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Cause and countermeasure way of rubble fires occurred after 2011 Great earthquake of Japan

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Abstract

This paper seeks for cause and countermeasure way of fires of huge amount of rubble which were produced after 2011 great earthquake of Japan. In 2011, we experienced many fires caused with rubbles which were produced from destroyed houses by the Great earthquake and tsunami in March 11, 2011, in Japan. Rubble includes various organic materials, and sometimes causes fires, which is used for fuel of power plants, or energy sources. It is very difficult to extinguish fire of such biomass fuel made from rubble in outdoor storage facilities. Here current studies for safety handling of these materials and proposed an evaluation method, is introduced, which is to use high sensitive calorimeters. And cause investigation work and countermeasure method, conducted by author is introduced. Our results regarding cause of fires are: initial of heat generation and fire are mostly by fermentation, and then oxidation process started after micro organism dead by high temperature, up to about 60℃. High sensitive calorimeters can detect small heat generation between room temperature and 80℃, due to fermentation or other causes. This heat generation sometimes initiated a real fire even outdoor, and produced some combustible gas. With understanding this process we recommend countermeasure way against such fires, to release heat from the pile, and prevent air entrainment into the pile to stop fermentation.

Keywords: rubble, high sensitive calorimeter, 2011 Great Earthquake of Japan.

1. Introduction

Huge amount of rubble was produced after 2011 Great earthquake and tsunami of Japan in March 11, 2011 which killed more than 15,000 people (including missing). Rubble was consisted of various materials, but mostly was consisted of combustible materials, such as destroyed wooden houses, interior materials, paper, and plastics. It is difficult to treat them, and huge amount of rubble piles existed in east-north disaster area of Japan. And we experienced more than 20 fires from these materials during summer and autumn in 2011. It is so difficult to extinguish a fire in huge rubble pile, and sometimes continued for several days. And sometimes a fire re-started because still huge combustible materials remained, and micro-organism existed in it. However there has not been conducted systematic cause investigation, research or report for such post-earthquake fires.

In this paper, we introduce these fires and our cause investigation research using high sensitive calorimeters such as C80, or TAM [1-4], and obtained that mostly fermentation was related with the cause of fires. Then we introduce our proposals for safety handling and countermeasure against such fires.

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2. Outline of the rubble fires that occurred in Miyagi Prefecture

There compiles examples of fires in Table 1 which we did cause investigation. In addition to these examples, more than 20 fires occurred in other eastern Japan. Figure 1 is an example picture of working for separation of the rubble piles.

Table 1. List of on-site survey conducted by authors

Location	Yuriage rubble outdoor storage area, Natori City, Miyagi Prefecture	Yuriage rubble outdoor storage area, Natori City, Miyagi Prefecture	Kozukahara rubble outdoor storage area, Natori City, Miyagi Prefecture
Occurrence	16 September 2011, 7:39 a.m.	19 September 2011, 3:06 a.m.	22 September 2011, 3:06 a.m.
Fire extinguished	20 September 2011, 4:40 p.m.	22 September 2011, 12:26 p.m.	22 September 2011, 11:35 p.m.
Existed major	Un-classified rubbles	Un-classified rubbles	Tatami
Materials	Length, 40 m; Width, 30 m; Height, 15 m	Length, 30 m; Width, 10 m; Height, 10 m	Length, 10 m; Width, 10 m; Height, 8 m
	Approximately 18000 m^3	Approximately 3000 m^3	Approximately 800 m^3
Burned area	Approximately 1200 m^2	Approximately 300 m^2	Approximately 100 m^2
Remarks	Aerial fire fighting was conducted.		

Fig. 1. A picture of rubble pile. During dealing with rubble, huge smoke and water vapor was produced and temperature of surface of materials are high, at least 60℃.

3. Experiments

3.1 Samples

The tests conducted in this study used the following five types of samples collected at the Yuriage and Kozukahara rubble outdoor storage area (Figs. 2–6). Tatami is a traditional flooring used in Japanese houses made by weaving straw and igusa (soft rush straw). The Kozukahara rubble outdoor storage space fire originated from an area where tatamis accumulated. Wood chips are accumulated as woody rubble that has been broken down into chips. The sludge obtained might contain many microorganisms and a large amount of moisture. These microorganisms are used in this study because they can possibly corrode other items in the rubble, promoting fermentation.

