A STUDY OF VARIOUS HEAT RESISTANT GLOVES FOR PREVENTION OF HEAT CONDUCTION

MAKAPORN PETKHIAW

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A STUDY OF VARIOUS HEAT RESISTANT GLOVES FOR PREVENTION OF HEAT CONDUCTION

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ABSTRACT

The study was conducted in the plastic manufacturing factory located in Rayong province. This study aimed to compare the effectiveness of heat resistance among various heat resistant gloves for prevention of heat conductivity. Four types of gloves selected in this study were Cotton-Cotton gloves, the white-knitting gloves that have double layer made from cotton (CC); Nylon-Cotton gloves, the gloves that have Nylon line in inner layer and Cotton line in outer layer (NC); Nylon-Kevlar gloves, the gloves that have Nylon line in inner layer and Kevlar line in outer layer (NK); and Cotton-Kevlar, the gloves that have Cotton line in inner layer and Kevlar line in outer layer (CK).

The methods of this study were 1) measurement of the temperature passing through four types of gloves 2) test for Clothing insulation level (Clo value) of CC gloves and CK ones 3) measurement of operators' fingertip skin temperature while wearing CC glove comparing with CK ones, and 4) interview for the subjective feeling while performing the job using CC gloves and CK gloves. The fingertip skin temperature and subjective feeling were conducted in eight operators.

Results revealed that Clo value of CC gloves and CK gloves were 0.47 and 0.36 respectively. The Clo value of CC gloves was higher than that of CK gloves. The thermal conductivity among those four types of gloves showed that CK gloves were the best in prevention of high temperature. The measurement of fingertip skin temperature when using CC gloves showed higher finger temperature than that of CK gloves (p value = 0.0039). The CK gloves were better than CC ones in terms of resistance to high temperature.

It is recommended that the CK gloves should be the alternative Personal Protective Equipment (PPE) for working with hot object or hot surface in order to prevent burn injury. Besides the good heat resistance, CK gloves were also effective in the abrasive resistance. It could be recommended that CK gloves could be a proper PPE for task, in which cutting hazards were presented. However, the weaving pattern of gloves should be studied for the better quality of heat resistance.

KEY WORDS: HEAT/GLOVES/BURNS/ FINGERTIP SKIN TEMPERATURE / PERSONAL PROTECTIVE EQUIPMENT

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การศึกษาถุงมือกันความร้อนเพื่อป้องกันการนำความร้อน

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วท.ม.(สุขศาสตร์อุตสาหกรรมและความปลอดภัย)

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บทคัดย่อ

การศึกษาครั้งนี้ได้ทำการศึกษาที่บริษัทผลิตเม็ดพลาสติกซึ่งมีสถานที่ตั้งอยู่ในจังหวัดระยอง โดยมีวัตถุประสงค์เพื่อเปรียบเทียบประสิทธิภาพของถุงมือสี่ประเภทในการนำความร้อน ถุงมือทั้งสี่ประเภท ที่นำมาศึกษาได้แก่ ถุงมือผ้าฝ้าย-ผ้าฝ้ายซึ่งเป็นถุงมือที่ทำจากผ้าฝ้ายหนาสองชั้น (CC); ถุงมือ ไนลอน-ผ้าฝ้าย เป็นถุงมือที่มีถุงมือไนลอนอยู่ชั้นในและถุงมือผ้าฝ้ายอยู่ข้างนอก (NC); ถุงมือไนลอน-เคฟลาร์ เป็นถุงมือที่มีถุงมือไนลอนข้างในและถุงมือเคฟลาร์อยู่ข้างนอก(NK); และถุงมือผ้าฝ้าย-เคฟลาร์ ซึ่งเป็นถุงมือที่มีถุงมือผ้าฝ้ายอยู่ข้างใน และถุงมือเคฟลาร์อยู่ข้างนอก (CK)

วิธีการที่ใช้ในการศึกษาครั้งนี้ได้แก่ 1) การวัดอุณหภูมิที่ผ่านจากวัตถุร้อนมาบนผิวของถุงมือ ทั้งสี่ประเภท 2) ทดสอบค่าความเป็นฉนวนของเส้นใยผ้า (Clo) 3) วัดอุณหภูมิปลายนิ้วของพนักงาน ขณะที่ทำงานโดยสวมถุงมือ CC เปรียบเทียบกับถุงมือ CK 4) สัมภาษณ์ความรู้สึกของพนักงานเพื่อ เปรียบเทียบระหว่างถุงมือ CC และถุงมือ CK ซึ่งการวัดอุณหภูมิปลายนิ้วและการสัมภาษณ์ความรู้สึก ได้ดำเนินการทดสอบกับพนักงานจำนวน 8 คน

ผลที่ได้จากการทดสอบค่า Clo พบว่า ถุงมือ CC มีค่า Clo เท่ากับ 0.47 และถุงมือ CK เท่ากับ 0.36 ค่า Clo ที่ได้จากการทดสอบของถุงมือ CC สูงกว่าถุงมือ CK การวัดค่าการนำความร้อนผ่านถุงมือ ทั้งสี่ประเภทพบว่าถุงมือ CK สามารถป้องกันการนำความร้อนได้ดีที่สุด และการวัดค่าอุณหภูมิที่ ปลายนิ้วพบว่าอุณหภูมิที่ปลายนิ้วของพนักงานขณะที่สวมถุงมือ CC ทำงานสูงกว่าเมื่อสวมถุงมือ CK (p value=0.0036) จึงสามารถสรุปได้ว่าถุงมือ CK สามารถป้องกันการนำความร้อนได้ดีกว่า ถุงมือ CC

จากการศึกษานี้เสนอแนะว่าถุงมือ CK สามารถเป็นอีกทางเลือกหนึ่งของอุปกรณ์ป้องกันอันตราย ส่วนบุคคล (PPE) สำหรับการทำงานกับวัตถุหรือพื้นผิวร้อนเพื่อป้องกันการบาดเจ็บจากการเกิด แผลไหม้ นอกจากคุณสมบัติในการป้องกันความร้อนแล้วถุงมือ CK ยังมีประสิทธิภาพในการป้องกัน การขีดข่วน ด้วยคุณสมบัตินี้ ถุงมือ CK จึงอาจเป็น PPE ที่เหมาะสมกับการทำงานที่เสี่ยงต่อการบาดหรือถูกของ มีคมขีดข่วน อย่างไรก็ตามการศึกษาเกี่ยวกับรูปแบบการทอของถุงมือควรมี การศึกษาเพิ่มเติมเพื่อพัฒนา ประสิทธิภาพการป้องกันความร้อนที่ดีขึ้น

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LIST OF ABBREVIATIONS

CC	=	double layer cotton gloves
NC	=	gloves made from nylon in inner and cotton in outer layer
NK	=	gloves made from Nylon in inner and Kevlar in outer layer
CK	=	gloves made from Cotton in inner and Kevlar in outer layer
Clo	=	clothing insulation value
cm	=	centimeter
UVR	=	ultra violet radiation
CNS	=	central nervous system
sq.ft	=	square foot
hr	=	hour
in	=	inch
Gpa	=	Giga Pascal
psi	=	pound per square inch
^{o}F	=	degree Fahrenheit
^{o}C	=	degree Celsius
w/mk	=	Watt per meter Kelvin
m^2K/W	=	square meter Kelvin per watt
kg	=	kilogram
S.D.	=	Standard deviation
min	=	minimum

CHAPTER I

INTRODUCTION

1.1 Background and Rationale

In recent year the population has been increased rapidly since the advance of technologies in the world. The demand of natural materials usage is also increased. In order to serve that increasing such demand, the Plastic has been popularly used to replace natural material such as wood, metal, etc. Such replacement caused intensive growth of the plastic manufacturing factories in past few years. The melt flow testing is an important quality process to measure the melt flow value of each plastic type to deliver the specification of molding process in most of the plastic manufacturing. There are lots of complaints from all workers during performing the melt flow index test especially while cleaning up a hot orifice. The complaints are mostly concerning about hot surface. Hot orifice has high temperature around 270-300 ^{o}C. The workers have to directly hold the hot orifice by hands in order to keep short time and efficiency of cleaning. As the results, the severe injuries from high temperature may occurred. In addition, the cutting injury from using wire-brush for cleaning is commonly found in the process. Compliance with the occupational health and safety management program, many procedures are implemented in the factory in order to minimize the risk. The safety training brought about the skill and knowledge of working procedure to workers. However that measure could not be properly functioned in the past.

This study is conducted to investigate the appropriate tool for workers to cope with high temperature. Gloves are developed to protect workers from high temperature.

1.2 General Objective

The main objective of this study is to compare heat resistance between CC gloves and CK gloves to be appropriate PPE for working with Melt Flow Index Testing machine in the plastic compounding factory.

1.3 Specific Objectives

1.3.1 To compare the CC gloves and the CK gloves in term of thermal resistance when using for testing melt flow index.

1.3.2 To compare the thermal subjective feeling of the workers between wearing CC gloves and CK gloves working with the melt flow index testing machine.

1.4 Research Hypothesis

1.4.1 Finger skin Temperature of the workers while using the CC cotton glove is higher than when using the CK gloves.

1.4.2 Psychophysical rating ballots of the workers while using the CC gloves is higher than using CK gloves in term of thermal state of fingers.

1.5 Variables

1.5.1 Independent variable

1.5.1.1 The type of gloves.

1.5.1.1.1 CC gloves

1.5.1.1.2 NC gloves

1.5.1.1.3 NK gloves

1.5.1.1.4 CK gloves

1.5.2 Dependent variable

1.5.2.1 Finger skin temperature

1.5.2.2 The psychophysical rating ballots

1.6 Scope of study

1.6.1 Melt flow index testing machine in the laboratory of the Plastic compounding factory.

1.6.2 Four types of heat resistant gloves were tested in the laboratory.

1.6.3 All workers who perform the melt flow testing in laboratory

1.6.4 Subjective feelings of workers in melt flow index process.

1.7 Definitions:

CC gloves: white-knitting gloves that have double layer made from cotton.

NC gloves: the gloves that have cotton lining in inner layer and cotton lining in outer layer

NK gloves: the gloves have nylon in inner layer and Kevlar in outer layer.

CK gloves: the gloves that have cotton in inner layer and Kevlar in outer layer

Leather gloves: is the pale green gloves made from buffalo leather with double or three line of seam on palm part

Wool-knitting gloves: is a brown thick knitting gloves (figure 3-3)

Kevlar: Aramid fibers. Generic name for aromic polyamide fibers, consisting of synthetic polyamides in which at least 85% of the amide linkages are directly attached to the aromatic ring. The fiber is difficult to ignite, does not propagate flame, and decompose at about 900F. Kevlar fibers and Kevlar fiber blends are commonly used in abrasion and heat resistant gloves. Kevlar is a trademark of the Dupont Company.

Nylon: is one of the most common polymers used as a fiber which has a long chain polyamide in which less than 85% of the amide linkages are attached directly to two aromatic rings.

Cotton: a natural fiber, which is the most textile in the world. Cotton fiber is composed of concentric layers.

Abrasion Resistance: The ability of a fiber or fabric to withstand surface wear and rubbing. The best-known test used in the USA is the Wyzenbeek method. The most widely accepted in Europe is the Martindale standard.

Elasticity (Elastic Recovery): The term elasticity describes the ability of a fabric to elongate (or stretch) when tension is applied, and to recover its original shape and size when the tension is released. If you stretch a rubber band and then let it go, it comes back to its original size. To test the elasticity of a material, stretch it 4 percent and then measure to see how closely it returns to its original length after being stretched is said to have satisfactory elasticity.

Clo (Clothing level): Clothing level is a property of the clothing and represents the resistance to heat transfer between the skin and the clothing surface.

Conduction: is the transfer of heat between materials that contact each other. Heat passes from the warmer material to the cooler material. For example, a worker's skin can transfer heat to a contacting surface if that surface is cooler, and vice versa.

Convection: is the transfer of heat in a moving fluid. Air flowing past the body can cool the body if the air temperature is cool. On the other hand, air that exceeds 35°C (95°F) can increase the heat load on the body.

Radiation: is the transfer of heat energy through space. A worker whose body temperature is greater than the temperature of the surrounding surfaces radiates heat to these surfaces. Hot surfaces and infrared light sources radiate heat that can increase the body's heat load.

1st Degree Burn (superficial burns): Reddened skin without blisters

2nd Degree Burn (partial thickness burns): Reddened skin with blisters (heals from bottom up, takes 2 to 3 weeks)

Small closed blisters (narrower than 1 inch) serve as a dressing and reduce pain. Also the blister fluid contains protective chemicals.

