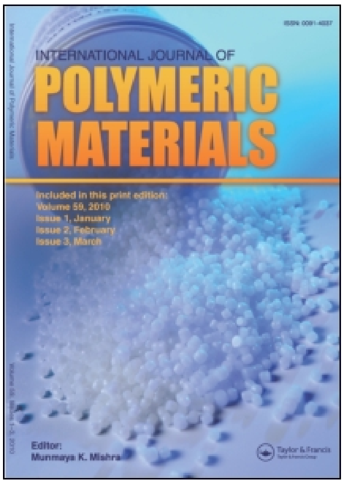

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Dielectric and Mechanical Behavior of Treated Paper Sheet

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The dielectric properties of different polymers, polymethyl methacrylate, polystyrene, mixture of them (1:1) and polyvinyl alcohol films were studied. Also, the dielectric and mechanical properties were measured to study the intermolecular interactions of paper sheet impregnated in the different polymers under investigation. The retained polymer on dipped paper sheet is lowest in case of mixed polymer solutions than that of each polymer solution alone. The retained polymer on paper sheet from aqueous polymer solution is lower than that dipped in organic solvent polymer solutions. The mixture of 1:1 PS and PMMA has a higher permittivity than that of each of both polymer alone. The treatment of paper sheet with polymer solutions improved their dielectric and mechanical properties, whereas the mixture of PS and PMMA is the best one for improving treated paper sheet.

Keywords: Paper treatments; polymethyl methacrylate; polystyrene; polyvinyl alcohol; dielectric properties; mechanical properties

1. INTRODUCTION

Paper is among the cheapest and best electrical insulating materials, since it has a high dielectric constant and low dielectric loss. Paper sheet is considered a net work structure consisting of cellulosic fiber with other non-cellulosic one. There are many methods used to improve and modify paper sheets according to the used purposes. Concerning the inter fiber bonding [1], starch additives, carboxymethyl cellulose [2], cellulose acetate [3], and xanthated cellulose [4] are the

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most used treatments. Also, among these methods the chemical treatment of pulp [5–7], such as acetylation, grafting and impregnation of paper sheets in resins [8], polymers [9] and cellulose derivative solutions [10, 11] are used to improve the electrical and mechanical properties of paper. Electrical insulating properties of Kraft paper impregnated in some resins were studied [12]. The results indicated that impregnation of Kraft paper in polyester amide improve their dielectric properties. The dielectric properties of cotton stalk wood and rice straw paper before and after impregnation with linseed oil was studied [13, 14].

The aim of this work is to study the dielectric properties and mechanical strength of treated paper sheet with different polymer solutions *e.g.*, polystyrene, polymethyl methacrylate and polyvinyl alcohol. The effect of different variables of these treatments is also investigated.

2. MATERIALS AND EXPERIMENTAL MEASUREMENTS

2.1. A-Materials

In this work, bleached sulfate wood pulp (Betula. Viscose) composed of 82.4% α-cellulose and 8.1% hemi cellulose was used. Polystyrene, polymethyl methacrylate, polyvinyl alcohol and solvent *e.g.*, benzene and acetone were used. All the above chemicals are commercial grade.

2.1.1. Preparation of Paper Sheet

Bleached pulp was beaten to 40 SR in valley beater. Paper sheet was made according to Swedish standard method (SCA) C-26:76.

2.1.2. Treatment of Paper Sheet

Paper sheets were weighted first before dipping in polymer solution to determine their basis weight. Papers were dipped in different polymer solutions with different concentrations (1.25–5%) for different time intervals (10–60 seconds). Some of the paper sheets were dipped in mixture solution of PS and PMMA 1:1 with concentration 1.25% for each of them for 30 seconds. After drying the retained polymer on paper sheets – in gm/m^2 – was calculated by difference in weight of paper before and after treatment.

2.2. Measurements

2.2.1. Dielectric Measurements

An AG-4311 B RCL-meter (Ando- Japan) was used to measure the permittivity and dielectric loss in the frequency range 0.1 – 100 kHz. The measuring cell used is similar to that used by Fernandez [15]. It consists of two parallel plates circular condenser made of copper, of 12 mm diameter attached to movable micrometer. It was calibrated using standard samples.

2.2.2. Mechanical Properties

Every test was carried out on five sheets. The strength properties of paper were determined according to Tappi standard [16]

$$\text{Breaking length} = \frac{\text{Tensile strength} \cdot 66700}{\text{Basis weight}}$$

$$\text{Basis weight} = \text{Weight of dried square meter of paper sheet at } 105°\text{C for } 3\,\text{h}$$

$$= \frac{\text{Weight of paper} \cdot 10000}{216(\text{Area of treated paper sheet})}$$

$$\text{Tear factor} = \frac{\text{Tear strength} \cdot 100}{\text{Basis weight}}.$$

3. RESULTS AND DISCUSSION

3.1. Retained Polymer

3.1.1. Effect of Polymer Kind

From Table I it is seen that, the retained polymer on treated paper sheet with the mixture of PS and PMMA 1.25% of each for 30 second is lower than that in case of PS or PMMA of the same concentration. This can be attributed to the intermolecular interaction between the

TABLE I Retained polymer on dipped paper sheets in different polymer solutions for the same time interval (30 sec.)

