PROPERTIES OF AIR MORTAR USING RECYCLED ROOF TILES

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ABSTRACT：It is necessary to be crushed and downsized to recycle the used roof tiles. The crushed roof tiles are including a large quantity of powders. This is called “the recycled roof tiles fine aggregate”. Characteristics of the crushed roof tiles are lightweight and porous structure. The ultimate aim of this study is the Application development of air mortar using the recycled roof tiles fine aggregate. In addition, it is the zero-emission of the used roof tiles. For the application of the tiled air mortar, cured physical properties were ascertained assuming “coating material” such as sand-scattering prevention which does not require high strength. In this study, we clarify the relationship between the void ratio and various strengths and further clarify the relation with the water permeability.

From experiments, when the sand cement ratio is small and the water cement ratio is large, air mortal is difficult to constrain foaming. Compressive strength of the air-mortal using the recycled roof tiles fine aggregate can be estimated from void ratio. Furthermore, the static elastic modulus, bending strength, tensile strength can be estimated from compressive strength. When the air quantity of the air-mortar is about 40 %, it has high water permeability. The recommended mixing proportion of the air mortar is that the sand cement ratio is 2.5, the water cement ratio is 40 % and the target air quantity is 40 %.

KEY WORDS：Recycled roof tiles, Fine aggregate, Air mortar, Void percentage, Compressive strength, Industrial by-product

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and various strength tests, modulus of elasticity tests, and hydraulic conductivity tests were conducted.