Large closed blisters (wider than 1 inch) may need debridement. They commonly break open and the dead skin then needs to be removed

All open blisters need trimming of the dead skin (can be done by caller or in the office). Most open blisters are empty of fluid. A blister with a small opening and slow fluid leak can be recognized by the appearance of wrinkled skin.

3rd Degree Burn (full thickness burns):

Deep burn with white or charred skin. The burned area loses sensation to pain and touch (feels numb). Usually needs a skin graft to prevent bad scarring if it is larger than a quarter (1 inch or 2.5 cm) in size.

CHAPTER II
LITERATURE REVIEW

There are many processes of quality tests to determine qualities of products. The melt flow index is one of those processes to verify the flow rate of melt plastic in order to set up the specification for molding process.

This study is focused on melt flow testing process because workers have to expose to the high temperature during the cleaning of the melt flow testing equipment, orifice. Automatic cleaning process is unfeasible for implementation. The melt flow testing process is the highest risk process of all quality test processes since it is required to perform for all types of products. In addition, the protective method is inadequate.

Thai regulatory requires that the employer must provide the appropriate personal protective equipments for employees when the working hazards present at the working environment. Operators, therefore, who working with the melt flow testing process, have potentially exposure to high temperature and it could introduce hand injury. Heat resistant gloves are provided for them (36).

2.1 Melt Flow Rate testing machine

2.1.1 The Melt flow rate testing machine compost of

2.1.1.1 Piston Rod Assembly - consists of a Piston and Rod, Guide Collar and replaceable Piston foot.

2.1.1.2 Charging Tool – is used to help charge the material into the cylinder chamber (barrel), and also helps to remove some of the entrapped air when charging material. Provide with a replaceable tip.

2.1.1.3 Specimen Tray – is usually placed under the furnace to catch the extrusion on the smooth side or turned over to the slotted side to hold multiple cut-off samples.

2.1.1.4 Orifice Drill – is used to help clean material out of the inside Diameter of the orifice.

2.1.1.5 Orifice – two standard ASTM D 1238 orifice are provided with the basic machine, and are made of hardened stainless steel.

2.1.1.6 Circular level – is used to check the Bore Alignment (level) of the cylinder. This level is made to fit over the end of the Piston Rod Assembly, with the piston and orifice in the cylinder.

2.1.1.7 Cut-off Tool – this U-shaped tool is used to cut-off the extruded sample at the bottom of the orifice.

2.1.1.8 Funnel – is used to help introduce a sample of material into the cylinder.

2.1.1.9 Orifice Remover – is used to push the orifice out of the barrel from the bottom of the furnace.

2.1.1.10 Cylinder Cleaning Tool – is used to help clean the cylinder after each test with the cotton cleaning patches.

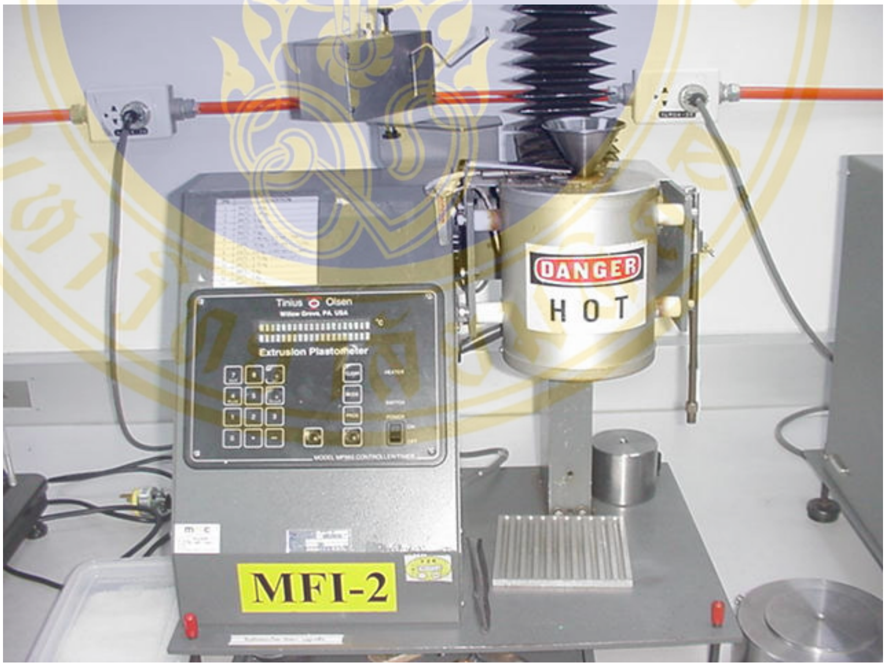


Figure 2-1 The Melt Flow Testing Machine

The melt flow-testing machine is semi operational machine. Some of operational steps need operator to involve such as preparation of plastic pellets before testing, cleaning contaminated equipment after testing, etc. That caused operator expose to high temperature when clean the hot equipment.

2.2.2 Melt Flow Rate Procedure

The steps of melt flow testing are presented below as in figure 2-2

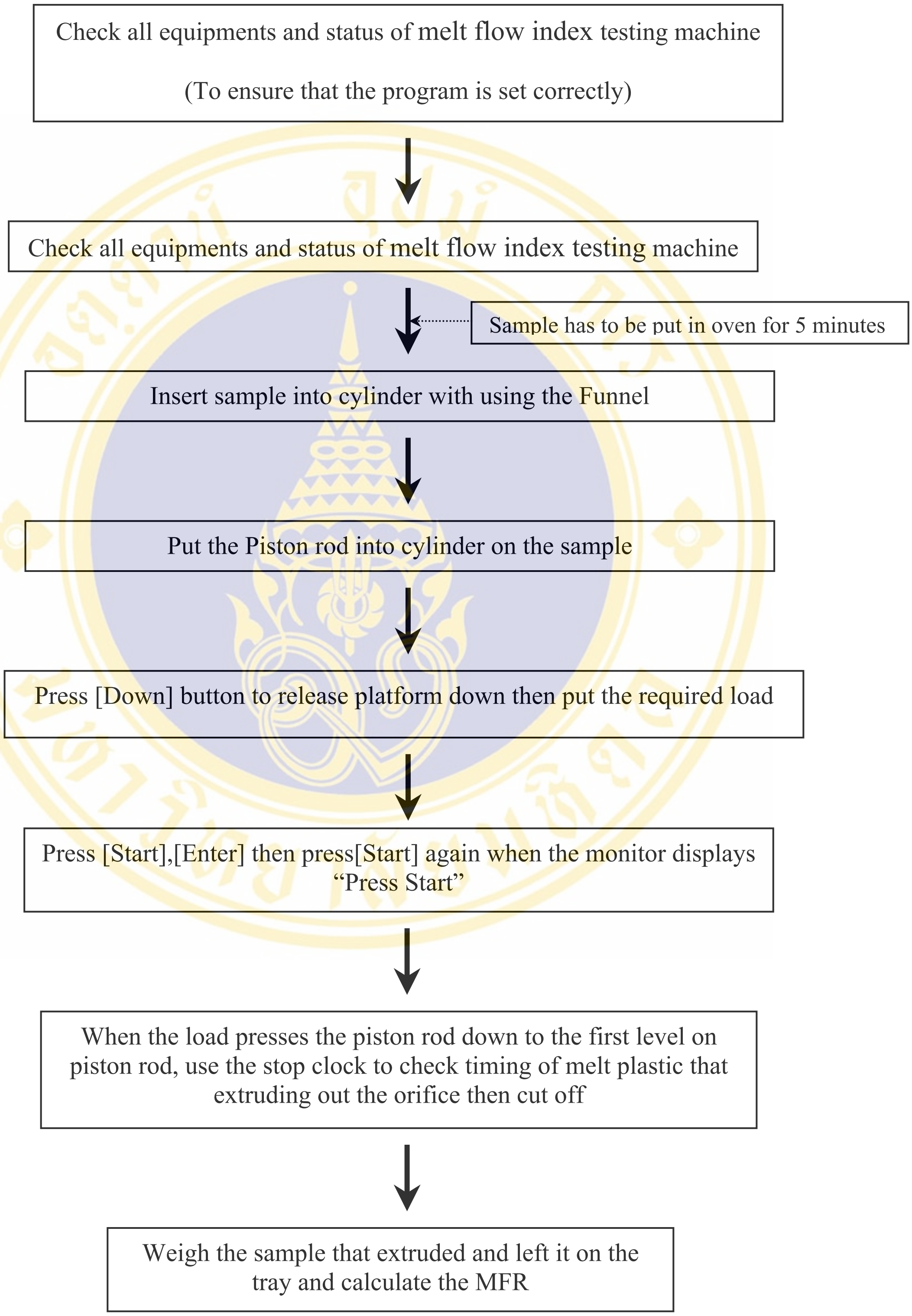


Figure 2-2 Melt flow testing steps

2.2 Human Skin

Skin is the largest organ in the body, both by weight and surface area. In adults the weight of skin accounts for about 16% of total body weight. Normally the skin separates the internal environment from the external. However, Skin disease and infections can compromise that barrier.

2.2.1 Skin Structure

Skin covers the entire surface of our bodies and protects our internal organs from the harsh elements of the environment. Skin varies in texture, structure and thickness and is made up of three components. The epidermis - comprised of living epidermal cells (keratinocytes) and the corneal layer (the protective outermost layer of dead keratinocytes). The dermis - made up of skin appendages such as hair follicles and sweat glands, surrounded by fibrous supporting tissue and collagen, and finally the subcutis - a layer of subcutaneous fat and fibrous tissue.

2.2.2 Epidermis

The epidermis (the strongest layer) forms the upper protective barrier of the skin. The outermost part or the corneal is comprised of millions of dead skin cells, which are shed and continually replaced by living cells (epidermal keratinocytes) that originate from the basal or germinative layer. Keratinocytes contain structural protein (keratin) and become progressively flattened as they advance upward from the basal layer to the corneal layer.

Melanocytes, among the basal cells of the epidermis, produce melanin, the protective pigment responsible for skin colour. Melanocytes are stimulated by sunlight; therefore produce sufficient melanin to protect the skin against harmful ultra violet radiation.

Vitamin D production in the skin is dependent on UVR (ultra violet radiation) penetrating epidermal cells to reach a particular chemical compound (ergosterol), which is important in the prevention of rickets and softening of the bones in elderly people.

Another type of cell within the epidermis is the Langerhans. Found in the middle section of the epidermis, these cells perform an immunological attack on foreign substances that penetrate the skin.

This layer of human skin can be easily damaged from burn, even the first degree one. Thus, a contacting with hot object could be decreased the skin function.

2.2.3 Dermis

The dermis (the skins majority) is comprised of collagen and connective tissue. Collagen is a fibrous protein produced by fibroblast cells scattered throughout the dermis and is responsible for most of the skin's mechanical strength. Blood vessels, lymph vessels, nerves and sensory receptors are embedded in the dermis, as are hair follicles (including their muscles), sweat glands and oil glands, formed from specialized epidermal cells that penetrate the dermis.

The sebaceous glands are responsible for the excretion of the skin's natural oil (sebum). There are two types of sweat glands. The apocrine sweat glands fail to open directly onto the skin surface, but drain into large hair follicles. They are located near the armpits and around the genitalia, while the second type, the eccrine sweat glands, are distributed over the skins entire surface. The secretion of the apocrine differs to that of the eccrine; it is thick and creamy in contrast to the watery solution of the eccrine glands. These glands aid in the removal of dirt and oil from the pores, help to regulate body temperature and also maintain the skin's PH balance.

