STUDY ON SAFE SURFACE TEMPERATURE FOR HANDLING*

Satoshi KAWASAKI[1)], Isamu MATUI, Satoshi TANABE Noboru YUASA

ABSTRACT : This paper describes thermal sensation of a palm in contact with a high temperature surface contacting time, temperature changes of a contact part using an artificial foot. Aluminum, stainless steel, granite, glass, acrylic resin, and wood were used for the test. The surface temperature of these materials were kept at 40 to 52℃ in the 20℃-room. The thermal sensation just after contact, contacting times felt "hot" and removed hand were estimated by 10 subjects aged 21 to 23 years old. As a result the thermal sensation just after contact differs in kind of material. The material with a higher contact coefficient feels hotter than that of lower even if the surface temperature is the same. The contact times felt "hot" and removed hand are able to estimate by the thermal sensation just after contact. The contact thermal sensation immediately after a contact can be evaluated by the temperature change after 1 min measured by the artificial foot.

Key words : Contact thermal sensation, Contact possible time, Contact limit time, Artificial foot, Hot surface,

1. Introduction

Workers have so many chances to contact a high temperature surface or a low temperature surface in construction work or daily life. Sometimes it gives rise to lowering of workability in work contacting a material at a high or low temperature and sometimes causes harming a human skin. It requires a safe surface temperature and safe working time not to disturb work.

Studies on contacting a high surface temperature in the past are as follows: Stoll et al[1)].irradiated radiation heat to the forearm skin and reported the limit temperature of pain was 43.2℃ at 200 μm under the skin. Probert[2)] calculated a safe tolerance contacting temperature from the thermal characteristics of the human skin, the extent of damage when the skin contacted a high temperature, and the contact coefficient of material. Ray et al[3)]. described that contacting a high temperature object was regulated by the contacting temperature and the contact coefficient and reported the surface temperature that a subject felt "hot" based on the result of test on a subject. P.P. Lele et al[4)]. made clear that the surface temperature, the contacting time and the thermal sensation when the back of a subject's hand touched a glass tube flowing hot water. Leon et al[5)]. elucidated the time and the skin temperature which caused "pain" and "blister" by irradiating the radiation heat of a lamp to the forearm part of a subject. Moritz et al[6)]. tested with the skin of pig in contact with hot water and found out the contact temperature and the contact time that the skin started the damage and reached the complete necrosis. Bueltner et al[7)]. numerically analyzed heat transmission and measured the time from starting of irradiation of radiator heat actually to the palm of a subject until the subject sensed "pain" and reported the average temperature of pain limit is 44.8 ± 0.4℃. As the standard on safe time of contacting on a high temperature surface, JIS, BS, MIL, EN, etc. exist as showed in Table. 1. Now, "Human contact

* Proceedings of The 5th Korea/Japan Joint Symposium on Buildings Materials & Construction Vol.5 August 2000 PP101～107, (韓国, 忠南大学校国際文化センター, 2000. 8 .18～19)

1) Daiichi Institute of Technology Univ, Prof, Dept. of Architecture, Faculty of Engineering

Table-1 Safe surface temperature of each standard　　Unit(℃)

Contact time	Standard*	Kind of material			
		Metal	Ceramic	Plastic	Wood
8 hours	EN	43	43	43	43
10 minutes	EN	48	48	48	48
1 minutes	EN	51	56	60	60
10～30 sec	EN	51	56	69	60
	JIS	55	55	70	70
	BS	55	65	75	75
	MIL	49	59	69	69
Less than 10 sec	JIS	60	60	75	75
	BS	60	70	85	85
	MIL	60	68	69	69

*EN563(1994), JIS A4002(1986), JIS A4422(1977)
MIL STD1472E, BSI PD6504 (1983)

Table-2 Kind of material and prescribed surface temperature

Test material	Thermal conductivity λ (W/m.K)	Density ρ (kg/m^3 $\times 10^3$)	Specific heat c(J/kgK $\times 10^3$)	Contact coefficient b* (J/m^{2}S$^{1/2}$K $\times 10^3$)	Prescribed surface temperature (℃)
Aluminum	210.00	2.70	0.90	22.6	40,42,44,46,48
Stainless steel	16.28	7.91	0.50	8.02	40,42,44,46,48,50,52
Granite	3.50	2.80	0.84	2.87	44,46,48,50,52
Glass	0.78	2.54	0.77	1.23	46,48,50,52
Acrylic resin	0.22	1.20	1.26	0.58	46,48,50,52,54
Wood	0.12	0.40	1.30	0.33	46,48,50,52,54

*$b=\sqrt{\lambda \rho c}$

with hot surface" is under laying-down in ISO TC 157 SC5 WG1.

