Evaporative Cooling Effect of the Pavement Covered with Reused *Sanshu* Roofing Tiles

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Abstract- Sanshu area located in the South of Nagoya City, Japan has been prosperous for the roofing tile industry. In recent years, this Industry has become environmentally conscious and has partially reused inferior goods generated during tile-manufacturing process as raw materials for roofing tiles. In addition, reusing methods of scrap tiles excreted from re-roofing and constructional demolition has been searched. On the other hand, in Nagoya, the thermal environment of summer is getting worse every year, because the artificial land-covering materials with high-heat capacity and without water permeability, such as asphalt, became common. In this study, the crushed roofing tile called Kawara ballast, a by-product from Sanshu roofing tile industry, was considered as material for water-permeable pavement. Its cooling effect from evaporation through the permeable ground surface would improve the outdoor thermal environment in summer. Experiments on the evaporative cooling effects of the pavement using the ballast were conducted to determine thermal characteristics of the pavement. The basic characteristics regarding the evaporative cooling effect of the ballast were experimentally investigated. The water absorption and the water retention properties were measured for each particle size. The saturated water content was found to be 13.2% and 10.5% for particle sizes 1-4mm and 4-10mm respectively. Field measurements were carried out during summer in Nagoya in a 300m^2 site to clarify the thermal behavior of water-permeable pavement with the crushed tiles. The results were compared with non-water permeable pavement and lawn-covered surface. It was confirmed that the pavement using the crushed Sanshu tiles is suitable for increasing cooling effect in summer.

1. INTRODUCTION

The thermal environment problem of urban areas in Japan, such as the expansion of heat island in summer, has been getting worse in recent years. Especially Nagoya, located in the center of Japan, shows the need for cooling-methods in the urban area, because it is remarkably hot in summer (Horikoshi, 1998). Instead of high thermal capacity materials, such as asphalt and concrete, ground-covering materials having an evaporative cooling effect are necessary. The use of tree and lawn vegetation is known as one of the methods to improve thermal environment in summer. Because the evaporation and the respiration from vegetation as well as the ground removes heat as the latent heat from these surfaces and nearby atmosphere. Regarding the other methods, there is a study by Akagawa who developed the continuation dampness pavement system (Akagawa 2000) and a study by Shirai who developed a passive cooling wall for evaporative cooling effect using a new wall brick (Shirai, 1996). In addition, there are several experiments that examined the influence of different types of ground-covering materials on thermal environment (Tsutsumi 1998; Ooi 1998; Okazaki 2002). However, the investigated samples and subjective areas were limited in these experiments. Hence some numerical simulation models have been proposed to design and evaluate thermal environment, which can simulate the evaporative cooling effect from the ground (e.g. Hagiwara et al. 2001). Each numerical simulation model for the evaporative cooling effect has to depend on the results of the actual measurement. There needs to obtain data regarding the water content characteristics for the new materials, which have evaporative properties.

On the other hand, Sanshyu area, located in the south of Nagoya, has been traditionally prosperous in Japan for the roofing tile industry. In this area, large quantities of waste from the tile production process and used roofing tiles are problems. For conservation of local resources, methods for recycling these disposal tiles have been examined. Disposal tiles from the production process are crushed, what is to be called Kawara ballast, and part of the material is mixed with clay of raw materials of Kawara. However, the rest of the ballast and wastes of used roofing tiles still have no utilization. In addition, the absorption ability of the ballast, unglazed pottery, is regarded as worth researching.

In this study, we evaluate the evaporative cooling effect of the new pavement using Kawara ballast and confirm the possibility of its utilization as the passive cooling materials for a pavement. Water absorptive characteristics of several kinds of Kawara ballast were examined. The thermal characteristics of the pavement were confirmed with the measurement at the outdoor test models in summer. It is worth to developing new utilizations of reused materials from local industry in order to contribute to the sustainable society and to improve the local environment.