3.2 Thermogravimetric differential thermal analysis

A thermogravimetric differential thermal analysis (TG-DTA) system (Rigaku Thermoplus TG 8120, Japan) was used to study the overall thermal characteristics of the above-mentioned samples. An open aluminum container (0.05 ml) was used to hold the samples. We studied the thermal characteristics of approximately 20 mg samples by heating them from room temperature to 600°C at a rate of 2 K/min with air circulating at a speed of 150 ml/min.

Fig. 2. Rotten tatami obtained at Yuriage.

Fig. 3. Rotten tatami obtained at Kozukahara.

Fig. 4. Wood chips obtained at Yuriage.

Fig. 5. Tatami obtained at Kozukahara

Fig. 6. Sludge obtained at Yuriage.

3.3 Calorimetry

A Calvet calorimeter (Setaram C80, France) was used for additional thermal testing. The C80 (Fig. 7) is a twin-type highly sensitive heat-flux calorimeter. It can reduce the effects of evaporation of water contained in the sample by using a high-pressure closed vessel (8 ml) and can take measurements from room temperature to 100°C, which is a difficult temperature range to measure using the TG-DTA system. For these measurements, the temperature was increased at a rate of 0.1 K/min. A 1500 mg sample in a closed stainless steel vessel raised the temperature in the vessel from room temperature to 300°C under limited-air atmosphere.

3.4 Highly sensitive isothermal calorimeter

In order to examine faint heat generation from the fermentation and oxidization of fatty acid ester in detail, measurements were conducted with a highly sensitive isothermal calorimeter (Thermometric TAM-III Sweden). The TAM (Fig. 8) can measure the amount of heat generated by microbial fermentation with nano-scale sample. A sample of approximately1000 mg was placed in a sealed container (4 ml), isothermally maintained at 50°C for three days and was measured to determine faint heat generation.

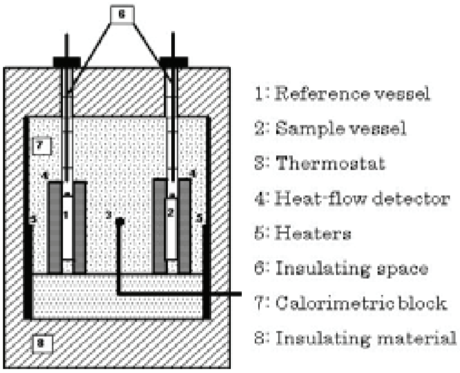

Fig. 7. Schematic diagram of the C80.

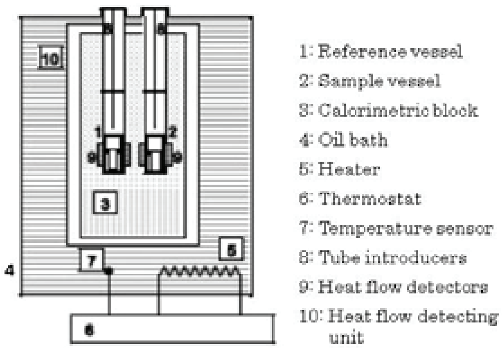

Fig. 8. Schematic of the TAM-III calorimeter.

4.Results and Discussion

4.1 Thermogravimetric differential thermal analysis

Figures 9–13 show the TG-DTA measurements result scanning rate of 2 K/min. Table 2 shows a summary of the mass loss at 100°C and the heat-generation-onset temperature. The heat-generation-onset temperature is that at which the DTA curve shifts by 0.1 μV (0.01 K) from the baseline where the DTA curve is constant. The horizontal axis represents the sample temperature and the vertical axis represents the weight loss. TG and DTA (thermal behaviour) curves are plotted in the above-mentioned graph. In the TG curve, the downward direction indicates a decrease in the weight and the upward direction indicates an increase in the weight.

