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The Correlation Between Surface Shapes and Heat Conduction

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1. Abstract

Our research question was based on the idea that the rate that object heat up might differ depending on the difference between their shapes even if they are made of the same substance. In this study, we prepared two kinds of rubber plates; one has holes on the surface, and the other does not. We heated them with a light bulb and compared how fast they got hot. As a result, we found that objects with holes need a longer time to reach a particular temperature than objects with no holes, which means that a shape with holes absorbs less heat.

2. Introduction

We heard that, when the inside of a car becomes hot due to sunlight or another heat source, the handle with holes on the surface is more difficult to warm up than one with no holes. Then we became interested in the relationship between the surface structure of an object and its temperature, and decided to investigate whether that relationship really exists or not. If we found that it exists, we would also like to research how and why it exists and what kind of structures are difficult to warm up. An example application of this research, could include preventing playground equipment made of metal from overheating in summer by changing the surface into something difficult to warm up. We might also be able to suppress the heat island phenomenon by creating buildings and roads with heat resistant structures.

3. Hypothesis 1

Objects with holes on the surface are more difficult to warm up than those with a flat surface.

4. Experiment 1

We conduct this experiment to check if such a phenomenon occurs.

4-1. Methods

In Experiment 1, we used the following tools to confirm the hypothesis 1.

(Figure 1) Rubber Plate A

(Figure 2) Rubber Plate B

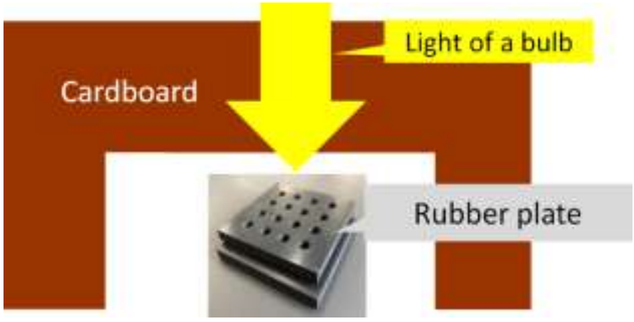
(Figure 3) Cardboard Box with Light Bulb

(Figure 4) Radiation Thermometer

・Rubber Plate A (length 100mm, width 87.4mm, thickness 10mm, mass 102.9g)
・Rubber Plate B (100mm square, thickness 10mm, mass 102.9g, 16 holes with a diameter of 10mm that penetrate the plate)
・Cardboard box (length 31.5cm, width 38.0cm, height 23.0cm)
・Incandescent lamp
・Radiation thermometer

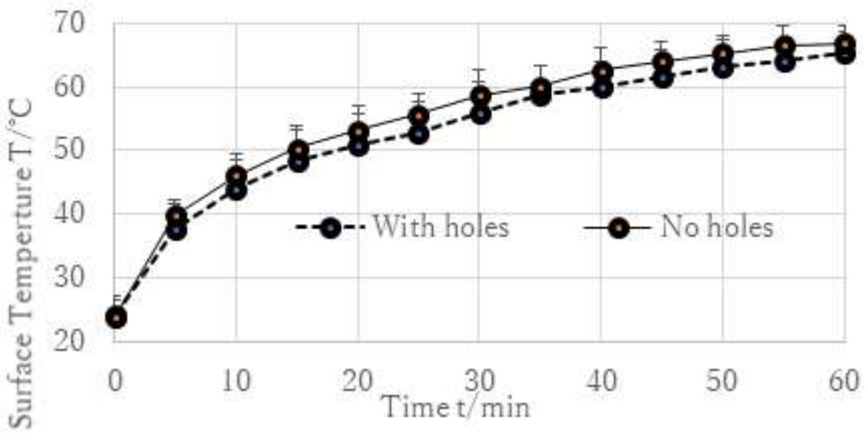
We heated each rubber plate from a fixed distance with an incandescent lamp in an enclosed space covered with a cardboard box. Every five minutes we removed the cover of the cardboard box for a fixed period of time and measured the temperature of the rubber plates with a radiation thermometer. In each experiment we heated the plates for an hour, and repeated the experiment 11 times in total.

