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## Mechanical properties of polyaniline/poly(methyl methacrylate) (PANI/PMMA) doped with metal chlorides blend films

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**Abstract** Polyaniline/poly(methyl methacrylate) (PANI/PMMA) conducting blends was prepared. PANI/PMMA doped with metal chlorides such as FeCl<sub>3</sub>, NiCl<sub>2</sub>, CoCl<sub>2</sub>, MnCl<sub>2</sub>, and CdCl<sub>2</sub> were also prepared. Crystal structure, surface morphology, and mechanical properties of these polyaniline blends have been studied. Blending PANI/Dodecylbenzenesulfonic acid (DBSA) with PMMA and doped with metal chlorides improved the mechanical properties of polyaniline. PMMA and metal chlorides increased the tensile modulus, and ultimate stress. The certain amount of these two materials that can be added with Polyaniline/Dodecylbenzenesulfonic to get the optimum mechanical properties was investigated.

**Keywords** Polyaniline, PMMA, Mechanical properties

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### 1. Introduction

Among conducting polymers, polyaniline (PANI) is probably the most widely explored due to its optical and electrical properties [1-6]. Besides, its ease of preparation, light weight, low cost, stability in air and good processibility [7-9] make it a good candidate in many applications such as electromagnetic interference shielding, electro-catalysts, rechargeable batteries, light-emitting diodes, chemical sensor, biosensor, corrosion devices and microwave absorption [10,11]. PANI exists in three forms of oxidation states: the fully reduced leucoemeraldine base (LEB), half-oxidized emeraldine base (PANI-EB) and fully oxidized pernigraniline base (PNB). A more conductive emeraldine salt form (PANI-ES) can be achieved by dispersing PANI-EB in an aqueous protonic or functionalized acids where protons are added to the –N= sites. A stable PANI/DBSA aqueous dispersion was obtained at the end of the polymerization process, with excess DBSA which forms micellar structures and also acts as a surfactant, which stabilizes the dispersion of the PANI-DBSA particles. The hydrophobic tails of free and bonded DBSA molecules are arranged in a way that they all turn to each other, while the hydrophilic groups of the free DBSA turn to the aqueous phase (Fig. 1). The molecular conformation of PANI-DBSA chains is affected both by the molecule-molecule (intramolecule) interactions and molecule-aqueous medium interactions.



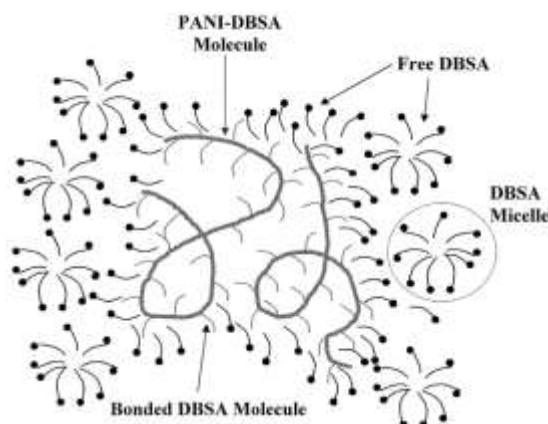


Figure 1: Model of aqueous dispersions of polyaniline with DBSA.

PANI/PMMA blend films were cast using chloroform as solvent, with controlled rate of evaporation in order to avoid phase separation during the solvent evaporation when polymer concentration increased beyond the cloud point. The PANI/PMMA blend films from PANI/DBSA were very uniform, homogenous and flexible at all compositions whereas those from PANI-HCl were grainy, rough and brittle even at low concentrations of PANI. This may arise from the higher compatibility /miscibility of PANI/DBSA with PMMA solution than that of PANI doped with HCl. Blending PANI with PMMA and doped with metal chlorides was improved the mechanical properties of polyaniline. In this work, PANI/DBSA blend with PMMA and metal chlorides in order to improve the mechanical properties. The additional of PMMA and metal chlorides increase the tensile modulus, and ultimate stress. Hence, the certain amount of these two materials in order to get the optimum mechanical properties was investigated

## 2. Experimental

### 2.1. Materials

Aniline monomer (sigma company and was distilled by vacuum system (pale yellow)). Aniline hydrochloride, 4-Dodecylbenzenesulfonic acid (DBSA, 90 %), Poly(methylmethacrylate) PMMA granules, (MW = 350,000 g/mol), Chloroform ( $\text{CHCl}_3$ ) and transition metal salt ( $\text{FeCl}_3$ ,  $\text{NiCl}_2$ ,  $\text{CoCl}_2$ ,  $\text{MnCl}_2$ , and  $\text{CdCl}_2$ ), were obtained from Fluka. The ammonium persulfate APS ( $(\text{NH}_4)_2\text{S}_2\text{O}_8$  (APS); (Oxford Laboratory Mumbai), and ammonia were bought from El-Gomhoria Chemical Company Alexandria, Egypt.