In the DTA curve, the downward direction indicates an endothermic reaction and the upward direction indicates an exothermic reaction. The thermal decomposition results of the rotten tatami obtained at Yuriage, rotten tatami obtained at Kozukahara, wood chips obtained at Yuriage and tatami obtained at Kozukahara are divided into three stages. The TG curve exhibits weight loss caused by dehydration at a temperature between the room temperature and 100°C. The greatest rate of weight loss at this stage was observed in the rotten tatami obtained at Yuriage. Weight loss caused by the oxidative decomposition of organic components was observed in all the samples in the temperature range from 180°C to 380°C. Heat generation and weight loss caused by carbide combustion were observed at temperatures exceeding 380°C. Exothermic onset temperature was highest in the sludge obtained at Yuriage at 198°C and ranged from approximately 160°C to 170°C in the other samples. It is believed that the oxidative decomposition of the samples resulted in fire as the temperature reaches these levels.

The wood chips obtained at Yuriage showed the most intense thermal behavior and are considered as a high fire risk. The rubble outdoor storage area contain rubble from buildings that collapsed as a result of the seismic vibration and subsequent tsunami. The high moisture content of the rotten tatami obtained at Yuriage is because the rubble was collected at buildings that collapsed as a result of the tsunami. As a result of the tsunami, heavy oils and marine fuels leaked from the gulf-coast facilities and fishing boats and got mixed with the rubble from areas received severe damage from the tsunami.

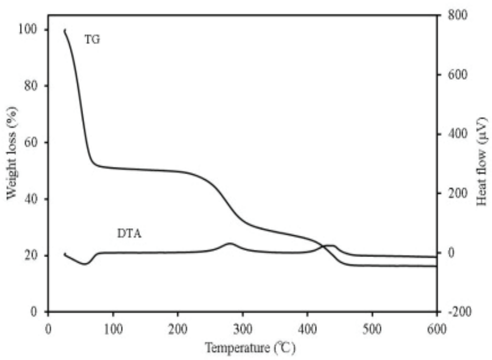

Fig. 9. TG-DTA results of Rotten tatami obtained at Yuriage.

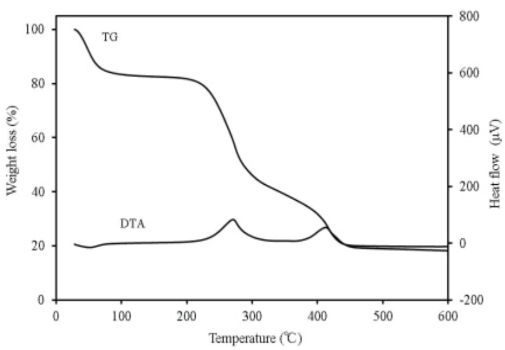

Fig. 10. TG-DTA results of Rotten tatami obtained at Kozukahara.

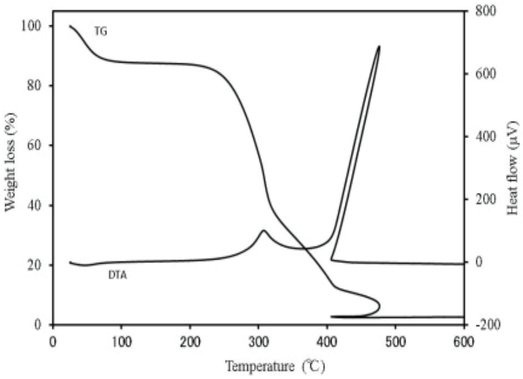

Fig.11.TG-DTA results of Wood chips obtained at Yuriage.

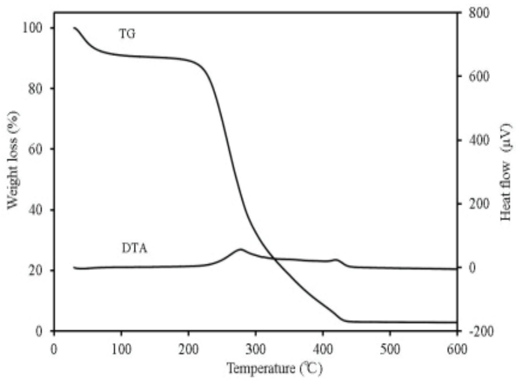

Fig. 12. TG-DTA results of Tatami obtained at Kozukahara.

