Chapter – 3

EXPERIMENTAL

3. Experimental

3.1 Material & methodology

In this research work, high functional conductive woven fabrics are developed with incorporation of conductive yarns in warp and weft. Conductive yarns included use of pure metal wires (silver, copper, aluminium, stainless steel etc.), copper and carbon jari, silver and copper plated nylon yarns, stainless steel/polyester blended yarns etc. Carbon jari is specially developed from trilobal and ring type carbon yarns.

Woven fabrics are developed with different variations like type of material (different conductive and non conductive materials), type of weave (plain & twill), type of conductive pattern (stripe & grid), warp & weft space (1, 3, 5, 6, 10, 14 mm) etc. on water jet and rapier looms. Water repellent fabrics are also developed as a special case for cleanroom applications.

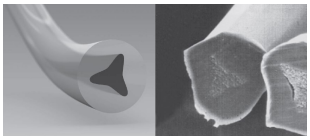
Yarn and fabric sample details are discussed below:

3.1.1 Yarn samples

Conductive yarn samples used in form of pure metal wire, metal blended yarn, metal plated yarn, metal jari, carbon jari and carbon yarn are given in Table 3.1:

Table 3.1 – Conductive yarn samples

Sample code	**Specification of yarns**
Pure metal wire	
Al	Aluminium wire (580D)
Cu-C	Copper wire (675D)
Cu-F	Copper wire (315D)
Ag	Silver wire (835D)
S.S.	Stainless steel wire (730D)

Metal blended yarn	
S.S./P	Stainless steel/Polyester blended yarn (170D) (20% Stainless steel staple fiber & 80% Polyester fiber)
Metal plated yarn	
CuN	Copper plated nylon filament yarn (75D)
AgN	Silver plated nylon filament yarn (175D)
Metal & Carbon jari	
CuJ	Copper jari (135D)
CJ-T	Carbon jari (Trilobal) (790D) (Carbon - Trilobal shaped conductive core surrounded by a sheath of polyester) 
CJ-R	Carbon jari (Ring) (435D) (Carbon - Ring shaped black carbon inside conductive nylon monofilament) 
Carbon yarn	
C	Carbon yarn (80D)

Non-conductive materials are used in form of cotton combed yarns (C1-warp & weft) and polyester continuous filament yarns (P1-warp, P2-weft, P3-warp & weft).

Denier and other basic tensile properties are tested for yarn samples and its results are presented in the Appendix.

3.1.2 Fabric samples

The dense conductive woven fabrics are made using Rapier loom and Water jet loom with incorporation of different conductive yarns as warp & weft into the fabrics (Fig. 3.1).

Fig. 3.1 – Weaving loom

Two different varieties of fabric are developed with following detail (Fig. 3.2):

1. Cotton conductive fabric samples with 1/1 plain weave
2. Polyester conductive fabric samples with 2/1 twill weave

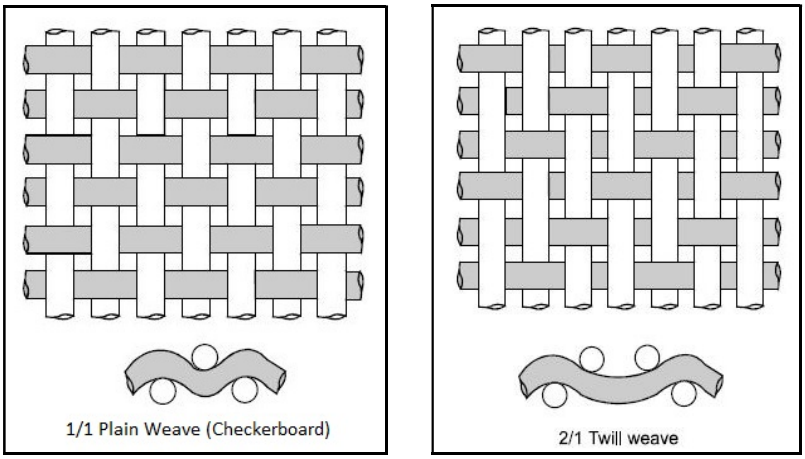


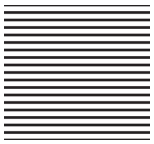
Fig. 3.2 – Plain weave and twill weave

Two different types of patterns were developed. One stripe pattern and the other one was grid pattern (Fig. 3.3)[107].

