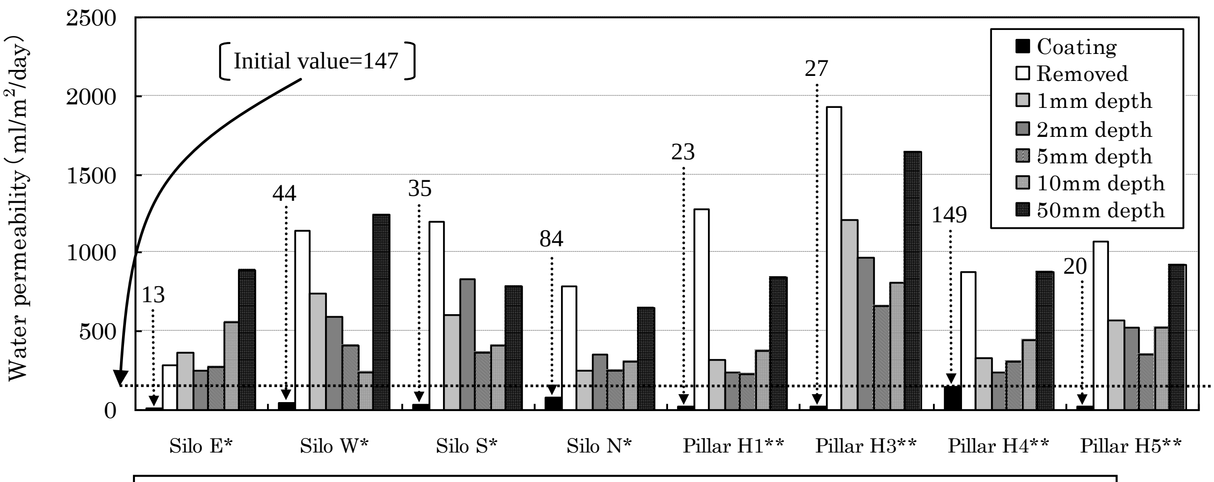
Impregnation depth of Silane water repellent. It is reported that the heat peak of silane appears in about 340°C. On the other hand, the main heat peak of polymers containing in the flexible PCM appears in 390°C, the secondary peak in 240°C. We canceled these data of surface and 1mm in depth, because we thought the possibility of mixing the heat peak of silane and polymer. The relation between the depth of the core and the heat peak area of silane single burning is shown in **Fig.5**. Because it became the maximum about 5mm in depth, the heat peak was detected within the range up to 10mm in depth, and the heat peak had not been detected in 20mm in depth, it was at least confirmed that silane is able to exist in 10mm in depth. It was also reported that the silane impregnationdepth was about 2-3mm. When the time was passed for years, it was confirmed to impregnate up to 5-10mm depth after over 20 years.



Notes * E:east, W:west, S:south, N:north
Each surface of cement silo or concrete wall

Figure 5. DTA result of the concrete cores

Water permeability. The test result of water permeability of the flexible PCM and each depth of the concrete core impregnated by silane is shown in **Fig.6**. Initial water permeability was 147 ml/m^2/day, and it was confirmed to improve 1/3 or less than initial after over 20 years, except for the results of Silo N and Pillar H4. It is thought that the flexible PCM became strong for years along with the hydration of cement particle. The effect of silane shows the most excellent waterproof



Note ** H:Heisei H1=1989, H3=1991, H4=1992, H5=1993 respectively

Figure 6. Water permeability of concrete core

property in the depth of about 5mm. It is thought that the effect remains in the depth of 2-10mm although it has disappeared on the surface of concrete as reported in the past.

Vapor permeability. The test result of vapor permeability of the flexible PCM and each depth of the concrete core impregnated by silane is shown in **Fig.7**. Initial vapor permeability was 72g/m^2/day, and it was confirmed that it maintains equal or more than initial performance after the longtime of about 20 years,