(Figure 4) Experimental Figure



4-2. Results 1

(Graph 1) Relationship between Elapsed Time and Surface Temperature



The surface temperature of the rubber plate with holes did not rise as much as that of the flat rubber plate.

The difference in temperature between the two plates appeared shortly after the start of the experiment, and the difference in temperature remained almost identical until the end of the experiment.

5. Analysis 1

Focused on rubber objects, it can be said that objects with holes on the surface are more difficult to warm up than those with a flat surface, which proves Hypothesis 1 to be right. Then we considered why objects with holes are more difficult to warm up, and thought that it might be because air in the holes prevents heat convection.

5. Experiment 2

5-1. Methods

In order to clarify whether air in the holes prevents heat convection, we conducted Experiment 2. In this experiment, we covered the rubber plates with a transparent aquarium instead of a cardboard box and filled the inside with incense smoke so that we can observe how air moves around the plate when they are heated. We observed the movement of air while heating the plate in the same way as Experiment 1 and measured the temperature

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5-2. Results 2

Contrary to Hypothesis 2, we could not observe smoke staying in the holes of the plate.

5-3. Analysis 2

From the result of Experiment 2, Hypothesis 2 proved to be wrong, which means that air inside the holes of the plate does not insulate the plates. We could observe air smoothly circulate around the inside of the aquarium, so we thought that air might be acting as a heat conveyor rather than insulation, and that it might be the reason why objects with holes are more difficult to warm up. The surface area of the plate with holes is larger than that of one with no holes, so the plate with holes might release more heat to air.

6. Verification

In order to confirm the consideration in "5-3. Analysis 2", we reanalyzed the results of Experiment 1, using the following formula to calculate the amount of heat loss of each rubber plate, and to clarify the relationship between surface area and heat loss.

(Formula 1) Heat Loss Formula

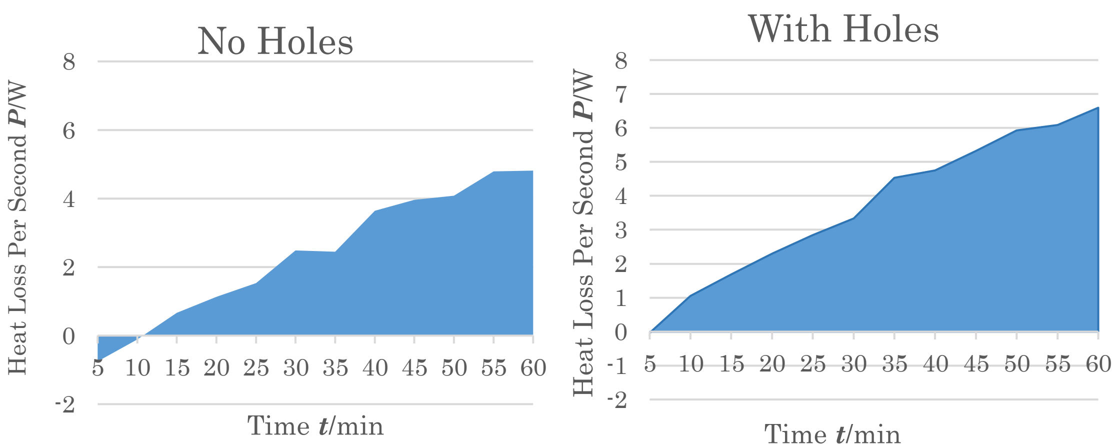
Heat loss [H]

$$H = F + G$$
$$F[W] = (D - E) \times A \times C$$
$$G[W] = (D^4 - E^4) \times B \times \sigma$$

F: Heat loss due to circulation (W) G: Heat loss due to radiation(W)
D: Object temperature (K) B: Object surface emissivity
E: Atmospheric temperature (K) A: Surface area(m^2)
σ: Stephan Boltzmann constant($W\ m^{-2}\ K^{-4}$) C: Circulation rate

(Graph 2) Relationship between Presence of Holes and Heat Loss

Filled Area=Heat Loss



Judging from these graphs, the plate with holes seems to lose heat more easily than one with no holes. However, we cannot fully verify Hypothesis 3 just with the results of Experiment 1, in which the rubber plates were heated by a light bulb and cooled by air at the same time, so we conducted Experiment 3 to verify Hypothesis 3 more objectively.