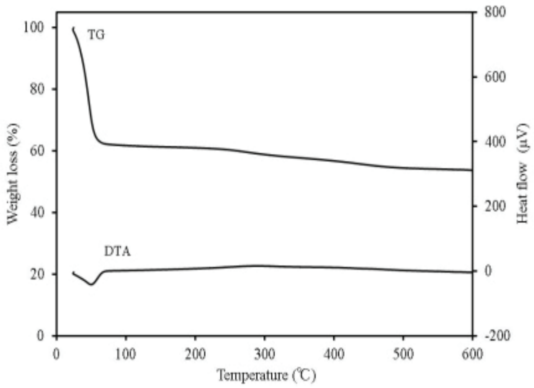

Fig. 13. TG-DTA results of Sludge obtained at Yuriage.

Table 2. Mass loss at 100°C and heat-generation-onset temperature

Sample	Mass loss at 100°C (%)	Heat-generation-onset temperature (°C)
Rotten tatami obtained at Yuriage	49.01	160.7
Rotten tatami obtained at Kozukahara	16.6	166.8
Wood chips obtained at Yuriage	12.08	163.5
Tatami obtained at Kozukahara	9.1	171.3
Sludge obtained at Yuriage	38.2	198.3

4.2 Calorimetry

Figures 14–18 show that the C80 measurements result scanning rate of 0.1 K/min. In addition, the heat-generation-onset temperature and total heat generated between the room temperature (25°C) and 80°C is summarised in Table 3. When a shift was detected in an exothermic direction after the start of measurement, the temperature at the beginning of the heat generation process was marked as the initial temperature. Immediately after the start of measurement, the heat generation process followed fermentation. The process mentioned above was observed in the rotten tatami obtained at Yuriage and Kozukahara, respectively and also in the wood chips obtained at Yuriage. Moreover, in all these samples, the process of heat generation was observed in the fatty acid ester at a temperature ranging from 80°C to 100°C, and was caused by the oxidative decomposition observed at temperatures higher than 100°C. In the past, fires have been reported because of the fermentation of wood chips piled up in large quantities. Furthermore, rotten tatami generates more heat and is considered to be a greater fire risk than wood chips. The process of heat generation leading to the combustion of these items begins with a small amount of heat generated from fermentation as a result of microbial activity. Next, the oxidation of the fatty acid ester contained within the items begins to occur as the temperature gradually rises, even if the microorganisms die, the temperature continues to rise and ultimately results in combustion. Monitoring the internal temperature of a large pile of rubble is one method to forecast fires occurring in such piles.

On the basis of the C80 results, it is desirable to incorporate the following safety measures. First, if the internal temperature of a pile of rubble is between 30°C and 50°C then fermentation begins and only a small amount of heat is generated from fermentation and breaking down the pile. Conducting heat dissipation treatment at this stage lowers the possibility of a further increase in temperature that could lead to combustion. Second, if the internal temperature of a pile of rubble is between 50°C and 80°C, the fermentation as well as the oxidation of fatty acid ester and materials produced by fermentation occurs. Thermal storage is already in progress at this stage and an immediate treatment is required. At this stage, breaking down the pile increases the oxygen supply to the area of thermal storage, rapidly increasing the temperature and the possibility of combustion. Accordingly, it is desirable to cover the pile with sand and cool down the pile with water, if necessary.

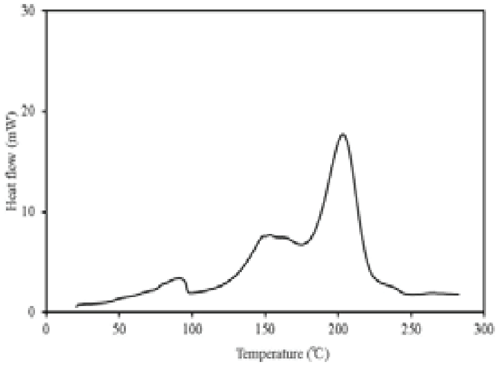

Fig. 14. C80 results of Rotten tatami obtained at Yuriage.

