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Agenda item 8)

INVESTIGATION OF A BURN THRESHOLD TO PREVENT SKIN BURN FROM THE HOT TEXTILE SURFACE OF RADIANT WARMERS

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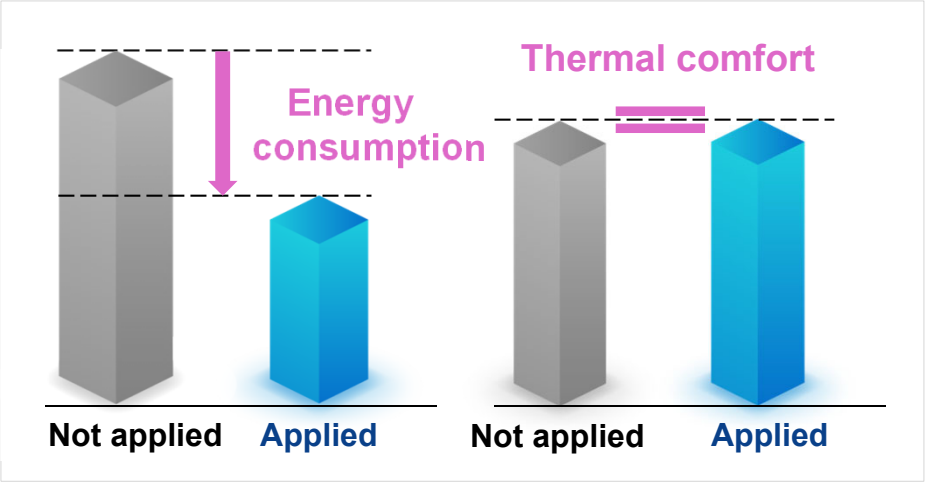
Radiant Warmers

Driving Range Decrease due to HVAC in EV

Mitsubishi Electric Vehicle, i-MiEV
- Cooling, 25% (max 44%) down
- Heating, 44% (max 63%) down



Local Heating Using Radiant Warmers

- Energy saving without heating the entire cabin space
- Fast thermal comfort to passengers
- Effective for legs, arms, fingers, and feet

UN/ECE Regulation for Safety

UN/ECE(Economic Commission for Europe of the United Nations) Regulation No 122※

"The surface temperature of any part of the heating system likely to come into contact with any driver of the vehicle during normal road use shall be measured with a contact thermometer. ***No such part or parts shall exceed a temperature of 70 ℃ for uncoated metal or 80 ℃ for other materials"****.*

Barrier to increase the warmer surface temperature enough for thermal comfort

※ UN/ECE Regulation No 122, Uniform technical prescriptions concerning the approval of vehicles of categories M, N and O with regard to their heating systems, 2020.

Objectives

- To figure out how the temperature limitations in EU Regulation No 122 were determined
- To assess the appropriate temperature limitations of warmer surface materials (textile)

References Before the Regulation No 122

- European Directive 78/548 "*on the approximation of the laws of the Member States relating to heating systems for the passenger compartment of motor vehicles*"

  2.2.2. the occupants of the vehicle cannot, during normal road use of the vehicle, come into contact with any parts of the device liable to cause burns. This condition shall be considered to be satisfied if the parts do not reach a temperature of 80 °C;

- Directive 2001/56/EC "*relating to heating systems for motor vehicles and their trailers, amending Council Directive 70/156/EEC and repealing Council Directive 78/548/EEC*"

  2. The surface temperature of any part of the heating system likely to come into contact with the driver of the vehicle during normal road use shall be measured with a contact thermometer. No such part or parts shall exceed a temperature of 70 °C for uncoated metal or 80 °C for other materials.

- No explanation about how such temperatures were determined is provided.

International Standard: ISO 13732

- ISO 13732 "*Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 1: Hot surfaces*" (1st edition: 2006-09-01)
  - Applicable to products used in any environment (not limited only to vehicles)
- Annex A in ISO 13732 describes the scientific background in detail.
- CENELEC Guide 29 "*Temperatures of hot surfaces likely to be touched*" (2007) also has similar contents.

1 Scope

This part of ISO 13732 provides temperature threshold values for burns that occur when human skin is in contact with a hot solid surface.

It also describes methods for the assessment of the risks of burning, when humans could or might touch hot surfaces with their unprotected skin.

This part of ISO 13732 also gives guidance for cases where it is necessary to specify temperature limit values for hot surfaces; it does not set surface temperature limit values.

NOTE 1 Such temperature limit values can be specified in specific product standards or in regulations in order to prevent human beings sustaining burns when in contact with the hot surface of a product.

