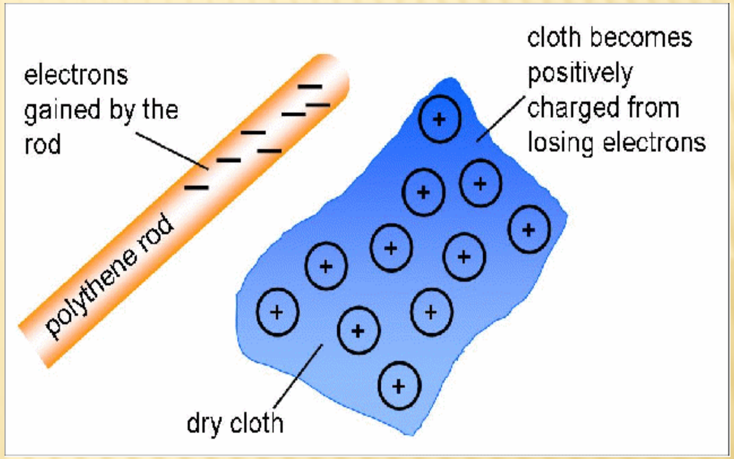
ELECTROSTATIC PROTECTION

1. Introduction

- The term **'electrostatic'** or **'static electricity'** refers to the phenomenon associated with the build up of electrical charges generated, for example, by contact and/or rubbing of two objects. Static electricity is generated by unbalancing the molecular configuration of relatively non-conductive materials.
- Many years ago the problems arising from static charges were relatively small with natural fibres in high humidity environments, but these problems became recognized as serious when synthetic fibres of a hydrophobic nature were introduced.
- The need for in-depth understanding of the fundamentals of electrostatics in several industries has been growing fuelled by the proliferation of synthetic fibres the use of atmospherically controlled environments, highspeed manufacturing, and static-sensitive devices.
- Even natural fibres like wool and cotton, when completely dry, are very poor conductors, but their conductivity increases in high-humidity atmospheres because they absorb substantial amounts of moisture of the order of 10%, calculated on the weight of the fibre.



- Electric charges on the clothing of operators are typically accumulated when the operator is moving around, i.e., by triboelectric effects (rubbing or separation of two materials).

- In electronics manufacturing environment specially designed protective clothing is often used to minimise accumulation and retention of the charge.

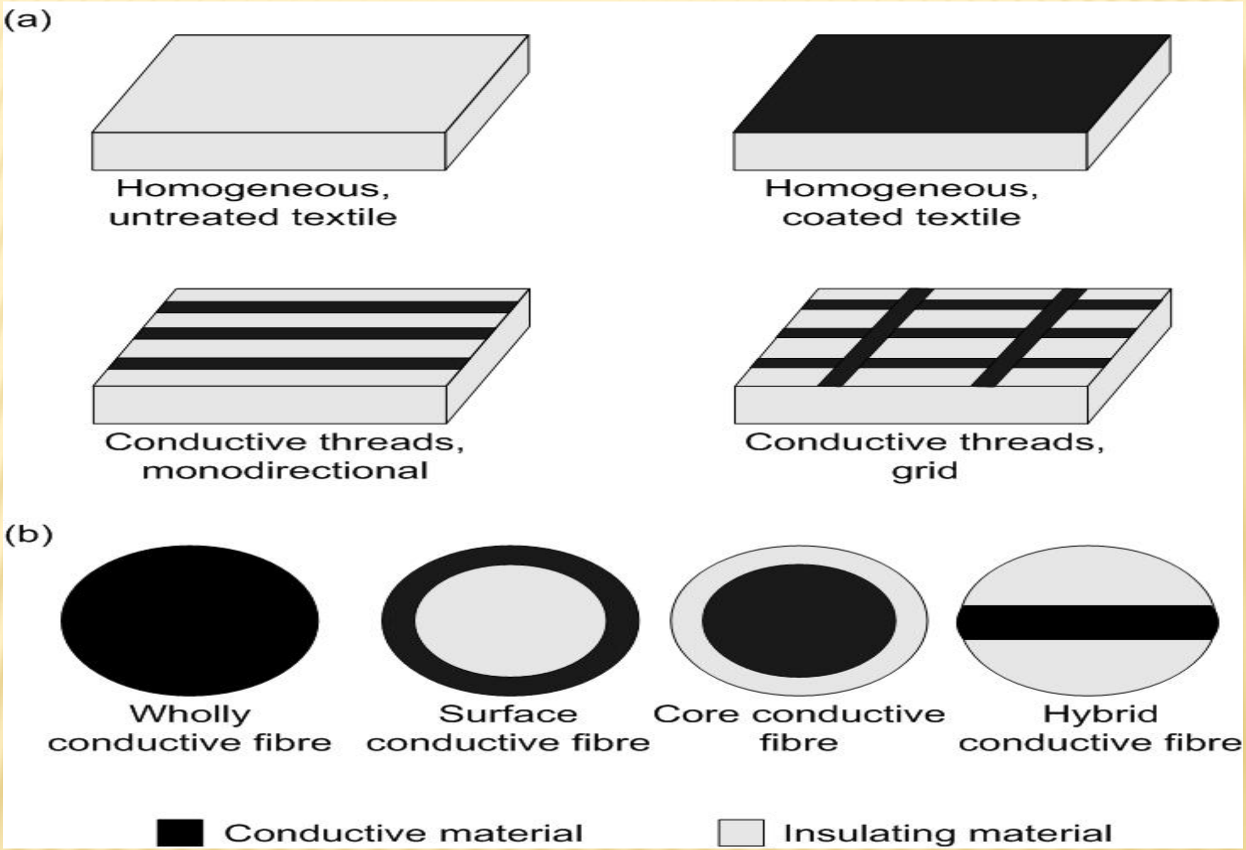
- This clothing, called an **ESD garment**, is worn over the ordinary clothing of the operator. Thus it should also provide shielding against any surface voltages or voltage transients arising from underlying garments. In some cases the ESD garments are not used just to prevent ESD damage to electronics but also to prevent the electronics from being damaged by the contamination of dust particles (cleanroom clothing).