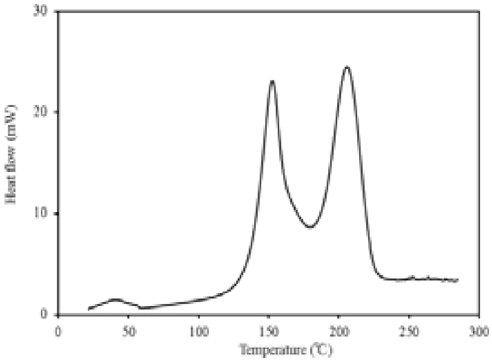

Fig. 15. C80 results of Rotten tatami obtained at Kozukahara.

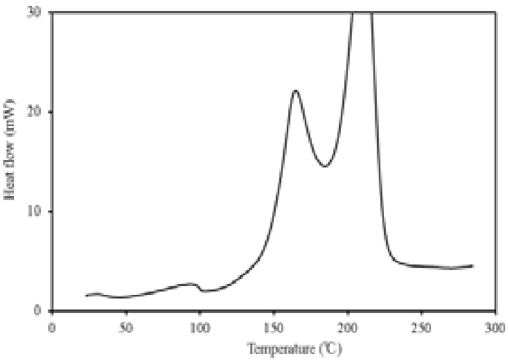

Fig.16. C80 results of Wood chips obtained at Yuriage.

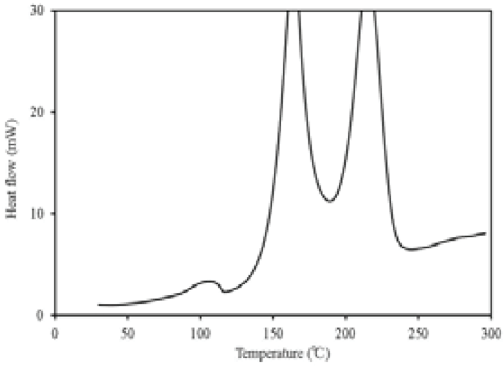

Fig. 17. C80 results of Tatami obtained at Kozukahara.

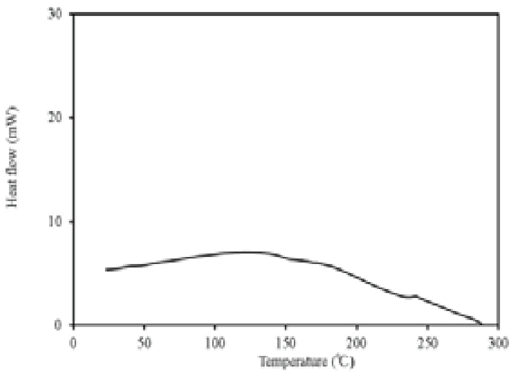

Fig. 18 C80 results of Sludge obtained at Yuriage.

Table 3. Heat-generation-onset temperature and total heat generated (room temperature at 80°C)

Sample	Heat generation onset temperature (℃)	Total heat generation (J/g) Room temperature to 80℃
Rotten tatami obtained at Yuriage	28.96	9.99
Rotten tatami obtained at Kozukahara	25.52	9.4
Wood chips obtained at Yuriage	29.44	1.47
Tatami obtained at Kozukahara	NA	≒0
Sludge obtained at Yuriage	NA	≒0