This part of ISO 13732 deals with contact periods of 0,5 s and longer.

It is applicable to contact when the surface temperature is essentially maintained during the contact (see 4.1).

It is not applicable if a large area of the skin (approximately 10 % or more of the skin of the whole body) can be in contact with the hot surface. Neither does it apply to skin contact of more than 10 % of the head or contact which could result in burns of vital areas of the face.

NOTE 2 In some cases, the results of contact with a hot surface can be more serious for the individual, for example:

— burns resulting in the restriction of airways;

— large burns (more than 10 % of the body surface) that can impair the circulation by fluid loss;

— heating of a large proportion of the head or whole body that could lead to unacceptable heat strain even in the absence of burning.

This part of ISO 13732 is applicable to the hot surfaces of all kind of objects: equipment, products, buildings, natural objects, etc. For the purposes of simplification, it mentions only products; nevertheless, it applies to all other objects as well.

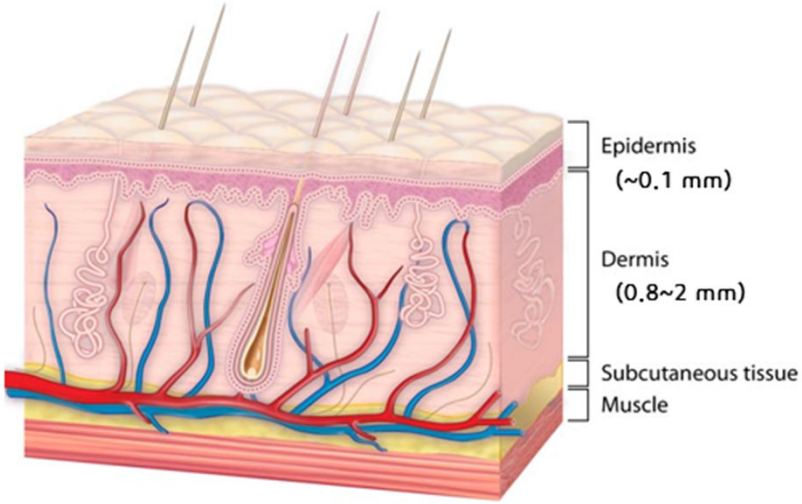
It is applicable to products used in any environment, e.g. in the workplace, in the home.

It is applicable to hot surfaces of products that may be touched by healthy adults, children, elderly people and also by people with physical disabilities.

It does not provide data for the protection against discomfort or pain.

Skin Structure and Factors to Cause Skin Burns

- Human skin is mainly comprised of four layers.
  - Epidermis, dermis, subcutaneous tissue, and muscle.
- Critical factors to cause skin burn are temperature and duration.
- Other factors such as contact pressure, skin thickness, and sweat also affect.



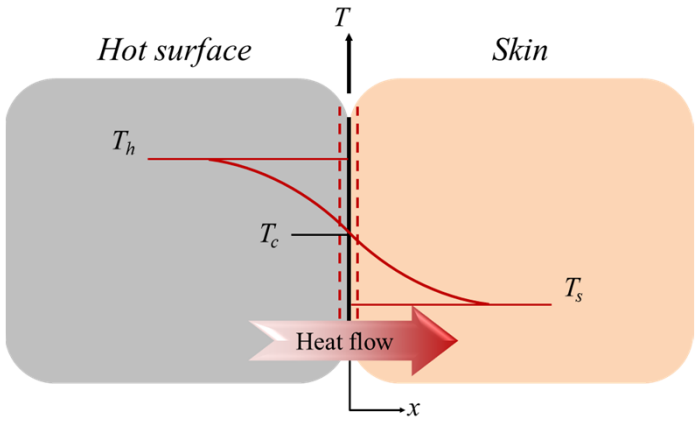
Definition of Burn Threshold in the ISO 13732

: surface temperature defining the boundary between no burn and a superficial partial thickness burn, caused by contact of the skin with this surface for a specified contact period

Classification	Description
superficial partial thickness burn (1^{st} degree)	in all but the most superficial burns, the epidermis is completely destroyed but the hair follicles and sebaceous glands as well as the sweat glands are spared
deep partial thickness burn (2^{nd} degree)	a substantial part of the dermis and all sebaceous glands are destroyed and only the deeper parts of the hair follicles or the sweat glands survive.
whole thickness burn (3^{rd} degree)	the full thickness of the skin is destroyed and there are no surviving epithelial elements

Terms for Temperatures

Term	Description	Symbol
Hot surface temperature	Temperature of a hot surface	T_h
Contact temperature	Temperature at the interface between hot surface and skin	T_c
Skin temperature	Temperature of skin	T_s