- The main purpose of ESD garments is to minimise risks of ESD failures to sensitive electronics due to charged clothing. Testing and evaluation of garments should take this into account.

- The protective clothing was typically either a pure cotton or cotton-mixture garment which could have been topically treated by hygroscopic agents. Such garments, as well as the test methods, satisfied the requirements of that time.

- Since then the electronics industry demanded increasing performances from the ESD protective clothing. At the same time there has been much progress in the textile industry. As a result the ESD-garments in use today are made of composite fabrics where a grid or stripes of conductive threads are present inside a matrix of cotton, polyester or mixtures of these materials.

➢While the presently available standard test methods for garments used in electronics industry have been developed for homogeneous materials, they do not allow a proper characterisation of the modern garments performances.Furthermore, it is not certain that they indicate how much the garments will protect the electronics from ESD.



(a) Structures of electrostatically homogeneous and heterogeneous textiles,
(b) structures of some commonly used conductive fibres.

Why and when ESD protective garments should be used?

➢The purpose of ESD protective garments is to minimise risks of ESD failures to sensitive electronics due to charged clothing. The required protection level depends on the susceptibility of the devices in production to Human Body Model (HBM) and Charged Device Model (CDM) ESD.

➢An ESD failure caused by charged clothing can, in practice, happen in two different ways;
1) by discharge from a charged device,
2) by a direct discharge to a device.

➢The electrostatic field external to garment depends on chargeability of outer clothing ability of charge dissipation of clothing ability of outer clothing to shield static electric field from clothing under the outer garment suppression of field external to the garment by coupling to grounded body or conductive threads of garment.

What is a good ESD garment?

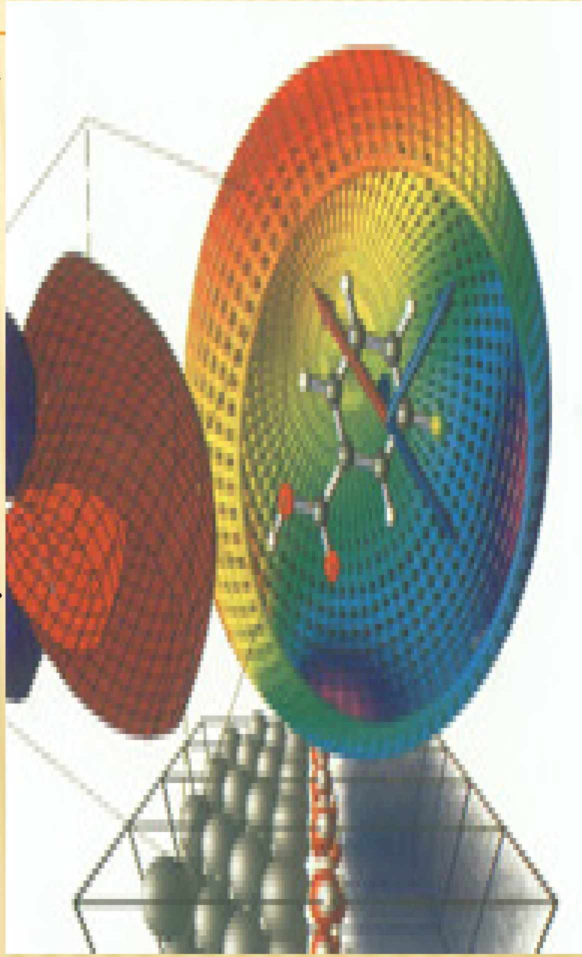
An ESD protective garment should ideally have the following functions:

- ➢ The protective garment should effectively shield the electric field originating from the insulating parts of the operators normal clothing.
- ➢ The protective garment should prevent direct discharges from the normal clothing of the operator.
- ➢ The protective garment should not itself cause similar problems, i.e., it should not cause an electrostatic field external to the garment and it should not constitute a potential source of direct electrostatic discharges.