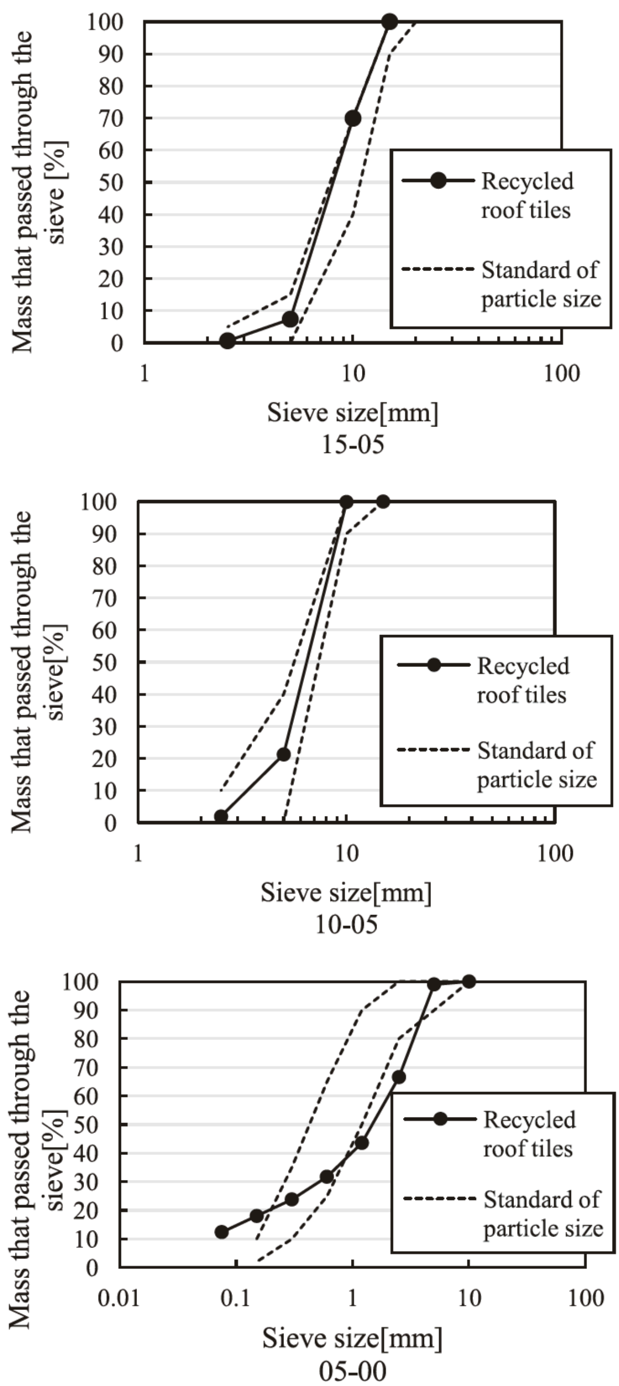

Fig. 1 Grading curve of crushed roof tiles

Table 1 Used materials for this study

Materials	Type	Symbol	Physical property of materials
Cement	Normal portland cement	C	Density : 3.16g/cm^3
Fine aggregate	Recycled roof tiles	T	Saturated surface-dry density : 2.21g/cm^3, Maximum dry density : 1.99g/cm^3, Absorption : 11.24 %, F.M. : 3.17, Solid content : 77.9 %, ACV : 22.52 %
	Crushed sand	S	Saturated surface-dry density : 2.68g/cm^3, Maximum dry density : 2.65g/cm^3, Absorption : 1.22 %, F.M. : 2.74, ACV : 2.86 %
Chemical admixture	High performance AE water reducing agent	SP	Polycarboxylic acid type, Non-air entrained type
	Foaming agent	Fa	Alkyl allyl sulfonate type

1. Introduction

It is estimated that about 1.5 million tons of used roofing tiles are generated annually as a result of house demolition, etc., and currently about 90% of these are disposed of as landfill. In order to recycle used roofing tiles generated in various parts of Japan, it is necessary to crush them into small pieces, sieve them to adjust the particle size, and grind them to the size of concrete aggregate, for example, according to their intended use. Fig. 1 shows the particle size curve of recycled resources (hereinafter referred to as "roof tile aggregate") made by crushing and grading used roof tiles according to the intended use. The dashed line in the figure is the "standard grain size of aggregate" in the Construction Edition of the Standard Specification of the Japan Society of Civil Engineers (JSCE). 15-5 mm and 10-5 mm equivalent tile aggregates fall within the standard grain size range, while 5-0 mm equivalent fine aggregate (hereinafter referred to as tile chips) is mostly above 1.2 mm and below 0.15 mm. With the goal of zero emissions of used roof tiles, this laboratory has focused on the lightweight and porous structure of tile chips and has been conducting research on air-mortar as a rational use destination in the state of high powder content at the time of discharge. In addition to methods for controlling fresh properties, this laboratory has developed an air-mortar using tile chips as fine aggregate We have shown that air-mixed mortar using tile chips as fine aggregate (hereinafter referred to as "tile air-mixed mortar") has high permeability1) , in addition to the control of fresh properties.

In this study, we first investigated the properties of the mortar from the viewpoint of property control in order to expand the applications of tile chips and tile air-mixed mortar. The application of tile air-mixed mortar was assumed to be "covering materials" such as for preventing flying sand, which does not require high strength. Since the compressive strength of air-mixed mortars is affected by the air content and sand-cement ratio in addition to the water-cement ratio, we set up formulations based on these parameters and discussed the effects of each on the compressive strength. Next, a formulation applicable to the coating material was selected,

2. compressive strength

2.1 Summary of Experiments

First, compressive strength tests were conducted at different air volumes from ordinary mortar to air mortar in order to determine the factors that affect the compressive strength of tile air-mixed mortar and the degree of influence of these factors. Ordinary Portland cement was used as cement, and tile chips were used as fine aggregate. ACV in the table indicates "crushed value" according to BS 812 Testing aggregates Part 110 (Methods for determination of aggregate cushy value: ACV) of the British Standards. The crushing test is performed on coarse aggregate.

The crushed sand in Table 1 was used in the tests described below. The table shows that the water absorption of tile chips is about 10 times higher than that of crushed sand. A high-performance AE reducer was used to control flowability (flow value), and a foaming agent was used to control air volume. First, in order to understand the relationship between compressive strength and air content, 54 formulations were used: three levels with sand-cement ratios of 2.0, 2.5, and 3.0; three levels with water-cement ratios of 30%, 40%, and 50%; and six levels with air content of 0%, 10%, 20%, 30%, 40%, and 50%.

Table 2 shows the formulation table. The amount of foaming agent added was determined based on an approximate curve obtained from preliminary experiments. The flow value of the fresh mortar was uniformly set at 180 ± 20 mm, and the target air volume was set within an allowable range of ± 5%, but data beyond the allowable range were also used from the standpoint of understanding the relationship between compressive strength and air volume.