#### 2.1.1. Polyaniline synthesis with indirect way of doping:

Polyaniline was synthesized in conventional route [12] in aqueous medium using mineral acid HCl as a dopant ion and an oxidizing agent ammonium persulfate,  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ , as initiator. Aniline monomer, acid dopant and oxidizing agent were taken in the molecular ratio of 1:1:1.1. Hydrochloric acid was taken in distilled water into which aniline monomer was added and stirred to get aniline-acid complex and kept in the freezing mixture to attain the reaction temperature of 0 - 5 °C.  $(\text{NH}_4)_2\text{S}_2\text{O}_8$  was dissolved in distilled water and kept in the freezing mixture. Both of these solutions attained the reaction temperature, following by mixing together and stirred well, and kept for six hours for the completion of reaction. Polyaniline powder formed was filtered, washed thoroughly with water to remove excess salts and dried at 40 °C in vacuum for 24 hrs to make it moisture free. Polyaniline (PANI) obtained was first neutralized with ammonia solution (2M), filtered, washed thoroughly (till pH was 7), dried and then crushed to fine powder. This powder was mixed with dodecyl benzene sulfonic acid (DBSA) externally (1:2 mole / monomer) and then dropped in chloroform and stirred for 24 hrs to obtain PANI-DBSA

#### 2.1.2. Blending of polyaniline with Poly(methylmeth acrylate)(PMMA):

PMMA is a well-known optically transparent engineering plastic, good solubility in many of the organic solvents, and the best solvent is  $\text{CHCl}_3$ . Since the PANI/DBSA synthesized as mentioned is found highly soluble in



chloroform, and can be used for the solution blending of PANI-DBSA with PMMA. Atactic PMMA was used in this work. PMMA stock solution was prepared by dissolving 5gms of PMMA in 150 ml of chloroform, so as to get the PMMA concentration of 1gm per 30 ml. The solubility of polyaniline doped with dodecylbenzenesulfonic acid (PANI/DBSA) was improved with additional doping (extra-doping) with DBSA. The solubility of PANI/DBSA (extra-doped) was 6.7g per 100 ml of chloroform. Required quantity of both solutions were taken and mixed well. The resultant solutions were stirred on magnetic stirrer continuously for 6hrs and then sonicated for half an hour to get homogeneous blend solution. These blends solutions were casted in petri dish to get the blend films of different thickness. The thickness was adjusted by using petri dishes of different diameters. The thicknesses of the obtained films were around 60 - 130 microns. These castings were carried out at ambient conditions with controlled rate of evaporation. These petri dishes were kept undisturbed till complete evaporation of the solvent was over and then the films of PANI-DBSA/PMMA blends were peeled off and dried thoroughly under vacuum for complete removal of solvent.

### 2.1.3. Preparation of PANI/PMMA doped with metal chloride:

PMMA stock solution was prepared by dissolving 5gm of PMMA in 150 ml of chloroform, so as to get the PMMA concentration of 1gm per 30 ml and then add to solution of polyaniline doped with metal chloride to form PANI/PMMA/Metal chloride.

## 2.2. Characterization

The XRD patterns of the prepared polymeric material and its blend were recorded using a Shimadzu XRD-7000 x-ray diffractometer with Cu K $\alpha$  radiation ( $\lambda = 0.15418$  nm). The corresponding intensities were measured for  $2\theta$  angles ranging from  $10^\circ$  to  $90^\circ$  with a step  $0.07^\circ$  per second. The morphology of the prepared samples and their blends were studied using a JEOL JSM-6360LA scanning electron microscope (SEM). Mechanical properties are determined from Tensile testing to determine elastic modulus, ultimate stress, and ultimate strain. In tensile testing, a shaped sample is placed in the grips of movable and stationary fixtures in a screw driven device, which pulls the sample until it breaks and measures applied load versus elongation of the sample.

## 3. Results and discussion

### 3.1 X-ray diffraction analysis (XRD):

The XRD patterns of the prepared films, PANI/DBSA/PMMA, PANI/DBSA/PMMA/CdCl<sub>2</sub>, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/PMMA/CoCl<sub>2</sub>, PANI/DBSA/PMMA/FeCl<sub>3</sub>, and PANI/DBSA/PMMA/MnCl<sub>2</sub> blends with are shown in Fig. 2.

As reported in most literature [10 -13], most of the forms of PANI essentially amorphous and show the presence of broad peaks stretching from  $2\theta$  between  $15 - 30^\circ$ . PANI is known to be semi-crystalline as it exhibits sharp XRD peaks in the diffraction angle ( $2\theta$ ) region of 15 to 30 degrees. However, for PANI/DBSA blends with PMMA, the XRD scans contained mainly broad amorphous halos as indicated in the Fig 2.a.