NA: No heat generation was observed during measurement temperature

4.3 Highly sensitive isothermal calorimeter

Figures 19–23 show the TAM measurements result. Table 4 summarizes the amount of heat generation. The amount of heat generation is summarized for 0-24 h of measurement, 24–72 h and for a combination of both periods. An experiment was performed in which distilled water was added to the above-mentioned samples (an amount equal to 20% of the sample), and the samples were measured to examine the effect of moisture content on heat generation. The TAM holding temperature was set at 50°C, because the microbial actively occurs in this temperature range [7] but gradually becomes inactive at higher temperatures [8]. On comparing the results of the samples of the existing material and the samples with additional moisture content, it was observed that the total amount of heat generated was greatest in the rotten tatami obtained at Kozukahara . Furthermore, by conducting an investigation on the thermal behavior of the rotten tatami obtained at Kozukahara, we observed a tendency for heat generation to begin immediately after the start of measurement and rapidly increase after a few hours. The reason behind this observation is the increase in the growth of microorganisms over time. Subsequently, we observed a tendency for the oxygen present in the sealed sample container to be consumed as a result of rapid fermentation, causing heat generation to cease. Since the process of heat generation ceased when there was less oxygen present, it is highly possible that the fermentation is aerobic. On observing the measurement results of the samples with the added moisture content, we inferred that all the samples generated a greater amount of heat than the samples that were measured without added moisture content. The tatami obtained at Kozukahara generated about 12 times the amount of heat. We noticed a different trend in the other samples in which rapid heat generation occurred immediately after the start of measurement and caused heat generation to cease after approximately 10 hours; however, heat generation continued for a long period of time in the tatami obtained at Kozukahara. On observing the tendencies of the samples to generate heat in the sludge, it was inferred that there was no rapid heat generation; however, the heat generation continued for a long period of time. The results of the TG-DTA system measurements showed a large amount of moisture content in the sludge.

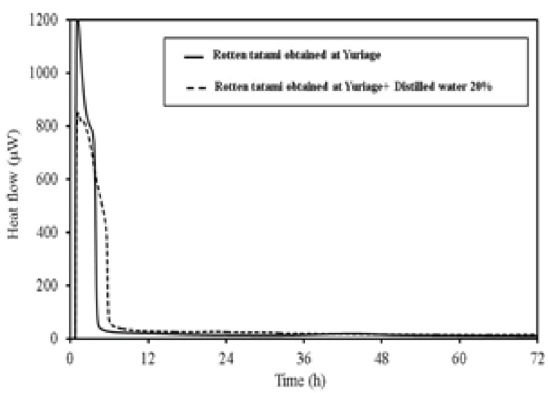

Fig. 19. TAM results of Rotten tatami obtained at Yuriage.

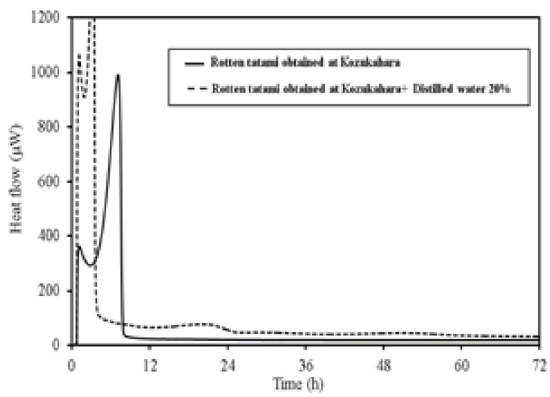

Fig. 20. TAM results of Rotten tatami obtained at Kozukahara.

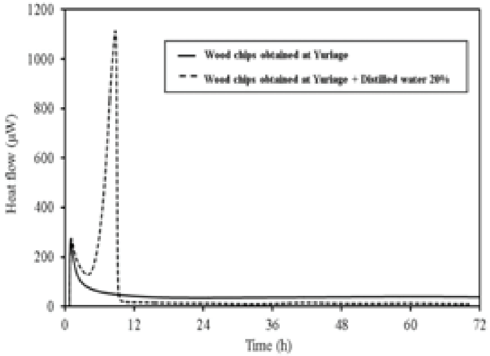

Fig. 21. TAM results of Wood chips obtained at Yuriage.

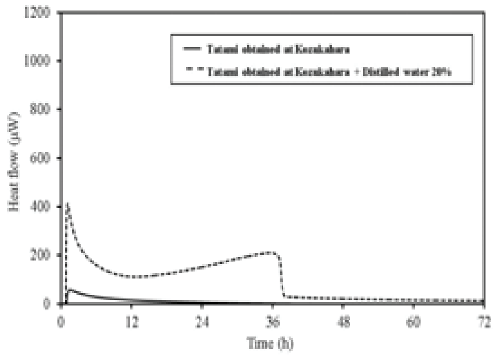

Fig. 22. TAM results of Tatami. obtained at Kozukahara

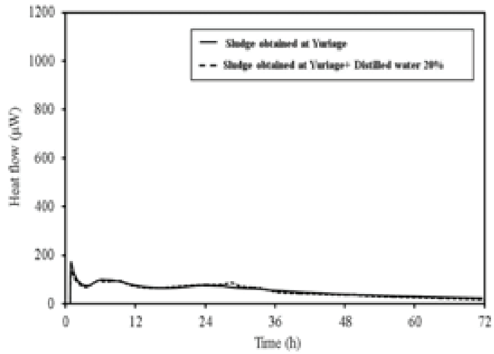

Fig. 23. TAM results of Sludge obtained at Yuriage.