Polymer	*Retained in gm/m*^{2}
PS (2.5%) in benzene	4.9
PMMA (2.5%) in acetone	4.8
PS + PMMA (1.25 + 1.25)	2.8
PVA (2.5%) in water	3.5

TABLE II Retained of different polymers at 5% concentration for 30 sec

Polymer	*Retained in gm/m*^{2}
PS in benzene	11.2
PMMA in acetone	10.8
PVA in water	6.2

two polymers, which increases the viscosity of the mixture than the original polymers, which restrict the penetration of the mixed polymer through the fiber paper sheet.

Another set of paper sheets were impregnated in 5% of PS, PMMA and PVA for 30 sec.

From Table II it is clear that the retained polymer of impregnated paper sheet in aqueous Solution of PVA has the lowest value. This is due to the low penetration velocity of the high viscosity solution of PVA in water. Also, the aqueous medium which used to dissolve PVA has a big role in decreasing penetration velocity of the polymer solution. Aqueous solution of PVA has higher polarizability than that of solvent solution of PMMA and PS, as a result of dipole–dipole interaction between polar groups. Adsorption of alcohol and water molecules on the adsorbent surface containing OH-group like cellulose molecules, complexes with hydrogen bonds are formed in addition to the non specific dispersion and induction interaction *i.e.*, chemical adsorption [17] with lower thickness formed, in case of PVA, than the physical adsorption in the other two polymers. In general the organic solvent polymer solution has a higher velocity than the aqueous polymer solution. So this enhance from the penetration velocity of the organic solvent polymer solutions through the fiber paper sheets and consequently the retained polymer increases. From Tables I and II, the retained polymer on paper sheets increases by increasing the polymer concentration.

3.1.2. Effect of Dipping Time

From Table III, it is clear to observe that the retained polymer in case of PS, PMMA and PVA increases by increasing impregnation time till for 30 seconds. This can be attributed to the increase of the coated layer on the paper sheets and increase of penetration velocity by the long time of dipping. After 30 seconds a very slightly increase in the retained polymer is observed. This is due to the saturation of the active centers on the surface of the fibers reaching to equilibrium state and also, due to increase in the formed-coated layer thickness decrease the penetration velocity of polymer solutions.

3.1.3. Effect of Polymer Concentration

It is clear from Table IV that the retained polymer increases by increasing the polymer concentration for all kinds of polymer under investigation. This is due to the increase of coated layer of polymer on the surface of the paper sheets. Also, the retained in case of PVA is lower than the other two polymers. This may be due to the high viscosity of the aqueous PVA solution which decrease its penetration velocity through the fiber paper sheet and the chemical nature of the adsorption process in case of PVA, *i.e.*, the velocity of aqueous solution is lower than the organic polymer solution. Also the aqueous solution

TABLE III The retained polymer on the dipped paper sheets in PS, PMMA and PVA solution 5% for different time intervals

Time (sec.)	*Retained polymer gm/m²*		
	PS	*PMMA*	*PVA*
10	10.8	9.8	5.1
30	11.2	10.9	6.2
60	11.3	11.0	6.8

TABLE IV Retained polymer on paper sheet for different concentration of Polymer' solution for 30 sec

Polymer concentration %	*Retained polymer in gm/m²*		
	PS	*PMMA*	*PVA*
1.25	2.4	2.9	2.0
2.50	4.6	4.9	3.5
5.00	11.0	11.3	6.2

causes a small swelling of the fiber of paper sheets which decrease from the penetration velocity of the aqueous polymer solution.

4. DIELECTRIC PROPERTIES OF DIFFERENT POLYMERS

The dielectric properties of PMMA, PS and PVA and also of mixture (1:1) of PMMA and PS were measured as a sheet in the used frequency range. PMMA, PVA and PS have the same value of permittivity ε' (1.8) while as, the mixture of the two polymers has higher permittivity (2.8) than each of them alone. This can be attributed to the rearrangement of the polymer chains in stack [18]. These stacks will decrease the dipole – interaction between similar chains and this will permits the chain to contribute in the dielectric constant. These values of permittivity are independent of frequency in this range, which means that they are static ones in this range of frequency.

The dielectric loss ε'' of PS is very small ranging from 0.00018 to .00054. Thus PS can be considered as a loss less material in the used frequency range. The dielectric loss of PMMA and the mixture (PS + PMMA) is relatively higher than that of PS (0.0026 – .0045) Although they can be considered as a low loss materials.

The different variables, which could affect dielectric properties of treated paper sheets with the previous polymer solutions, will be discussed here in some details.

4.1. Effect of Different Polymers

The dielectric properties of paper sheets before and after impregnation with nearly the same retained (2.8 gm/m^2) of different polymers PS, PMMA and mixture 1:1 of them were measured within the frequency range 0.1 – 100 kHz. Variation of permittivity ε', dielectric loss ε' and $\tan\delta$ as a function of the frequency of the applied field are graphically represented in Figure 1. In general, it can be noticed that the dielectric constant of the investigated samples decreases by increasing frequency due to the dielectric dispersion. This dispersion in ε' can be explained by the lag of the molecules behind alteration of the applied electric field. Also, it can be noticed that the electrical permittivity ε' of the treated paper sheets are higher than that of the untreated one. This can be attributed to the absorbency and diffusion of the polymer solution through the fibers of paper sheets. This will causes a decrease in the porosity and captured of air. The treated paper sheet with mixed polymers (PS + PMMA) have higher permittivity over the whole frequency range due to high polarity of the side groups and of other flexible portions of cellulose. On the other hand the treated paper sheet with PS or PMMA has nearly equal values of permittivity indicating the equal ability to condense with paper fibers through the physical adsorption.