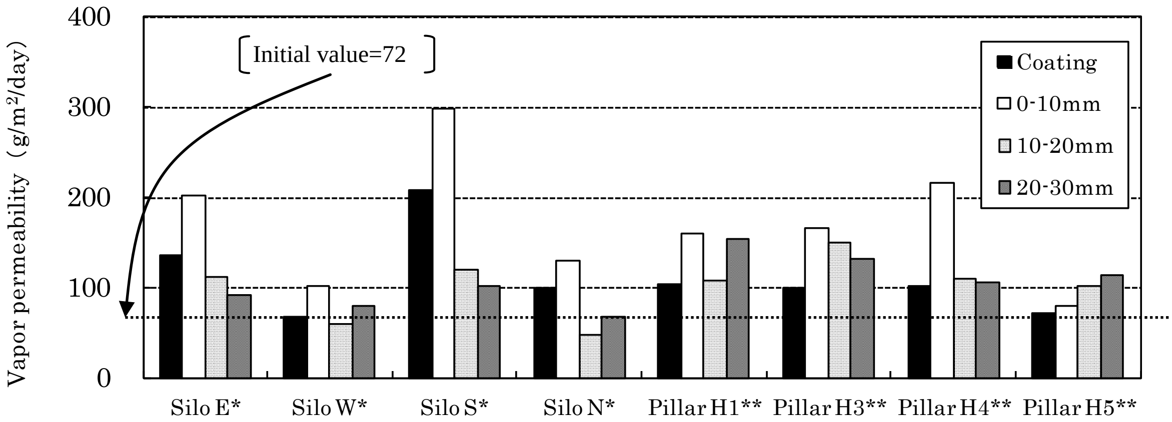


Figure 7. Vapor permeability of concrete core

Adhesive strength of flexible PCM. Adhesive strength test results until about 5years, in addition to the test result after about 20years are shown in **Fig.8**. Adhesive strength is thought to be almost tensile strength of flexible PCM because demolition occurs in flexible PCM itself. Adhesive strength increased with elapsed years, it became about twice the initial performance of 0.4N/mm2 after 4-5 years. It is thought that this is because tensile strength of flexible PCM increased along with the hydration of cement. On the other hand, it showed only a slight increase when it was under an oceanic environment such as piers (Beam of pier) the strength appearance of the polymer film is delayed under the moist environment. It was confirmed that adhesive strength of flexible PCM maintained the high performance of 0.8-1N/mm^2 after over 20years.

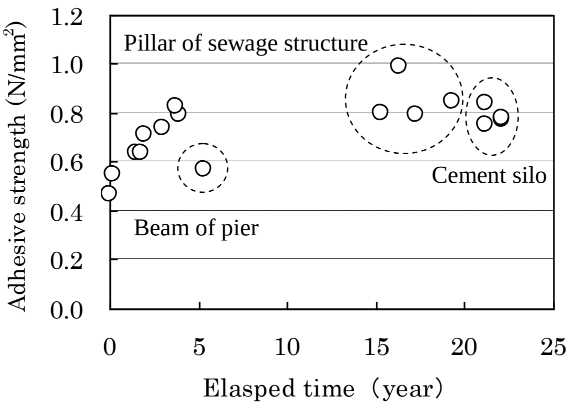


Figure8. Adhesive strength of flexible PCM

Crack elongation of flexible PCM. Crack elongation test results until 2-3 years, in addition to the test result after about 20 years are shown in **Fig.9**. Crack elongation of flexible PCM showed a decreasing tendency for early 2 years. Flexibility of the PCM was thought to be lost along with the hydration of the cement particle. However, an increasing tendency was shown after about 20 years. This situation was not able to be explained by the hydration of cement particle, we will describe this reason later. Moreover, the result of sunshine carbon arc promotion test for 1500 hours is shown in **Fig.10**. The result showed the same decreasing tendency as outdoor exposure for 2 years. In addition, crack resistance under indoor environment (Pillar of sewage structure) showed more excellent than that of outdoor exposure.

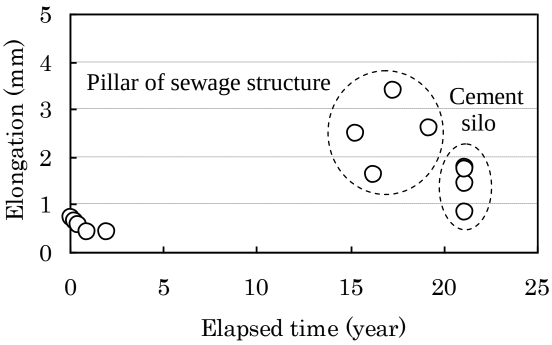


Figure 9. Crack elongation of flexible PCM

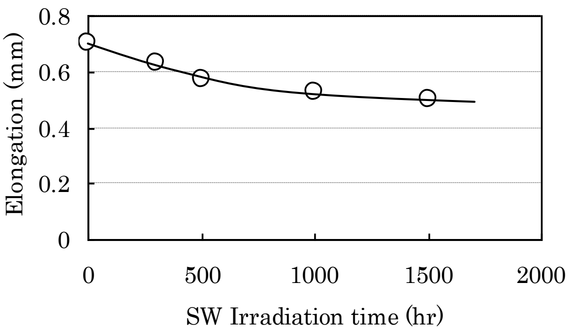


Figure 10. Crack elongation of flexible PCM after sunshine carbon arc promotion test

SEM observation of flexible PCM. SEM observation result of flexible PCM is shown in **Fig.11**. There were no damages in the polymer film after over 20 years, and excellent durability was confirmed.