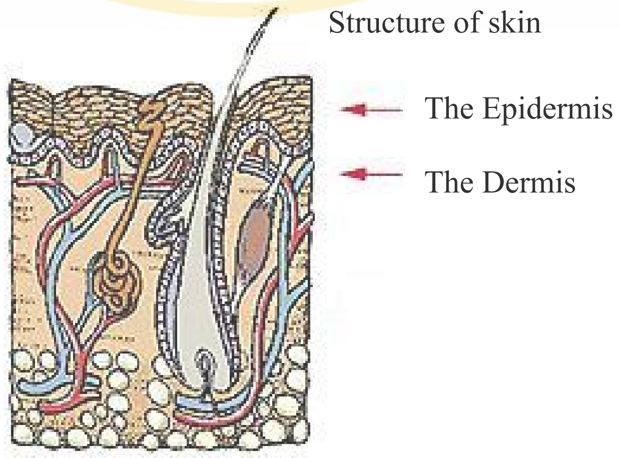


Figure 2-3 The structure of human skin

2.2.4 Function of Skin (2)

The skin performs a complex role in human physiology:

- Protects the rest of the body from toxins, injuries, the sun, and temperature extremes in the external environment
- Preserves the stability of the body's inner environment and keeps it in place
- Helps the body to regulate heat
- Communicates information about physical and emotional states
- Provides identification through unique finger- and sole-prints

Table 2-1 Function of skin

Functions	Structure
Protection from harmful agents of external environment: biological germs, ultraviolet light & chemicals	Epidermis
Preservation of a balanced internal environment	Epidermis
Shock absorber	Subcutaneous fat
Temperature regulation	Blood vessels & eccrine sweat glands
Insulation	Subcutaneous fat
Sensation	Nerve endings
Lubrication	Sebaceous glands
Protection & grip	Nails
Calorie reserve	Subcutaneous fat
Vitamin D synthesis	Epidermis
Body odour	Apocrine sweat glands
Psychosocial	Hair & Nails

2.2.5 The Skin thickness of finger

Since most cold or hot surface contact is made with the fingers, where epidermis thickness is probably more variable than anywhere else on the body. This dimension become of utmost importance. The pulp of the fingers is rich in nerves, sensors, arterirs and septa. (Figure 2-4) but less in fat.

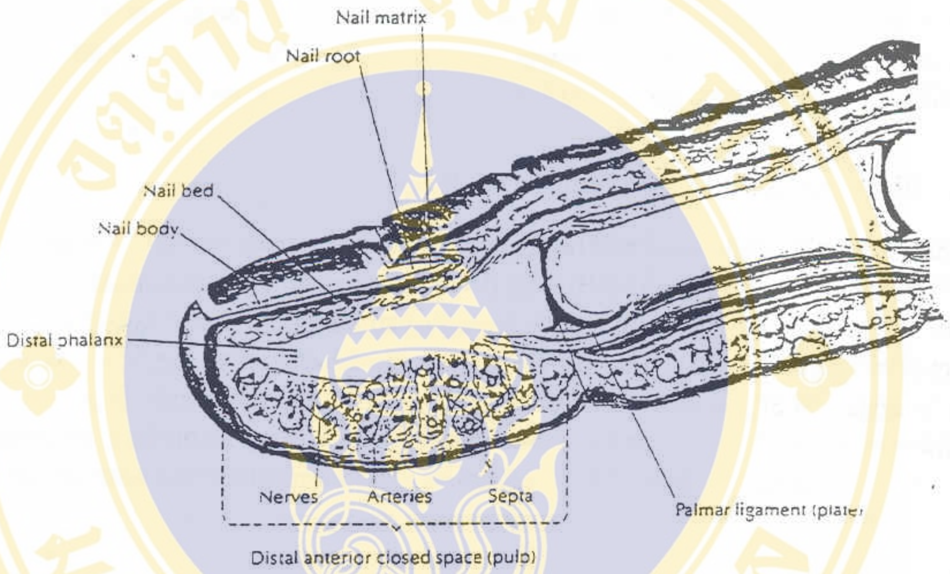


Figure 2-4 The sagital section of the finger (37)

2.2.6 Sensory Apparatus of the skin (2)

The skin is innervated with around one million afferent nerve fibers. Most terminate in the face and extremities; relatively few supply the back. The cutaneous nerves contain axons with cell bodies in the dorsal root ganglia. Their diameters range from 0.2-20 μm. The main nerve trunks entering the subdermal fatty tissue each divide into smaller bundles. Groups of myelinated fibers fan out in a horizontal plane to form a branching network from which fibers ascend, usually accompanying blood vessels, to form a mesh of interlacing nerves in the superficial dermis. Throughout their course, the axons are enveloped in Schwann cells and as they run peripherally, an increasing number lack myelin sheaths. Most end in the dermis; some penetrate the basement membrane, but do not travel far into the epidermis.

Sensory endings are of two main kinds: corpuscular, which embrace non-nervous elements, and 'free', which do not. Corpuscular endings can, in turn, be subdivided into encapsulated receptors, of which a range occurs in the dermis, and non-encapsulated, exemplified by Merkel's 'touch spot' which is epidermal.

Each Merkel's touch spot is composed of a battery of Merkel cells borne on branches of a myelinated axon. A Merkel cell has a lobulated nucleus and characteristic granules; it is embedded in the basal layer of epidermal cells, with which it has desmosomal connections; it contains intermediate filaments composed of low molecular weight keratin rather than neurofilament protein.

The Pacinian corpuscle is one of the encapsulated receptors. It is an ovoid structure about 1mm in length, which is lamellated in cross-section like an onion, and is innervated by a myelinated sensory axon which loses its sheath as it traverses the core. The Golgi-Mazzoni corpuscle found in the subcutaneous tissue of the human finger is similarly laminate but of much simpler organization. These last two lamellated end organs are movement and vibration detectors.

The Krause end bulb is an encapsulated swelling on myelinated fibers situated in the superficial layers of the dermis. Meissner corpuscles are characteristics of the papillary ridges of glabrous (hairless skin) skin; they are touch receptors; they have a thick lamellated capsule, 20-40 µm in diameter and up to 150 µm long. Ruffini endings in the human digits have several expanded endings branching from a single myelinated afferent fiber; the endings are directly related to collagen fibrils; they are stretch receptors.

Free nerve endings, which appear to be derived from non-myelinated fibers, occur in the superficial dermis and in the overlying epidermis; they are receptors for pain, touch, pressure and temperature. Hair follicles have fine nerve filaments running parallel to and encircling the follicles; each group of axons is surrounded by Schwann cells; they mediate touch sensation.

2.3 Connection to the Central Nervous System (CNS) (2)

The brain receives two types of sensations: (1) superficial sensations, including pain, temperature and crude touch, and (2) deep sensations, including sense of position, sense of movement, vibration sense, muscle sense and fine touch. Some superficial and deep sensations must reach the cortex to be felt. These are: (1) tactile localization, tactile discrimination and stereognosis, (2) mid-zones of temperature (between very hot and very cold values), and (3) sense of position and movement.

2.3.1 Pathway of pain, temperature and crude touch sensations:

The first order neuron is present in the posterior root ganglion. Its dendrite passes to the periphery to act as a pain receptor, while its axon passes towards the spinal cord. In the spinal cord, it ascends for one or few segments at the tip of the posterior horn forming the Lissauer's tract, and then ends around the cells of the substantia gelatinosa of Rolandi, which are present at the tip of the posterior horn of the grey matter.

1. The second order neuron is present in the substantia gelatinosa of Rolandi. Its axon crosses to the opposite side in the anterior commissure near the central canal, then ascends in the lateral spinothalamic tract (ventral spinothalamic tract, in case of crude touch) to terminate in the thalamus.
2. The third order neuron is present in the thalamus. Its axon travels in the posterior limb of the internal capsule behind the pyramidal fibers and terminates in the sensory area of the cerebral cortex (areas 1, 2, and 3).

2.3.2 Pathway of deep sensations and fine touch:

2.3.2.1 The first order neuron is also present in the posterior root ganglion. Its dendrite passes to the periphery, while its axon enters the spinal cord and ascends directly (without relay) in the posterior column of the spinal cord, forming the Gracile and Cuneate tracts. The two tracts end in the medulla around the Gracile and Cuneate nuclei.

2.3.2.2 The second order neuron is present in the Gracil and Cuneate nuclei of the medulla. Its axon crosses to the opposite side then ascends in the brain stem (forming the medial lemniscus) to reach the thalamus where it terminates.

2.3.2.3 The third order neuron is present in the thalamus. Its axon passes upwards in the internal capsule to end in the sensory area of the cerebral cortex.

2.4 Temperature sensation (2)

The human being can perceive different gradation of cold and heat which are discriminated by at least three different types of sensory eng-organs: the cold receptors, warmth receptors and the pain receptors. The pain receptors are stimulated only by serious condition of heat or cold. They are stimulated after exposed sufficiently severe to cause damage from the excessive temperature (6).

Receptors for warmth and cold are specialized free nerve endings; a rise in skin temperature above body temperature causes a sensation of warmth, while a fall in skin temperature below body temperature is experienced as cold sensation; pain is felt if skin temperature increases above 45 °C or decreases below 10 °C; the mucous membrane of the mouth is less sensitive than the skin, thus tea can be drunk at a temperature which is painful to finger.

Temperature sensation is related to how people fell and is therefore a sensory experience and a psychological phenomenon (27). It is not impossible to define sensation in physical or physiological term. There have been many studies which have correlated physical conditions and physiological response with thermal sensation of groups of individuals have been based. The thermal sensation is determined by the 'thermal state' of the body and not an environmental component. (28)

The pain receptors are stimulated only by extreme degrees of heat or cold and therefore are responsible, along with the cold and warmth receptors, for “freezing cold” and “burning hot” sensation. (38)

2.5 Principle of Heat (5)

Heat is the vibration of molecules in a substance. Even in solid object the molecules that make them up move around. The hotter an object is, the more the molecules jump and jive. When they are very excited, they will even break the solid structure and the substance then undergoes a phase shift from solid to liquid. Similarly when the molecular motion is too vigorous for the liquid phase, the substance enters the gaseous phase.

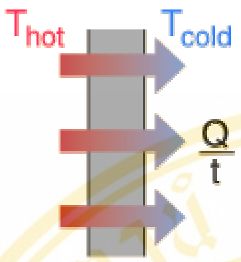
It's possible for different areas of an object to have different heat levels. The difference between the hot part of an object and the cold part is called its "thermal gradient". When a molecule vibrates it passes along a little of its exuberance to neighbouring molecules. They too begin to vibrate but the original molecule now vibrates a little less because some of its excitement has been taken by its neighbours. This is how heat spreads through a substance.

2.5.1 Heat Transmission

2.5.1.1 Heat Conduction (3)

Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones. For heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of conduction heat transfer is in figure 2-5.

$$\frac{Q}{t} = \frac{\kappa A(T_{hot} - T_{cold})}{d}$$



Q = heat transferred in time = t

κ = thermal conductivity of the barrier

A = area

T = temperature

d = thickness of barrier

Figure 2-5 Heat conduction transfer rate

Thermal conductivity (K) is the measurement of the speed at which heat travels through a material through conduction. In the United States thermal conductivity (also referred to as the “k” value) is commonly expressed in term of the number of BTUs of heat, which will travel through one square foot of material, which is one inch thick when there is on degree F temperature difference across the material.

This expression is often stated as BTU/in/hr/sq.ft/F. The lower the “k” value the better the thermal insulation. The term “R” value is frequently used to describe the performance of insulation materials. The “R” value is simply the reciprocal of the “k” value. Therefore, the higher the “R” value, the better the insulation quality.

R value can be computed for Clo value from the formula of 1 Clo = 0.155R m^2K/W.

Table 2-2 Thermal conductivity of some common materials (5)

MATERIAL	CONDUCTIVITY ("k")	INSULATIVE ("R")
Copper	2712.00	.00037
Aluminum (6061)	1160.00	.00086
Aluminum (5052)	960.00	.00104
Lead	245.00	.004
Stainless Steel (316)	113.00	.00885
Glass	5.00	.20
Polyester FRP (hand laid)	0.48	2.08
Polyethylene Foam	0.43	2.33
Wood (dry)	0.33	3.03
Polyester FRP (pultruded)	0.31	3.26
Glass Wool	0.29	3.45
Polystyrene (expanded)	0.28	3.57
Cork Board	27	3.70
Polystyrene (extruded)	0.21	4.80
PVC (Klegecell)	0.21	4.80
Polyurethane Foam	0.17	5.88
Air	0.16	6.25
BARRIER Ultra-R	0.02	50.36
Total Vacuum	0.004	250.00

2.5.1.2 Heat Convection (3)

Convection is heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it. Convection above a hot surface occurs because hot air expands, becomes less dense, and rises. Hot water is likewise less dense than cold water and rises, causing convection currents, which transport energy. Convection is thought to play a major role in transporting energy from the center of the Sun to the surface, and in movements of the hot magma beneath the surface of the earth.