Comparing the dielectric loss ε' of the treated paper sheet of the same retained polymer, Figure 1b. It is noticed that that loss factor of the treated paper with PS > mixture of PS + PMMA > PMMA. This is in parallel with the polarizability of these polymers. The difference in the dielectric loss ε' of these treated paper sheets decreases by

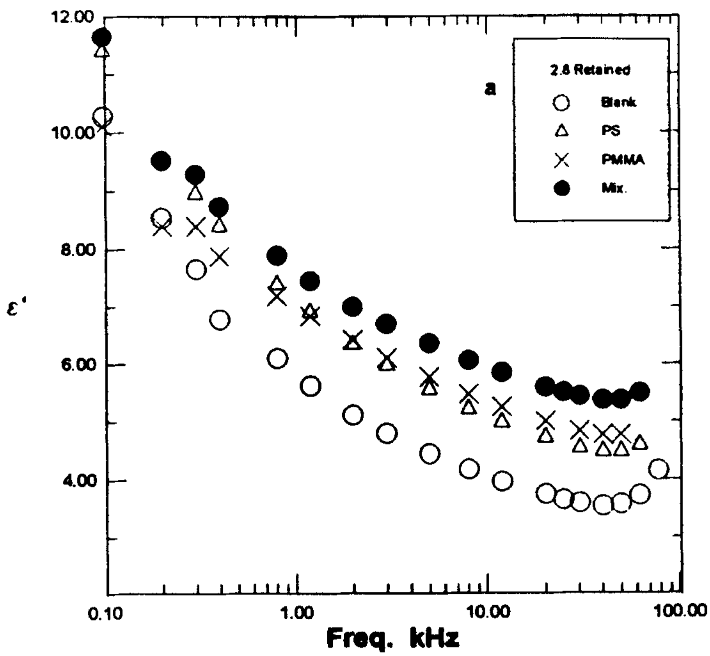


FIGURE 1 The different dielectric parameters *vs.* frequency of treated paper sheets with the same retained (2.8 gm/m^2) of different polymers in comparison with the untreated one. (a) Permittivity, (b) Dielectric loss, (c) Dissipation factor.

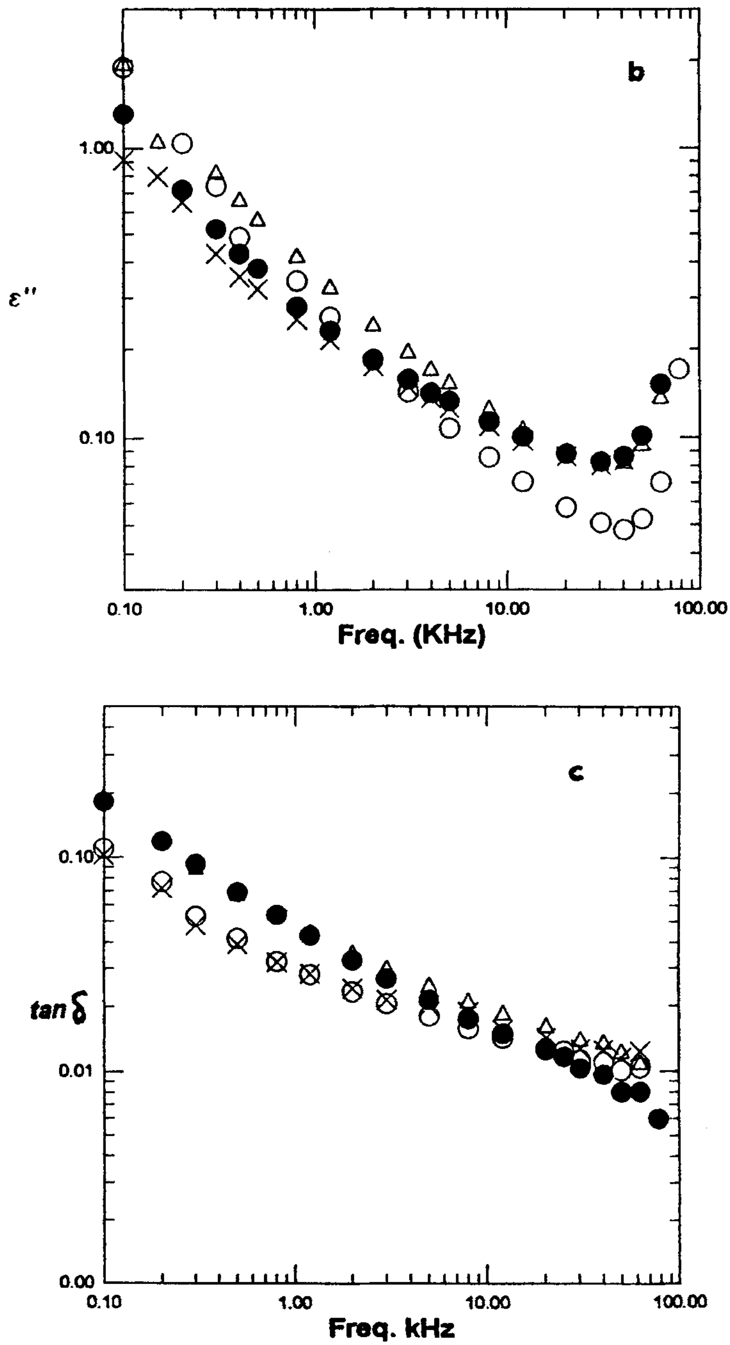


FIGURE 1 (Continued).

increasing frequency and reaches to the same value in the frequency range 30–40 kHz. At this frequency the paper sheet treated with mixed polymers have the lowest value of dissipation factor ($\tan\delta$) than the untreated and treated paper sheet with PS Figure 1c. Thus it is clear that the dielectric properties of the treated paper sheet with the mixture is the best one.