Table 4. Heat generation at 50°C

Sample	Heat generation (J/g), 0-24h	Heat generation (J/g), 24-72h	Heat generation (J/g), 0-72h
Rotten tatami obtained at Yuriage	11.21	2.24	13.44
Rotten tatami obtained at Yuriage +Distilled water 20%	13.92	3.11	17.02
Rotten tatami obtained at Kozukahara	13.09	3.06	16.15
Rotten tatami obtained at Kozukahara + Distilled water 20%	15.69	6.54	22.23
Wood chips obtained at Yuriage	4.48	6.30	10.78
Wood chips obtained at Yuriage + Distilled water 20%	12.17	1.88	14.05
Tatami obtained at Kozukahara	1.69	0.35	2.04
Tatami obtained at Kozukahara + Distilled water 20%	13.14	11.17	24.31
Sludge obtained at Yuriage	6.67	6.90	13.58
Sludge obtained at Yuriage + Distilled water 20%	6.86	7.14	14.00

Although sludge is not an item that will burn intensely on its own, the results from the TG-DTA system and TAM collectively indicate that sludge might contain large quantities of water and microorganisms and corrode other items, thereby playing an auxiliary role in their fermentation. The TAM results of the samples with added moisture content suggest that, if there is a fire that has been hosed down and extinguished, there is a possibility of subsequent fermentation and heat generation leading to further ignition if items prone to fermentation are located near the water-treated area. Therefore, it is necessary to continuously monitor the area around the source of fire, even after the fire occurred.

5. Countermeasure to avoid occurring fire

Base on our results and past experience [5-8], it is known that most fires of rubble occurred in the combustible materials piles because of initiation of heat generation with fermentation. There are two types of fermentation, that is, aerobic and anaerobic. First one needs enough air to keep microorganism activity and generate heat. The other one does not need enough air, and generates very small heat but produce combustible gas such as methane, hydrogen.

Inside of the pile of rubble, there exists air flow (Fig. 24). In Fig. 24, oxygen concentration measured at point A, was about 20%, though oxygen from point B was less than 15% measured by our on-site study in another industrial waste and wood chip pile [9]. And oxygen was consumed inside the pile along with air flow. Therefore to stop air entrainment into rubble pile and to keep poor air condition is most important to prevent heat generation and fire. Most air entrains through the low part of the face of slope of pile, and to cover low part of face of slope with incombustible materials such as iron plate, sand, or soil is recommended.

To remove heat from the inside of rubble pile which is accumulated by fermentation, to penetrate tubes into the hot part of rubble pile is recommended. Fig. 25 shows an example of tubes penetrated in a pile of industrial waste, which was to release heat and gas.

To monitor the temperature through the tube is important to know situation inside rubble. And to monitor major gas concentration through the tube is also important. Table 5 shows roughly modes of temperature and gas emission. There may exist two or three modes at the same time, because it is not uniform condition inside pile.

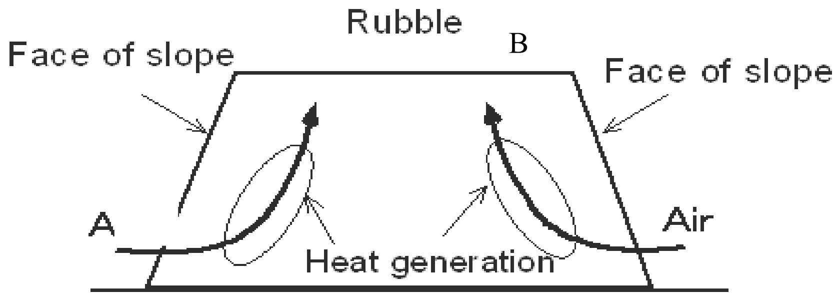

Fig. 24. Schematic illustration of the air entrainment into rubble pile.