TG/DTA analysis on flexible PCM. Crack elongation of flexible PCM showed an increasing tendency after about 20years, although it decreased after about 2 years. DTA on polymer film itself with and without cement particle were conducted to consider the mechanism. The result of this comparison test and the cement silo east side are shown in **Fig.12**. Secondary heat peak at 240°C is shown only in the polymer film with cement particle and the peak area showed an increasing tendency after about 20 years.

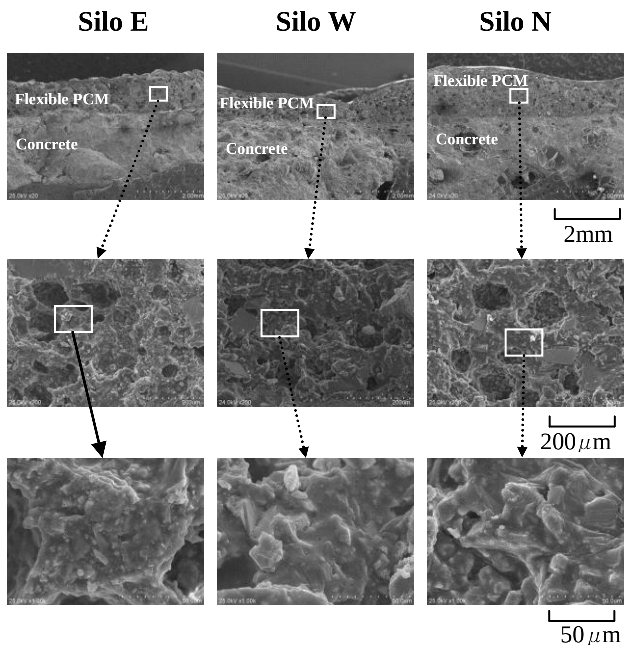


Figure11. Microstructure of flexible PCM observed by SEM

Main heat peak at over 300°C occurred because of decomposition of soft component of polymer film, secondaryheat at 240°C occurred because of hydrolysis of side carbon chain of soft component of polymer film. Elongation of flexible PCM decreased until early 2 years because the hardening with the hydration of cement particle is a dominant factor. However it increased after about 20 years because elongation of polymer film itself increased due to interaction between the polymer film formation and cement particle hydration.