This study aims at elucidating the relation between the surface temperature and the contact time in contact with a palm from the view point of safety and workability of work in contact with a material surface of high temperature. This report describes thermal sensation of a palm in contact with a high temperature surface in a sensory test, contact possible time, temperature changes of a contact part using an artificial foot.

2. Test method

(1) Test materials

As showed in Table. 2, six kinds of materials (in dimensions of 300×300mm, thickness 10mm) with different thermal properties were used. The test was carried out setting 8 levels of prescribed surface temperatures.

(2) Heating unit

The heating unit for the test materials is shown in Fig. 1. The heating part of this unit comprises a flat heater (silicone rubber heater, 100V, 540W) equipped with a 1 mm thick copper plate for uniform temperature of the surface.

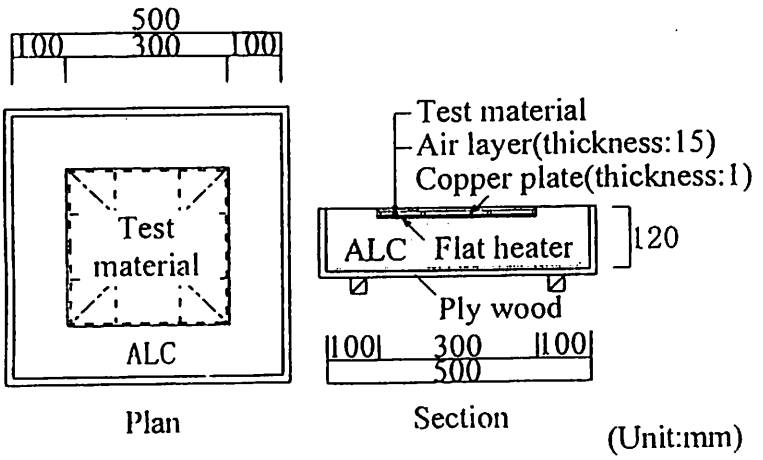

Fig.1 Heating unit for test material

A lattice with a 1 mm thick and 15 mm wide wood block was assembled to provide a 15 mm thick air layer on the copper plate.

The test materials was heated by the radiation heat of the copper plate. The surface temperature of a test material was controlled by a volt slider and the voltage and the current in keeping a prescribed surface temperature were measured. The surface temperature of a test material was measured by a thermocouple (JIS C 6201 T, diameter 0.32 mm.) adhered on the central part of a test material by an adhesive tape and controlled with the prescribed temperature ±0.3℃.

(3) Sensory test

1) Subject

The subjects were five male students and five female students at ages 21-23. Every subject was kept in rest for 30 min. before the test.

2) Measurement of temperature of a contact part

The test was carried out in a room under a temperature of 20± 1℃. The temperature of contact part between a palm and a test material was measured by the thermocouple contacting a palm adhered with a medical tape. The pressure of contacting the palm on the test material was about 1 kg.

3) Evaluation of contact thermal sensation

A subject put a palm on the material and evaluated the contact thermal sensation as showed in Table. 3. The contact thermal sensation was evaluated immediately after the contact, after 5 min., and 10 min.

4) Contact possible time and contact limit time

The time until a subject sensed hot after contacting on a material was made the contact limit time. The time until a subject removed his hand from the material for not going on touch. The maximum of the contact time was 10 min.

Table-3 Evaluation of contact thermal sensation

Points in evaluation	Sense
6	Too hot to touch
5	Very hot
4	Hot.
3	Slightly hot.
2	Warm
1	Slightly warm
0	Neutral
−1	Slightly cold
−2	Cold
−3	Very cold
−4	Too cold to touch