4.2. Effect of Retained Polymers

The dielectric properties (ε', ε' and $\tan\delta$) of paper sheet with different retained of PS at different frequencies is shown in Figure 2. It can be noticed that, although the paper sheet of 11.3 gm/m^2 retained polymer has the lowest dielectric loss and dissipation factor, its permittivity is lower than that of the untreated paper sheet. This can be attributed to higher condensation of polymers on paper sheets through hydrogen bond linkages and consequently saturation of active side groups of

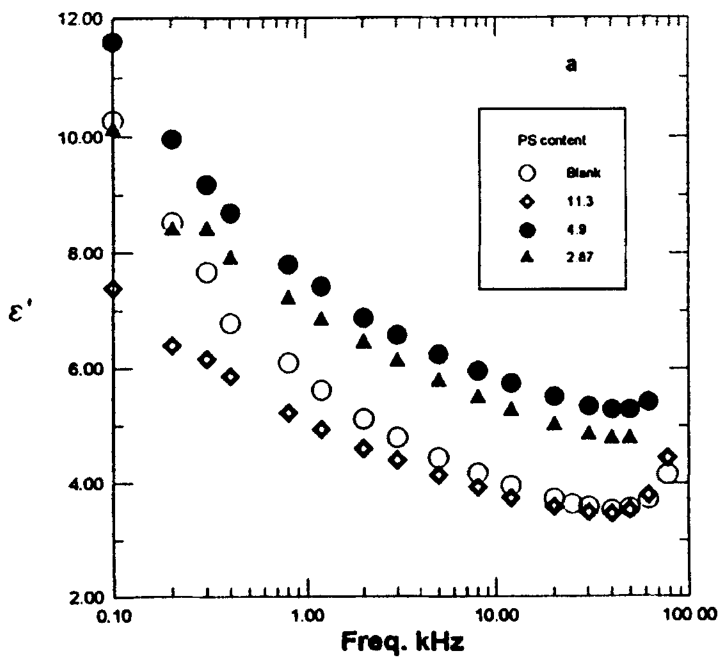
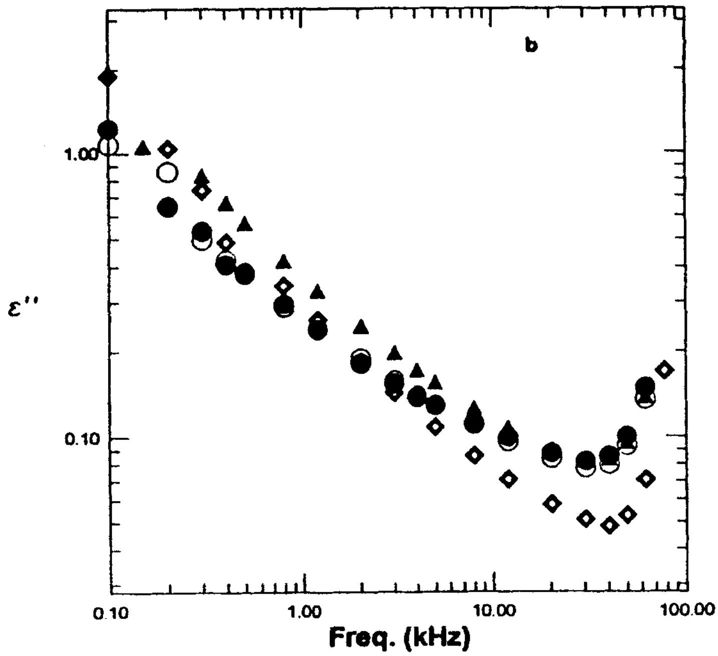


FIGURE 2 The different dielectric parameters *vs*. frequency of different retained values in gm/m^2 for PS. (a) Permittivity, (b) Dielectric loss, (c) Dissipation factor.



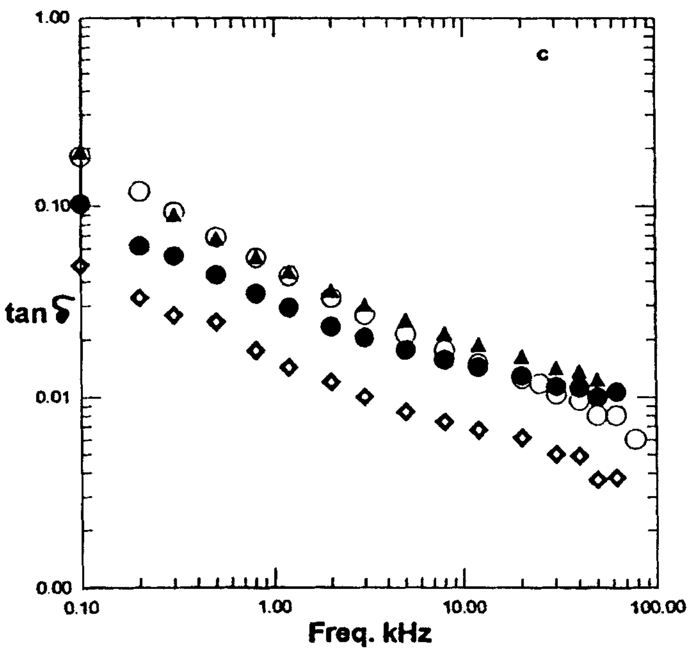


FIGURE 2 (Continued).