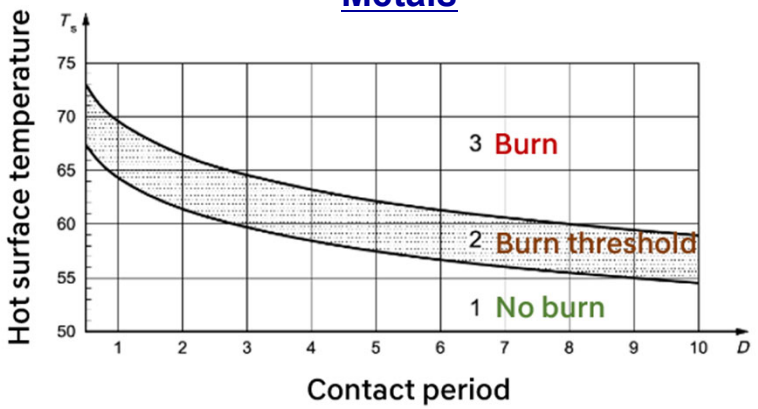


Sketch of the skin in contact with a hot surface

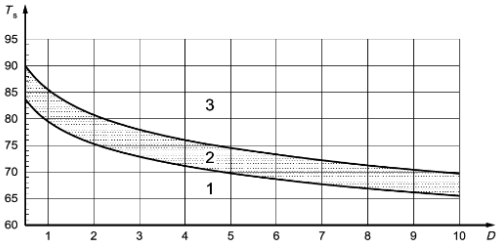
Burn Thresholds in the ISO 13732

- The ISO-13732 prescribes burn threshold bands for 4 groups of materials.
  1) metal
  2) ceramics, glass, and stone
  3) plastics
  4) wood
- Textiles, the surface material of radiant warmers, are not included.

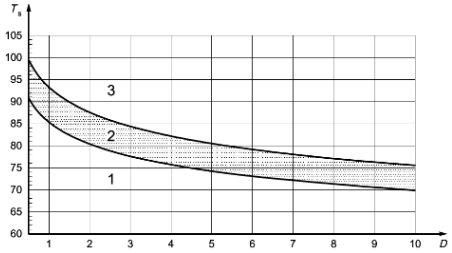
Metals



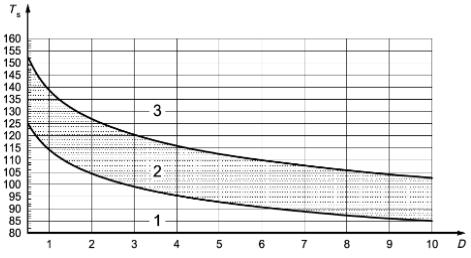
Ceramics, glass, and stone



Plastics



Wood



Determination of Contact Period

- A general selection of the contact period is 1 second, which corresponds to the quick withdrawal following pain sensation under unintentional contact.
- The temperature limitations in Regulation No 122 are likely to be determined from the burn threshold bands when skin burn occurs after 1 second.

Table B.1 — Guidance for the selection of contact periods

Contact period up to	Examples of touching a hot surface	
	Unintentional	Intentional
0,5 s	Touching a hot surface and fastest possible withdrawal following pain sensation without restriction of movement	— [a]
1 s	Touching a hot surface and quick withdrawal following pain sensation	— [a]
4 s	Touching a hot surface and extended reaction time	Activation of a switch, pressing a button
10 s	Falling against a hot surface without recovery	Prolonged activation of a switch, slight adjustment of a handwheel, valve, etc.
1 min		Turning a handwheel, valve, etc.
10 min		Use of control elements (controls, handles, etc.)
8 h		Continuous use of control elements (controls, handles, etc.)

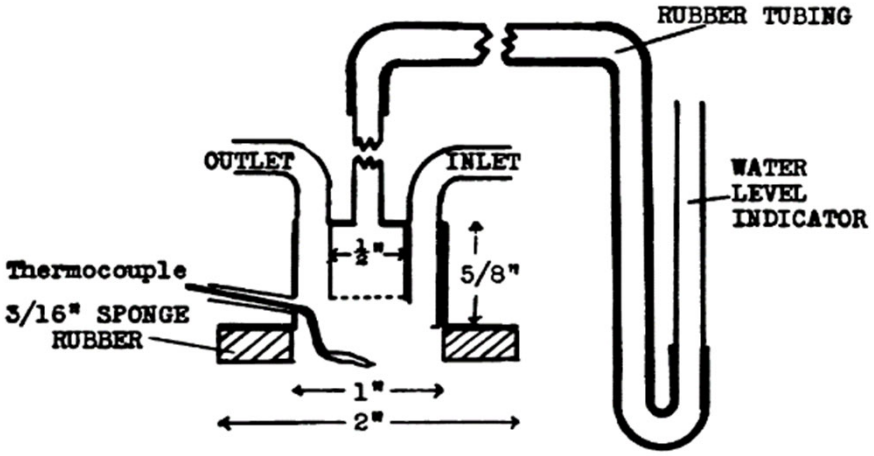
[a] Not applicable.

