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Electromagnetic interference shielding effectiveness of copper plated fabrics

P Ganesan[1,a], T Karthik[1], A Muthu Kumar[1] & D Maruthamani[2]

[1]Department of Textile Technology, [2]Department of Chemistry, PSG College of Technology, Coimbatore 641 004, India

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Electroless plating of copper on cotton and polyester fabrics has been done with varying $CuSO_4$ concentration (8, 12, 16 and 20 g/L) and temperature (30°, 40°, 50° & 60° C) for 30min at all levels. The plating depositions are characterized by scanning electron microscope and X-ray diffraction respectively. The physical properties, such as tensile strength, tear strength, abrasion resistance and electromagnetic interference shielding performances have also been investigated. It is found that the tensile and tear strength of cotton and polyester fabrics decrease with the increase in $CuSO_4$ concentration. The abrasion resistance of copper plated cotton fabric decreases more than that of polyester fabric. The surface resistance of the copper plated polyester fabric shows poor electrical resistance and the electromagnetic interference shielding effectiveness, but has high shielding effectiveness up to 30dB than cotton fabrics.

Keywords: Copper plating, Cotton, Electroless plating, Electrical resistance, EMI shielding, Polyester

1 Introduction

In recent years, the interest in industrial textiles has grown, particularly in the studies on deposition of metallic layers onto the fabric surface either for industrial application or for home decorative[1]. The deposition of metallic substances on the fabrics enhances their range application in the field of radiation and filtrations due to the increase in electrical and electronics components which emit electromagnetic (EM) wave, causing electromagnetic interference problems[2]. Electromagnetic shielding is a process by which a material is able to reduce the transmission of electromagnetic radiation that affects human and electronic equipment. An EM wave consists of an electric component and a magnetic component perpendicular to each other and propagates at right angles to the planes containing two components. As the wave impedances are different for these two components, the barrier reflection follows different characteristics[3].

The total shielding effectiveness (SE) of a conductive barrier in decibel (dB) is the sum of reflection losses (R), the absorption losses (A) and Re reflection losses (R_r), as shown below:

$$SE = R + A + R_r \qquad \dots (1)$$

Hence, for electromagnetic shielding, the material should have high electrical conductivity and magnetic permeability. Thus, from the studies, it is evident that the electroless plating has more advantage than other methods because of its excellent conductivity and uniform coating. It can be used for coating in any form, such as yarn, fabrics and in garment stages. In the conventional activation processes, noble metal palladium is usually employed as the catalyst sites to initiate the electroless plating[4,5,6]. The cost of the palladium has increased in recent years, which makes the electroless plating method costly. Thus, it is very important to develop a cost effective activation technique. Electroless plating is a metal deposition process in which reduction of metal ion takes place on the catalytic surface without the use of electrical energy. Even though lots of work has been carried out with electroless copper plating on fabric, very few studies are focused on palladium free electroless plating[4,7].

This work therefore focuses on the copper plating over cotton and polyester fabrics by palladium free electroless plating and study of their physical properties such as tensile strength, tear strength and abrasion resistance. The surface characteristics of copper plated fabrics are also investigated in detail using SEM and XRD. Further the electromagnetic shielding effects of the treated fabrics are also reported.

2 Materials and Methods

2.1 Materials

Plain weave cotton (EPI × PPI=168 × 112, warp and weft count= 90^s Ne, GSM = 85) and polyester fabric (EPI × PPI= 120 × 80, warp and weft count =

[a] Corresponding author.
E-mail: ganeshg007@gmail.com

60^s Ne, GSM = 82) were selected for this research work. All the chemicals used in this study were of AR grade. Stannous chloride ($SnCl_2$), hydrochloric acid (HCl), Silver nitrate ($AgNO_3$), ammonium per sulphate ($(NH_4)_2S_2O_8$), cupric sulphate ($CuSO_4$), formaldehyde (HCHO), sodium potassium tartrate ($KNaC_4H_4O_6{\cdot}4H_2O$), sodium hydroxide (NaOH) and washing powder were used. The fabric used for plating has a dimension of 15 × 15 cm^2.