both polymers on paper surface as mentioned before. Thus, the decrease of the activities of side polar OH-groups of cellulose reduce the orientation polarization and hence dielectric constant ε', dielectric loss factor ε'. On the other hand the permittivity for the retained value 2.87 is higher than that of the untreated one, also, its loss and dissipation factor is higher due to the mobility of the free OH-groups and other side chains. The paper sheet with retained value 4.9 of PS shows a detectable increase in permittivity and decrease in dissipation factor than that of untreated paper. Thus it can be concluded that, the treatment of paper sheet with 4.9 gm/m^2 retained of PS improved its insulating properties.

The electrical properties of paper sheet with different retained values of PMMA are shown in Figure 3. The permittivity of the impregnated paper sheet in PMMA is greater than the untreated one. The lowest retained polymer 2.4 has the highest permittivity. Increasing the retained value the permittivity of the paper sheet slightly decreases.

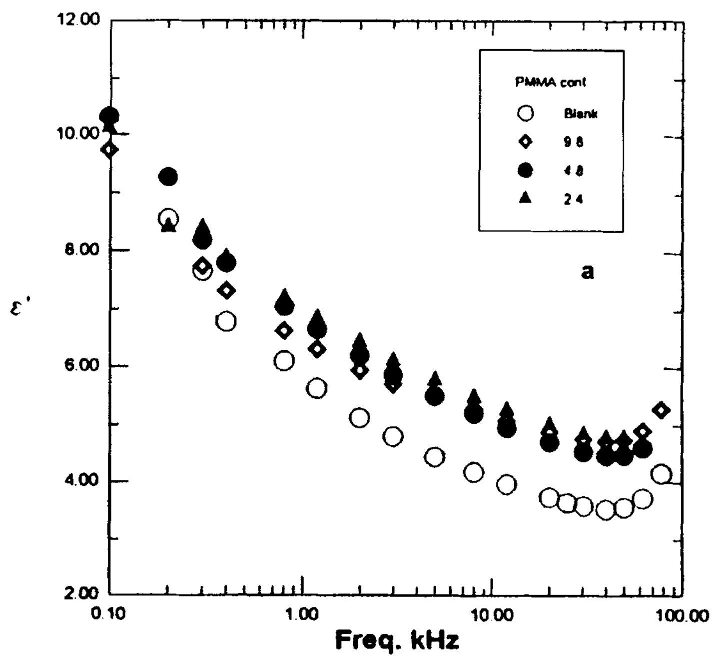


FIGURE 3 The different dielectric parameters *vs.* frequency of different retained values in gm/m^2 for PMMA. (a) Permittivity, (b) Dielectric loss, (c) Dissipation factor.