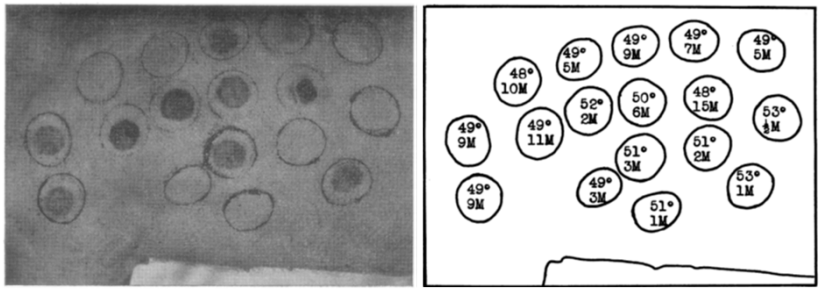
Burn threshold band when skin burn occurs after 1 second

Material	Metal	Ceramics	Plastics	Wood
Burn threshold (°C)	64 ~ 70	79 ~ 85	85 ~ 93	113 ~ 137

Experiment to Evaluate Skin Burn by Moritz and Henriques

- Moritz and Henriques※ measured the contact temperature using porcine and human skins when skin burn occurs in 1947.
- The contact temperature was maintained using a rapidly flowing stream of hot liquid.
- “The surface of the skin could be maintained at the temperature desired without the establishment of an appreciable gradient (<0.1 ℃) between it and the source of heat.”



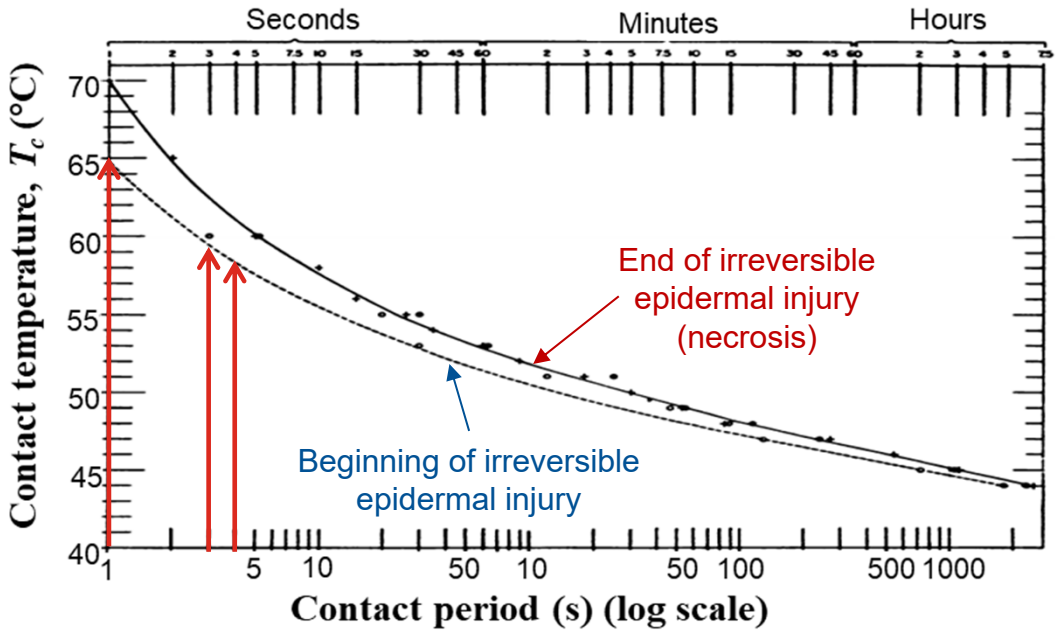


※ Moritz AR, Henriques FC. The relative importance of time and surface temperature in causation of cutaneous burns. Am J Pathol 1947;23(5).

Contact Temperature When Skin Burn Occurs

- Skin burn was evaluated by the contact temperature.