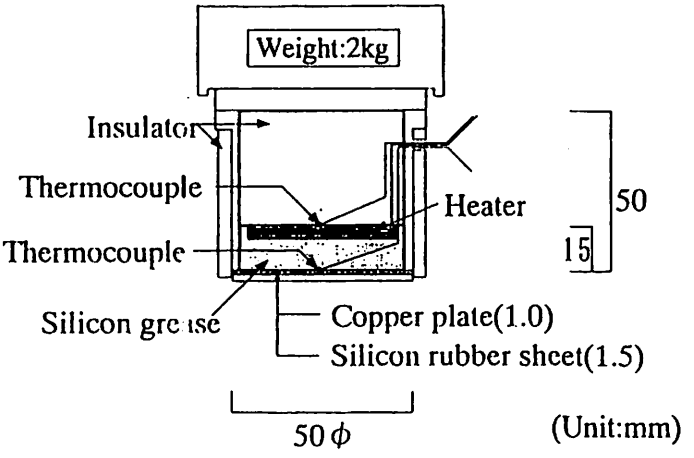

Fig.2 Artificial foot

(4) Measurement of temperature of contact part by artificial foot

1) Structure of artificial foot

The structure of the artificial foot used is shown in Fig. 2.

① The foot[9] was a vessel made of plastic with 50 mm of inner diameter, 50 mm of height, and 5 mm of wall thickness and filled with silicon grease. The face contacting with the material was a 1.0 mm thick copper plate adhered with a 1.5 mm thick silicon rubber sheet.

② The artificial foot had a disk shape heater. The temperature of the heater was controlled by a thermostat, which was set at a position 15 mm away from the copper plate so that the surface temperature reaches 30℃ (corresponding to human skin temperature) when the inner temperature is set at 33℃ (corresponding to temperature of deep part in hand or foot).

③ The inner part was filled with silicone grease (specific heat: 0.46 J/kg・K, specific gravity : 2.53kg/m³, heat conductivity: 0.628 W/m・K).

④ The temperature of central part of the artificial foot was measured by a thermocouple. The surface temperature was measured by a thermocouple attached on the copper plate.

⑤ A 2 kg weight was loaded on the artificial foot during contacting.

2) Measurement of temperature of contact part of artificial foot

The artificial foot was brought in contact with a material when the temperature of its central part reached 33℃ and the surface temperature 30℃ constantly by a condition exposed in air at 20 ± 1℃. Then the temperature of contact part of the artificial foot was recorded for 10 min.

3. Result and discussion

(1) Relationship between surface temperature of material and contact thermal sensation

The relation between the surface temperature of material and the contact thermal sensation immediately after contact is shown in Fig. 3 and the relation between the surface temperature of material and the contact thermal sensation after 10 min. is shown in Fig. 4.

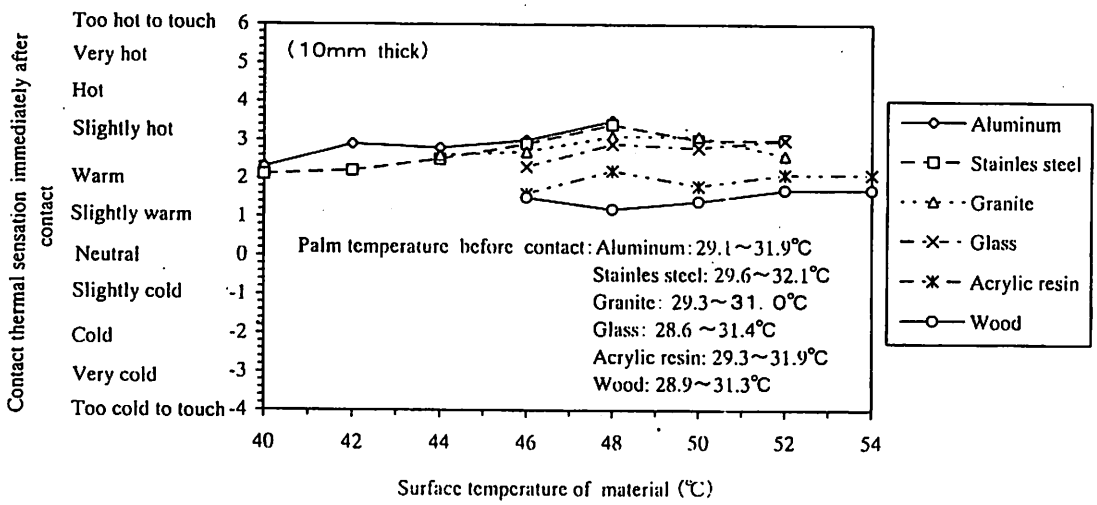

Fig-3 Relation between the surface temperature of material and the contact sermal sensation immediately after contact. (Average)