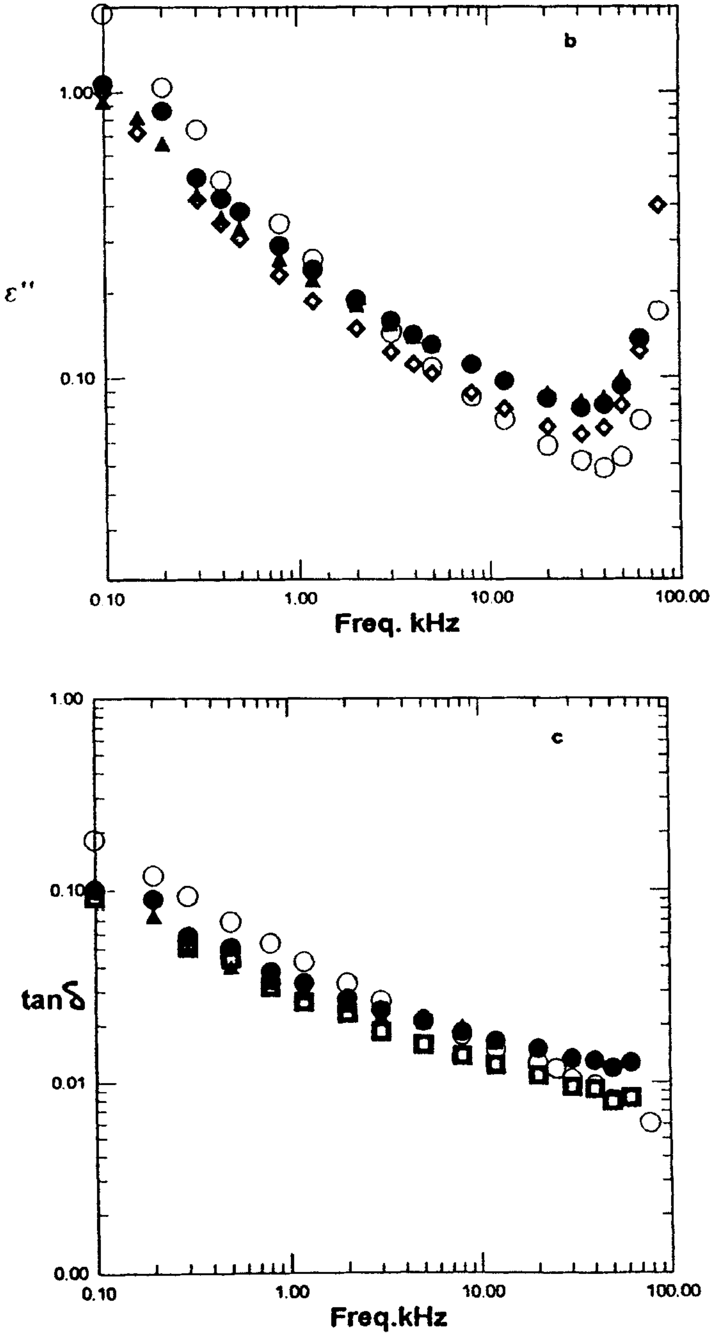


FIGURE 3 (Continued).

The dielectric loss in the part of the frequency range (0.1 – 2 kHz) for the treated paper sheet is less than that of the untreated one. Also the retained value of 2.4 has the smaller dielectric loss. This is in accordance with the previous result for paper sheet impregnated in PS with 4.9 gm/m^2. Thus in this range of frequency, it can be said that the treatment of paper sheet with retained value 2.4 give the most improvement for the dielectric properties. In the range 2 – 100 kHz, The dielectric loss of the paper increased by impregnation in PMMA solutions. Although the dissipation factor decreases for the impregnated paper sheet and decrease nearly linear with frequency.

To give a clear information about the electrical behavior of paper sheet, by impregnation, the dissipation factor must be considered. The permittivity and dissipation factor of paper sheet with different retained values of PS and PMMA at 1.2 kHz is shown in Figure 4. It is clear that the permittivity of the treated paper sheet increases by increasing retained value and reaches its maximum values for PS and PMMA at retained values 4.9 and 2.4 gm/m^2 respectively.

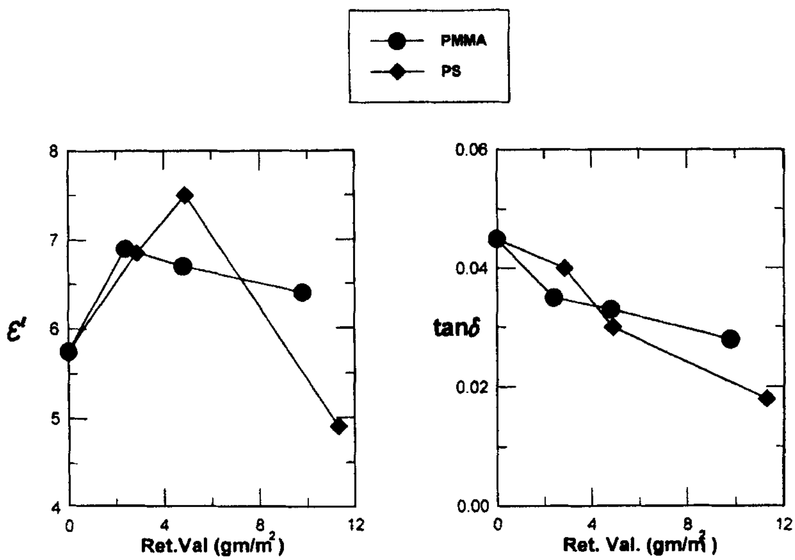


FIGURE 4 Effect of retained value on the dielectric constant (ε') and dissipation factor ($\tan\delta$) for PS and PMMA.

The dissipation factor tan δ of the treated paper sheet with PMMA and PS decreases gradually with increasing retained polymer value. In case of paper sheet impregnated in PMMA the dissipation factor shows smaller effect with retained value.

The dielectric properties ε', ε'' and tan δ of impregnated paper sheet in polyvinyl alcohol solution with retained values of 6.2 and 6.8 gm/m^2 is shown in Figure 5. From this figure it is clear that the permittivity of the impregnated paper sheets is greater than that of untreated ones. Paper sheet of 6.2 gm/m^2 – retained polymer has a higher permittivity than that of 6.8. This can be attributed to the increase of H-bond between polymer and cellulose of the fiber of paper sheet by increasing retained polymer. On the other hand, tan δ of the impregnated paper sheet in polymer solution is slightly lower than the untreated paper sheets. Also, it can be noticed that tan δ of the paper sheet decreases with increasing retained value and frequency till about 20 kHz.