Air-mixed mortar was mixed by the mix-home method (in accordance with the usual JIS), and fresh tests were conducted in accordance with the NEXCO test method "Test Methods for Air-mixed Mortar and Air-mixed Milk: JHSA313", and air volume and flow tests were conducted. Furthermore, the air volume for each specimen was calculated individually from the mass of the specimen at the time of casting.

Table 2 Unit weight

Combination	Sand cement ratio (S/C) [-]	Water cement ratio (W/C) [%]	Air content [%]	Unit weight [kg/m^3] Water W	Cement C	Roof tiles T	SP C×[%]	Fa C×[%]
2.0-30-0	2.0	30	0	197	657	1315	1.75	0
2.0-30-10	2.0	30	10	177	592	1183	1.75	0.05
2.0-30-20	2.0	30	20	158	526	1052	1.75	0.1
2.0-30-30	2.0	30	30	138	460	920	3.5	0.2
2.0-30-40	2.0	30	40	118	394	789	3.5	0.5
2.0-30-50	2.0	30	50	99	329	657	3.7	1
2.0-40-0	2.0	40	0	247	617	1233	0.5	0
2.0-40-10	2.0	40	10	222	555	1110	0.5	0.01
2.0-40-20	2.0	40	20	197	493	987	0.5	0.03
2.0-40-30	2.0	40	30	173	432	863	0.8	0.16
2.0-40-40	2.0	40	40	148	370	740	0.8	0.4
2.0-40-50	2.0	40	50	123	308	617	0.6	1.2
2.0-50-0	2.0	50	0	290	581	1162	0.1	0
2.0-50-10	2.0	50	10	261	523	1046	0.09	0.01
2.0-50-20	2.0	50	20	232	465	929	0.11	0.1
2.0-50-30	2.0	50	30	203	407	813	0.3	0.5
2.0-50-40	2.0	50	40	174	349	697	0.3	0.8
2.0-50-50	2.0	50	50	145	290	581	0.4	1.2
2.5-30-0	2.5	30	0	172	572	1430	4.5	0
2.5-30-10	2.5	30	10	154	515	1287	4.25	0.2
2.5-30-20	2.5	30	20	137	458	1144	5	0.27
2.5-30-30	2.5	30	30	120	401	1001	5	0.3
2.5-30-40	2.5	30	40	103	343	858	4	0.5
2.5-30-50	2.5	30	50	86	286	715	4	1
2.5-40-0	2.5	40	0	216	541	1353	0.8	0
2.5-40-10	2.5	40	10	195	487	1218	0.8	0.01
2.5-40-20	2.5	40	20	173	433	1082	0.8	0.04
2.5-40-30	2.5	40	30	152	379	947	1.4	0.2
2.5-40-40	2.5	40	40	130	325	812	1.2	0.5
2.5-40-50	2.5	40	50	108	271	677	1.5	1.5
2.5-50-0	2.5	50	0	257	513	1284	0.5	0
2.5-50-10	2.5	50	10	231	462	1155	0.5	0.01
2.5-50-20	2.5	50	20	205	411	1027	0.8	0.1
2.5-50-30	2.5	50	30	180	359	899	0.8	0.5
2.5-50-40	2.5	50	40	154	308	770	0.6	1
2.5-50-50	2.5	50	50	128	257	642	0.6	1.5
3.0-30-0	3.0	30	0	152	507	1520	5	0
3.0-30-10	3.0	30	10	137	456	1368	5	0.1
3.0-30-20	3.0	30	20	122	405	1216	5	0.24
3.0-30-30	3.0	30	30	106	355	1064	5	0.3
3.0-30-40	3.0	30	40	91	304	912	5	0.8
3.0-30-50	3.0	30	50	76	253	760	5	1.5
3.0-40-0	3.0	40	0	193	482	1447	1.2	0
3.0-40-10	3.0	40	10	174	434	1302	1.5	0.01
3.0-40-20	3.0	40	20	154	386	1157	1.5	0.1
3.0-40-30	3.0	40	30	135	338	1013	1.8	0.15
3.0-40-40	3.0	40	40	116	289	868	1.8	0.5
3.0-40-50	3.0	40	50	96	241	723	2	1.2
3.0-50-0	3.0	50	0	230	460	1380	0.6	0
3.0-50-10	3.0	50	10	207	414	1242	0.8	0.003
3.0-50-20	3.0	50	20	184	368	1104	0.7	0.025
3.0-50-30	3.0	50	30	161	322	966	0.7	0.1
3.0-50-40	3.0	50	40	138	276	828	1.2	1
3.0-50-50	3.0	50	50	115	230	690	1.1	1.5

＊T is saturated.