2.2 Methods

2.2.1 Electroless Plating Process

Electroless copper plating was carried out through multistep process including pre-treatment, sensitization, activation, copper plating and post treatment for stopping copper reduction, rinsing and drying. All fabric samples were subsequently rinsed with 5% detergent at room temperature of 25 ± 2°C for 20 min. The samples were then rinsed in de-ionized water. Surface sensitization was conducted by immersing the samples into an aqueous solution containing 10 g/L $SnCl_2$ and 40 ml/L 38% HCl acid at 25°C for 10 min. The specimens were subsequently rinsed in de-ionized water and activated by immersing them into a solution containing $AgNO_3$ (10 g/L) and 28% NH_4OH (10 ml/L) at 25°C for 20 min. Later the samples were rinsed with a large volume of de-ionized water for more than 5 min to prevent contamination of the plating bath. The fabric samples were subsequently immersed in the electroless copper plating bath at 30°C for 20 min. The bath composed of 15 g/L $CuSO_4$-$5H_2O$, 20 ml/L HCHO (37% aqueous solution), 40 g/L $NaC_4H_4O_6$ - $4H_2O$ & 10 g/L NaOH. In the post-treatment stage, the samples were rinsed with de-ionized water at 40°C for 20 min and dried in an oven at 60°C. The concentration of copper and the processing temperature were changed to study their effect on electromagnetic shield (EMS). Different concentrations of $CuSO_4$ (8, 12, 16, and 20 g/L) were used with a standing time of 30 min and room temperature of 25 ± 2^0C. Considering the process parameters, temperature plays an important role in copper deposition rate, thus temperature was varied (30°, 40°, 50° and 60°C) with 16 g/L $CuSO_4$ and 30 min standing time.

2.2.2 Surface Characterisation

The surface morphology of copper plating was studied using a scanning electron microscope (SEM) operated at 3kV(Model JEOL-JSM-6396). The phase structure of copper plated sample was characterized using X-ray diffraction (XRD) (XRD-6000), operated with a CuKα (1.54A) technique by seifert analyze, the 2θ range used was 10^o-70^o. The apparent crystalline size of the samples was determined by Scherrer formula.

2.2.3 Physical Properties Assessment

The copper plated cotton and polyester fabric samples were tested for tensile strength (ASTM D5035), tear strength (ASTM D1424) and abrasion resistance (ASTM D4966).

2.2.4 Electrical Resistivity Measurements

The electrical resistance measurements were performed on all the samples after conditioning them under standard atmosphere. The resistance was measured ten times on each side of the samples and the average values were taken. The AAATC 76 – 1995 standard test method was used to measure the resistance of the samples and the surface resistivity of the fabric was calculated using the following relationship:

$$R = R_s\ (I/W) \quad \dots (2)$$

where R, is the resistance in ohms; $R_{s,}$ the sheet resistance or surface resistivity in ohms/square; I, the distance between the electrodes in cm; and W, the width of each electrode in cm.

2.2.5 Measurement of EMSE

The evaluation of electromagnetic shielding effectiveness (EMSE) of textile fabrics was carried out using an Aglient E5061 A5062A/E 50652A ENA series RF network analyzer. A coaxial transmission holder was used for holding the fabric sample during testing as per ASTM D 4935 standards. The instrument consists of signal generator and a signal receiver to measure the various properties associated with the device under the test. The instrument is able to measure both the near field and the far field shielding effectiveness of planar materials, as shown below:

$$\mathrm{SE} = 20 \log P_{\mathrm{i}}/P_{\mathrm{t}} \quad \dots (3)$$

where P_i is the voltage received with sample; and P_t, the voltage received without sample.

The output from the vector signal analyzer (VNA) is in the form of a graph showing a various s-parameters. Hence, it is required to convert the data from the graphical form to a quantifiable form in order to explain the behavior of the material. A user - friendly data acquisition system and software have been developed and interfaced between the vector network analyzer and the output to generate the required output in terms of shielding effectiveness parameters needed to calculate the electromagnetic shielding effectiveness in terms of S11 (reflected/ incident) and S21 (transmitted / incident) values. The actual shielding effectiveness is only transmitted/ incident values i.e. S21 values.