In woven fabrics, weft space & warp space of conductive yarns in millimetre were fixed as per the following:

- Weft space in cotton conductive fabrics: 1, 6, 10, 14
- Weft space in polyester conductive fabrics: 1, 3, 5 & 6
- Warp space in polyester conductive fabrics: 5

Stripe pattern



Grid pattern

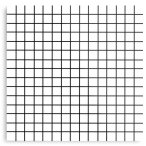


Fig. 3.3 – Stripe and grid patterns

Different variants of conductive fabrics are developed according to incorporation of pure metal wires, metal blended yarns, metal plated yarns, metal jari, carbon jari and carbon yarns into polyester or cotton yarns. Conductive fabric sample codes and its technical details are given below:

Table 3.2 – Pure metal wire incorporated cotton conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-01	C1	C1	Ag	6	72	72
S-02	C1	C1	Cu-C	6	72	72
S-03	C1	C1	Cu-F	6	72	72
S-04	C1	C1	Al	6	72	72
S-05	C1	C1	S.S.	6	72	72

* Plain weave, Stripe pattern

Table 3.3 – Metal blended yarn incorporated cotton conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-06	C1	C1	S.S./P	1	72	72
S-07	C1	C1	S.S./P	6	72	72
S-08	C1	C1	S.S./P	10	72	72
S-09	C1	C1	S.S./P	14	72	72

* Plain weave, Stripe pattern

Table 3.4 – Metal blended yarn incorporated polyester conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-10	P1	P2	S.S./P	1	82	82
S-11	P1	P2	S.S./P	3	82	82

* 2/1 Twill weave, Stripe pattern

Table 3.5 – Metal plated yarn incorporated cotton conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-12	C1	C1	AgN	6	72	72
S-13	C1	C1	CuN	6	72	72

* Plain weave, Stripe pattern

Table 3.6 – Metal plated yarn incorporated polyester conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-14	P1	P2	CuN	1	82	82
S-15	P1	P2	CuN	3	82	82

* 2/1 Twill weave, Stripe pattern

Table 3.7 – Metal jari incorporated cotton conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-16	C1	C1	CuJ	1	72	72
S-17	C1	C1	CuJ	6	72	72
S-18	C1	C1	CuJ	10	72	72
S-19	C1	C1	CuJ	14	72	72

* Plain weave, Stripe pattern

Table 3.8 – Carbon jari incorporated cotton conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-20	C1	C1	CJ-T	6	72	72
S-21	C1	C1	CJ-R	6	72	72

* Plain weave, Stripe pattern

Table 3.9 – Carbon jari incorporated cotton conductive fabric samples (water repellent)*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-20W	C1	C1	CJ-T	6	72	72
S-21W	C1	C1	CJ-R	6	72	72

* Plain weave, Stripe pattern

Table 3.10 – Metal jari & carbon jari incorporated polyester conductive fabric samples*

Sample no.	Warp yarn	Weft yarn	Weft conductive yarn	Weft space (mm)	EPI	PPI
S-22	P1	P2	CuJ	1	82	82
S-23	P1	P2	CJ-R	3	82	82

* 2/1 Twill weave, Stripe pattern

Table 3.11 – Carbon yarn incorporated polyester conductive fabric samples (stripe & grid)

Sample no.	Warp yarn	Weft yarn	Warp conductive yarn	Weft conductive yarn	Weft space	EPI	PPI
S-24*	P3	P3	-	C	5	136	92
S-25**	P3	P3	C	C	6 (Warp space-5)	136	92

* 2/1 Twill weave, Stripe pattern & ** 2/1 Twill weave, Grid pattern

3.2 Yarn testing

Yarn samples were tested for denier and tensile properties. For the denier, standard weighing balance and for the tensile properties, Lloyd LRX tensile tester were used with the following set up and for both tests 25 readings were taken (Fig. 3.4).

Traverse speed: 100 mm/min

Gauge length: 200 mm

Load cell: 2500 N

Fig. 3.4 – Lloyd tensile tester

3.3 Fabric testing

The properties of conductive fabrics can be judged and optimized by the following properties:

3.3.1. Surface resistivity

Conductive fabric samples were prepared; five measurements for each fabric samples were measured & their mean values were recorded. Surface resistivity were measured according to ASTM D257 with the help of Megger MIT510/2 (Insulation resistance tester - 5 kV) & 16008A Resistivity cell (Fig. 3.5)[108-109].