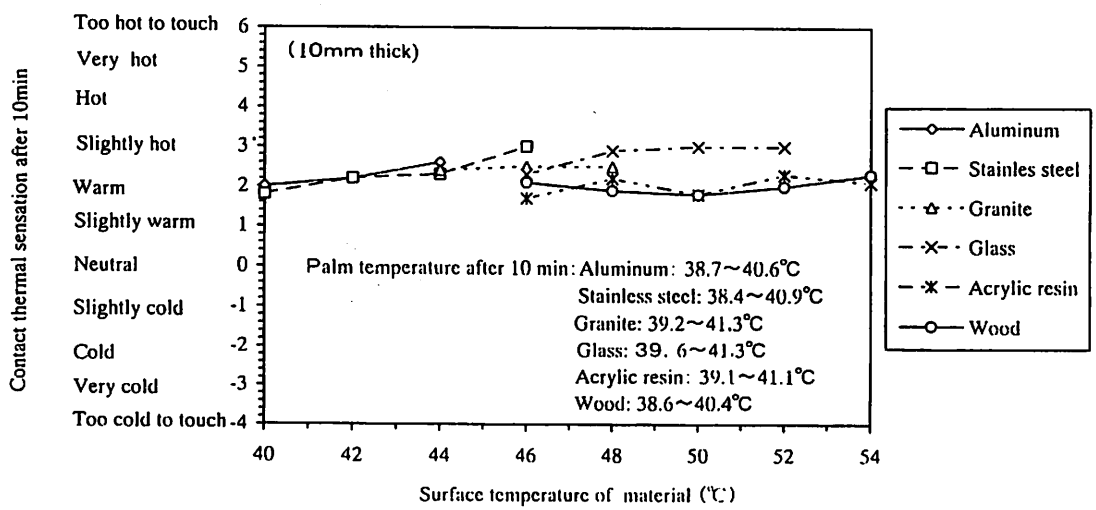

Fig-4 Relation between the contact thermal sensation after 10 min. and the surface temperature of material (Average)

The contact thermal sensation immediately after contact with aluminum, stainless steel, granite, and glass are within a range from "warm" to "slightly hot" and the higher the contact coefficient, the hotter the sense. However, the difference of the thermal sensation after 10 min between materials became smaller. Because the temperatures of palm after 10 min show almost the same value.

It is considered that though the contact thermal sensation is different as described above according to the kind of materials immediately after contact when a palm is brought in contact with a high temperature surface, the temperature of material becomes lower than the initially set surface temperature since a hand at about 30℃ is contact with the surface for 10 min., the temperature becomes lower than the initially set surface temperature and the temperature lowering is remarkable in a material with a large contact coefficient.

(2) Contact thermal sensation immediately after contact and contact possible time and contact limit time

The relation between the contact thermal sensation immediately after contact and the contact possible time is shown in Fig. 5. The relation between the contact thermal sensation immediately after contact and the contact limit time is shown in Fig. 6. Both relations show smooth curve and the contact possible time and the contact limit time

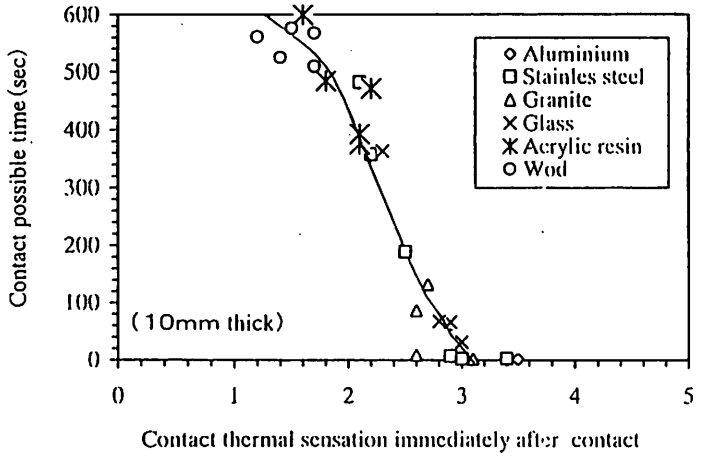

Fig-5 Relation between contact thermal sensation immediately after contact and the contact possible time