3 Results and Discussion

3.1 Analysis of Surface Characterisation

3.1.1 SEM Analysis

The surface morphology of the copper plated cotton and polyester fabrics was examined by using an SEM. For the plated fabrics a layer of metal deposition is observed on the surface (Fig. 1). The surface structure of the coated polyester fabrics [Fig. 1 (d)] shows more uniform coating when compared with a cotton fabric, that shows some rough surface after the plating process [Fig. 1 (b)].

3.1.2 XRD Analysis

The coating structures of Cu plated cotton and polyester fabrics were analyzed using XRD. The XRD patterns of untreated and treated cotton and polyester fabrics show Cu deposition peaks at 2θ = 22°, 44°, 52° which are the characteristic peaks of cubic metallic Cu, represented as 111 and 200 planes respectively.

3.2 Analysis of Physical Properties

The physical properties of copper plated cotton and polyester fabrics are shown in Tables 1 and 2 for varying concentrations and temperatures respectively. The fabric thickness of control fabric and copper plated cotton and polyester fabrics with respect to various concentrations and different temperature levels has been studied. Before copper coating the initial fabric thickness values of cotton and polyester fabrics are found to be 0.16 mm and 0.21 mm respectively. After copper plating, increase in fabric thickness is noticed in both cotton and polyester fabrics which confirms the deposition of copper on the surface of fabric.

3.2.1 Tensile Strength

Tensile strength values of control fabric and copper treated samples before and after the treatment are shown in Tables 1 and 2. It is observed that after electroless copper plating the tensile strength of cotton plated with copper increases; higher tensile strength is observed at lower copper concentration of

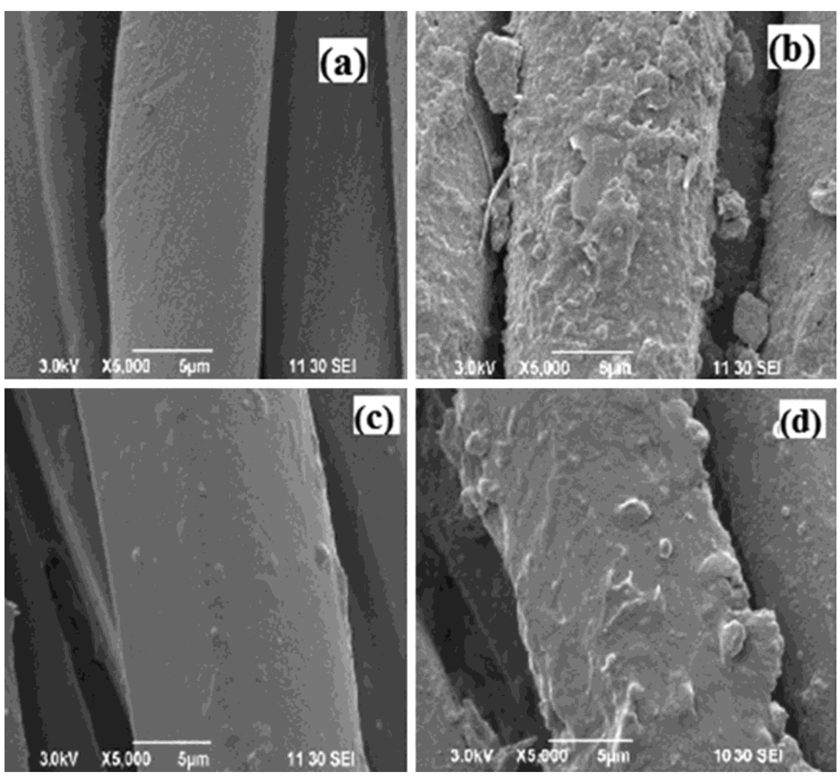

Fig. 1—SEM images of plated fabrics (a) untreated cotton, (b) copper plated cotton, (c) untreated polyester, and (d) copper plated polyester