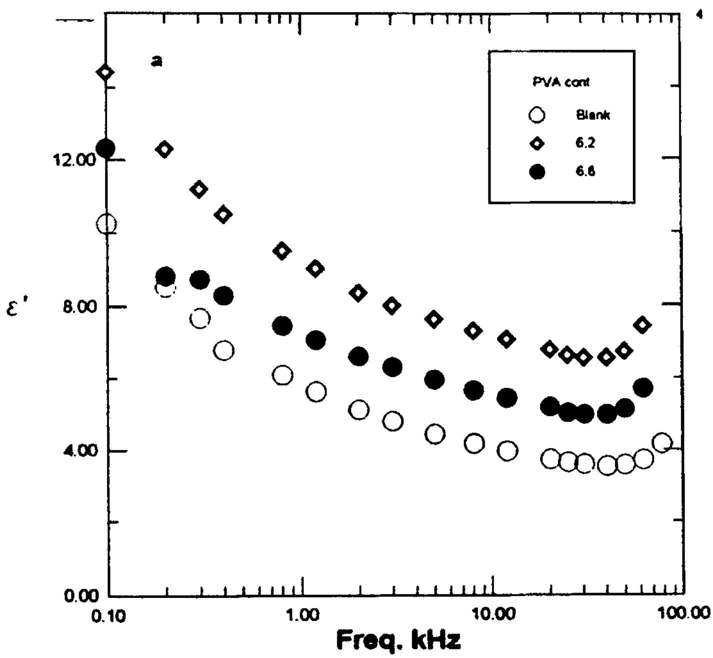
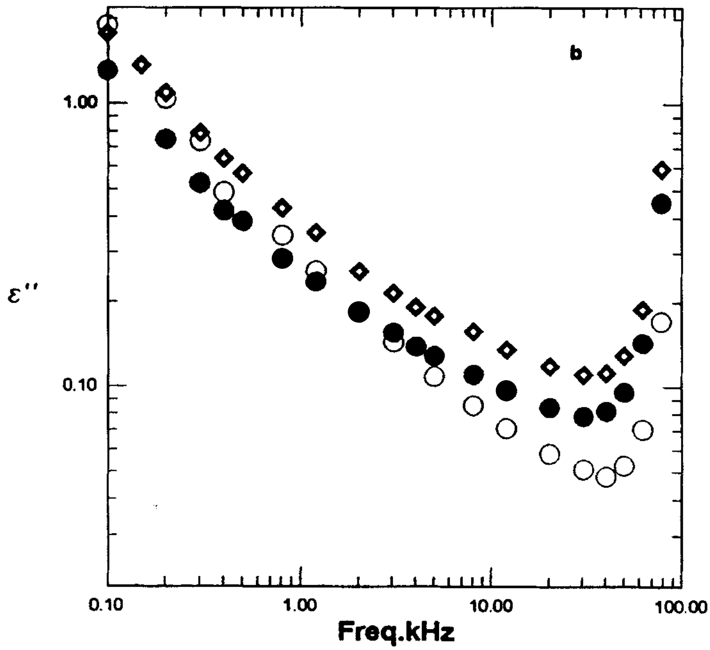


FIGURE 5 The different dielectric parameters *vs.* frequency of different retained values in gm/m^2 for PVA. (a) Permittivity, (b) Dielectric loss, (c) Dissipation factor.



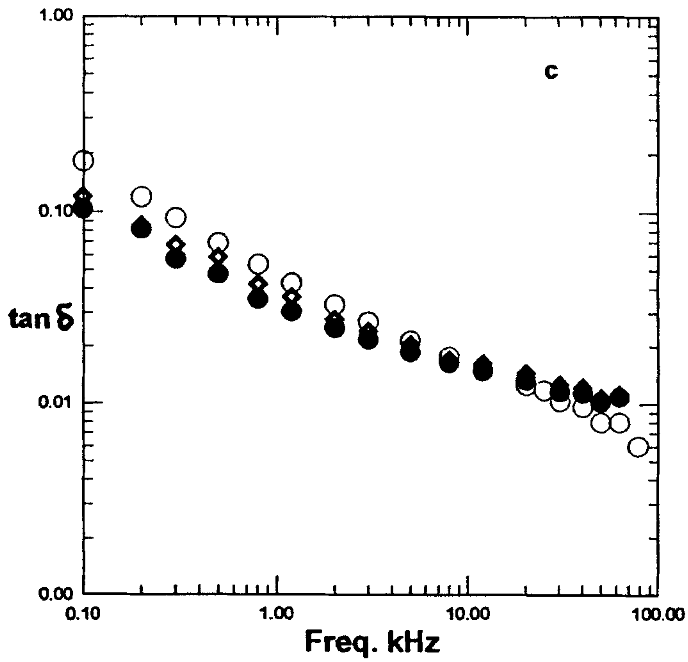


FIGURE 5 (Continued).

5. MECHANICAL PROPERTIES OF TREATED PAPER SHEETS

5.1. Effect of Different Polymers

Breaking length of paper sheets before and after impregnation in different polymer solutions of the same concentration (5%) for (30-sec.) is given in Table VI. Generally, the breaking length of the paper sheets improved by impregnation in polymer solutions. The treated paper sheet with PVA has the highest value of breaking length, although it has the lowest retained polymer. This can be attributed to the high bonding strength and adhesion power of the fiber–fiber and fiber polymer bond. Also the polyvinyl alcohol polymer is more elastic than the two other polymers. So this will increase from the elasticity of the fiber paper sheets and conseqantily the breaking length was increased.

This high adhesion force of PVA than the other polymers causes also a good strong and elastic coated layer on the surface of the paper sheets than the other two polymers.

5.2. Effect of Polymer Mixture

From Table VII it is clear that, the impregnated paper sheet in the mixture of PMMA and PS has the highest value of breaking length

TABLE VI Breaking length of treated paper sheets with different polymer solutions of concentration 5% for 30 sec

Polymer used	*Retained polymer gm/m²*	*Breaking length km*
Blank (untreated)	0.0	2.7
PS	11.3	3.6
PMMA	11.0	3.9
PVA	6.2	5.2

TABLE VII Breaking length of impregnated paper sheet in 2.5% PS, PMMA and mixture of them for 30 sec

Polymer used	*Retained gm/m²*	*Breaking length*
PMMA	2.4	3.6
PS	2.9	3.91
PMMA + PS	2.8	

than that impregnated in both of them alone. This can be attributed to the formation of semi compatible mixed polymer (PMMA, PS) with high chain and consequently the adhesion force between polymer and fiber is increased. On the other hand the mixture of the two polymers produces a polymer with high elasticity than each of them alone. This will causes increase in the fiber bonding in the paper sheet with high elasticity than polymethyl methacrylate or polystyrene polymers.