＊The amounts of SP and Fa were determined one by one while mixing.

Compressive strength tests were conducted in accordance with "JIS A 1108 Test Method for Compressive Strength of Concrete. Three cylindrical specimens of 50 x 100 mm dia. each were prepared, sealed with vinyl to prevent moisture from escaping, and hermetically cured for 28 days at 20 ± 2.5°C, 60 ± 20%. Demolding was performed the day before the prescribed compressive strength test.

2.2 Test Results and Discussion

Fig. 2 shows the relationship between pore ratio and compressive strength for each sand-cement ratio. The pore ratio is the value obtained by dividing the "volume of pore: cm3" by the "volume of solid phase: cm3." The pore ratio is 0.00 and 1.00 when the air content is 0 and 50%.It can be seen that some formulations cannot meet the target air content depending on the formulation conditions.In particular, when the sand-cement ratio is small and the water-cement ratio is large, it is difficult to constrain foaming.Focusing on the sand-cement ratio, in general, the larger the sand-cement ratio, the lower the unit cement paste volume and the lower the strength, with similar results.In addition, with the formulation used in this study, the strength difference due to the difference in water-cement ratio became smaller as the sand-cement ratio increased.Comparing the effect of water-cement ratio for the same sand-cement ratio formulation, the water-cement difference became even smaller as the air content increased.This result indicates that the effect on the strength of the tile-air mortar is also not the water-cement ratio, but the air content.In tile-air mortars, where the aggregate itself is porous, the water in the pores inside the aggregate is considered to be used for the hydration reaction.From the results of this test, it is considered that as the sand-cement ratio increases, the effect of the voids in the tile chips also becomes more pronounced, resulting in a smaller strength difference due to the difference in water-cement ratios.The compressive strength of tile air-mortar with a pore ratio of 0.70 (approximately 42% air content) or higher showed little difference depending on the water-cement ratio.In other words, the effect of air content was found to be significant. The results of compressive strength tests showed that the compressive strength of all formulations exceeded 1 N/mm2 .Since the application of the coating material does not require structural strength, 1 N/mm2 was judged to be sufficient.It was found that there is an exponential relationship between pore ratio and compressive strength, and that compressive strength can be estimated from the pore ratio.