2. WATER ABSOPTIVE CHARACTERISTICS OF KAWARA BALLAST

Two kinds of roofing tiles are produced at Sanshu tile industry. One is called Touki Kawara and another one is called Ibushi Kawara. Both of them are made of almost the same raw materials, which include 3% of Kawara ballast, and are baked at around 1100 degrees Celsius. Particle sizes of clay and the process of producing are different. Touki Kawara is glazed roofing tile and Ibushi Kawara is baked without glaze. It is made so that the water may not soak into the roofing tiles. But Kawara ballast has unglazed surface and is easy to be infiltrated by water. There is few data of water infiltration into the ballasts. In order to clarify the characteristics of water absorption and water retention of the ballast made from each Kawara, the two following experiments were carried out:

Kawara ballast is sifted to particle less than 10mm size during the production process of the ballast at Sanshu area (Fig. 1). On these experiments, two kinds of ballast with different particle were used for both measuring samples of Ibushi Kawara and Touki Kawara. Each kind of ballast was divided by particle size from 4mm to10mm and from 1mm to 4mm.

Table 1 Mean saturated water content of Kawara ballast.

Type of material	Touki ballast		Ibushi ballast	
Particle size [mm]	1 - 4	4 - 10	1 - 4	4 - 10
Mean sarturated water content (mass by mass)[%]	13.2	10.5	11.7	9.4

2.1 WATER ABSORPTION CHARACTERISTICS

To clarify the water absorption characteristics of the ballast, the saturated water content were obtained by the experiment based on JIS A1203. After 4 kinds of the ballast absorbed water for 24 hours in the artificial

Fig. 1 Particles of Touki ballast with less than 10mm.

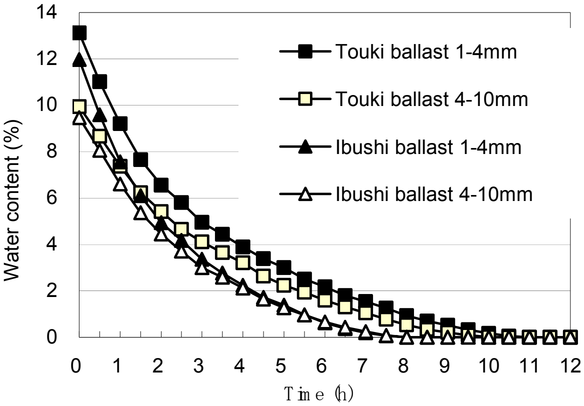

Fig. 2 Transition of water content of each Kawara ballast at a 40 degrees Celsius atmosphere.

climate chamber, the weight of these samples were measured. While they absorbed water, the artificial climate chamber was set at a 20 degrees Celsius temperature and 50% relative humidity. These samples were dried for 24 hours at 105 degrees Celsius with a constant temperature dryer, and the weight of each sample was measured again. The saturated water contents of the materials were calculated from the weight of entirely dried samples and the absorbed ones. This process was repeated five times and their mean value was adopted.

The average saturated water content of each sample is shown in Table 1. The saturated water content of Touki ballast was higher than that of Ibushi ballast. In addition, the saturated water content of the small particle was higher than the large one. The evaporative cooling effect and retaining rainwater ability were expected for Touki ballast, because its saturated water content is higher.

2.2 DRYING SPEED CHARACTERISTICS

To investigate the water retention characteristics of both Ibushi and Touki ballast, the drying speed of test samples were observed. These samples were the same as those used in the experiment of chapter 2.1. The 4 kinds of measuring samples absorbed water for 24 hours in the artificial climate chamber at 20 degrees Celsius and 50%RH. These samples were set in the constant temperature dryer, and their weight was measured every 30 minutes till they were completely dried.

Fig. 2 shows the results when the dryer temperature is 40 degrees Celsius. Ibushi ballast dried faster than Touki ballast and large particles of 4-10mm dried faster than small particles. Therefore, continual evaporative cooling effect should be expected by using smaller particle of Touki ballast.

2.3 PROPOSAL OF PAVEMENT MADE OF KAWARA BALLAST

Touki ballast is suitable for the pavement material because the evaporative cooling effect is expected from the results above. The ballast with small particle shows higher performance of absorption and retention of water. In addition, the previous investigation of roofing tile ballast (Tsuboi, 2001) indicates that small particle ballast has low permeability. The following test models covered with the ballast were made to cool the outdoor space efficiently as follows. Large particles of Touki ballast were placed at the upper part of the pavement as the water permeable and absorptive layer, and small particles were placed at the bottom part of the pavement as the earth-water retaining layer.

3. EVAPORATIVE COOLING EFFECT OF THE KAWARA BALLAST PAVEMENT

3.1 SUMMARY OF FIELD MEASUREMENT

To compare the evaporative cooling effects of the pavement covered with different materials, seven kinds of test models were constructed in the Nagoya Human Science Park, southern part of Nagoya. The field measurements were conducted in the summer of 2003.