Table 1—Tensile strength, tear strength and surface resistivity of control and copper plated fabric at varying concentration

Concentration g/L	Tensile strength, lbs		Tear strength, kg		Abrasion resistance, % wt. loss		Surface resistivity, Ω/square	
	Cotton	Polyester	Cotton	Polyester	Cotton	Polyester	Cotton	Polyester
Control fabric	35	50	96	300	15	8	15	No resistance
8	60	45	83	204	13	0	8	4.8
12	55	45	70	172	15	0	5	1.3
16	40	50	70	160	7	0	10.5	14
20	40	60	65	128	14	8	14.3	11

Table 2—Tensile strength, tear strength and surface resistivity of control and copper plated fabric at different temperatures

Temperature °C	Tensile strength, lbs		Tear strength, kg		Abrasion resistance, % wt. loss		Surface resistivity, Ω/square	
	Cotton	Polyester	Cotton	Polyester	Cotton	Polyester	Cotton	Polyester
Control fabric	35	50	96	300	15	8	15	No resistance
30	40	45	70	160	7	0	0.105	0.14
40	40	60	65	140	0	0	52	95
50	45	65	60	130	0	0	30	78
60	25	70	58	135	0	0	27.6	72

8 g/L. As copper concentration increases the tensile strength decreases slightly and later as copper concentration is increased the tensile strength is also increased up to 60 lbs[8,9]. It is observed from the Table 2 that the tensile strength of cotton fabric decreases, but that of polyester fabric increases while increasing the temperature. Also noticed that when tensile strength decreases the elongation of the material also decreases gradually. While comparing studies carried out at room temperature and at higher temperature the tensile strength of cotton fabric decreases.

3.2.2 Tear Strength

The Tables 1 and 2 show the tear strength of treated and control fabric samples tested as per ASTM D 1424 standards, using Elmendorf tear strength tester. The tear strength for both cotton and polyester fabrics decreases after copper coating. Initially there is 13% weight reduction in plated cotton fabric ($CuSO_4$ concentration of 8 g/L) but maximum of 39% tear strength loss is observed for the same cotton fabrics at 60°C. The tear strength of polyester fabric also decreases from 32% (room temperature plated) to 55% (plated at 60°C); there is a drastic change in the tear strength of polyester fabric as compared to that in cotton fabric [10,11].

3.2.3 Abrasion Resistance

The control cotton fabric shows weight loss of 15% and there is no much difference in weight loss % of copper coated cotton fabrics, but polyester fabric shows good abrasion resistance value compared to cotton fabric. The control polyester fabric shows only 8% weight loss and the copper coated polyester fabrics do not show any weight loss.

3.3 Electrical Resistivity Measurement

The electrical resistivity of the control and copper plated samples were measured by two probe resistivity measurement techniques in a normal environment (65% RH). Tables 1 and 2 show that polyester plated fabric shows good electrical conductivity than cotton fabric. On increasing the temperature of the plating process the electrical conductivity of the fabric decreases for both cotton and polyester fabrics, as on theoretical part electromagnetic shielding depends up on electrical conductivity of the material[11,12].

3.4 Electromagnetic Interference Shielding Effectiveness

EMISE was studied with electromagnetic waves with the frequency range 0.3MHz – 1.5GHz. The test was carried out to measure the electromagnetic shielding effectiveness in terms of S11 (reflected/incident) and S21 (transmitted/incident) values. The influence of concentration and temperature on EMISE is shown Tables 3 and 4 respectively.