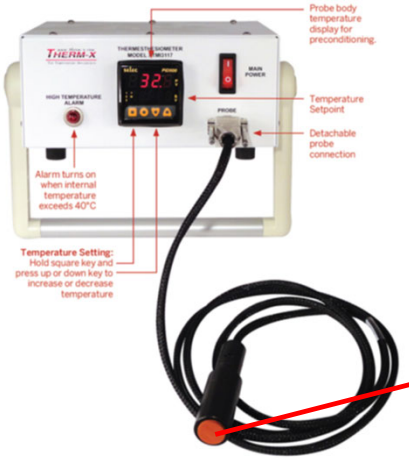
Contact period	1 sec	3 sec	4 sec	1 min	8 hour
Contact temperature (T_c)	65 °C	59 °C	58 °C	51 °C	43 °C



Thermesthesiometer

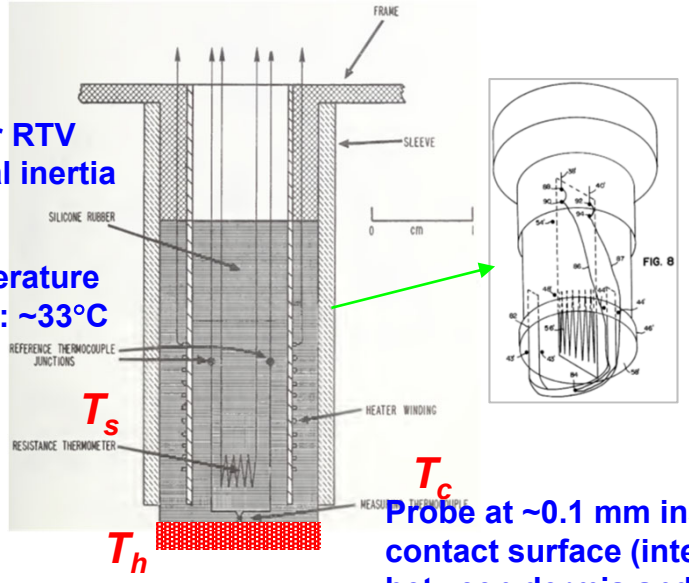
- The hot surface temperature (T_h) is easier to use than the contact temperature (T_c) for estimating skin burn.
- Marzetta※ developed an instrument (thermesthesiometer) to measure the hot surface temperature and the contact temperature.

Thermesthesiometer



silicone rubber RTV (similar thermal inertia to human skin)

Internal temperature inside fingers: ~33°C



T_s

T_c

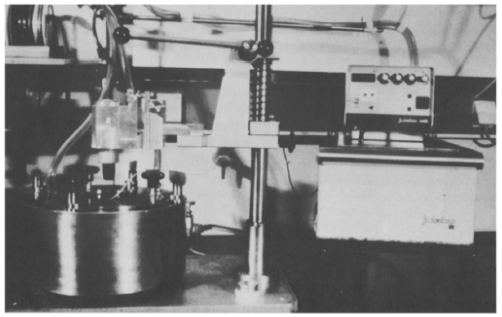
T_h

Probe at ~0.1 mm inside from the contact surface (interface between dermis and epidermis)

※ Marzetta L. A thermesthesiometer – an instrument for burn hazard measurement. IEEE Transactions on Biomedical Engineering, September 1974, pp. 425–427.

Measurement of Hot Surface Temperature by Materials

- Siekmann※ experimentally investigated the relation between the contact temperature and the hot surface temperature using a thermesthesiometer for various materials.



- ASTM C1057† is based on this procedure.

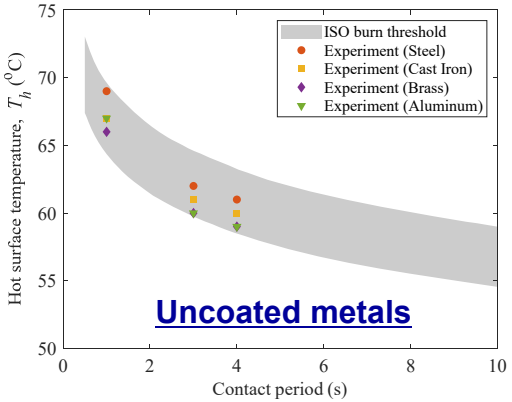
Material	Hot Surface Temperature, T_h (℃)		
	for T_c= 65 ℃ (1 sec)	for T_c= 59 ℃ (3 sec)	for T_c= 58 ℃ (4 sec)
Metal			
Aluminum	67	60	59
Brass	66	60	59
Cast iron	67	61	60
Steel	69	62	61
Glass, ceramic			
Glass (float glass)	86	78	77
Ceran (glass ceramic)	80	73	71
Concrete	80	72	70
Plastics			
Polyamid 11-12	86	76	73
Plexiglass	–	84	83
Teflon	–	87	85
Wood	115	95	93