(1) Test Models of Pavement

Seven kinds of test models and their placements are shown in Fig. 3. The dimensions of each test model are 5m x 5m. The perimeters of the test models were insulated with foamed polystyrene board of 30mm thickness and also waterproofed as to minimize the influence from the sides. Fig. 4 shows the sections of the test pavement models. Type 1 and 2 are the models using the ballast. The structure of Type 1, as shown in Fig. 5, is as follows; whole roofing tiles stand at intervals of 20mm on the lower layer with relatively smaller particle than that of upper layer.

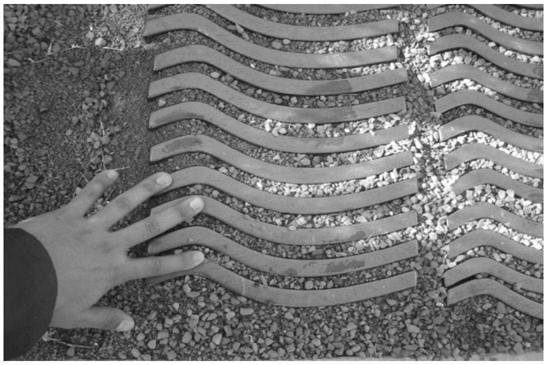

Fig. 5 The outdoor surface in Type 1.

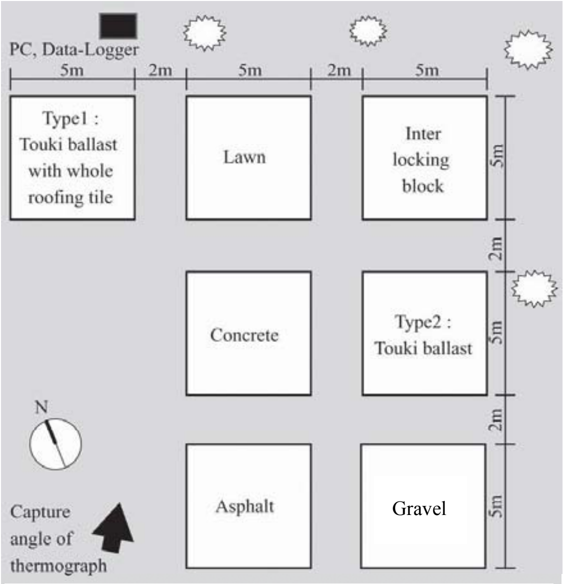

Fig. 3 Site plan of test models in the test field of Nagoya.

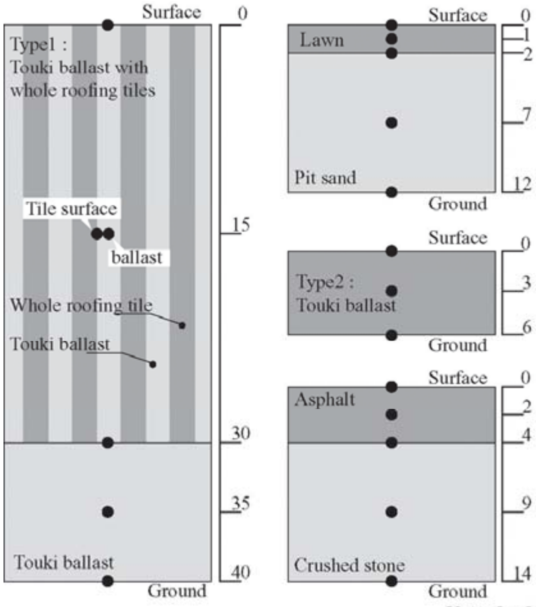

Fig. 4 Cross-section of test models and locations of internal thermocouples(ϕ = 0.3mm).