2.Principles of electrostatics

- It has been stated that the static electrification between two insulators of the same material is increased by asymmetric friction or temperature difference found that the electric charge of two sheets of polyester depended mainly on their thickness rather than on their asymmetric friction.

- The static charge which is involved in a spark phenomenon is often generated on the clothing or footwear of the individual and transferred onto the skin. Hence, the charging characteristics of clothing and shoes play a critical role in determining the possibility to produce a spark which could ignite flammable gases.



- An electrostatic system can be represented by a simple circuit . It contains four elements: a charge generator , **I**, to represent the charge generating mechanism, a capacitor, **C**, on which charge is stored, a resistance, **R**, which represents the charge relaxation mechanism in the electrically stressed insulator, and **a spark gap** which limits the maximum charge that can be held in the system. The magnitudes of the capacitance and resistance determine the decay time (or relaxation time) of the charge in the system:
$T = RC$

2.1.Electrostatic properties of materials

➢Materials differ in their propensity to lose some of their electrons when in contact with another material.

➢When two bodies make contact, that which has the lower work function loses electrons to that with the higher work function. Work function is the minimum energy required to extract the weakest bound electron from its maximum excursion distance from the surface to infinity (Gallo and Lama, 1976).
There are three main types of contact:

1. metal-metal
2. metal-insulator
3. insulator-insulator.

The last two are important to the phenomenon of charge generation on textiles.

2.2. Charge generation

- For materials which are poor conductors of electricity (insulators), as are most textiles and polymers, the causes of charging are very complex.

- In good conductors, the charging is largely electronic in nature, but the surface of textiles is usually contaminated with additives, finishes, dirt and moisture, in all of which resides an abundance of ions.
- In this case, charging may comprise electrons, ions and charged particles of the bulk materials, or any combination of these.
- Charges may be generated between a non-conductor and a conductor by induction.
- Charging that occurs when two solids come into contact has been referred to as contact charging, frictional charging, tribo-electric charging and triboelectrification.

2.3 Charge dissipation

- There are substantial differences in the ways a charge is dissipated, depending on whether it is located on an insulated conductor or on an intrinsically insulative material.

- In both cases, there are also differences that depend on whether the dissipation is carried out by charge carriers already present or if these carriers are created by the process itself.

2.4 Effect of environmental conditions

- Fibres vary significantly in quantity of water vapour they absorb. Most textile fibres absorb moisture (water vapour) from the air. As the relative humidity (RH) of the air increases, the amount of moisture absorbed generally increases.

- The amount of moisture a fibre contains has a profound effect on the electrical properties of the fibre. The rate of absorption depends on a variety of factors: temperature, air humidity, wind velocity, surrounding space, thickness and density of material, nature of the fibre.

- Several researchers have reported the great effect environmental conditions have on electrical characteristics of textile materials. Hearle (1953) found that the moisture content of a textile fibre is the most important factor in determining its electrical resistance. Hearle and others have shown that the resistivity of yarns and other textile materials increases exponentially with decrease in the relative humidity of the environment with which they are in equilibrium.

- Not only the electrical resistivity of a fibre is affected by changes in its moisture content.

- Onogi et al. (1997) reported interaction effects of temperature and moisture content in either fibre or ambient air, and their combined influence on static dissipation from textile surfaces.

- They reported variation in the critical water content of different fibres at various temperatures. Critical water content is a characteristic of the structure of the polymer structure of the fibre.

- Absorbed water in a sample with less than this critical water content could not carry of the line relating the rate constant of charge dissipation for various fabrics and the free water, and found that at all temperatures the slopes for each fabric were quite different.

- Thus, they concluded that the rate constant for charge dissipation into the air does not generally depend on only the amount of free water in the textile fabric, but also on the vapour pressure of water (absolute humidity).