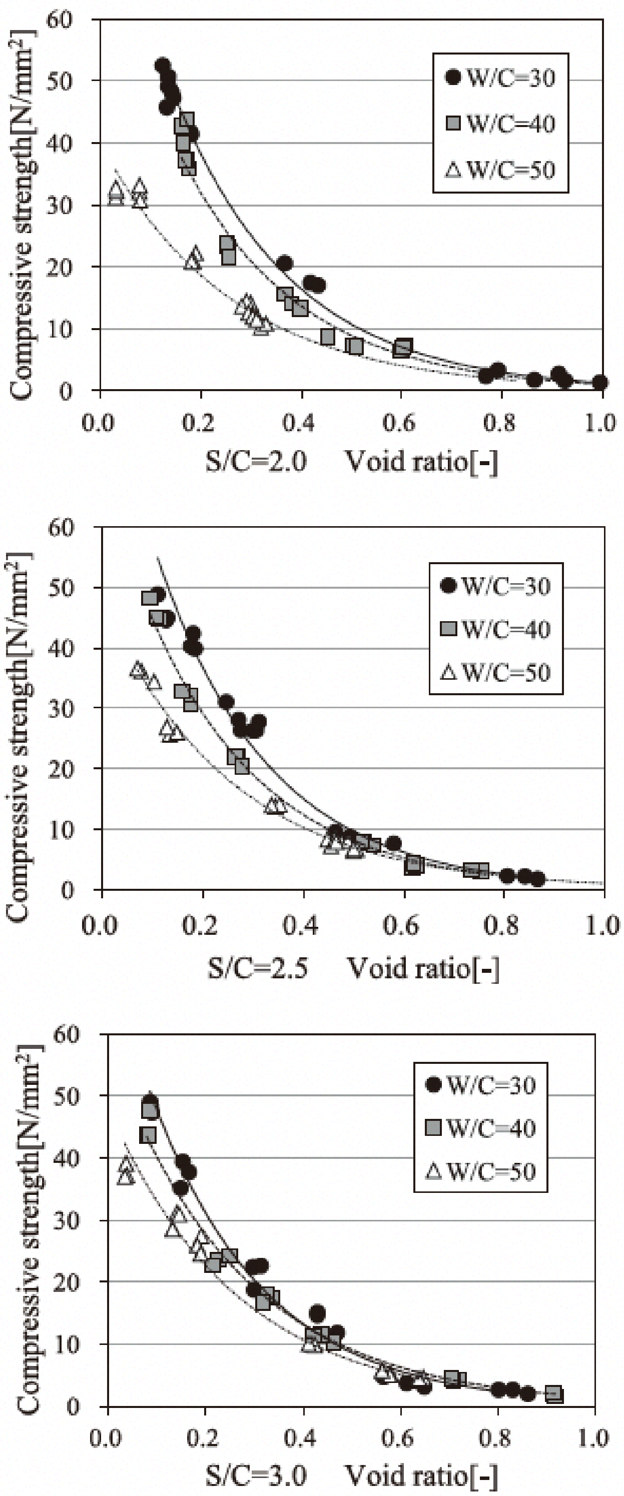

Fig. 2 Relationship between Void ratio and Compressive strength

Table 3 Unit weight

Combination	Sand cement ratio (S/C) [-]	Water cement ratio (W/C) [%]	Air content [%]	Unit weight [kg/m³]			
				Water W	Cement C	Roof tiles T	Sand S
T-2.5-40-0	2.5	40	0	216	541	1353	0
T-2.5-40-20			20	173	433	1082	0
T-2.5-40-40			40	130	325	812	0
S-2.5-40-0	2.5	40	0	243	606	0	1516
S-2.5-40-20			20	194	485	0	1213
S-2.5-40-40			40	146	364	0	909

3. Static Modulus of Elasticity, Curing Conditions and Strength Development

3.1 Summary of Experiment

Static modulus of elasticity tests were conducted to determine the deformation performance after curing, as well as to determine the onset of strength development at different ages and under different curing conditions.

Table 3 shows the mixing table. The air content was chosen to be 40% based on the permeable pavement standard (previously reported1), because an air content exceeding 40% satisfies the minimum permeability of 0.01 cm/s for permeable pavements. In addition, the sand-cement and water-cement ratios, which play a role in strength, were set at 2.5 for the sand-cement ratio and 40% for the water-cement ratio, considering that low strength is sufficient for use as an anti-scattering coating material and that increased air content will reduce strength. For comparison, we prepared specimens with 0% air, 20% air, and crushed sand (hereinafter referred to as "crushed sand air mortar") in the same formulation. The specimens were prepared as in the compressive strength test, and were sealed and cured in water. Static modulus of elasticity and compressive strength tests were conducted at 7, 28, and 91 days of age (only the compressive strength test was conducted for the underwater cured specimens).

3.2 Test Results and Discussion

Fig. 3 shows the relationship between compressive strength and static modulus of elasticity. The slope of the approximate straight line for the tile air-mortar is slightly smaller than that for the crushed sand air-mortar, but the values are almost the same. There is a proportional relationship between compressive strength and the modulus of static elasticity, and the modulus of static elasticity can be estimated from the compressive strength.

Fig. 4 shows the relationship between compressive strength and the age of the specimens for each target air content.

The average air content of the actual specimens was 8.5%, 19.9%, and 37% for tile mortar, and