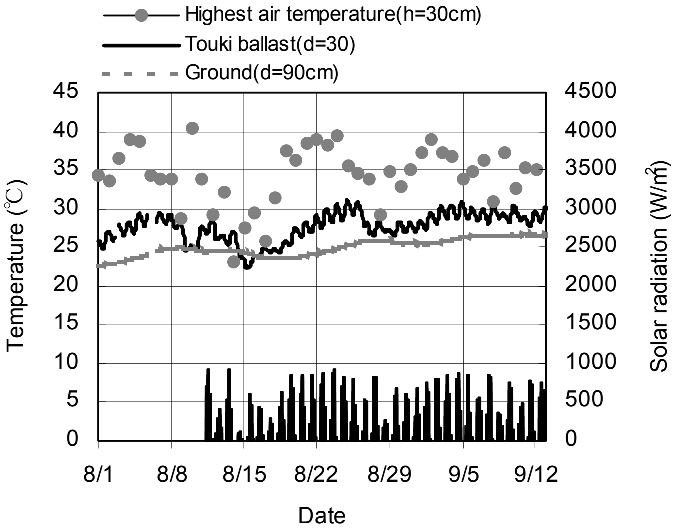

Fig. 6 Outdoor climate and internal temperature of Type 1 from Aug. 1 to Sept. 12.
locations of internal thermocouples(ϕ = 0.3mm).

The remaining spaces were filled with Touki ballast. Type2 was constructed with only Touki ballast at 60mm depth. The gravel model was constructed with around 30mm particle sizes of gravel at 60mm depth. The inter-locking blocks used in this measurement are water permeable and are made of recycled concrete. They were constructed with 60mm depth on the sand of 20mm depth.

(2) Method of measurement

Fig. 4 shows the positions of waterproofed T-typed-thermocouples placed in the test models. The vertical distributions of air temperature were measured above the surface of the test models with solar shaded T-typed-thermocouples at 100cm, 30cm, 10cm and 2cm height. The air temperature and the underground layer temperature of the test models were automatically recorded by data-logger every 10 minutes. The measurement has been conducted since August 1st., 2003. Wind direction and velocity were obtained from the air pollution monitoring system of the Ministry of Environment, which is located 900m distant from the test field, Those data were utilized and analyzed in the present study. The rainfall data from Nagoya Meteorological Observatory was also used.

To examine the thermal behavior of the pavement precisely, relative humidity, long wave radiation, wind direction and wind velocity were measured every 30 minutes, and thermographs of the surface of the test models were measured every hour. This measurement took place on August 22nd., a clear day.

In addition, to determine the water absorption characteristics of the ballast after rainfall, samples of the ballast were obtained from the surface, 10cm and 20cm of depth, and from the bottom of Type 1. The water content of each sample was measured.

3.2 RESULTS AND DISCUSSION

(1) Climate during the field measurement

Fig. 6 shows the outdoor climate, the ballast layer temperature (depth = 30cm) of Type 1 and the underground temperature at 50cm from the bottom of Type 1. This data was obtained from August 1st. to

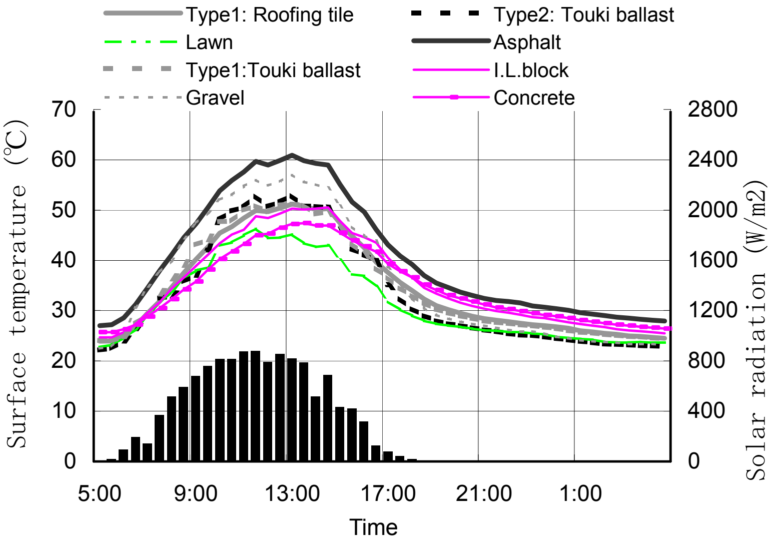

Fig. 7 Surface temperature of test models and solar radiation on a clear day (Aug. 22).