3. Electrostatic hazards

Electrostatic spraying

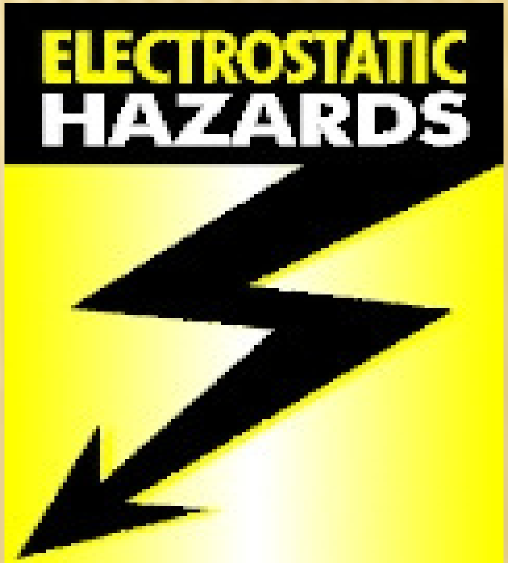
- Static electricity has long been cited by investigators as a possible cause of accidental ignition of flammable or explosive liquids, gases, dust, and solids

- Many cases have been documented (Scott, 1981; Crow, 1991) where charges generated on an object reach the level at which the resistance of the air gap between the object and a conductor at a lower potential breaks down, producing a spark.

3.1 Requirements for an electrostatic discharge (ESD)

- Static electricity manifests its destructive nature through ESD. The electrostatic build-up on people or materials, particularly non-conductive materials such as textiles, can be significant in dry conditions.
- Workers in the oil and gas industries have expressed opinions that some thermal protective clothing they are required to wear may not be safe due to its static propensity.

- Many still hold a traditional belief that 100% cotton garments are less prone to static electricity than are garments of more thermally stable fibres. This belief is based on
- measurements of certain electrical properties taken under conditions of relatively high humidity and may be misleading for low-humidity environments.



3.2 Maximum charge density

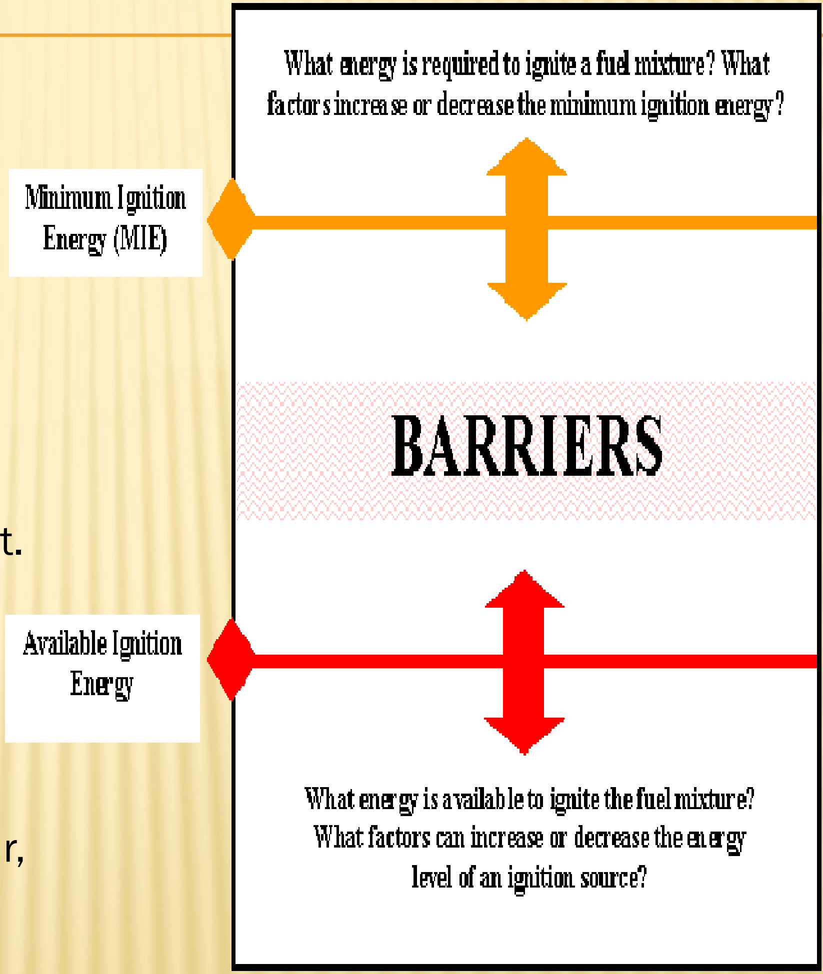
➢The factors which determine the maximum density of charge that can remain on a surface without discharging into the surrounding medium are complicated. They are nevertheless important because discharge into the surrounding medium can set a limit to the charge obtained by friction charging.

3.3 Minimum ignition energy (MIE)

➢The ignition energy of a gas, vapour or dust depends strongly on the percentage of flammable material present. At low concentrations the ignition energy is high but decreases to a minimum at some critical concentration before rising again on further increasing the concentration.