Surface resistivity was determined from measurement of Surface resistance between two electrodes forming opposite sides of a square. Fabric sample was inserted into sample holder and charged for 1 minute at 250V. Surface resistivity (ohm) results were taken at 27± 2° C.

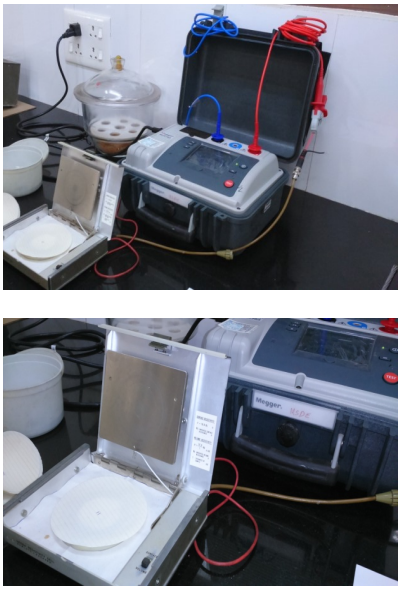


Fig. 3.5 – Megger MIT510/2 & 16008A Resistivity cell

3.3.2. Field (Signal) strength - Development of set up & testing

Special set up is developed to measure field strength protection level % of conductive fabrics. EMF source of range 2.4 – 2.48 GHz is used outside the metal case as shown in Fig. 3.6. Fabric is mounted on the fabric holder and the signal transmitted from the fabric is analyzed on opposite side at field strength analyzer inside the metal cage.

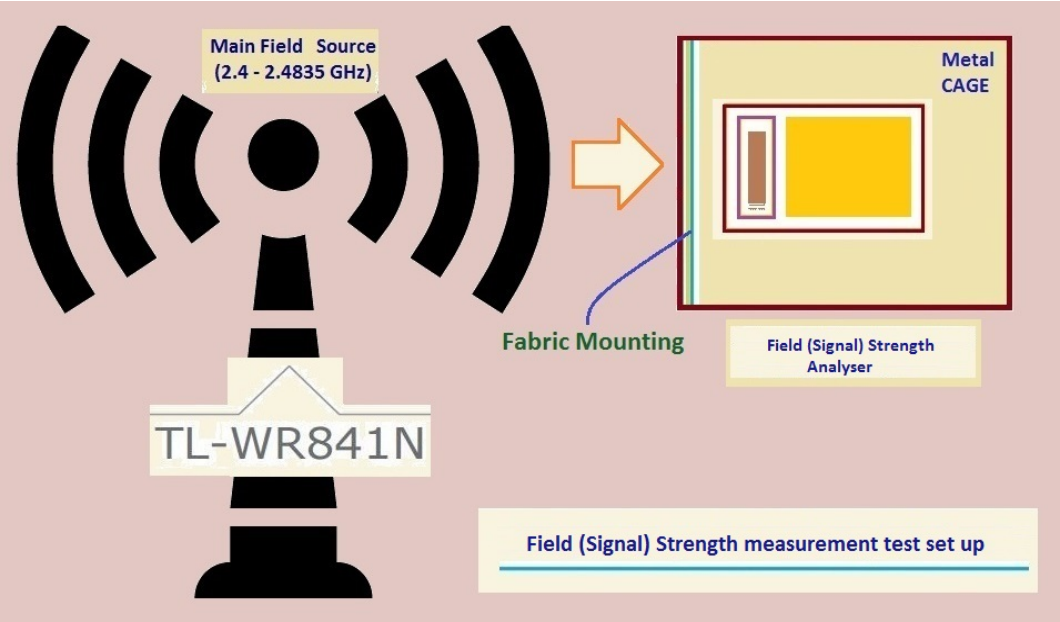


Fig. 3.6 – Field (Signal) strength test set up

Details of field source TL-WR841N is given below:

Antenna	: 2 X 5dBi Detachable omni directional antenna
	(dBi - decibels relative to isotropic radiator)
Frequency	: 2.4-2.4835GHz
Transmit Power	: CE: <20dBm, FCC: <30dBm (Decibels in Milliwatt)
External Power	: 9VDC / 0.6A
Wireless Standards	: IEEE 802.11n, IEEE 802.11g, IEEE 802.11b
Interface	: 4 10/100Mbps LAN PORTS, 1 10/100Mbps WAN PORT

3.3.3. Air permeability

Air permeability of conductive fabric was measured with TEXTTEST air permeability tester[110]. Here, Air permeability was determined up to 2500 pascal pressure according to ASTM D 737-2012[111]. This test measures in cubic centimetre per second a conductive fabric resistance to air flow rate.