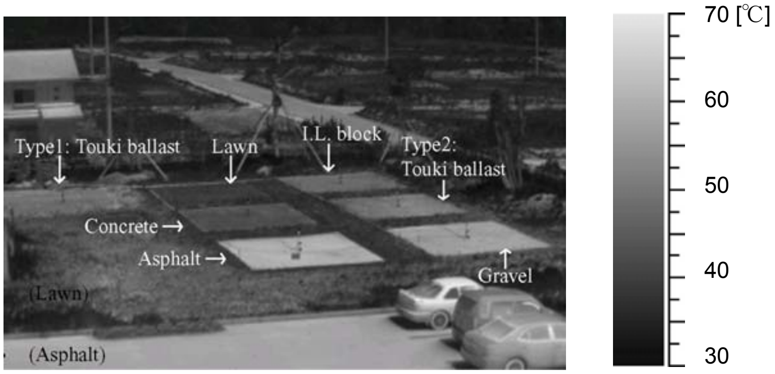

Fig. 8 Thermograph of test models at noon on a clear day (Aug. 22).

September 12th, 2003. The ballast layer temperature is much more influenced by daily climatic changes than the underground. The daily range of the ballast layer temperature is less than 2 K.

(2) Surface temperature on a clear day

The surface temperatures of each test model obtained on August 22nd, a clear day, are shown in Fig. 7. The surface temperatures of Type 1 and 2 remained lower than that of asphalt and higher than that of lawn during the daytime. The maximum difference of surface temperature between Type2 and lawn was 8K, and between asphalt and Type2 was 10K. The surface temperatures of Type1 and 2 gradually decreased along the time and became closer to the surface temperature of lawn. Especially in Type 2 with only Touki ballast, there was a drastic drop of the surface temperature around 5 p.m. The surface temperature of Type 2 shifted with the change of the solar radiation because heat capacity of Type 2 with shallower depth is lower than that of Type 1. It tended to be same for the surface temperature of gravel. This temperature becomes the same as lawn temperature from 8 p.m. Fig. 8 shows the thermograph of all test models at 12:00 noon on August 22nd. The surface temperature of Type 1 and 2 indicates the same horizontal distribution with that of

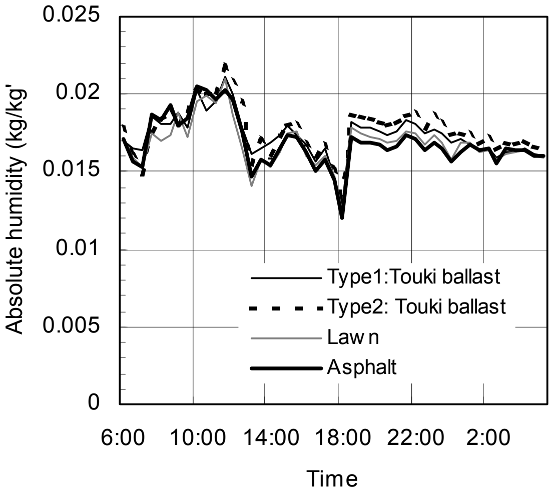

Fig. 9 Absolute humidity over the test models of Type 1 and 2 on the clear day (Aug. 22).

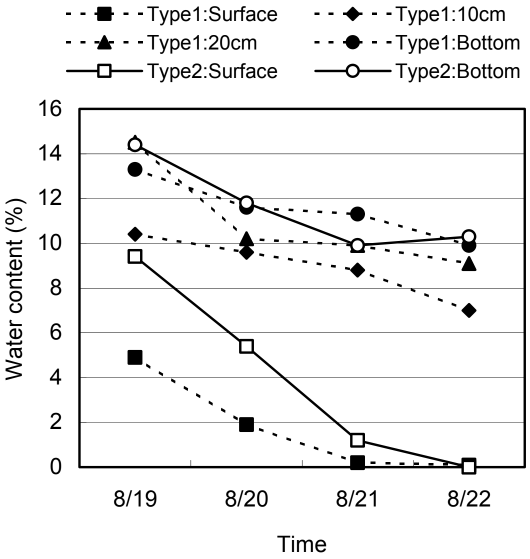

Fig. 10 Transitions of water content of Touki ballast of Type 1 and 2 from Aug.19 to 22.

inter-locking blocks. It is around 10 K lower than that of asphalt and gravel. The surface temperature of concrete is around 10K lower than that of Type1 and 2. It is considered that the concrete had not dried and contained moisture because it passed only a few months after concreting. The relative observation about the test model and other models of concrete will have to be continuously carried out.