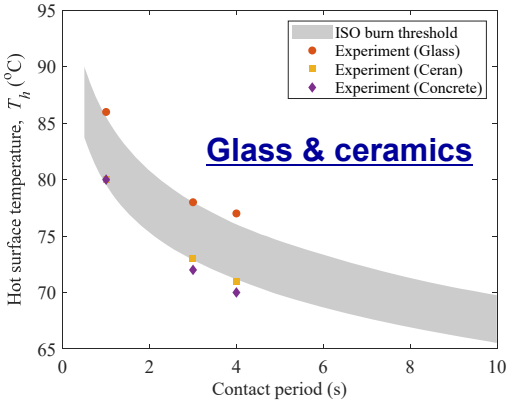
※ Siekmann H. Recommended maximum temperatures for touchable surfaces. Appl Ergon 1990;21(1):69–73.

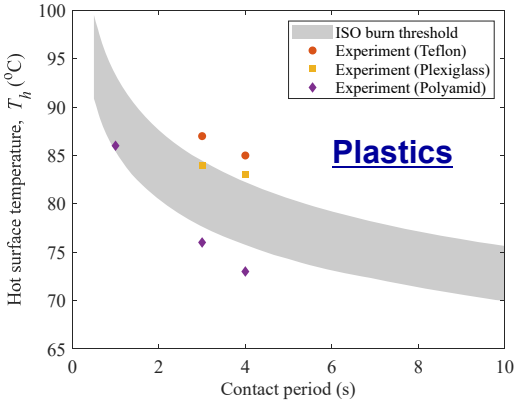
† ASTM C1057 Standard practice for determination of skin contact temperature from heated surfaces using a mathematical model and thermesthesiometer.

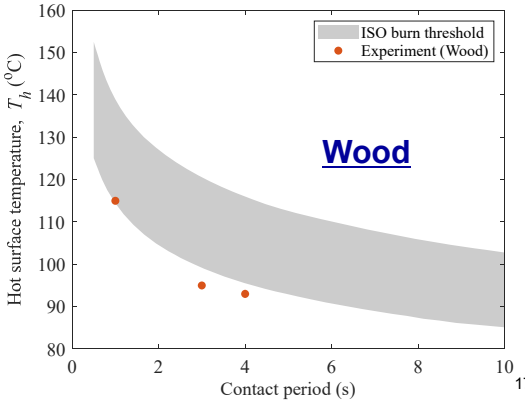
Comparison of Hot Surface Temperatures

- The measurement data of hot surface temperature by Siekmann agree with the burn threshold band in ISO-13732.
- We confirmed that the ISO-13732 was established based on measurement using the thermesthesiometer.







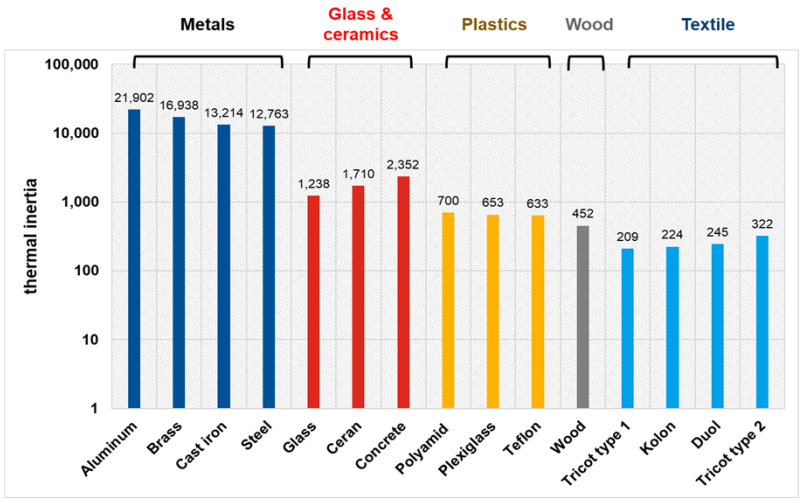


Guideline for Unspecified Materials in the ISO 13732

- The thermal inertia of an unspecified material has to be compared with the thermal inertias of the specified groups of materials: metals, ceramics and glass materials, plastics or wood.
- The material can then be accorded a burn threshold value from the material group with the same thermal inertia.
- The thermal inertias of textiles are typically smaller than those of specified materials.