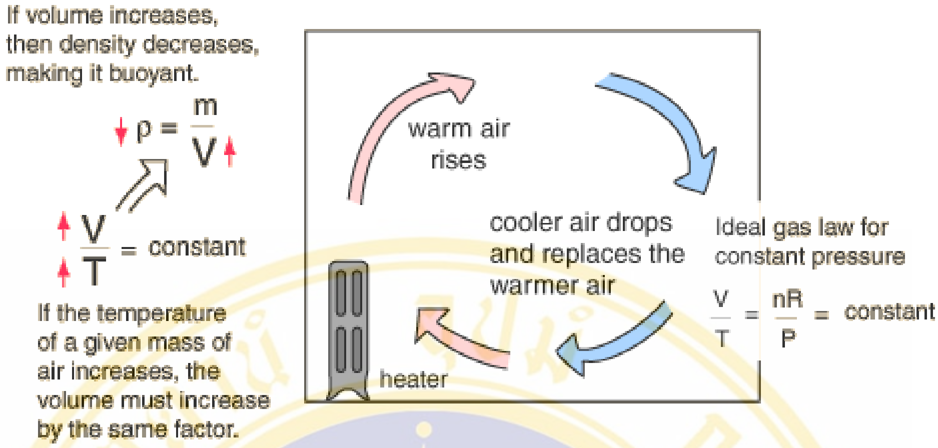


Figure 2-6 Heat convection process (3)

It is difficult to quantify the effects of convection since it inherently depends upon small nonuniformities in an otherwise fairly homogeneous medium. In modeling things like the cooling of the human body, we usually just lump it in with conduction.

2.5.1.3 Radiation

Radiation is heat transfer by the emission of electromagnetic waves which carry energy away from the emitting object. For ordinary temperatures (less than red hot"), the radiation is in the infrared region of the electromagnetic spectrum. The relationship governing radiation from hot objects is called the Stefan-Boltzmann law:

$$P = e\sigma A(T^4 - T_c^4)$$

Where

P = radiated power
A = radiating area
σ = Stefan's constant
$\sigma = 5.6703 \times 10^{-8}$ watt/m^2 K^4
e = emissivity (=1 for ideal blackbody)
T = temperature of radiator
T_c = temperature of surroundings

2.5.1.4 Heat Transfer by Vaporization

If part of a liquid evaporates, it cools the liquid remaining behind because it must extract the necessary heat of vaporization from that liquid in order to make the phase change to the gaseous state. It is therefore an important means of heat transfer in certain circumstances, such as the cooling of the human body when it is subjected to ambient temperatures above the normal body temperature.

2.6 Clothing Level (Clo)

Clothing level is a property of the clothing and represents the resistance to heat transfer between the skin and the clothing surface.

Clo is the amount of insulation necessary to maintain the comfortable skin temperature of 88-89 F for the hard, neck and torso, 75 F for the hands and feet, and an ambient temperature of 70 F.

The Unit normally used for measuring clothing insulation is the Clo Unit, but the more technical unit is m2K/W. The formula of Clo unit is:

$$1 \text{ Clo} = 0.155 \text{ m}^2\text{K/W}$$

The Clo scale is designed so that a naked person has a Clo value of 0.0 and someone wearing a typical business suit has a Clo value of 1.0. An overall Clo value can be calculated if the persons dresses and the Clo values for each individual garment worn is simply added together.

2.6.1 Clo Values are additive

Summing the clo value of individual component will approximate the total system clo. (30,31).

Total clo is estimated by adding the clo values of the components and correcting for surface area, fit, and air layer effects. This procedure was developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers.

2.6.2 Effect of Clothing on Heat Exchange (26)

The clothes we wear can have a profound effect on the heat exchange process. It is the insulating effects of clothing that reduce heat loss to the environment. When it is cold, of course, reduced heat loss is beneficial, but when it's hot, clothing interferes with heat loss and can be harmful.

The insulation value of most material is a direct linear function of its thickness. The material itself (Whether it's wool, cotton, or nylon) plays only a minor role. It is the amount of trapped air within the weave and fibres that provides the insulation. If the material is compacted or gets water-soaked, it loses much of its insulating properties because of the loss of trapped air.

The insulation is very much dependent on the thickness of the material and less on the fibre types. The fibre mainly influence the amount of radiative heat transfer, as they reflect, absorb and re-emit radiation. This effect is of minor importance relative to the thickness (except for special relative clothing) can be seen in figure 2-7(34), where the insulation of a range of different clothing materials is presented in relation to their thickness.

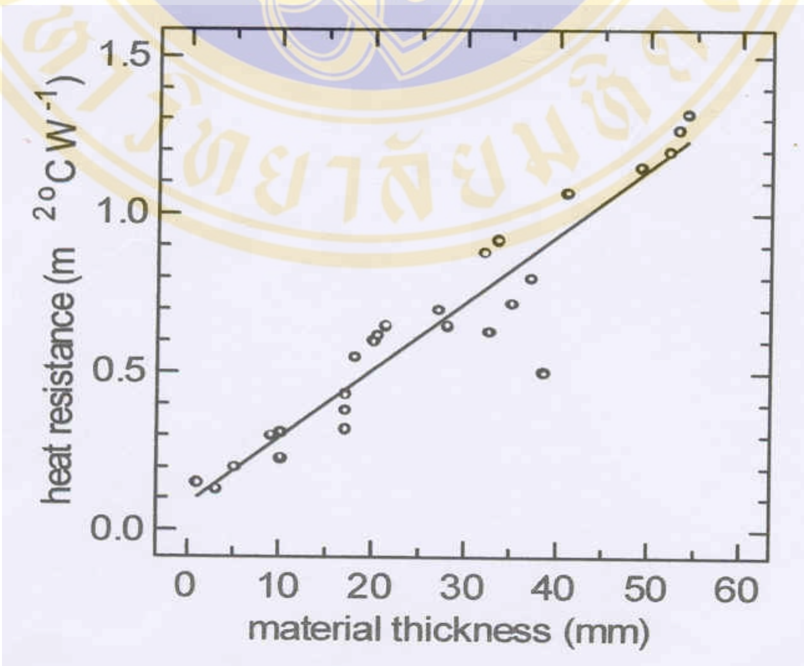


Figure 2-7 Relation between clothing material insulation and the material thickness

2.7 The properties of fabrics and fibers

2.7.1 Nylon (20)

Nylon is one of the most common polymers used as a fiber. Nylon is found in clothing all the time, but also in other places, in the form of thermoplastic. Nylon's first real success came with its use in women's stocking, in about 1940. They were a big hit, but they became hard to get because the next year the United States entered World War II, and nylon was needed to make war materials, like parachutes and ropes. But before stockings or parachutes, the very first nylon product was a toothbrush with nylon bristles.

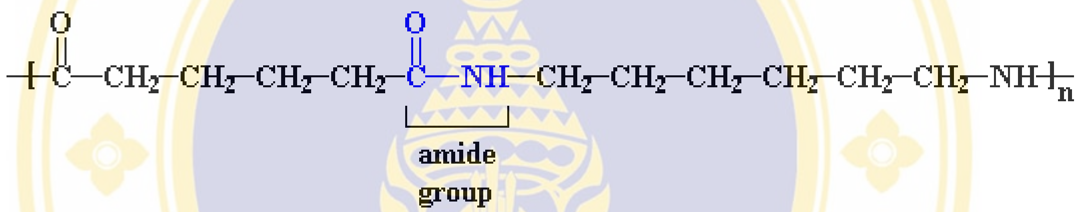


Figure 2-8 The structure of nylon

Nylons are also called polyamides, because of the characteristic amide groups in the backbone chain. Nylon has a long chain polyamide in which less than 85% of the amide linkages are attached directly to two aromatic rings. If more than 85%, it becomes an aramid fiber such as Kevlar. Proteins, such as the silk nylon was made to replace, are also polyamides. These amide groups are very polar, and can hydrogen bond with each other. Because of this, and because the nylon backbone is so regular and symmetrical, nylons are often crystalline, and make very good fibres.

Various types of nylon are described by numbers that relate to the number of carbon atoms in the various reactants. Effect of heat: Sticks at 445°F, Melts at 480°F, Yellows slightly at 300°F when held for 5 hours. The most extensively used type of nylon in gloves is Nylon 6/6.

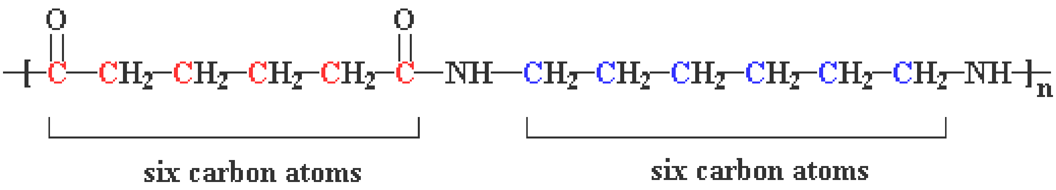


Figure 2-9 Structure of Nylon 6,6

The nylon in the structure above is called nylon 6,6, because each repeat unit of the polymer chain has two stretches of carbon atoms, each being six carbon atoms long. Other nylons can have different numbers of carbon atoms in these stretches.

Nylons can be made from diacid chlorides and diamines. Nylon 6,6 is made from the monomers adipoyl chloride and hexamethylene diamine as in figure 2-8.

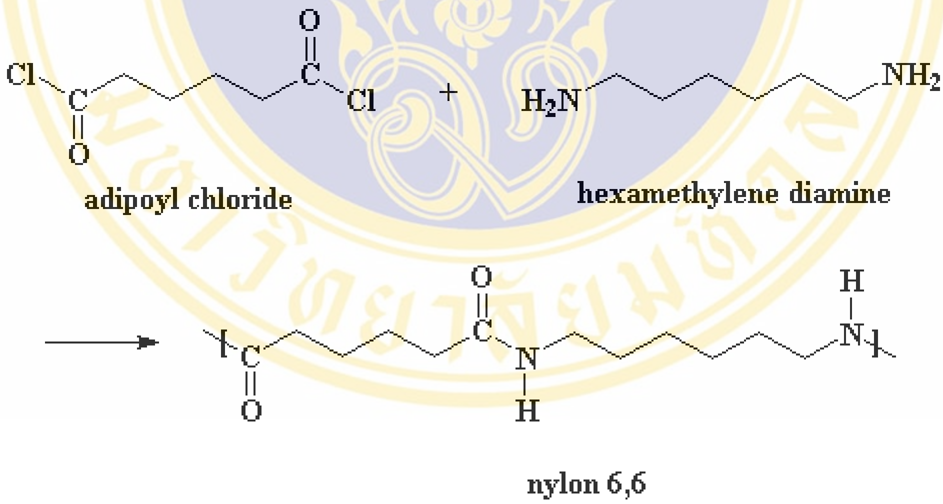


Figure 2-10 Structure of adipoyl chloride and hexamethylene diamine

This is one way of making nylon 6,6 in the laboratory. But in a nylon plant, it's usually made by reacting adipic acid with hexamethylene diamine.

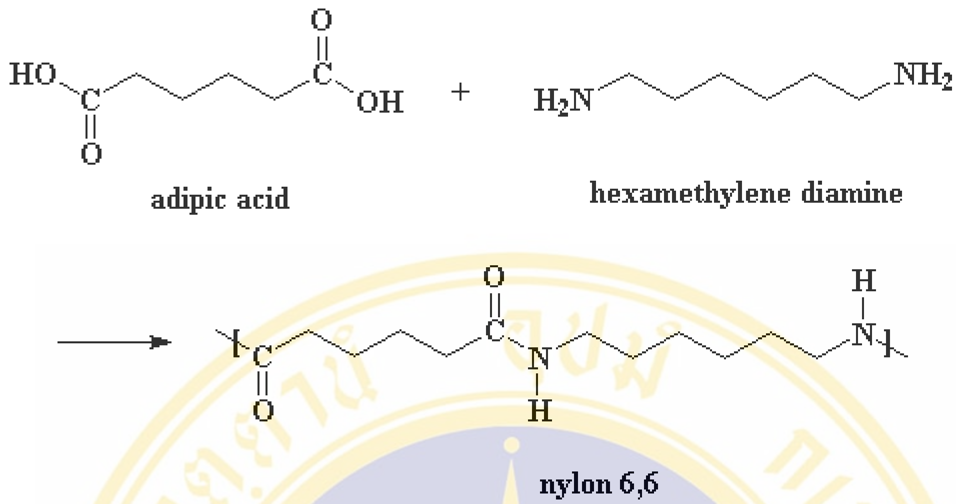


Figure 2-11 Structure of adipic acid and hexamethylene diamine

Another kind of nylon is nylon 6. It's a lot like nylon 6,6 except that it only has one kind of carbon chain, which is six atoms long.