Fig. 25. Picture of tubes penetrated into the pile of industrial waste materials.

Table 5. Temperature and gas emission mode inside the pile

Mode	Temperature	Major gas Emission	Remarks
Fermentation(Anaerobic)	～ca 40℃	CO_2, CH_4, H_2S*	Small heat generation
Fermentation(Aerobic)	～ca 60℃	CO_2, CH_4, H_2S*	Larger heat generation than anaerobic mode
Oxidation of fatty acid ester	60～80℃	CO_2, CO, CH_4	Diminish of micro-organism activity
Water vaporization	80～100℃	H_2O	Drying process
Incomplete-combustion	ca 100℃～	CO, CH_4, CO_2, H_2	Smaller heat generation
Complete-combustion	ca 100℃～ (160～170℃～)	CO_2, CO	Huge heat generation, become a real fire

*: When sulfur or sulfur-compound exist

Based on information of temperature and gas emission, we can estimate mode inside the pile. When the temperature is higher than 60℃, it is danger to start heat generation by chemical process which is much larger than that of fermentation. Therefore, when the temperature inside the pile becomes more than 60℃, heat should be removed through the tube which is penetrated into the pile. Water spray is also useful to cool down the temperature inside the pile. However it may be difficult to put water and cool the hottest area inside the pile. And water also promotes fermentation.

If carbon monoxide is measured, it should be combustion occurred inside the pile. Our experience shows oxygen concentration is about 10 to 15 % at the tube when combustion started [9]. And sometimes hydrogen sulfide is found at the top of rubble pile, when sulfur or sulfur-compound exists in the pile. Hydrogen sulfide is very danger for workers and firemen, so to monitor its concentration is important.

Even though the fire is extinguished, sometimes it re-starts because still there is huge combustible material and micro-organisms exist. Therefore we have to monitor the temperature of pile until it becomes cool. It is known fermentation mostly stops above 60℃. Then chemical reaction, oxidation of fatty acid ester starts [7]. Around 80-90℃, temperature increase stops because of water vaporization. If there is no immediate plan for disposal, fire-fighting sand and other fire-fighting equipment should be made available on the site.

6. Conclusions

Based on the results of the TG-DTA system measurements, the oxidative decomposition of the different types of rubble used in this study, except for sludge, began at temperatures between 160°C and 170°C and combustion took place if temperatures rose within this range.

As shown in the results of the C80 measurements, the process of heat generation leads to combustion in the rubble in which a small amount of heat generates from fermentation as a result of microbial activity. Next, oxidation of contained fatty acid ester begins if adiabatic conditions are adequate, resulting in a further rise in temperature and, subsequently, oxidative decomposition begins ultimately leading to combustion. We also observed the process of heat generation immediately after the start of measurement, which is considered to be a result of fermentation in the wood chips and rotten tatami samples in this study. At a temperature of 100°C or less, rotten tatami sample is believed to generate more heat than wood chips.

As shown in the results of the TAM measurements, all samples generated a greater amount of heat as a consequence of adding moisture content. Therefore, it is believed that the greater the moisture content of an item, the more prone it is to fermentation and generates heat more easily. This suggests that precaution is required during the warm rainy season when there are periods of repeated rainfall. In addition, even if there is a fire that has been hosed down and extinguished, there is a possibility of subsequent fermentation and heat generation leading to further ignition when there are items prone to fermentation located near the water-treated area. Therefore, it is considered necessary to continuously monitor the area around the source of fire, even after that fire has been extinguished.

To monitor temperature and gas emission is very important. As a safety precaution, a pile of rubble should be broken down regularly and it should not be kept in a pile for a prolonged period of time. If possible, at the time when a tube is penetrated into the pile to dissipate heat, a thermocouple should be inserted through the tube to monitor the internal temperature. In addition, rubble should be separated into types based on the tendency to ferment, and the heat generated during fermentation should be disposed first. If there is no immediate plan for disposal of rubble, fire-fighting sand and other fire-fighting equipment should be made available on the site.

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