7. Experiment 3

7-1. Methods

To quantify how differently the two kinds of rubber plates cool down, we conducted Experiment 3 with the same equipment as Experiment 1. Below is the method of this experiment. We conducted it five times in total.

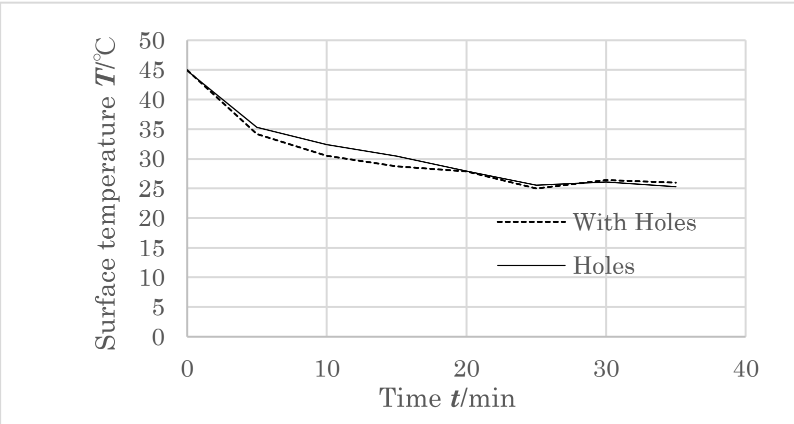
First. Heat the two plates with a light bulb in a cardboard box till they reach 45℃

Second. Stop heating the plates and remove the cardboard box

Third. Leave the plates on the experiment desk and take the temperature of them every 5 minutes

7-2. Result 3

(Graph 1) Relationship between Elapsed Time and Surface Temperature



We could observe little difference in the temperature of the two plates.

7-3. Analysis 3

We believe there was little difference in temperature between the two plates, because the method of Experiment 3 was inappropriate to compare how fast the two plates could cool down. Instead we should have taken into consideration that the rubber plates were giving off heat not only to the air, but also to the desk which both plates were sat on. In future experiments we should suspend the plates so that when we test the temperature of the plates, the contact area with the desk doesn't interfere with our data.

We can analyze the heat conduction of the rubber plates to the outside when they cool down by separating it into two aspects; conduction to air around the plates and conduction to the experiment desk. The two plates had the same surface area in the flat part, so their contact area with the experiment desk was equal to each other, which means that the amount of heat conduction of them to the desk was almost same.

Taking this into account, Experiment 3 was not appropriate for measuring the difference of the two plates.

8. Conclusions

We made two hypotheses (Hypothesis 2 and 3) to explain why a plate with holes is more difficult to warm up than one with no holes. However, Hypothesis 2 was rejected and Hypothesis 3 has not been fully proven yet. After all, the only thing we were able to find in this study was that “as for rubber, objects with holes are more difficult to warm up than those with no holes.”

9. Future Outlook

We would like to test Hypothesis 3 further. We consider it effective to calculate the heat flow rates of the two kinds of rubber plates to only air using the formula explained in section “8 Verification."

And, when heated with a light bulb, a rubber plate gradually warms up from the surface, so heat conduction of it occurs not only to air or other objects but also to the inside of the object. This is likely to be relevant with how and why plates warm up, so we think it effective to use a thermocouple to investigate the temperature of the inside of the plates in future experiments.

10. References

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