➢The lowest energy required to cause ignition of the material, or a mixture of it in critical concentration with air, is known as the minimum ignition energy (MIE). There is no standard method to measure the energy required to ignite flammable gases.

➢Typically, a known mixture of gas and air is placed in a grounded Plexiglas box which contains an electrode. A charge is discharged through the electrode, either from a charged person or from a capacitor.



4. Measurement techniques

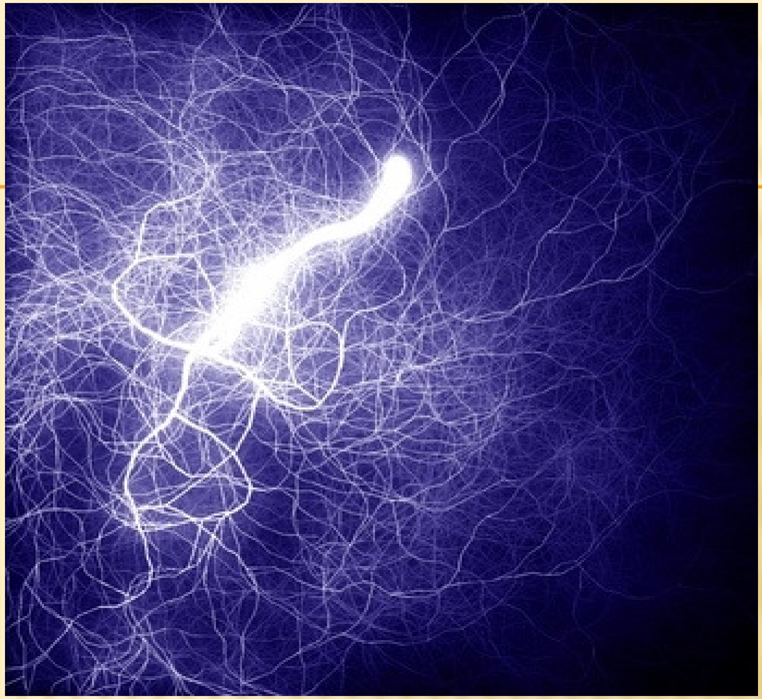
There have been two main approaches to assessing the electrostatic propensity of textile materials. One is to measure the charge built up on a clothed person or the electrical capacitance of a body (human-body model); the second is to measure some electrostatic characteristics of textiles (e.g., surface resistivity, charge decay rate, peak potential, etc.) in small-scale tests.

4.1 Small-scale tests

- Several standard methods to measure different static characteristics are utilized,

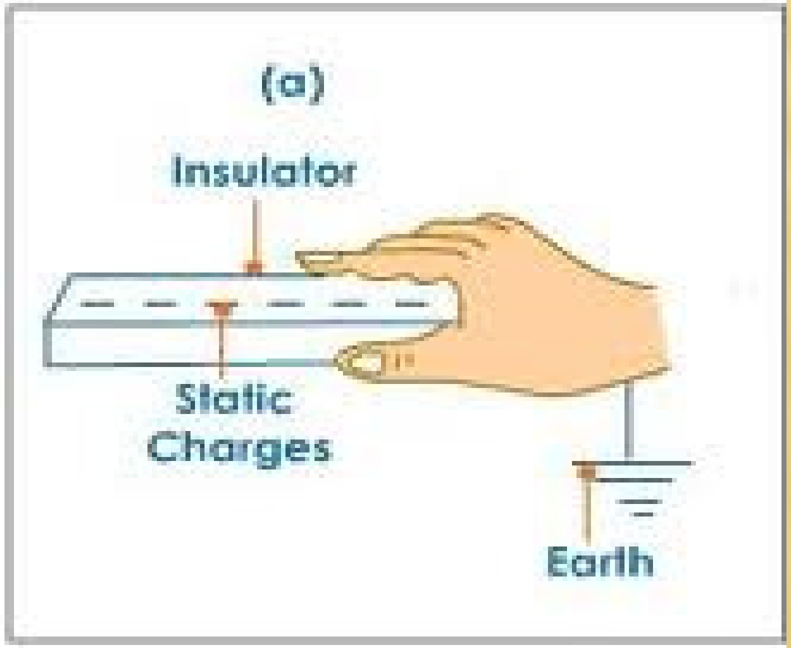
but there is generally a lack of correlation between small-scale and human-body data. Small-scale tests normally measure the electrostatic characteristics of an insulator and do not represent the real phenomenon of a charged clothed human body being discharged through a grounded object. Measurements in small-scale tests are different from measurements in human-body experiments as their physical quantities are different in value and order of magnitude. Several conditions are involved in real-life sparks: electrostatic discharges are the result of the typical charge generation processes (tribo-electrification, induction and conduction charging), charge accumulation, type of materials involved, capacitance of the system, atmospheric conditions, etc. In order to understand better and control the various parameters which are related to ESD, the use of appropriate instrumentation, measurements, and standardized test methods is necessary.