thermal inertia: $\lambda = \sqrt{k \rho c}$

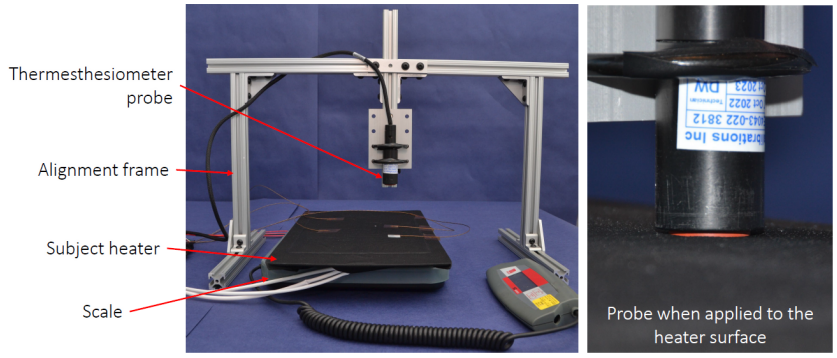
thermal conductivity: k
density: ρ
specific heat: c



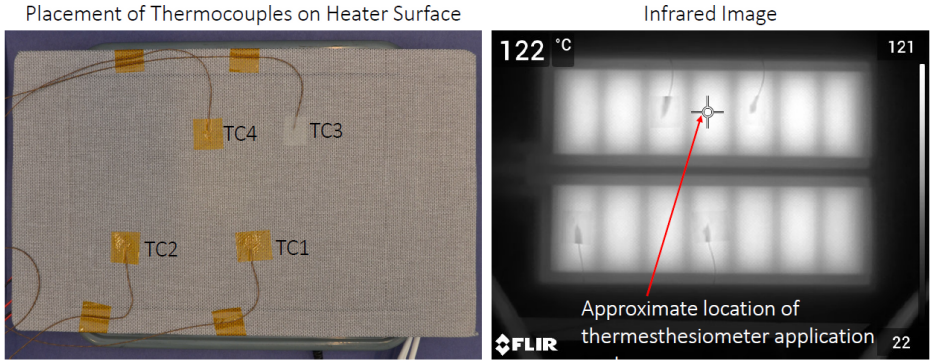
Measurement of Hot Surface Temperature for Textiles

- Hot surface temperatures of 3 textile samples were measured 3 times each using a thermesthesiometer.
- Approximately 2~3 kg of force was applied for the appropriate contact between warmer and probe.
- Warmer surface temperatures were recorded by an IR camera and 4 thermocouples.