5.3. Effect of Retained Polymer

It is clear that the breaking length increases by increasing the retained polymer reach to their maximum value at retained polymer 4.6 and 4.9 gm/m^2 for PMMA and PS respectively. This can be attributed to the increase of inter fiber bonding between polymer and fibers of the paper sheet. Increasing the retained polymer more than these values of breaking length begin to slightly decrease. This can be attributed to that the increase of retained polymer increases the bonding between polymer and fiber to a value at which causes a hardness of fiber and consequently the brittleness of the fiber is occurred. On the other hand, the breaking length of dipped paper sheets in polystyrene polymer solution is higher than that in case of dipped paper sheets in polymethyl methacrylate polymer solution. This attributed to the increase of the fiber bonding between polystyrene and fibers of paper sheet more than between polymethyl methacrylate and fiber of paper sheets.

6. TEAR FACTOR

Tear factor of the treated paper sheets reaches to its maxima 232 and 263 in case of retained polymer 10.8 and 10.9 gm/m^2 for PS and PMMA respectively. Although the retained polymer is nearly equal, the tear factors for paper sheet treated with PMMA is higher than that of PS. This can be attributed to that the hardness of PS is more than PMMA, which causes a hardness of the fiber, and consequently increases brittleness of treated paper sheet. Increasing the retained polymer more than these values, the tear factor decreases due to the increase of the brittleness of the fiber, which results from the increase of the hardness, and inters fiber bonding.

TABLE VIII Breaking length of paper sheet with different retained values

Polymer	Retained polymer gm/m^2	Breaking length
	2.4	3.6
PMMA	4.6	4.0
	11.0	3.99
	2.9	3.91
PS	4.9	4.3
	11.5	4.2
Blank		2.7

TABLE IX Retained polymer and tear factor as a function of dipping time In PMMA and PS solution of the same concentration 5%

Time of dipping 5% polymer solution	Retained gm/m^2 PS	Retained gm/m^2 PMMA	Tear factor PS	Tear factor PMMA
10	10.8	9.8	232	219
30	11.2	10.8	223	263
60	11.9	11.0	196	239.6

TABLE X Tear factor and retained values of different polymer solutions of 2.5% concentration

Polymer	Retained	Tear factor
PS	2.8	160
PMMA	2.4	220
PMMA + PS	2.8	215.5

The paper sheet treated with mixture of PS and PMMA 1:1 produces a sheet with retained polymer nearly as in case of PS and slightly decrease than PMMA, Table X,

The tear factor of this treated sheet with a mixture of two polymers is between that of PS and PMMA. This can also attributed to the hardness of PS PO.

References

[1] Swanson, J. W. and Tappi, J. (1961). **142A**, 44.
[2] Fahmy, Y. and El-Saied, H. (1974). *Holzforschung*, **28**, 28.
[3] Ibrahem, A. A., Nada, A. M. A., El-Meadawy, S. A. and Yoysef, M. A. (1983). *Acta Polym.*, **34**, 177.
[4] Heikal, S. O. and Sefain, M. Z., Indian Pulp and Paper, Dec.-Jan., 1998.

[5] Heikal, S. O. and Ibrahem, A. A. (1983). *Research and Industry*, **28**, 176.
[6] El-Meadawy, S. A., Ibrahem, A. A. and El-Saied, H. (1979). *Cell. Tech.*, **13**, 183.
[7] Fahmy, Y. and El-Saied, H. (1974). *Holzforschung*, **28**, 6.
[8] Serell, S. E. (1966). Proc. Royal Garden London Sept. 4–9, p. 15.
[9] Nada, A. M. A. and Ayoub, M. H. J. (1997). *Elastomers and Plast.*, p. 2911.
[10] Nada, A. M. A., Ibrahem, A. A., Yousef, M. A. and El-Meadawy, S. A. (1983). *Acta Polym.*, **34**, 181.
[11] Nada, A. M. A. and Ibrahem, A. A. (1981). Indean Pulp of paper, April–May, p. 21.
[12] Salman, A. A., El-Anwar, I. and Dawy, M. (1989). *Egypt Soc. Eng. Soc. Chem. Eng.*, Egypt, p. 2.
[13] Mounir, M., Abel Fattah, H. A. and Mobarak, F. (1996). *International Conf. Chem. Tech. of Fiber and Textiles*, Cairo, Egypt, p. 243.
[14] Mobarak, F., Abdel Fattah, H. A. and Mounir, M. (1996) *International Conf. Chem. Tech. Fiber and Textiles*, Cairo, Egypt, p. 229.
[15] Fernandez, A. M. and Srivastava, O. M. (1977). *J. App. Cryst.*, **10**, 32.
[16] Tappi standards, Technical Association of the Pulp and Paper Industry, N.Y. (1957).
[17] Gersimov, Y. A. and Dreving, V. (1974). "Physical Chemistry" Vol. 1, Mir Publisher Moscow.
[18] Long, R. E., Sparks, R. A. and Trulood, K. N. (1965). *Acta Cryst.*, **18**, 923.