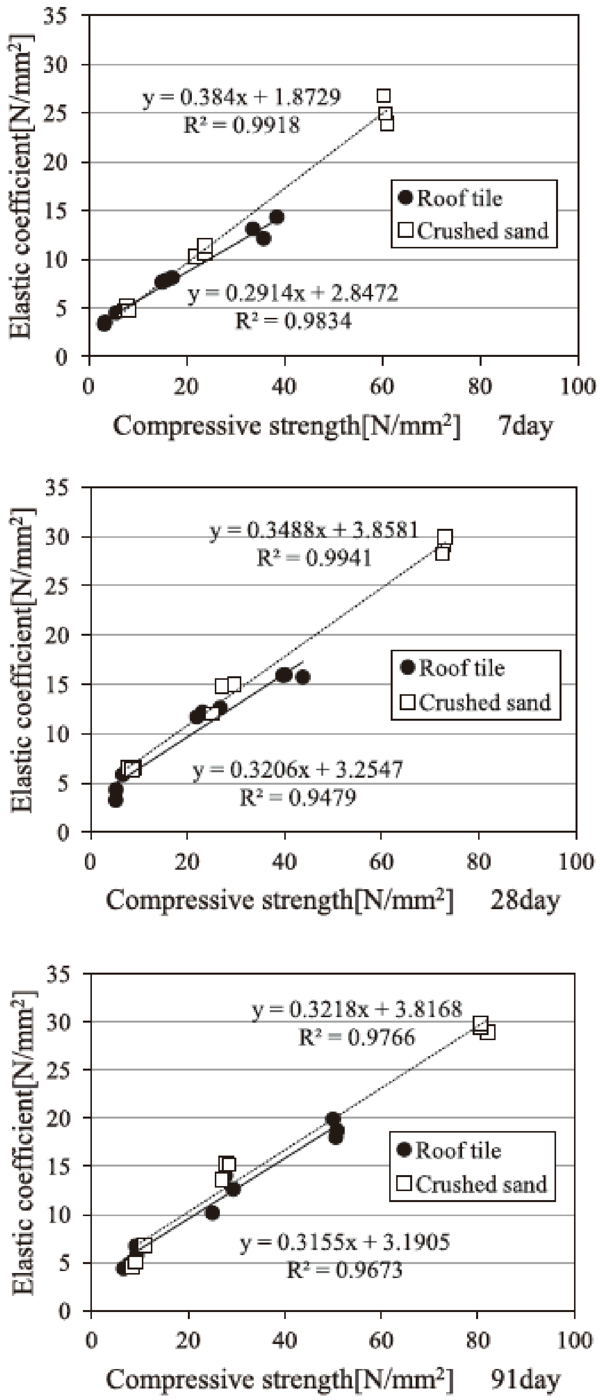

Fig. 3 Relationship between Compressive strength and Elastic coefficient

2.6%, 22.8%, and 38% for crushed sand mortar, compared to the target air content of 0%, 20%, and 40%.

It was difficult to keep the air content low in the mortar with tile chips, and the results showed that the air was easily entrained. The figure shows that the strength development of the tile air mortars with target air content of 20 % and 40 %, which had similar air content, showed that the compressive strength asymptotically approached that of the crushed sand air mortar as the age of the material increased in the sealed curing process. However, the results were not similar when the air content was 0 %, since the air content of the crushed sand air-mixed mortar specimens was 2.6 %, while that of the tile air-mixed mortar specimens was 8.5 %, indicating that the effect of air content on strength was significant. By the way, the specimens with higher air content showed more strength loss than the crushed sand air-mixed mortar under under underwater curing at 91 days of age. This is due to the fact that the unit paste volume of the tile air-mortar was smaller and the voids were larger, and in addition, the voids were filled with water again after the hydration reaction progressed under under submerged curing, which may have led to crack initiation and propagation even at low stress2). In addition, the higher air content resulted in smaller differences among the materials.

4. permeability

Although it is realistic to apply tile air-mixed mortar as a shatterproof covering, it is desirable that rainwater and other substances permeate into the underlying layer without accumulating on the surface. Therefore, permeability tests were conducted using the formulations shown in Table 4, with a target air content of 40% to meet the lower limit of 0.01 cm/s of permeability, based on the standards for permeable pavements. In order to compare the effects of differences in fine aggregate, the unit fine aggregate content was determined so that the unit water content and unit cement content were the same. Thus, the sand-cement ratio was 2.5 for the tile air-mixed mortar and approximately 3.0 for the crushed sand air-mixed mortar. Permeability tests were conducted in accordance with the "Draft Permeability Test Method for Porous Concrete (JCI-SPO3-1).