4.2 Electric field



➢An electrostatic field exists in the region surrounding an electrically charged object. This charged object, when brought in close proximity to an uncharged object, can induce a charge on the formerly neutral object. This is known as an induced charge. In most situations, it is the electric field from the charge which causes electrostatic effects. One technique for evaluating the possible sparking hazard is therefore to measure the electric field intensity (V/m) at the surface of the charged fabric.

4.3. Charge



➢There has been an ongoing discussion whether measuring voltage from an insulator is correct or not. Some authors have stated that it is not possible to characterize a charged insulator with a single voltage value. Others have stated that measuring surface voltage from a charged insulator is meaningful. The surface voltage of a charged insulator can be measured only in the case of a thin uniformly charge insulator (such as a fabric) backed by a grounded conductor.

4.4 Resistance and charge decay

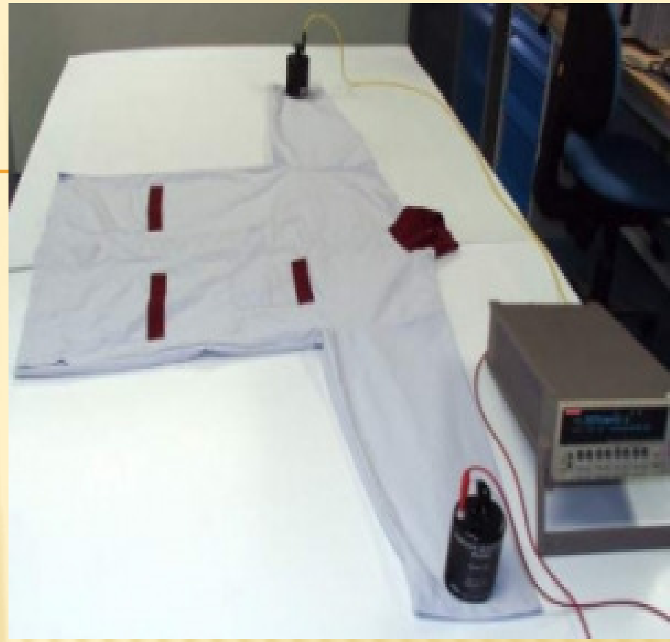
Measurement of electrical resistivity is a frequently used method for the evaluation of static propensity of textiles. One of the most accepted small-scale methods used is;

- surface resistivity

- ASTM D257 Standard Test Methods for d-c Resistance or Conductance of Insulating Materials

➢The advantages of this kind of measurement over the determination of surface potentials are many. Measurement of electrical resistivity is described as simple and reproducible, and commercial equipment is widely available.

➢Measurement of charge decay rate on fabrics is another well known and industry-wide method and Federal Test Standard 191A Method 5931 Determination of Electrostatic Decay of Fabrics. In using a charge decay meter to measure the dissipation rate, decay time indicates the ability of the surface to transfer the electrons from a charged body through the work surface to ground. Thus, the greater the resistance, the slower the charge decay rate.



4.5 Voltage

Material Static Charge Accumulation Resistance Test is used to evaluate the static electrical charge generated by tribo-electrification and the rate of discharge on protective clothing. This tribo-charging device is based on the system developed by the National Aeronautics and Space Administration (NASA) in the late 1960s.

4.6 Human-body model

There is no standard method for measuring the static charge built up on a person. The generally accepted method is for a person to walk in a controlled fashion into a Faraday cage. This is a wire cage onto which is induced an equal but opposite charge to that on the person entering it. This induced charge is recorded to give a measure of the static electricity on the person.

Most human-body experiments have been conducted in the United States,

Canada and the United Kingdom. Measurements of the charges generated between different materials agree somewhat with rankings in existing tribo-electric series, where materials placed close to each other develop less static charge than those ranked further apart.

Some conclusions are that the static propensity of clothing depends on such factors as temperature, humidity, the type of textile, the type of charge mechanism, and the nature of the footwear worn.

5 .Abatement of static electricity

➢There are two distinct differences in the electrostatic performance of conductors and insulators. The first difference is that a charged conductor can dissipate all the energy stored in its field in a single discharge, neutralizing its entire charge. The second difference is that a charged conductor needs only to be connected to ground from a single point of its surface through a suitably conductive path to have its charge eventually migrated.

➢A discharge from a charged insulator, on the other hand, neutralizes only part of the charge and hence dissipates only part of the energy stored in the field. Furthermore, charges on an insulator cannot be removed by connecting the surface of an insulator to ground.