For untreated materials, cotton fabric shows higher shielding effectiveness than polyester fabric. After electroless copper plating with varying $CuSO_4$ concentration, copper pleated polyester fabrics show higher shielding effectiveness as compared to copper plated cotton fabrics[8,9]. While varying the $CuSO_4$ concentration, copper coated (12 g/L) fabric shows higher shielding effectiveness followed by 8, 16 and 20g/L coating on cotton fabrics. On increasing the

Table 3—Effect of concentration on EMISE of copper plated cotton and polyester fabrics

Concentration g/L	EMISE, dB																	
	0.3 MHz		100 MHz		300 MHz		500 MHz		700 MHz		900 MHz		1.1 GHz		1.3 GHz		1.5 GHz	
	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P
0 (Control)	0.941	-2.44	-3.7	-4.17	13.4	13.9	-3.12	-3.54	-1.36	-3.44	0.286	-0.88	5.88	1.62	7.26	2.11	4.68	3.13
8	0.523	-0.722	4.18	7.01	22.1	24	9.15	11.8	17.2	19.9	10.2	13.2	20.9	24.7	20.5	22	15.9	19
12	0.976	-0.912	4.85	7.12	23.6	29.9	10.3	13.7	18.5	21.9	11.9	15.1	23.3	27.5	22.6	24.5	17.6	20.9
16	0.0481	-0.949	5.38	3.64	20.3	27.6	9.45	11.1	17.7	19.7	10.9	14	21.3	26.8	20.9	23.5	16.1	20.4
20	0.132	-1.28	4.34	0.860	20.8	25.8	8.5	10.1	16.7	18.3	9.71	11.4	19.4	22	19.4	18.6	14.8	16

Table 4—Effect of temperature on EMISE of copper plated cotton and polyester fabrics

Temperature	0.3 MHz		100 MHz		300 MHz		500 MHz		700 MHz		900 MHz		1.1 GHz		1.3 GHz		1.5 GHz	
°C	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P	C	P
Control	0.941	-2.44	-3.7	-4.17	13.4	13.9	-3.12	-3.54	-1.36	-3.44	0.286	-0.88	5.88	1.62	7.26	2.11	4.68	3.13
30	0.048	-0.095	5.38	3.64	20.3	27.6	9.45	11.1	17.7	19.7	10.9	14	21.3	26.8	20.9	23.5	16.1	20.4
40	-0.487	-1.87	0.207	-3.99	2.11	15.3	-0.14	-3.06	2.51	-1.76	0.647	-0.56	0.362	3.26	-0.42	4.01	-1.32	3.42
50	-2.41	-0.85	-4.66	-3.79	11.9	16.1	-3.59	-2.85	6.86	-1.14	1.94	-0.52	7.87	3.74	4.90	3.84	3.78	1.51
60	-0.877	-1.78	-2.12	-2.77	17.1	17.7	3.51	-2.13	11.6	-0.59	3.63	0.024	11.7	6.21	9.62	6.85	7.91	3.75

$CuSO_4$ concentration beyond 12 g/L there is decrease in electromagnetic shielding values, the polyester fabrics with varying $CuSO_4$ concentration also follow the same trend.

On increasing the temperature, there is a decrease in electrical conductivity. The electromagnetic shielding value decreases at the initial stages of temperature (40°C and 50°C) and at further higher temperature the copper plated cotton fabrics show higher shielding effectiveness than the polyester plated fabrics. Hence, the increase of the temperature during the coating process does not have an effect on electromagnetic shielding effectiveness and their end use product.

4 Conclusion

The SEM photograph at different magnification levels demonstrates the presence of copper plating on cotton and polyester fabrics. The presence of copper particles on cotton and polyester fabrics is clearly proved by the XRD analysis. The tensile strength of copper plated cotton fabrics increases with the increase in $CuSO_4$ concentration but the tensile strength decreases with the further increase in temperature. However, polyester fabric plated with copper shows increased tensile strength at all conditions. Tear strength of copper plated cotton and polyester fabrics decreases with the increase in temperature and $CuSO_4$ concentration. Copper plated polyester fabrics show good abrasion resistance than copper plated cotton fabric. The electrical conductivity study shows that polyester fabrics with $CuSO_4$ concentration of 12 g/L at room temperature give good electrical resistance as compared to cotton fabrics. The shielding effectiveness of copper plated polyester fabric with $CuSO_4$ concentration of 12 g/L shows high electromagnetic shielding up to 15 db and cotton fabric shows shielding value up to 12 db.

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