Fig. 5 shows the relationship between air content and hydraulic conductivity. The permeability was larger for the crushed sand air-mixed mortar, which is opposite to the result of Kuroki et al.'s study1) . However, the coefficient of determination was 0.9779 when the regression line was obtained by combining the data of tile air-mixed mortar and crushed sand air-mixed mortar from Fig. 5. The permeability of the tile air-mixed mortar with 43%

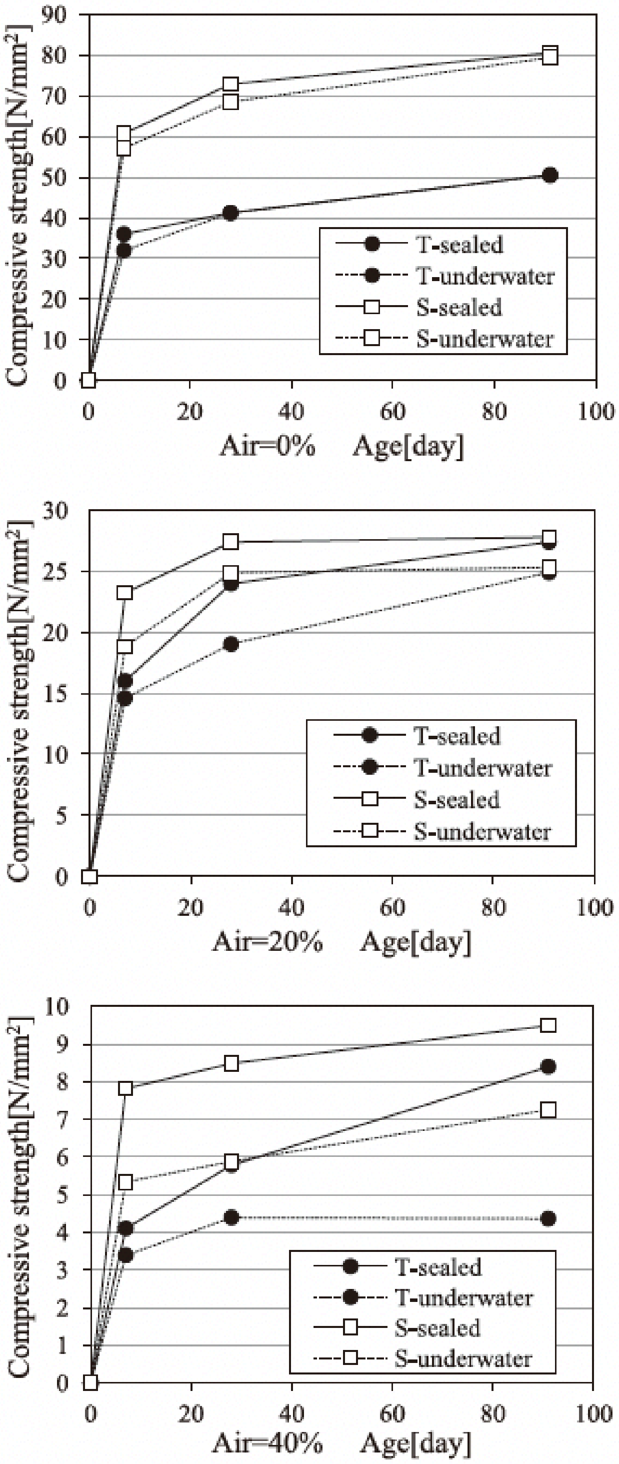

Fig. 4 Compressive strength development

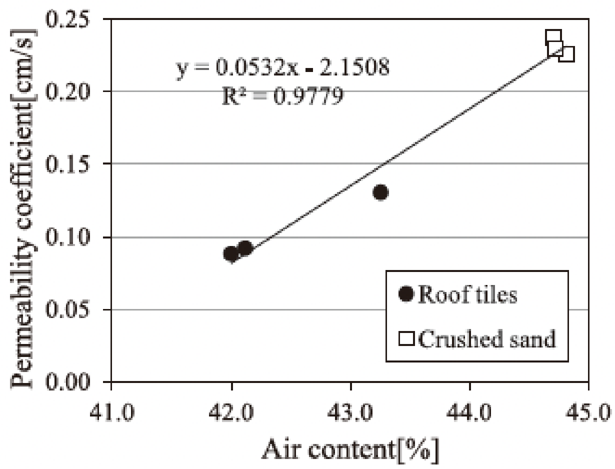

Fig. 5 Relationship between Porosity and Permeability coefficient

air content is 0.20 cm/s, even though the target air content is the same (40%), according to the test results of Kuroki et al.1), in which the sand cement ratio of the tile air-mixed mortar is 2.0 and the water cement ratio is 30%. The results show that the permeability of the air-mixed air-mixed mortar is 0.20 cm/s. This suggests that air content and hydraulic conductivity have a proportional relationship, but the proportional coefficient may change depending on the mixing conditions, and the correlation is an issue to be addressed in the future.