- Most static charge removal processes do not involve actual removal of an electric charge from the charged object. The exception is charged conductors. In all other situations, the neutralization consists of oppositely charged carriers, either ions or electrons, being drawn to the excess charge. The field from the neutralizing charge superimposes the original field, and the resulting reduced field is then interpreted as a reduction or removal of the charge.

- In principle, there are three methods for neutralizing charges on insulators:

- conductance through the bulk of the material, conductance along the surface of the material, and the attraction of oppositely charged ions from the air. The next
- three sections are based on one of these methods of neutralization.

5.1 Materials and their design

➢There has been an increasing research to provide insulative materials an appropriate conductivity without affecting their other advantageous properties, usually mechanical ones.

➢This is usually achieved by mixing the material with inherently conductive additives. The best-known example of such an intrinsic antistatic agent is carbon black. Carbon black can be added to a variety of polymeric materials and is used when the resulting blackening of the base material is acceptable.

➢For many years, the most important area of use for carbon black was conductive rubber.

➢Another use of carbon black is in the manufacturing of textile products and antistatic floor coverings. The textile fibres can be made with either a central core of carbon black and a sheath of polyamide or, conversely, with a central core of aramid fibre and a sheath of carbon black.

A different approach is to use special high-performance antistatic fibres:

1.Metal
2.Metallized
3.and bi-component fibres containing conductive features are among those used.

5.2 Manufacturing

➢The basic rule for fighting the unwanted effects of static electric charges is to ground all conductors that might become charged or exposed to induction from other charged objects. Ungrounded charged conductors can produce discharges ranging from weak current pulses that may harm only the most sensitive electronic components to energetic sparks that may cause explosions and fires.

➢In the electronics and other industries, grounding through footwear and a floor covering is a widely accepted procedure in many areas of the electronics industry. The device employed for this purpose is a wrist strap, which consists of a band or chain, similar to an expandable watchband and made of metal and conductive plastic or conductive fibres, and a strap that connects the band to ground.

5.3 Finishing

➢It is often possible to render highly insulative textile materials sufficiently surface-conductive, even at relatively low humidities, by treating the surface with antistatic agents (topical antistatic finishes). Some finishes have been developed that attempt to decrease static build-up by one or more of three basic methods:

➢ (1) by increasing the material's conductivity, whereby the charged electrons move to the air or are grounded, (2) by increasing absorption of water by the finish, providing a conductive surface on the fabric that carries away the static charge, and (3) by neutralizing negative and positive charges.

➢Chemically speaking, antistatic agents are amphipathic compounds, their molecules containing a hydrophobic group to which is attached a hydrophilic end group. According to the nature of the end group, the agents are divided into cationic, anionic, and onionogenic agents. Cationic materials are usually highmolecular quaternary ammonium halogenides or ethoxylated fatty amines or amides. Anionic materials can be sulfonated hydrocarbons, and nonionogenic materials can be polyalkylene oxide esters.