2.7.1.1 Good characteristics of Nylon:

1. Strength. Nylon is one of the strongest synthetics made.
2. Elongation. Nylon stretches from 18 to 40 percent, which is well above military specifications of 20 to 25 percent.
3. Elasticity. Nylon returns to 100 percent of its original length.
4. Weight. Nylon fibers are very strong for their weight; therefore, the fabrics manufactured of nylon fibers are lightweight fabrics.
5. Resistance to abrasion. Nylon does not have enough resistance to last forever under all the rugged use parachutes get, but it is better than any other material tested for parachute use.
6. Resistance to mildew and insects. Nylon has no food value. This makes it unappetizing to moths and other insects. It cannot support the growth of mildew.

2.7.1.2 Limitations of Nylon

1. Moisture regains. If percentage of moisture a fiber absorbs from the air is less than 5 percent, the fiber is difficult to dye and builds up the static electricity when rubbed. The moisture regain of nylon is only 4.2 percent, so we can expect the static electricity to develop as we service the assembly.
2. Resistance to sunlight. As the mentioned earlier that yellow dye improves resistance to ultraviolet light damage. This is why yellow dye is added to deceleration canopy material. In addition, a chemical known as Chemstrand "R" has been developed, which, when added to nylon fiber as the yarns are manufactured, makes nylon more resistant to ultraviolet light.
3. Heat resistance. Nylon has a relatively low melting point, 482 F, which makes it very susceptible to damage from heat. This is why it is so important that suspension lines be stowed properly. In the rapid deployment sequence, line crossing each other will break from the friction heat generated.

2.7.2 Kevlar (16)

Kevlar is an aromatic polyamide, or aramid, fiber introduced in the early 1970s. The chemical composition of Kevlar is poly para-phenyleneterephthalamide (PPD-T). It is made from a condensation reaction of para-phenylene diamine and terephthaloyl chloride. The resultant aromatic polyamide contains aromatic and amide groups. Polymers with high breaking strength often have one or both of these groups.

The aromatic ring structure contributes high thermal stability. The para configuration leads to stiff, rigid molecules that contribute high strength and high modulus.

Para-aramid fibers belong to a class of materials known as liquid crystalline polymers. When PPD-T solutions are extruded through a spinneret and drawn through an air gap during fiber manufacture, the liquid crystalline domains can orient and align in the flow direction. Kevlar can acquire a high degree of alignment of long, straight polymer chains parallel to the fiber axis. The structure exhibits anisotropic properties, with higher strength and modulus in the fiber longitudinal direction than in the axial direction. The extruded material also possesses a fibrillar structure. This structure results in poor shear and compression properties for aramid composites. Hydrogen bonds form between the polar amide groups on adjacent chains and they hold the individual Kevlar polymer chains together.

Tensile modulus is a function of molecular orientation. As a spun fiber, Kevlar 29 (a high toughness variant) has a modulus of 62 GPa (9 Mpsi). Heat treatment under tension increases crystalline orientation. The resulting fiber, Kevlar 49, has a modulus of 131 GPa.

The tensile strength of Kevlar ranges from about 2.6 to 4.1 GPa. This is more than twice that for conventional fibers like Nylon 66. Tensile failure initiates at the fibril ends and propagates via shear failure between the fibrils.

Kevlar behaves elastically in tension. In compression, it shows nonlinear, ductile behavior. It exhibits yield at compression strains of 0.3 to 0.5%. This corresponds to formation of structural defects known as kink bands. These bands are related to compressive buckling of the aramid molecules.

Aramid fibers are noted for toughness and general damage tolerance. Tensile elongation of Kevlar 29 is about 4%.

The aromatic structure gives the fibers a high degree of thermal stability. They decompose in air at about 425 C and are inherently flame resistant. Aramids have a slight negative longitudinal coefficient of thermal expansion of about -2 x 10^-6/K and a positive transverse expansion of 60 x 10^-6/K. They have a low thermal conductivity that varies by about an order of magnitude in the longitudinal versus transverse direction.

Table 2-3 Kevlar Chemical Resistance (16)

Acids - Concentrated	Poor
Acids - Dilute	Fair
Ultraviolet Light	Fair
Alcohols	Good
Alkalis	Good
Aromatic Hydrocarbons	Good
Greases and Oils	Good
Halogens	Good
Ketones	Good

2.7.2.1 Advantages

- Three times the strength of nylon and polyester.
- Half the weight and volume of nylon.
- Can with stand high temperatures before losing strength.
- Heat resistant to 750 degrees F.
- Flame resistant.
- Low elongation.
- Resists most acids.

2.7.2.2 Disadvantages

- Poor abrasion resistance.
- Poor sunlight (UV) resistance.
- 3-13% strength lose when wet

Form the heat resistant and fibre strength characteristic of Kevlar; it became populated fibre in many kinds of heat resistant products. Anyway, this good characteristics limit

Table 2-4 Fiber Characteristics (15)

Generic Fiber Type	Nylon	Polyester	Kevlar	Manila
Bulk Strength[1]	1.0	0.9-1.1	2.7	0.33
Weight	1.0	1.21	1.26	1.21
Working Elastic Elongation[2]	1.0		0.10	0.70
Coefficient of Friction[3]	0.10-0.12	0.60	0.10-0.12	0.15
Melting Point	460 F	480 F	Chars at 800 F	Chars at 350 F
Cold Flow[4]	Negligible	Negligible	Negligible	Negligible

* Using Nylon as a basis of 1.0

[1]Bulk Strength is defined as strength per circumference squared.

[2]Working Elastic Elongation is defined as rope actually in use under a cycling load.

[3]Coefficient of Friction is based on reluctance to slip or slide.

[4]Cold Flow is defined as fiber deformation (elongation) due to molecular slippage under a constant steady static loading situation. Fibers that have this inherent characteristic will display extremely low or negligible creep if minor fluctuations occur in the rate and/or frequency of load levels.

Table 2-5 Classification Hazards and Recommended Glove Protective

Nature of Hazard	Degree of Hazard	Protective Material
Abrasion	Severe	Reinforced heavy rubber, staple-reinforced heavy leather
	Moderate	Rubber, Plastic, leather, polyester, Nylon, Cotton
Sharp Edges	Severe	Metal mesh, staple-reinforced heavy leather, Kevlar-steel mesh
	Moderate	Leather, terry cloth (Aramid fiber)
	Mild with Delicate work	Lightweight leather, polyester, nylon, cotton
Cold		Leather, insulated plastic or rubber,

Nature of Hazard	Degree of Hazard	Protective Material
		wool, cotton, cold resistant specially fabrics. Loose fitting gloves for liquid nitrogen or carbon dioxide
Heat	High temperature (>350 C)	Heat resistant specialty fabrics
	Medium high temperature (up to 350C)	Normex, Kevlar, Zetex, heat-resistant leather with linings.
	Warm temperatures (up to 200 C)	Normex, Kevlar, Zetex, heat-resistant leather, terry cloth (Aramid fiber)
	Less warm temperature (up to 100C)	Chrome-tanned leather, terry cloth.
General Duty		Cotton, terry cloth, leather, rubber, plastic
Product Contamination		Thin-film plastic, lightweight leather, cotton, polyester, nylon

*Adapted from Safety in fogram produced by the Canadian Center for Occupational Heath and Safety

Structure of Kevlar

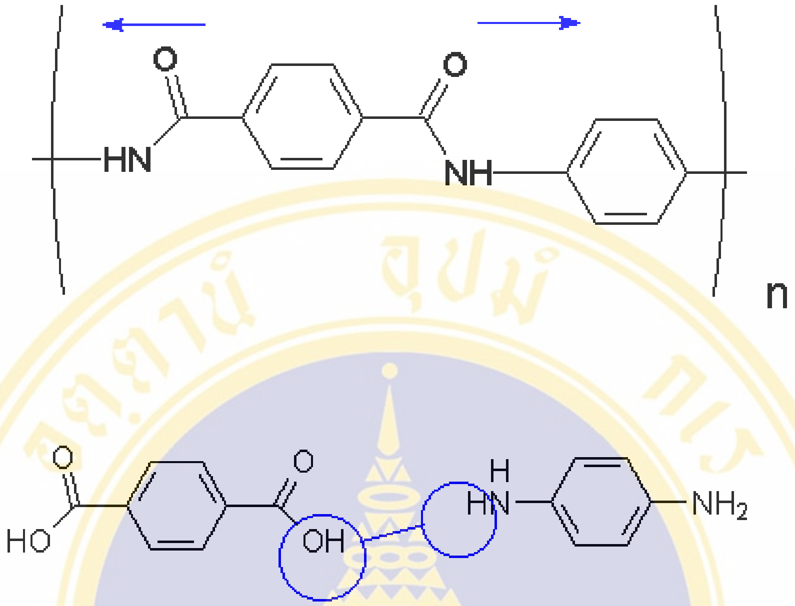


Figure 2-12 Structure of Kevlar

The Kevlar structure has 2 carbonyl-groups and 2 amine-groups that make the Kevlar stronger than Nylon and Cotton.

2.7.3 Cotton (11)

Cotton is the most used textile fiber in the world. Its current market share is 56 percent for all fibers used for apparel and home furnishings and sold in U.S. (8). It is generally recognized that most consumers prefer cotton personal care items to those containing synthetic fiber.

2.7.3.1 Fiber structure and formation

Each cotton fiber is composed of concentric layers. The cuticle layer on the fiber itself is separable from the fiber and consists of wax and pectin materials. The primary wall, the most peripheral layer of the fiber, is composed of cellulosic crystalline fibril (9). The secondary wall include closely packed parallel fibrils with spiral winding of 25-35^{o} and represent the majority of cellulose within the fiber. The cotton structure, and its chemical structure are presented in figure 2-10 and figure 2-11 respectively.

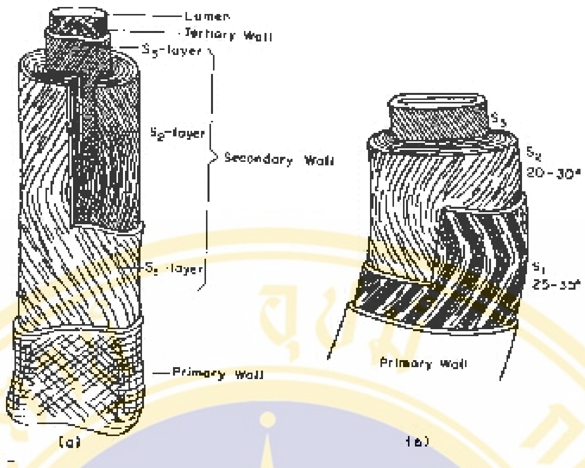


Figure 2-13 Cotton structure

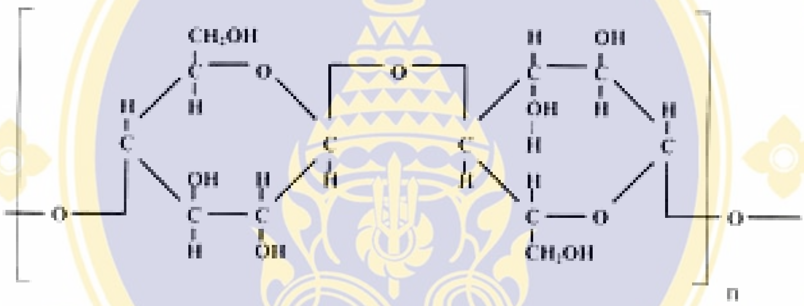


Figure 2-14 Cotton chemical structure

2.7.3.2 Chemical properties of cotton

Cotton swells in a high humidity environment, in water and in concentrated solutions of certain acids, salt and bases. The swelling effect is usually attributed to the sorption of highly hydrated ions. The moisture regain for cotton is about 7.1 ~ 8.5% and the moisture absorption is 7~3 % (18).

Cotton is attacked by hot dilute or cold concentrated acid solutions. Acid hydrolysis of cellulose produces hydro-celluloses. It is not affected by cold weak acids. The fiber shows excellent resistance to alkalis. There are a few other solvents that will dissolve cotton completely. One of them is a copper complex of cupramonium hydroxide and cupriethylene diamine (19)

Cotton degradation is usually attributed to oxidation, hydrolysis or both. Oxidation of cellulose can lead to two types of so-called oxy-cellulose (20), depending on the environment, in which oxidation take place.

Also, cotton can degrade by exposure to visible and ultraviolet light, especially in the presence of high temperature around 250 –397 oC (18) and humidity. Cotton fibers are extremely susceptible to any biological degradation.