Sample 1 Sample 2 Sample 3



Experimental setup to measure T_h

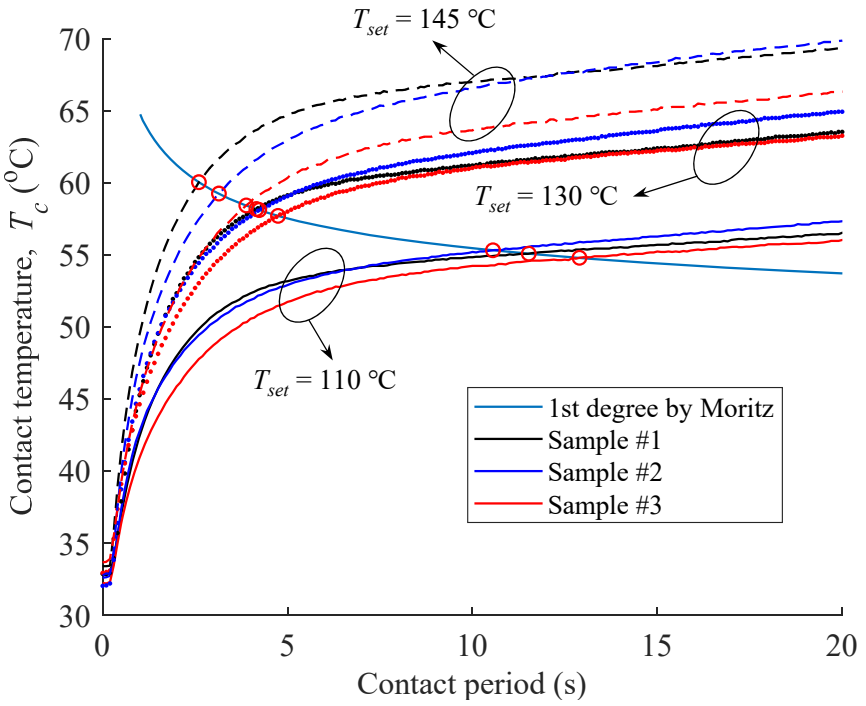


Temperature measurement using an IR camera

Evaluation of Skin Burn from Hot Textiles

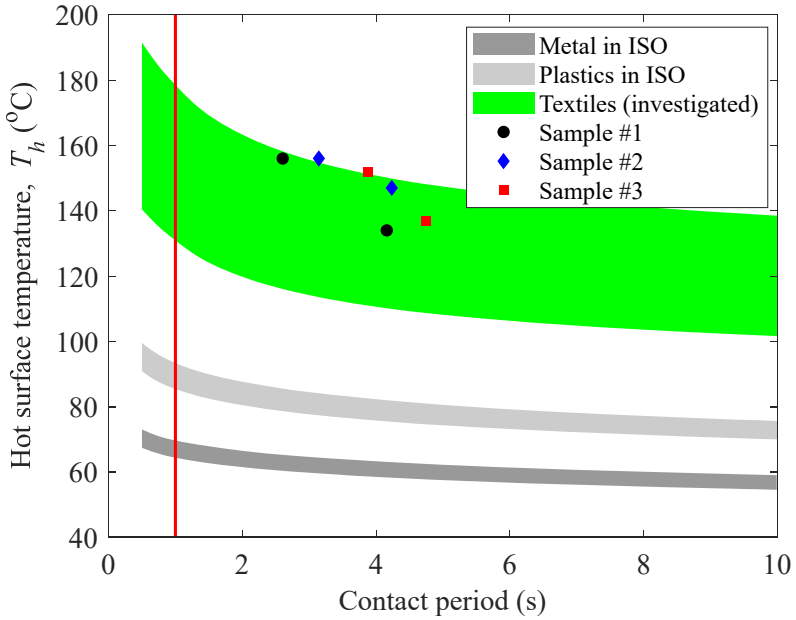
- The contact periods to skin burn are longer than 1 second even if the hot surface temperature (IR) exceeds 150 ℃.
- Based on the contact period of 1 second, the sample textiles do not cause skin burn at least up to 150 ℃.

Sample #1	T_h	115 °C	134 °C	156 °C
	Time to burn	11.52 s	4.16 s	2.60 s
Sample #2	T_h	122 °C	147 °C	156 °C
	Time to burn	10.56 s	4.23 s	3.14 s
Sample #3	T_h	116 °C	137 °C	152 °C
	Time to burn	12.89 s	4.74 s	3.88 s



Investigation of Burn Threshold for Textiles

- We investigated the burn threshold band of textiles using the thermesthesiometer data of the 3 samples and the thermal inertias of the 4 samples .
- We found that the temperature to cause skin burn from hot textile surfaces after 1 second approximately ranges from 130 to 180 ℃.



Summary

- The UN/ECE Regulation No 122 prescribes the surface temperature of any materials in vehicles not to exceed 80 ℃ for preventing skin burn.
- This regulation does not allow the effective operation of radiant warmers for local heating in EVs, which requires the surface temperature larger than 80 ℃.
- Skin burn is a function of not only hot surface temperature but also contact period and material properties.
- After a thorough literature review, we strongly believe that the temperature limitations in the Regulation No 122 were determined based on the similar scientific background of the ISO 13732.
- Following the procedure using thermesthesiometer measurement and heat transfer theory as in the ISO 13732, we suggested a burn threshold of textile materials.
- Based on the contact period of 1 second, the hot surface temperature of textiles as large as 130 ℃ does not cause skin burn.

Appendix. Material Properties

Material	Thermal conductivity (W/m·K)	Specific capacity (J/kg·K)	Density (kg/m^3)	Thermal inertia (J/s$^{1/2}$·m^2·K)
Metals				
Aluminum	203	872	2,710	21,902
Brass	85.5	377	8,900	16,938
Cast iron	52.0	460	7,300	13,214
Steel	45.3	461	7,800	12,763
Glass, ceramics				
Glass (float glass)	0.88	670	2,600	1,238
Ceran (glass ceramic)	1.46	795	2,520	1,710
Concrete	2.43	922	2,470	2,352
Plastics				
Polyamid 11-12	0.21	2,100	1,110	700
Plexiglass	0.2	1,810	1,190	653
Teflon	0.35	1,200	2,000	633
Wood	0.18	1,720	660	452

Appendix. Material Properties

Material	Thermal conductivity (W/m·K)	Specific capacity (J/kg·K)	Density (10^3·kg/m^3)	Thermal inertia (J/s$^{1/2}$·m^2·K)
Fabrics				
Tricot type 1	0.20	524	0.419	209
Kolon	0.21	538	0.445	224
Duol	0.25	592	0.405	245
Tricot type 2	0.30	733	0.472	322