(3) Absolute humidity and water content after rainfall

The absolute humidity of each test model obtained on August 22nd at 30cm height is shown in Fig. 9. The absolute humidity above Type 1 and 2 is not only higher than that of asphalt but also of lawn from noon to midnight. The water content of the ballast in Type 1 and 2 were measured from August 19th to 22nd after the rainfall. The precipitation of rainfall from August 14th to 17th was 115mm at the Nagoya District Meteorological Observatory. The transitions of water content in Type 1 and 2 are shown in Fig. 10. The water contents of surface ballast in Type 1 and 2 decreased day by day and became absolutely dry after 4days from the rainfall. On the other hand, the water content of internal ballast at 10cm of depth remained more than 7% after 4days from the rainfall. It indicates a high property of water content of the ballast in the underground layer. It was also confirmed that there is few differences of the water content property between Type 1 and 2, even though the depth of Type 1 is about seven times deeper than that of Type 2.

(4) Surface temperature and air temperature after the rainfall

Fig. 11 shows the transitions of the surface temperatures of Type 1, Type 2, asphalt and lawn after the rainfall. The surface temperature of Type 1 and 2 fluctuated similar to that of lawn and remained less than 46 degrees Celsius for three days after the rainfall. The temperature of Type 2 reached more than 54 degrees Celsius on August 22nd. As for the transitions of water content in Fig.9, the surface temperatures of Type 1 and 2 were fairly influenced by its water content. Fig. 12 shows the transitions of differential air temperature at 2cm, 10cm and 100cm of height from the surface of Type 2 and asphalt. There is little difference at 100cm of height, but some difference at 2cm and 10cm of height. It represents the evaporative cooling effect by retained water in the ballast as shown in Fig. 10.

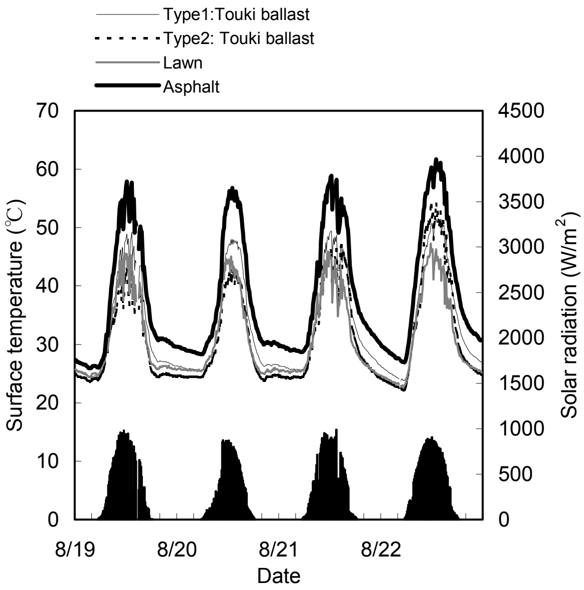

Fig. 11 Transitions of surface temperature of test models after the rainfall.

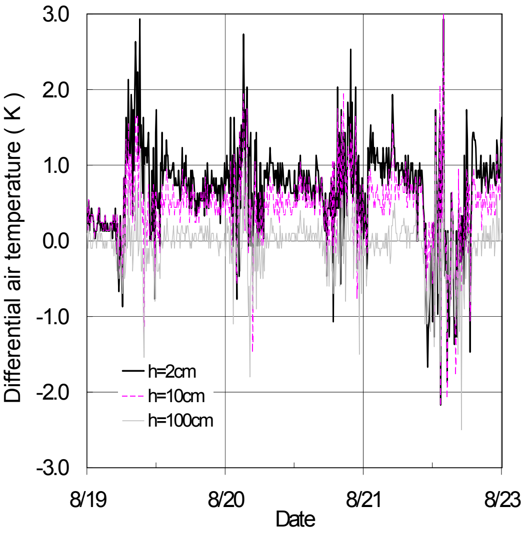

Fig. 12 Transitions of difference between air temperature over asphalt and Touki ballast (Type 2).

4. CONCLUSIONS

The pavement using Kawara ballast was examined on its water absorption property and evaporative cooling effect by using both of the chamber test and the field measurement. It was confirmed that the test models of the pavement using the ballast had an evaporative cooling effect after the rainfall and the effect remained for a few days. However, this cooling effect was found to be less than the effect of lawn. The cooling effect of the pavement using only the ballast at 6cm of depth appeared much more effective than that of the pavement using whole roofing tiles at the same depth. The application suitability of the reused Kawara ballast to urban pavement in summer was confirmed.

Our further work will be directed at investigating the influence of the pavement's cooling effect on the human body in summer and at examining the property of rainwater storage to avoid flood in the urban area.

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