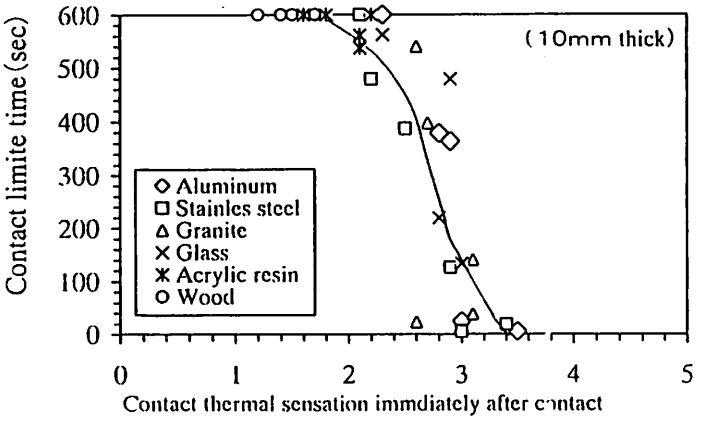

Fig-6 Relation between contact thermal sensation immdiately after contact and the contact limite time

can be expressed by the contact thermal sensation immediately after contact.

(3) Temperature change of contact part of artificial foot

Temperatures of contact part of the artificial foot and the palm of subject are shown in Fig. 7. The temperatures of palm before the contact are different by subjects, but all the temperature of palm quickly rises in 1 min. after the contact and gradually rises after that. On the other hand, the temperature of artificial foot kept rising as time elapsed. The temperature change of artificial foot is slightly different from that of a subjects palm. Since the temperature of palm quickly rises for 1 min. after a contact and gradually rises thereafter, the temperature after 1 min. after contact is noticed as a physical quantity to evaluate the contact thermal sensation.

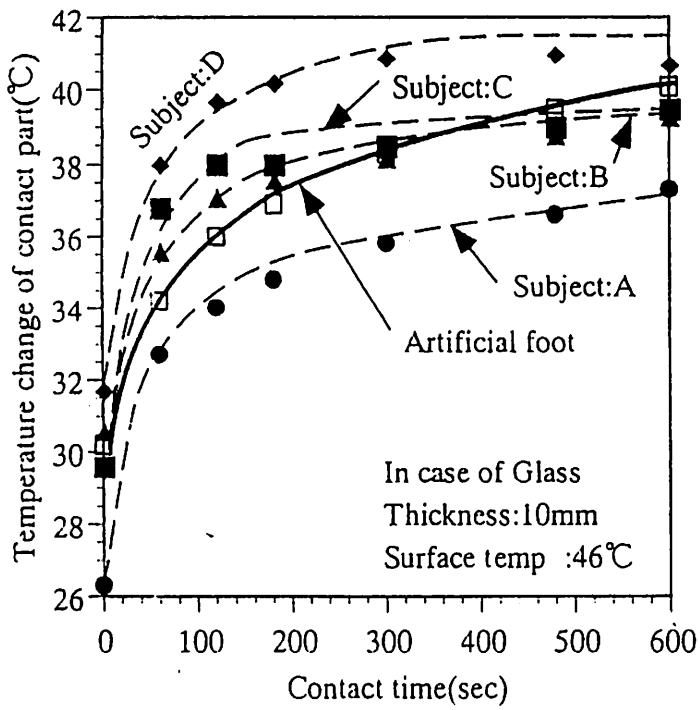

Fig.7 Temperature of contact part of artificial foot and palm of subject

(4) Relation between surface temperature and temperature change of contact part after 1 min.

The relation between surface temperature and temperature change of contact part after 1 min. by the artificial foot is shown in Fig. 8. The temperature change of contact part is calculated by the equation (1):

$$ {}_cT_1 = T_1 - T_0 \quad \cdots\cdots (1) $$

where

${}_cT_1$: Temperature change of contact part(℃)

T_1: Temperature of contact part after 1 min. (℃)

T_0: Surface temperature of artificial foot before contact (℃)

The temperature change of contact part is different according to kinds of materials and surface temperatures. The temperature change was largest in aluminum and stainless steel, granite, glass, acrylic resin, and wood followed in that order. This order matches the contact coefficient of material.