2.8 Hand Skin Burn

Burns to the hand are common. Most are small and confined to the upper limb but some are part of a major burn. Although the hand comprises a small surface area, management of a hand burn assumes a high priority because of its functional importance. The majority of hand burns can and are managed without complication in Accident Departments and General Practitioner Surgeries. A minority, however, need early Specialist intervention.

The thermal burn results from exposure to hot surface or liquids with a temperature above 115 ^{o}F or (29)

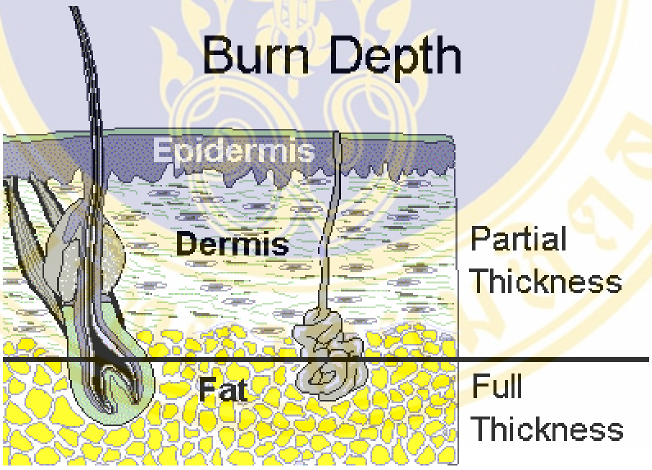


Figure 2-15 Burn dept on human skin

The depth of a burn is simply divided in partial thickness and full thickness. Partial thickness burns have the capacity to heal rapidly because of the presence of viable dermal components. Re-epithelialization occurs from both the base and the edge of the burn-wound and healing should be complete within 21 days. Full thickness burns only heal from the edge and therefore healing is slow in anything but the smallest burns. Delayed healing results in a poor quality contracted scar, which, in the hand, inevitably compromises function.

2.9 Classification of burns (32)

2.9.1 First-Degree burns: First-degree burns involve only a redness of the skin, which indicates a mild inflammation. The most common first-degree burn is sun-burn. First-degree burns from fires may result from a much greater amount of radiation received during a shorter period of time. Contacts between the skin and a hot surface will produce similar type of burns.

Table 2-6 Effect on Skin in contact with surfaces at different temperatures (33)

Temperature (^oF)	Sensation of effect
212	Second-degree burn on 15-second contact
180	Second-degree burn on 30-second contact
160	Second-degree burn on 60-second contact
140	Pain: tissue damage (burns)
120	Pain: Burning heat
91 ± 4	Warm: Neutral (physiological zero)
54	Cool
37	Cool heat
32	Pain
Below 32	Pain; tissue damage (freezing)

2.9.2 Second-degree burns; second-degree burns are much more serious than first-degree burns. Blisters of the skin will form, and in the severer cases, fluid will collect under the skin.

- Skin beneath the blisters is extremely sensitive, red in color, and exudes considerable amounts of fluid.
- Sometime much more painful than third-degree burns.
- The most common cause, like the first-degree burns, is solar radiation

2.9.3 Third-degree burns; the skin, subcutaneous tissue, red blood cells, capillaries, and sometimes, muscle are destroyed. Burns may be white, light gray, brown, or even charred black. Although the damage is more serious, the destruction of the never endings in third-degree burns can cause less pain than lesser burns which leave them exposed.

CHAPTER III
MATERIALS AND METHODS

The study was conducted in the plastic manufacturing factory located in Rayong province. It aimed to compare the effectiveness of the CC gloves and CK gloves for working with the melt flow index machine.

3.1 Study Design

This study was designed to evaluate and compare the temperature resistance between CC gloves and CK gloves. It was experimental study which was determined the skin temperature and psychophysical rating ballots of the workers.
All workers were selected to be subjects as judgmental sampling with the criteria as followings:

- Workers have been working on melt flow testing process for at least two months.
- Workers have been trained on how to work with melt flow testing machine.

Table 3-1 Physical characteristics of the subjects and work experiences

Subject No.	Age (year)	Weight (kg)	Height (cm)	Work experiences (year)
1	34	60	168	5
2	30	75	165	4
3	27	48	155	4
4	25	57	166	4
5	27	53	152	3
6	27	44	148	3
7	24	45	158	1
8	28	51	164	2
$\overline{X}$	27.750	54.125	159.5	3.25
SD.	3.1033	10.09	7.329	1.28

Note $\overline{X}$ = Arithmetic Mean

S.D. = Standard Deviation

3.2 Instrumentation

3.2.1 Heat resistant gloves

3.2.1.1 White nylon gloves

3.2.1.2 Cotton gloves

3.2.1.3 Kevlar gloves

3.2.1.4 Leather gloves

3.2.1.5 Wool-knitting gloves

3.2.2 Measurement tools

3.2.2.1 TM20 Thermo-Collector (YOKOGAWA, Japan)

3.2.2.2 Thermometer to measure the room temperature

3.2.2.3 Alarm clock

3.2.3 Questionnaire

Psychophysical rating ballots were used to collect information about thermal sensation. The questionnaire was developed by Nielsen & group, 1989 (Appendix)

3.3 Study Methods

3.3.1 Problems investigation

The last 24 months accident reports from this studied plastic manufacturing factory were reviewed. Five cases of primary burn accidents relating to melt flow testing process were reported.

One of the root causes of those accidents that were investigated was an improper protective glove. Three kinds of heat resistant gloves are used for trial in order to solve the problems but each of them has individual limitations as well as generated other problems.

3.3.2 Pilot test of existing commercial heat resistant gloves

3.3.2.1 Leather gloves

Two types of commercial leather gloves as presented in figure 3-1 and figure 3-2 were used by workers. Those gloves have been complained on their sizes and their hardness. The workers have hard times to hold the melt flow testing equipment. That could damage such equipment and would also affect the quality testing result. Furthermore, the seams of those gloves are too strong. That could hurt the workers' fingers and may cause uneasily cleaning.

Figure 3-1 Commercial leather gloves type I

Figure 3-2 Commercial leather gloves type II

3.3.2.2 Wool-knitting gloves

The commercial wool-knitting gloves as in figure 3-3 have been worn by workers when they were performing the cleaning of melt testing equipment. Even though the gloves sizes and material properties help solving some problems, they still generated the other problems. For example, fluff from the wool hair cause the difficulty in the cleaning process. The wool fiber could also be left on the hot equipment, orifice. That may cause the under qualification for the cleaning standard.

Figure 3-3 Commercial wool-knitting gloves

3.3.3 Clothing Level (Clo) Testing

Regarding the review of the hazard and recommendation gloves which is adapted from Safety in program produced by the Canadian Center for Occupational Heath and Safety as in table 2-3, Kevlar gloves are recommended to use when one works with medium temperature between 200 °C to 350 °C.

The Clo value measurement of Kevlar cloth was conducted in the laboratory of Physics and Engineering Department, Ministry of Science.

One square foot size and 3.2 millimeter thickness of Kevlar cloth was prepared for the Clo value measurement. The result from Laboratory is a Thermal conducted value (k). It can be calculated for "R" from below formula:

$$R = X/K$$

Where X = thickness of measured 1 sq.ft. cloth

K = Thermal conduct value

K value, the result from laboratory test.

Clo value was calculated from 1 Clo = 0.155R m^2K/W.

3.3.4 Effect of thermal conduction measurement procedure

3.3.4.1 Prepare the pieces of CC gloves, NC gloves, NK glove and CK gloves but cutting the gloves on palm area, the size approximately 2x2 inches.

3.3.4.2 Place the piece of gloves on the table surface in the chamber. Affix the thermal probe on top of piece of gloves.

3.3.4.3 Put the hot orifice, which is left in 300 ^{o}C barrel for 3 minute, under the gloves. The hot orifice must be put underneath where the thermal probe end located.

3.3.4.4 Record the temperature from the display of the Thermo Collector after 1 minute of the detection.

Figure 3-4 Thermal probe was affixed on other site of the piece of gloves

3.3.5 Experimental procedure

3.3.5.1 Eight subjects in this study are the workers working on melt flow process.

3.3.5.2 All subjects were informed on the purpose of the study. The subjects have to wear gloves during the test.

3.3.5.3 The subjects selected the gloves randomly.

3.3.5.4 The sensors were attached on the subjects' thumbs and index fingers (figure 3-5) for measuring the finger skin temperature while they are cleaning the melt flow testing equipment. (figure 3-6)

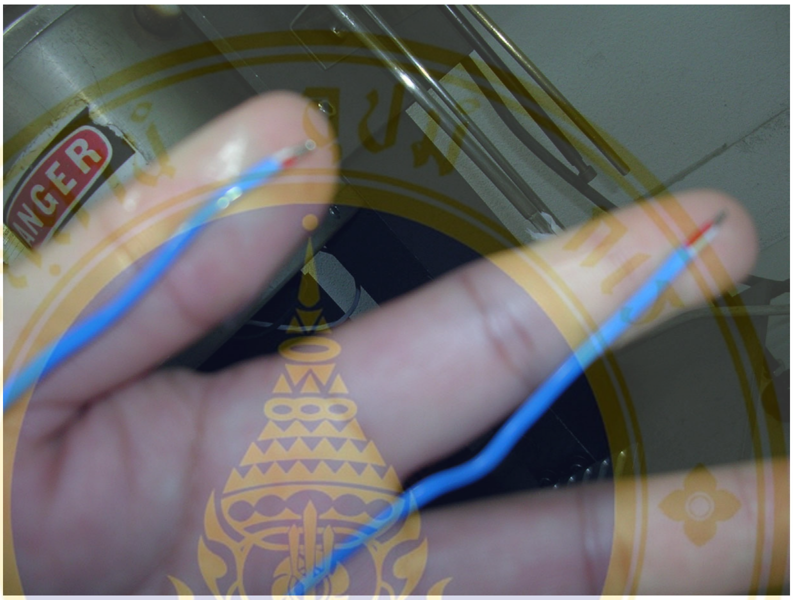


Figure 3-5 Thermal sensors attached on operator fingers

Figure 3-6 Operator wearing CC gloves while cleaning a hot orifice

3.3.5.5 The subjects were interviewed their feeling after three cleaning the melt flow-testing equipment by using CC gloves comparing with the using CK gloves. The interview process was conducted on time flame as in figure 3-7.

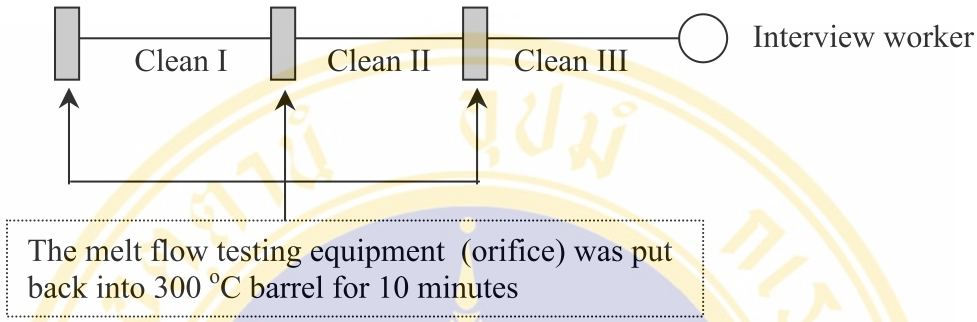


Figure 3-7 The time frame of subjective feeling interview

3.4 Method of measurement

3.4.1 Measurement of skin temperature

The skin temperature was measured at fingertips of worker's thumb and index fingers by attaching the sensor probes to monitor the local skin temperature.

The Measurement Procedure

1. Workers are attached the sensor probes on their fingertips of thumb and index finger respectively.
2. Another ends of such probes are inserted into port A and B of the Thermo-collector.
3. When workers took out the hot melt flow equipment, orifice, the skin temperature is starting detected. The recorded temperature is average temperature within 60 seconds of an exposure.

3.4.2 Measurement of psychophysical rating ballots.

The principle of subjective response determination is to record the worker's feeling. There have been many useful studies to "correlate" physical conditions and physiological response with psychological response. However, there is no model provides more accurate prediction than measuring psychological response directly.

3.5 Statistical Analysis

3.5.1 Percentages and means for thermal transfer on four types of heat resistant gloves

3.5.2 The comparisons of the differences of finger skin temperature, between using different heat resistant gloves were determined by Wilcoxon matched paired signed-Ranked test with $\alpha = 0.05$.

CHAPTER IV
RESULTS

The heat resistance study of new modified gloves comparing with the ordinary gloves was conducted in both laboratory and field test.