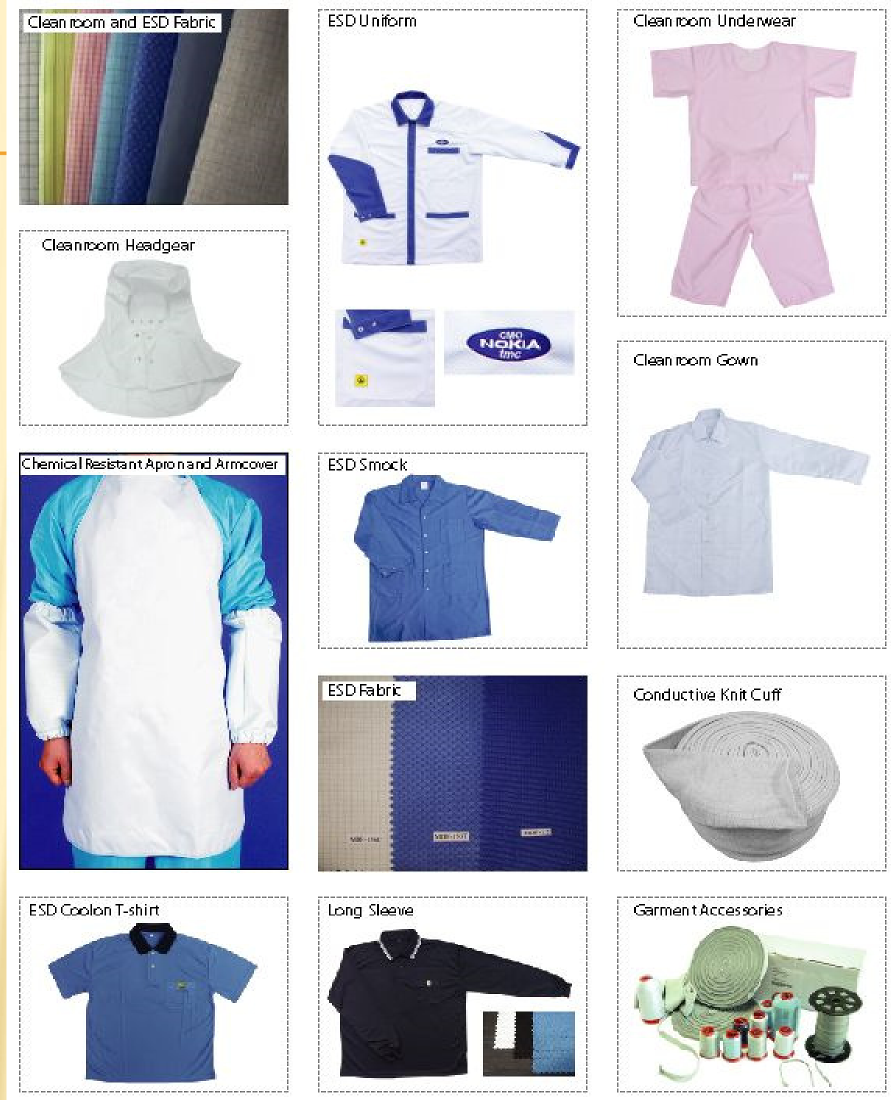
6. Future trends

➢There has been an increasing demand for personal protective equipment (PPE) in the last few decades due to greater awareness about worker's health and safety in hazardous work environments.

Significant research has also been carried out in developing protective textile materials and clothing against different hazards such as;

chemical,
thermal,
impact,
biological and nuclear or electromagnetic radiation.

➢current challenge is to develop the critical materials and components to enhance the protective performance of PPE without affecting other performance properties such as electrostatic propensity.


Clean room and ESD Fabric
ESD Uniform
Clean room Underwear
Cleanroom Headgear
Clean room Gown
Chemical Resistant Apron and Armcover
ESD Smock
ESD Fabric
Conductive Knit Cuff
ESD Coolon T-shirt
Long Sleeve
Garment Accessories

Anti-electrostatic fabric

➢One area of research that has attracted a substantial amount of attention in the manufacturing of electronic textiles (e-textiles) and other high-tech applications is the development of electrically conductive polymers since they were discovered two decades ago, and new developments are reported regularly in the literature, as follows:

1) Y. Sano et al. (1997) modified the antistatic behaviour of a poly(ethylene therepthalate) fiber. In this technique, blend polyester fibres containing poly(ethylene terephthalate/5-sulfoisophthalate) (SIP-PET) were prepared by blend spinning and then treated with various cationic surfactants in the process of high-temperature dyeing.

2) F. Seto et al. (1999) investigated the surface modification of synthetic fiber fabrics via corona discharge treatment and subsequent graft polymerization. Polyethylene (PE) nonwoven fabric and polyamide-6 (PA-6) nonwoven fabric were used as base fabrics. Acrylic acid (AAc) was graft polymerized onto the fabrics via corona discharge pre-treatment. They found that charge dissipation decreased drastically by grafting with PAAc.

3) Cheng et al. (2001a) studied the development of conductive knitted fabric reinforced thermoplastic composites, with the intention to use them in electrostatic discharge applications. Conductive knitted fabric composites were made using polypropylene as the matrix material, glass fibers as the reinforcement, and copper wires as the conductive fillers. They found that the electrostatic discharge attenuation of knitted fabric reinforced thermoplastic composites can be tailored by changing the fabric knit structure, stitch density, and composition of the knitting yarn.

4) Zhou and Liu (2003) studied the surface resistivity of a treated polyurethane (PU) elastomer membrane. Vinyl acetate (VAc) was grafted onto PU using benzoyl peroxide as photoinitiator.

5) Jia et al. (2004) developed and characterized conductive composites consisting of an epoxyanhydride matrix with poly aniline-coated glass fiber (PANI-GF) combined with bulk PANI as conductive fillers.

- With the emerging of new protective textiles where sensors, wireless communication and computing technologies are integrated into conventional protective textile assemblies, the evaluation of their performance may require the capability of measuring other paramaters than typical electrostatic properties such as conductivity/resistivity. These may include radio frequency levels and data transfer rates. In addition, more sensitive testing equipment and stringent product specifications will be required as most of these e-textiles function with tiny voltages. The literature has not reported yet any current research to determine the effect of these integrated technologies on the electrostatic propensity of protective textile materials and products.

- Textiles for protection / edited by Richard A. Scott, Imprint Cambridge : Woodhead Publishing ; Boca Raton : CRC, 2005