The test samples, free from tension, was placed across the test head. The clamping arm was pressed down to start the test & appropriate measuring range was selected on range switch. The Air permeability test results of conductive fabrics were digitally displayed and recorded.

3.3.4. Fabric particle density transfer rate (F-PDTR) - Development of set up & testing

In this research work, special work is done in direction of development of cleanroom fabric particle density transfer rate tester. This tester has two chambers each of which has individual fan. One chamber has input air fan and other has output air fan. Both the fans can run at same speed ranging from 0 to 1,800 RPM ±10%. Fabric is mounted in between these two chambers without any air leakage.

Fabric particle density transfer rate (min. particle detection capacity: 0.8 microns) is measured in two units mg/m^3 & voltage with variable fan speed. Temperature and humidity is also displayed on the software screen along with other data in log text (Fig. 3.7, 3.8 & 3.9).

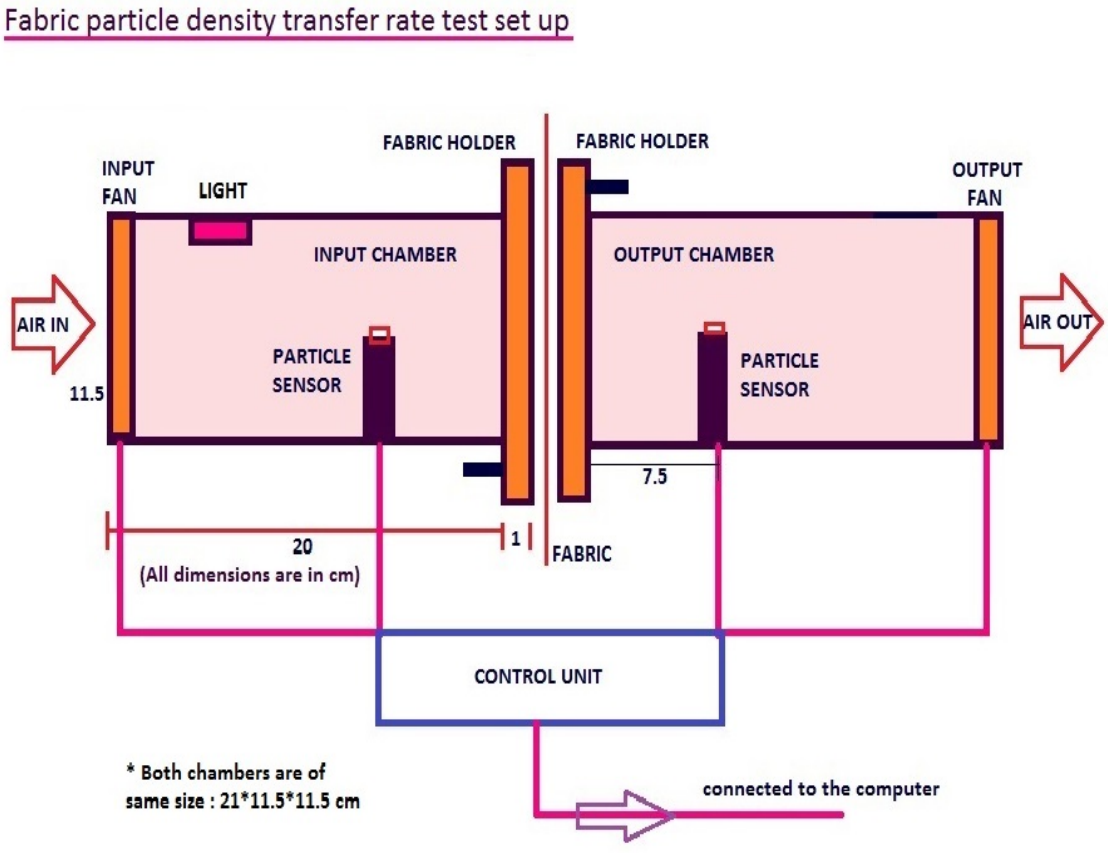


Fig. 3.7 – Fabric particle density transfer rate test set up

Fig. 3.8 – Images of fabric particle density transfer rate tester

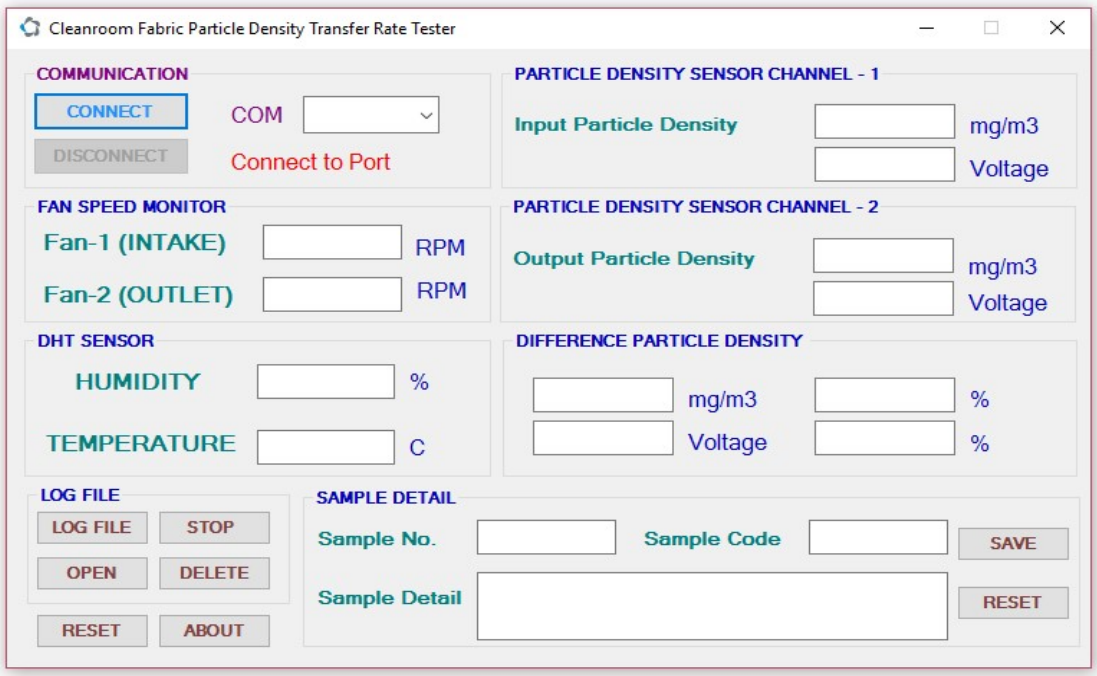


Fig. 3.9 – Software screen picture

LOG Text output

Date and Time: 00-00-0000 PM 0:00:00