The physical properties of CC gloves and CK gloves are presented in Table 4-1. The Clothing Level measurement was conducted in the laboratory of Physics and Engineering Program, Department of Science Service, Ministry of Science and Technology.

Table 4-1 Physical properties of CC gloves and CK gloves.

Properties	CC gloves	CK gloves
Materials	Double layer of Cotton	Inner: Cotton Outer: Kevlar
Thickness (mm)	6.36	5.68
Clothing level (Clo)	0.47	0.36

4.1 Effect of thermal conduction

The measured temperature from hot orifice passes through CC gloves and three types of gloves represent the effect of thermal conduction. The results are presented in table 4-2. The measurement procedure is shown as figure 4-1.

Table 4-2 Measured temperature of thermal conduction in four types of gloves

Type of gloves	Number of testing						
	1	2	3	4	5	$\overline{x}$	SD
CC	95.9	98.7	97.0	98.7	93.7	96.80	1.88
NC	122.5	125.7	124.7	123.9	122.9	123.94	1.17
NK	115.3	113.5	115.5	118.9	117.7	116.18	1.90
CK	83.3	82.3	82.1	79.9	84.1	82.34	1.41

Remarks: Type I gloves are made from double layers of cotton.

Type II gloves are made from Kevlar in outer and Nylon in inner layer

Type III gloves made from Nylon in inner and Kevlar in outer layer

Type IV gloves are made from Cotton in inner and Kevlar in outer layer

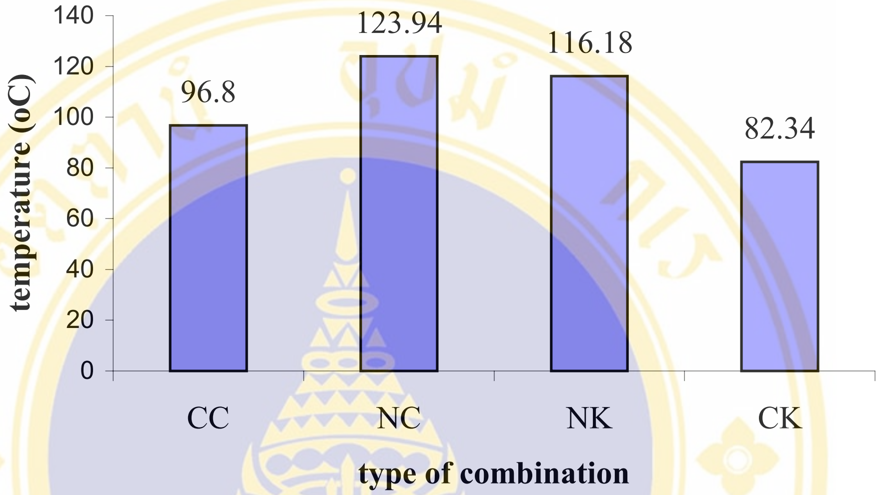


Figure 4-1 Graph of thermal conduction of each type of gloves including CC gloves

The measurement is performed under controlled temperature at 24.3 ^{o}C, then recorded the temperature from display of the thermo collector at 1 minute of detection duration. The orifice was left in 300 ^{o}C barrel for 3 minutes at least.

4.2 Thumb and index finger skin temperature

The temperature of thumb and index fingers, during the performing of orifice cleaning are presented in table 4-3 and table 4-4 respectively. The medians of finger skin temperature of wearing CC gloves were significantly higher than the one of CK gloves (p value < 0.05).

Table 4-3 Thumb and index finger skin temperature of wearing CC gloves and CK gloves.

Subject	Finger skin temperature	
	CC gloves	CK gloves
Subject 1	48.40	40.92
Subject 2	47.30	42.70
Subject 3	46.60	41.02
Subject 4	48.18	40.70
Subject 5	46.82	42.06
Subject 6	49.90	40.60
Subject 7	47.88	40.84
Subject 8	47.50	40.68

The test statistic for comparison of heat resistance between CC gloves and CK gloves is Wilcoxon matched paired Signed-Rank test with $\alpha = 0.05$ (p value = 0.0039).

There is the difference of heat resistance between CC gloves and CK ones.

Calculation of the test statistic T is shown in table D-2.

4.3 Subjective response

The psychological rating ballots of wearing the CC gloves and CK gloves were presented in the terms of thermal comfort and thermal sensation. The results were shown that the operators felt hotter when using CC gloves comparing to CK ones in term of the Thermal state of finger (p value = 0.007)

Thermal state of finger

	N	X	SD	SE Mean
CC gloves	8	5.250	0.707	0.250
CC gloves	8	4.250	0.463	0.164

95% CI for mean difference: (0.368, 1.632)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.74

P-Value = 0.007

Operators feelings were not different between wearing CC gloves and CK gloves performing the melt flow testing in term of thermal comfort/discomfort, thermal state of whole body, thermal state of trunk, thermal state of face and thermal state of toe. See table D-1 of the subjective interview results.

Table 4-4 The summary of Psychophysical rating ballots

Condition	Thermal State of									
	Whole body		Trunk		Face		Finger		Toe	
	OR	NM	OR	NM	OR	NM	OR	NM	OR	NM
Very cold	-	-	-	-	-	-	-	-	-	-
Cold	-	-	-	-	-	-	-	-	-	-
Slightly cold	-	-	-	-	8	8	-	-	-	-
Neutral	8	8	8	8	-	-	1	6	8	8
Slightly hot	-	-	-	-	-	-	4	2	-	-
Hot	-	-	-	-	-	-	3	-	-	-
Very hot	-	-	-	-	-	-	-	-	-	-

Remarks: CC = Ordinary gloves

CK = New modified gloves

CHAPTER V
DISCUSSION AND CONCLUSION

This study demonstrated the effectiveness of wearing CK gloves comparing with the CC ones. The subjective feelings were integrated into this study in order to verify the efficiency of CK gloves implementation.

All operators working on the melt flow testing process were selected to participate in this study. All of them were at least 2 months experienced in that position as well as were already trained on how to work with the melt flow testing machine.

5.1 Discussion

5.1.1 Capability of subject

All operators have to pass the GR&R process. It is the quality process to measure their capabilities individually on the precision and accuracy. In addition, the interview of subjective feeling was conducted by same person in order to prevent any errors from inter-observer variations.

5.1.2 Systematic errors

- Method error: The error can occur during the data collection because of movement of operator's fingers while they are cleaning the melt flow testing equipment. It has potential for the false positive since the thermal sensor probe moved away from the finger skin. The adhesive tape was applied on subjective fingers to prevent the movement of such thermal sensor probe.

- Personal error: The skin temperature was detected by Thermo-collector. It is an easy read digital instrument. It can prevent the error estimation in case of the instrument is analog system. The measured temperature was read by same person.

- Instrumental error: Finger skin temperature was measured by the Thermo-Collector, which has been calibrated by qualified agency.

5.1.3 Study results

5.1.3.1 Clothing insulation

Clo value is normally used for measuring clothing insulation. Clo value of ordinary gloves and new modified gloves is presented in table 4-1. The naked skin has Clo value of 0.0.

According to the glove's design, the outer of the CK gloves was Kevlar. It was selected in order to prevent the conductive heat from hot metal through the finger skin. Furthermore, the Kevlar is also good for abrasive prevention as recommended by the Canadian Center for Occupational Health and Safety. Therefore, it could contribute the prevention of potential cut injury.

The Clo value of the CK gloves was higher than the CC gloves from material testing. Consequencely, this outcome indicated that the CK gloves resisted the heat conduction better than the CC ones. These relate to the mechanical construction of fabrics (for instance wind resistance and the ability of fibers to support thick fabrics), and to intrinsic properties of fibers (for instance, absorption, and reflection of heat radiation, absorption of water vapor, wicking of sweat)(35).

5.1.3.2 Effects of thermal conduction

CC gloves and three types of modified gloves were measured on thermal conduction. The resulted was presented in table 4-2 and the graph is shown in figure 4-1.

Reference to the characteristic of Nylon fiber on its elasticity, it can returns to 100 percent of its original length. It was preferred by the operators since it was fit perfectly to the operators' hands. However, nylon has limitation, the low heat resistance. It would easily be damaged by the hot melt flow testing equipment. The testing temperature is normally higher than 250 ^{o}C.

In addition, the graph as shown in figure 4-1 demonstrated that the CK gloves, the inner layer made from nylon, have a limitation of heat resistance. Hence, the most interesting modified gloves are the one making from Kevlar in outer layer and Cotton in inner layer.

5.1.3.3 Thumb and index finger temperature

The thumb and index finger temperatures are measured by the Thermo-Collector. The two thermal sensor- probes automatic linked the detected result to the Thermo- Collector display. The result is shown in digital number.

While operators were cleaning the Melt flow equipment, both of their thumbs and index fingers needed to move around it. That could cause the sensor loss of skin temperature detection. The temperature showed on the Thermo-collector display might be the measured temperature from only one finger. It could be defined as an instrumental error. Nevertheless, the tapes were applied to secure the sensor firmly attached on fingers and eliminated the chance of sensor moving away from the measuring fingers.

The temperature conducted from hot orifice through the finger skin was average temperature between thumb and index finger. The temperature should be the peak one from them. It related to the temperature that could burn the human skin.

5.1.3.4 Subjective response

The results of thermal responses from subjects by applying the Psychophysical rating ballots were presented in Chapter IV. The room temperature was set between 24-25 ^{o}C. All subjects felt neutral in term of body temperature, face temperature and toe temperature during they wearing both types of gloves. For finger temperature, some subjects felt slightly hot while using the CC gloves but they felt neutral while using the CK gloves. As a result, the temperature conducted from hot melt flow testing equipment can be better reduced by the CK gloves than CC gloves.

5.1.3.5 Hand Dexterity

During the finger skin temperature measurement, the researcher observed that the workers spent lesser time in the cleaning process while wearing the CK gloves comparing with wearing CC gloves. It implied that the hand dexterity could be increased when the workers wore the CK gloves to cleaning the hot orifice.

Form the investigation of effects of nine glove designs on manual performance (39) found that there are both thermal effects and glove effects on manual performance.

5.2 Conclusion

This study was design to compare four combinations of many kinds of gloves in term of heat resistance. Two most interesting combination gloves are CC and CK gloves. Both of them are using in the melt flow testing process in the plastic compounding factory in order to compare skin temperature when using CC gloves to CK gloves.

Moreover, this study also was designed to determine subjective feeling when using CC gloves and CK gloves to perform the melt flow testing process. The subjective feeling was interview by using the questionnaire of Psychophysical rating ballots. The result of the study is concluded as below:

5.2.1 The result of Clo value

The Clo value is computed from K value. K value is the result from the thermal resistance of clothing in the laboratory of the Physics and Engineering Department, Ministry of Science. K value of Cotton cloth and Kevlar cloth are 0.021 w/mk and 0.030 w/mk respectively. Clo value computing from such K of CC glove is 0.47 and the one of CK glove is 0.36. It concluded that clo value of CC glove is higher than the one of CK gloves.

5.2.2 The result of heat resistance

Form the graph shown in figure 4-1 can be summarized that among all of tested gloves, the CK gloves is the best one in term of hear resistance. CK gloves resisted to the heat better than CC gloves, NC gloves and CK gloves.

5.2.3 Skin temperature

The result from data analysis of the heat conduction pass through the finger skin between wearing the CC gloves and CK gloves are different (p-value = 0.0039). The skin temperature of thumb and index finger when using CC gloves are higher than using CK gloves.

5.2.4 The result of Subjective Feeling

This study found that Psychophysical rating ballots had no significant difference at thermal comfort, thermal state of whole body, face, trunk and toe.

All operators felt hotter on both their thumbs and index fingers when wearing of CC gloves to perform the melt flow testing than wearing of CK gloves. (p value = 0.007)

CHAPTER VI
RECOMMENDATIONS

6.1 Recommendations for future study

This study showed that the clothing insulation of CK gloves is lower than the CC ones but the result of testing in laboratory of thermal conduction was shown in opposite way. The CK gloves resisted the high temperature, which conducted from hot orifice through the finger, better than the CC ones. For the future study, it should be recommended here that:

1. Study the pattern design for glove weaving and compare the clothing insulation.
2. The skin temperature should be recorded the peak ones in order to present the highest temperature that could be exposed by workers.
3. Compare the Kevlar in many weaving-patterns to compare the elasticity and thermal resistance in order to select the best of Kevlar for glove modification.
4. The study of laboratory test of should be carried out in the climatic chamber, which the environment can be controlled. The air velocity, temperature and relative humidity can be set.
5. The CK gloves were modified follow the commercial size which convenience for worker's hand size in generally. The study on the anthropometry of the worker's hands should be conducted in order to the provide gloves in appropriate size for worker.
6. This study was conducted on only thermal conductivity between hot orifice and operators' fingers. It focused on the heat transferred from hot orifice pass the gloves though the fingers. The ventilation of heat from fingers or gloves and air should be considered in the next study.
7. The heat cumulating on operators' fingers in case of poor ventilation between fingers and air should be carried out in the next study. This is to find the recommendation of gloves in order to prevent burn injury to operators.