In the data presented here, the coefficient of determination of the regression line indicates that the effect of aggregate on the hydraulic conductivity of air-mortar is small and that the effect of air content is significant, but there is little experimental data on the effect on hydraulic performance, which is an issue for the future.

Table 4 Unit weight

Combination	S/C [-]	W/C [%]	Air content [%]	Unit amount [kg/m^3]			
				Water W	Cement C	Roof tiles T	Sand S
T-2.5-40-40	2.5	40	40	130	325	812	0
S-3.0-40-40	3	40	40	130	325	0	984

5. Relationship between Compressive Strength, Crack Tensile Strength and Bending Strength

5.1 Summary of Experiment

Cracking and tensile strength tests and flexural strength tests were conducted to determine the correlation between compressive strength and cracking and tensile strength. The materials used are shown in Table 1 and the formulations are shown in Table 3. The specimens for the cracking and tensile strength tests were made of steel formwork of 150mm x 300mm in diameter, and the height of the specimens was about 2/3 of the height of the formwork. The specimens for the flexural strength test were 100 mm x 100 mm x 400 mm steel formwork. For both tests, three specimens of each formulation were prepared and cured in water for 28 days.

5.2 Results and Discussion

Fig. 6 shows the relationship between compressive strength and tensile strength, and Fig. 7 shows the relationship between compressive strength and flexural strength. Both tensile and flexural strengths have a logarithmic relationship with compressive strength, and it can be said that tensile and flexural strengths can be estimated from compressive strength. There is no clear difference in the relationship between compressive strength, flexural strength, and tensile strength depending on the aggregate used

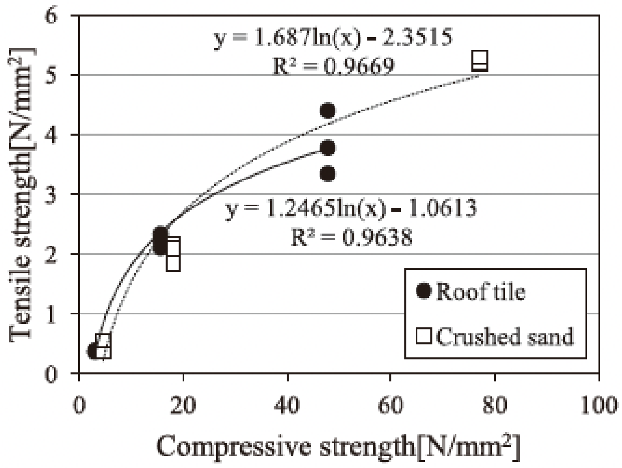

Fig. 6 Relationship between Compressive strength and Tensile strength

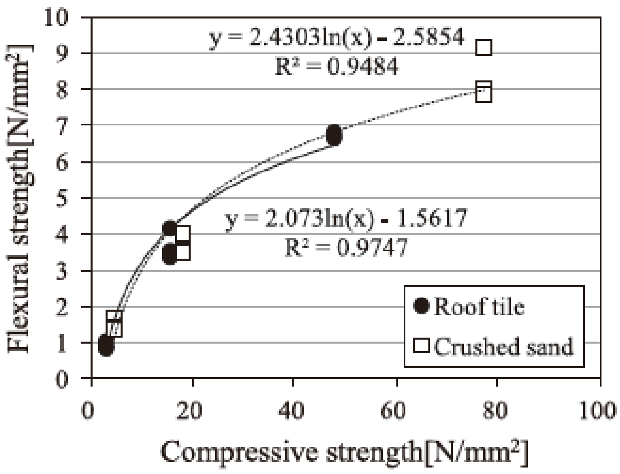

Fig. 7 Relationship between Compressive strength and Bending strength

6. Conclusion

(1) Experiments revealed the effects of air content, sand-cement ratio, and water-cement ratio on the compressive strength of tile air mortar, and the degree of these effects.

(2) From the results of strength tests, it was found that compressive strength and permeability can be estimated from the pore ratio, and static modulus of elasticity, bending strength, and tensile strength can be estimated from the compressive strength.

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