Cleanroom fabric particle density transfer rate tester

Sample Detail

Sample No.
Sample Code
Sample Description

Fan Speed Monitor

FAN 1 Intake
FAN 2 Outlet

Particle Density Sensor

Particle Density Sensor Channel 1 (mg/m^3)
Particle Density Sensor Channel 1 (Volatge)

Particle Density Sensor Channel 2 (mg/m^3)
Particle Density Sensor Channel 2 (Voltage)

Difference Particle Density (mg/m^3)
Difference Particle Density (Voltage)

DHT Sensor

Humidity (%)
Temperature (C)

Technical details of important parts of cleanroom fabric particle density transfer rate tester

- Particle sensor : Compact optical sensor
  Mfg. by SHARP Corporation, Japan
  - Elements : Consist of Infrared emitting diode (IRED) & Photo-transistor (diagonal arrangement)
  - Detection : reflected light of dust in air.
  - Effective : It is effective to detect very fine particle
  - Size : 4.5cm(1.8inch)X3cm(1.2inch)X1.8cm(0.7inch) (L X W X H)

- Minimum particle detection value : 0.8 microns
- Sensitivity : 0.5 V/(0.1 mg/m^3)

- Temperature Sensor : LM 35 (Mfg. by National Semiconductor)
  - Accuracy : ±¼°C at room temperature
  - Calibration : Directly in Celsius (Centigrade)

- Fan
  - Speed (R.P.M.) :1800 RPM (±10%)
  - Air flow (Cubic feet per minute) : 21.7 CFM ±10%
  - Air pressure (mmH_2O) : 1.62 mmH_2O ±10%
  - Dimension : 80 X 80 X 25 mm