8. Subjective interview was conducted by researcher. That may introduce bias. For further study, multiple choices should be written in paper and give to operator to pick up the choice which can represent their feeling.

6.2 Recommendations for the factory

Pertaining to the comparison of finger skin temperature while using CC gloves and CK gloves as presented in table 4-3, the CK gloves is better than the CC ones in term of thermal resistance. For financial concerns, the cost of CK gloves (105 baht) is higher than the CC ones (10 baht). However, the CK gloves are last longer than ordinary ones. The CK gloves can be reused many times than the CC ones. This could help the factory save its cost expense.

In addition, the CK gloves properties: easy to clean, and prevent the growth of fungus in case of too much humidity in testing room. This could protect the workers from the exposure to such biological hazard.

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APPENDIX

The questionnaire "Psychophysical rating bollots"

Developed by Nielsen et. al (1989)

Name……………………………………Surname…………………………………….

Date…………………………………………Time……………………………………….

1. How do you feeling thermally?
    1. Comfortable
    2. Slightly uncomfortable
    3. Uncomfortable

2. How is the overall thermal state of your whole body?
    1. Very cold
    2. Cold
    3. Slightly cold
    4. Neutral
    5. Slightly warm
    6. Warm
    7. Hot

3. How is the overall thermal state of your face? Very cold
    1. Very cold
    2. Cold
    3. Slightly cold
    4. Neutral
    5. Slightly warm
    6. Warm
    7. Hot

4. How is the overall thermal state of your fingers?
    1. Very cold
    2. Cold
    3. Slightly cold
    4. Neutral
    5. Slightly warm
    6. Warm
    7. Hot

5. How is the overall thermal state of your toes?
    1. Very cold
    2. Cold
    3. Slightly cold
    4. Neutral
    5. Slightly warm
    6. Warm
    7. Hot

Table B-1 Thumb and index finger skin temperature of wearing ordinary gloves.

Subject	1	2	3	4	5	Avg
1	47.5	48.4	47.9	49.8	48.4	48.4
2	46.8	46.9	48	47.1	47.7	47.3
3	45.8	48	45.9	46.3	47	46.6
4	50.8	49.7	49.3	48.7	47.4	49.18
5	47	47.2	47	46.6	46.3	46.82
6	48.9	51.4	49.9	50.6	48.7	49.9
7	46.9	48	47.3	49	48.2	47.88
8	48	47.9	47.7	47	46.9	47.5

Table B-2 Thumb and index finger skin temperature of wearing new modified gloves

Subject	1	2	3	4	5	Avg
1	40.3	40.7	41.3	40.6	41.7	40.92
2	44.1	41.3	42.3	43.1	42.7	42.7
3	40.5	41.5	41.2	40.8	41.1	41.02
4	40.9	40.7	40.5	40.3	41.1	40.7
5	42.5	42.2	41.7	42.3	41.6	42.06
6	39.8	40.5	41.2	41.5	40	40.6
7	41	40.3	41	40.7	41.2	40.84
8	40.1	40.5	41	40.8	41	40.68

Figure C-1 The Thermo-Collector and stopwath

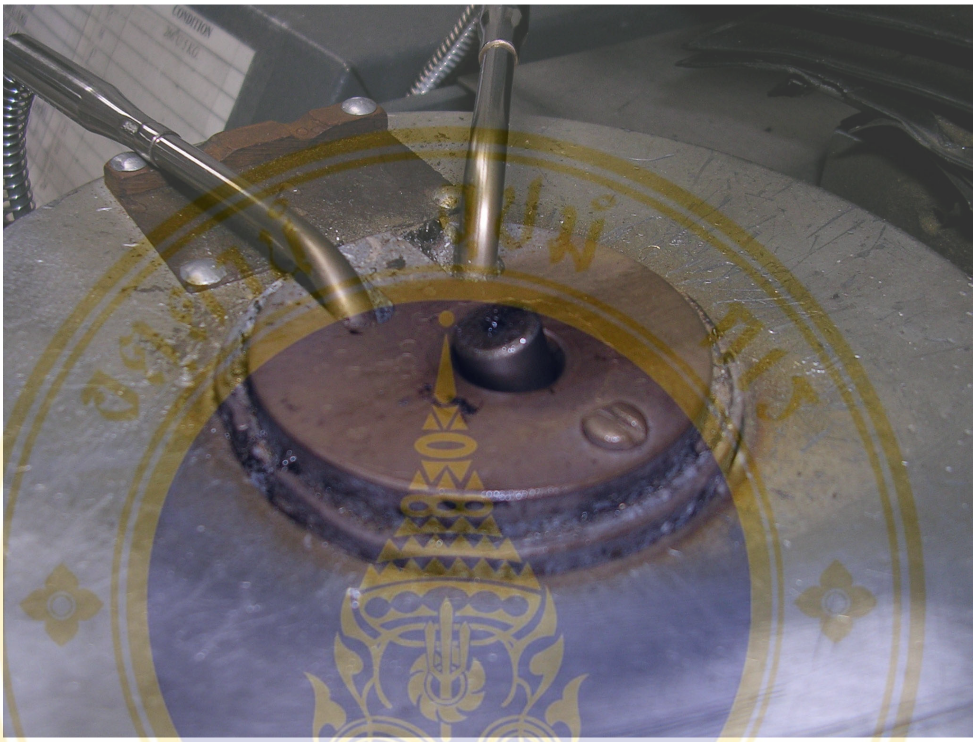

Figure C-2 The Melt Flow Testing machine, Orifice

Figure C-3 The Orifice Cleaning process

Figure C-4 Melt flow process is being tested by operator

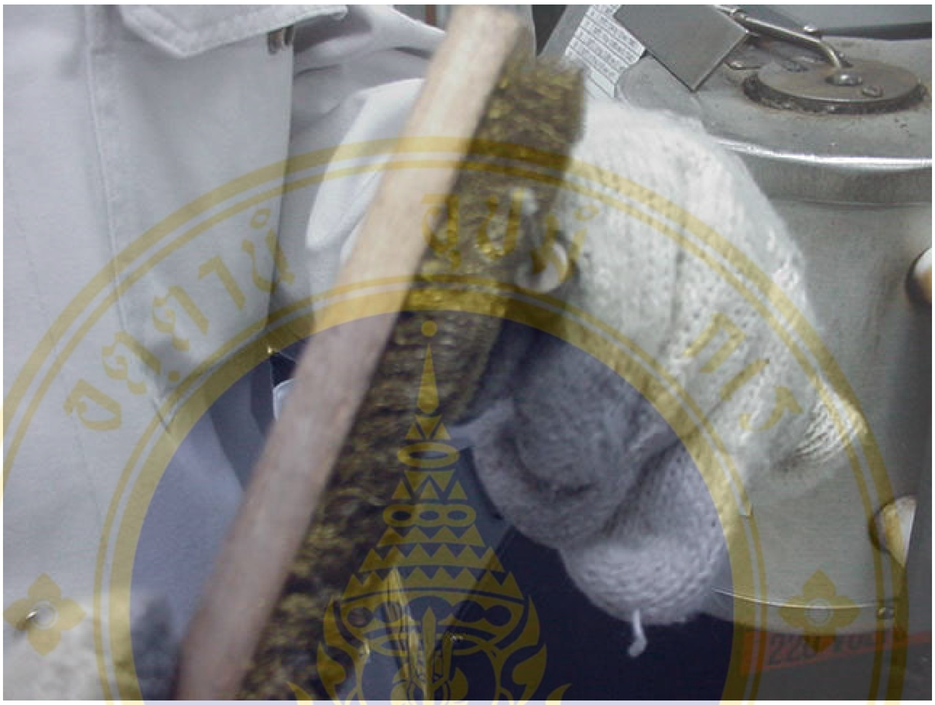

Figure C-5 Operator is cleaning the hot orifice with wire brush

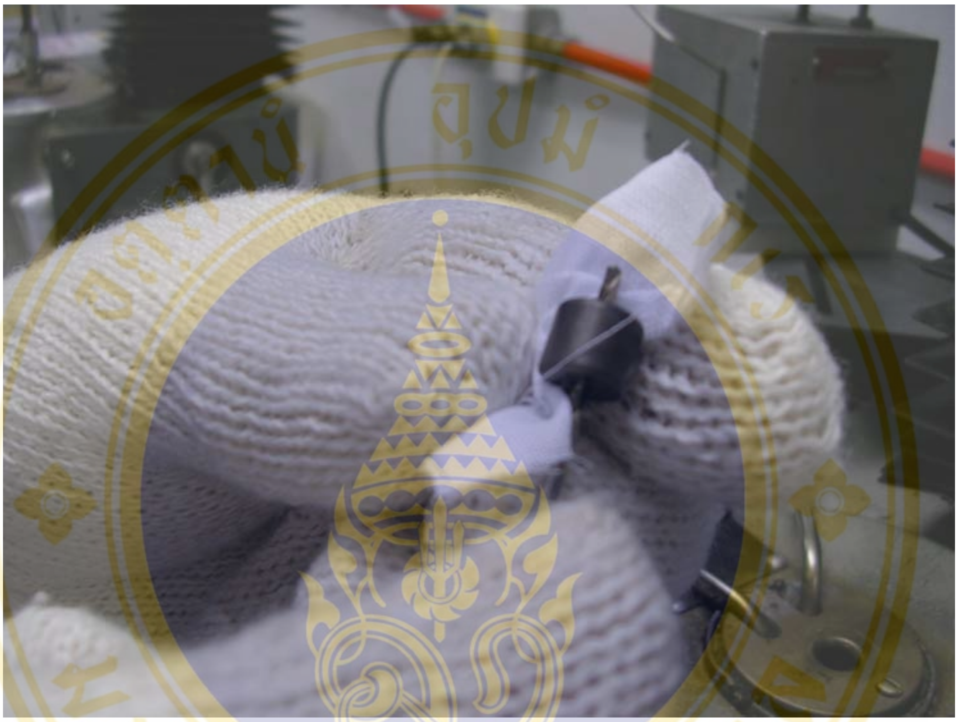

Figure C-6 Worker is cleaning the hot orifice with cotton cloth

Figure C –7 The Cleaning equipment- wire brush and cutter blade

Figure C-8 Hot orifice while cleaning with CC gloves

Table D-1 The number of psychophysical rating ballots while wearing CC gloves and CK gloves

Thermal comfort/discomfort

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	-	-
Neutral	8	8
Slightly hot	-	-
hot	-	-
Very hot	-	-

Thermal State of Whole body

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	-	-
Neutral	8	8
Slightly hot	-	-
hot	-	-
Very hot	-	-

Thermal State of Trunk

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	-	-
Neutral	8	8
Slightly hot	-	-
hot	-	-
Very hot	-	-

Thermal State of Face

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	8	8
Neutral	-	-
Slightly hot	-	-
hot	-	-
Very hot	-	-

Thermal State of Finger

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	-	-
Neutral	1	6
Slightly hot	4	2
hot	3	-
Very hot	-	-

Thermal State of Toe

Condition	CC gloves	CK gloves
Very cold	-	-
Cold	-	-
Slightly cold	-	-
Neutral	8	8
Slightly hot	-	-
hot	-	-
Very hot	-	-

Table D-2 Calculation of the test statistic T

Finger skin temperature (°C)				
CC gloves	**CK gloves**	**d_i**	**Rank of d_i**	**Signed rank of d_i**
48.40	40.92	-7.48	6	-6
47.30	42.70	-4.60	1	-1
46.60	41.02	-5.58	3	-3
48.18	40.70	-8.48	7	-7
46.82	42.06	-4.76	2	-2
49.90	40.60	-9.30	8	-8
47.88	40.84	-7.04	5	-5
47.50	40.68	-6.82	4	-4
				$T^+ = 0$, $T^- = 36$, T=0

n = 8 and T = 0, p value = 0.0039

BIOGRAPHY

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