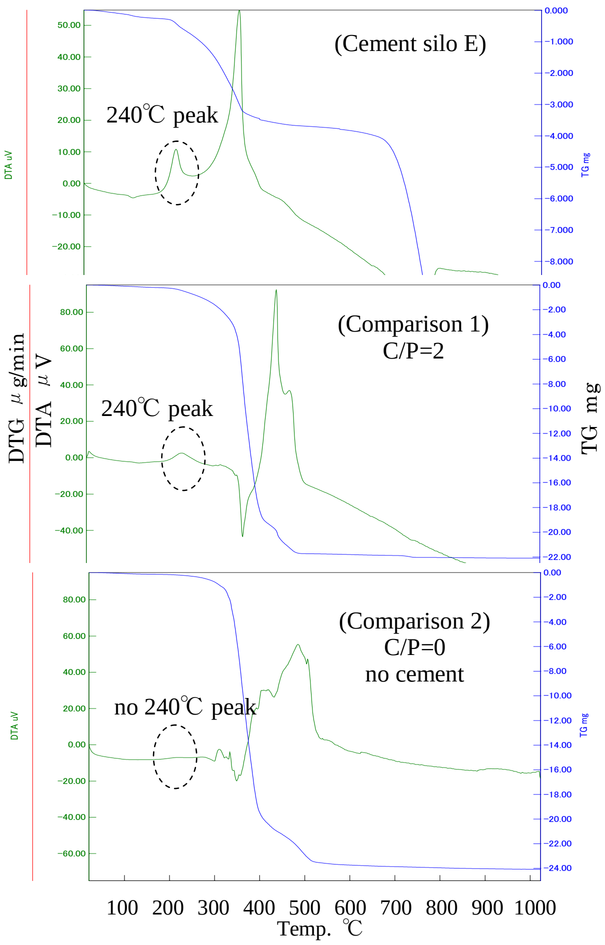


Figure 12. TG−DTA result of flexible PCM

EDXS analysis on flexible PCM. The result of the cement silo west side is shown in **Table3** and **Fig.13** as an example of the EDXS analysis result of flexible PCM. It was confirmed that unhydrated belite (C_2S) and flux phase (alminate and alminoferrite) definitely existed within the cement particle after about 20 years. Alite, belite, alminate and alminoferrite in a normal cement particle showed about 90% hydration after half a year. It is estimated that the hydration of cement particle is extremely inhibited because it is surrounded by the polymer film.
It is confirmed that silane water repellent exists at the depth of 2-10mm from concrete surface, it also maintains waterproof property and vapor permeability, and those performances are equal to or more than an initial after about 20 years. Adhesive strength of flexible PCM coating increased to twice of the initial after 5 years, and maintains same performance after about 20 years. Moreover, the crack elongation performance of flexible PCM coating increased after 20 years although it decreased at short years until 2 years. We estimate that it is because of the interaction of cement hydration and polymer film formation. In addition, hydration of the cement particle was remarkably inhibited, and the polymer film had almost no damage after over 20 years.

CONCLUSION

It is confirmed that silane water repellent exists at the depth of 2-10mm from concrete surface, it also maintains waterproof property and vapor permeability, and those performances are equal to or more than an initial after about 20 years. Adhesive strength of flexible PCM coating increased to twice of the initial after 5 years, and maintains same performance after about 20 years. Moreover, the crack elongation performance of flexible PCM coating increased after 20 years although it decreased at short years until 2 years. We estimate that it is because of the interaction of cement hydration and polymer film formation. In addition, hydration of the cement particle was remarkably inhibited, and the polymer film had almost no damage after over 20 years.

Table3. EDXS result of flexible PCM

Items		Spectrum 1	Spectrum 2	Spectrum 3
Elemental analysis (%)	Na_2O	1.02	0.00	1.41
	MgO	0.00	2.22	0.70
	Al_2O_3	1.37	13.16	2.97
	SiO_2	33.07	4.16	77.31
	K_2O	1.03	0.00	2.06
	CaO	61.84	47.38	9.19
	MnO	0.00	1.51	0.00
	Fe_2O_3	1.67	31.56	3.95
CaO/SiO_2		2.00	12.20	0.13
CaO/Al_2O_3		82.07	6.55	5.63
$CaO / (Al_2O_3 + Fe_2O_3)$		46.15	2.59	3.04
Estimated substance		C_2S	Flux phase	Hydrated cement

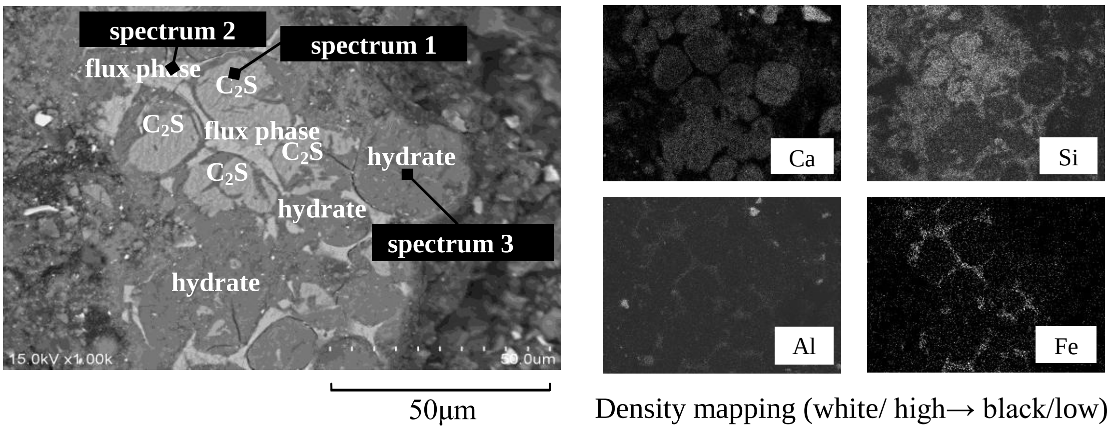


Figure 13. EDXS result of flexible PCM

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