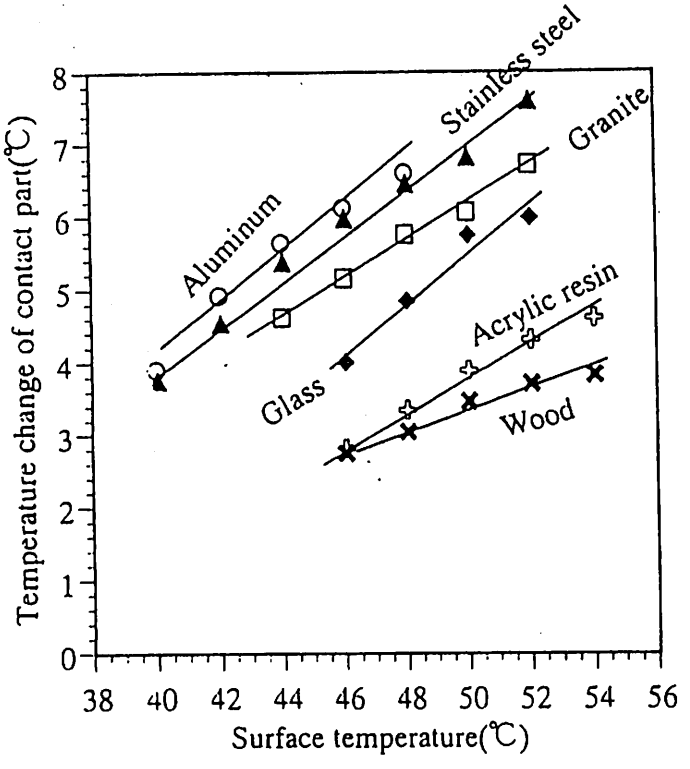

Fig.8 Relation between the surface temperature of material and the temperature change of contact part

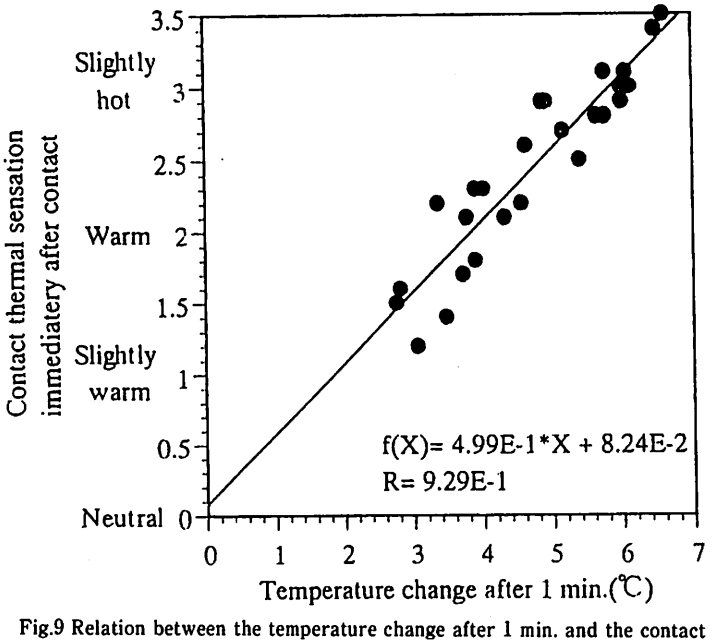

Fig.9 Relation between the temperature change after 1 min. and the contact thermal sensation immediately after contact

(5) Relation between temperature change after 1 min. and contact thermal sensation immediately after contact

The relation between temperature change and contact thermal sensation immediately after a contact is shown in Fig.9. The relation between both has some scatter but can be shown in one straight line. According to the result, it is evaluated "hot" when the temperature change is 5.8 ℃ and "warm" when 3.8 ℃. The contact thermal sensation immediately after a contact on a high temperature surface largely changes by kinds and surface temperatures of a material, but it can be evaluated by the temperature change after 1 min. measured by the artificial foot as an index.

4. Conclusion

The test results are summarized as follows:

(1) In case of a contact with a high temperature surface, the contact thermal sensation immediately after contact remarkably differs according to materials, but the difference becomes smaller after 10 min.

(2) The contact possible time and the contact limit time can be evaluated by the contact thermal sensation immediately after a contact.

(3) When the artificial foot is brought in contact with a material, the state of change in the temperature of contact part is slightly different from the trend by the palm of a human hand.

(4) In case of a high temperature surface, the contact thermal sensation immediately after a contact can be evaluated by the temperature change after 1 min.

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