### 3.1.1 Crystal size and lattice strain (Microstrain):

Strain is defined as the deformation of an object divided by its ideal length,  $\Delta d/d$ . In crystals there we can observe two types of strain Uniform strain and Non-uniform strain. Uniform strain causes the unit cell to expand/contract in an isotropic way. This simply leads to a change in the unit cell parameters and shift of the peaks. There is no broadening associated with this type of strain. Non-uniform strain leads to systematic shifts of atoms from their ideal positions and to peak broadening. This type of strain arises from the following sources:

- Point defects (vacancies, site-disorder)
- Plastic deformation (cold worked metals, thin films)
- Poor crystallinity



If  $\Delta d$  is the change in the  $d$ -spacing between the pure PANI powder ( $d_i$ ) and metal chlorides doped PANI powder ( $d_f$ ) samples, the corresponding uniform strain ( $k$ ), considering the distribution of metal chlorides species in the lattice to be uniform, is calculated by implying the following equation [14]:

$$k = c(d_f - d_i)/d_i = c\Delta d/d_i \quad (1)$$

Where  $c$  is a material dependent constant.

We have examined the changes in non-uniform strain in accordance with the crystalline size by implying the Williamson and Hall equation [15]:

$$\beta \cos \theta = 4\varepsilon \sin \theta + \frac{K\lambda}{D} \text{ and } \beta = \sqrt{\beta_{\text{sample}}^2 - \beta_{\text{silicon}}^2} \quad (2)$$

Where  $K$  is a shape factor correction and equal to 0.89,  $D$  is the effective crystallite size.  $\beta_{\text{sample}}$  and  $\beta_{\text{silicon}}$  are the full widths at half maxima (FWHM) of the broadened peaks of the sample and a silicon crystal free from defect, respectively. The use of silicon crystal free from defects enables to determine the instrumental broadening. A plot of  $(\beta \cos \theta)$  vs.  $\sin \theta$  produces a straight line of slope equal to  $(4\varepsilon)$  and an intercept equals to  $(K\lambda/D)$  as shown in Fig. 4.

The uniform strain decreases when metal chlorides blended with PANI/DBSA/PMMA. The inter-planer lattice spacing 'd' shifts to the lower side compared with the PANI/DBSA/PMMA suggesting the compressive strain in lattice [14] (Fig. 3). The broadening of some peaks supports presence of the non-uniform strain, which changes from one region to the other region within the same grain attributing to the non-uniform distribution of metal chlorides species in the PANI/DBSA/PMMA lattice.

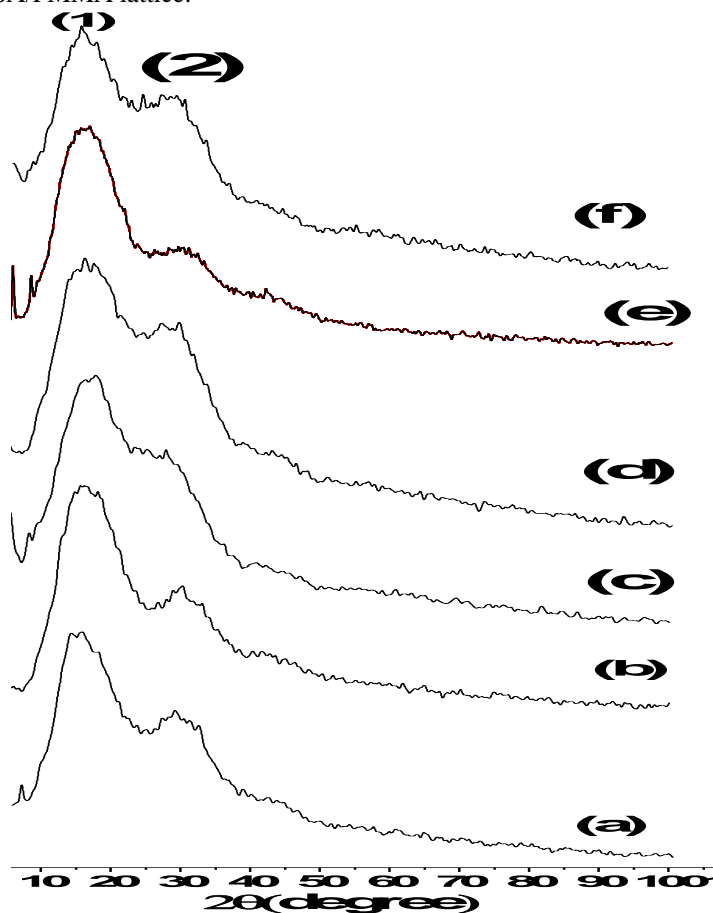


Figure 2: XRD patterns of films (a) PANI/DBSA/PMMA, (b) PANI/DBSA/PMMA/ $\text{NiCl}_2$ , (c) PANI/DBSA/PMMA/ $\text{CoCl}_2$ , (d) PANI/DBSA/PMMA/ $\text{FeCl}_3$ , (e) PANI/DBSA/PMMA/ $\text{MnCl}_2$  and (f) PANI/DBSA/PMMA/ $\text{CdCl}_2$  blends

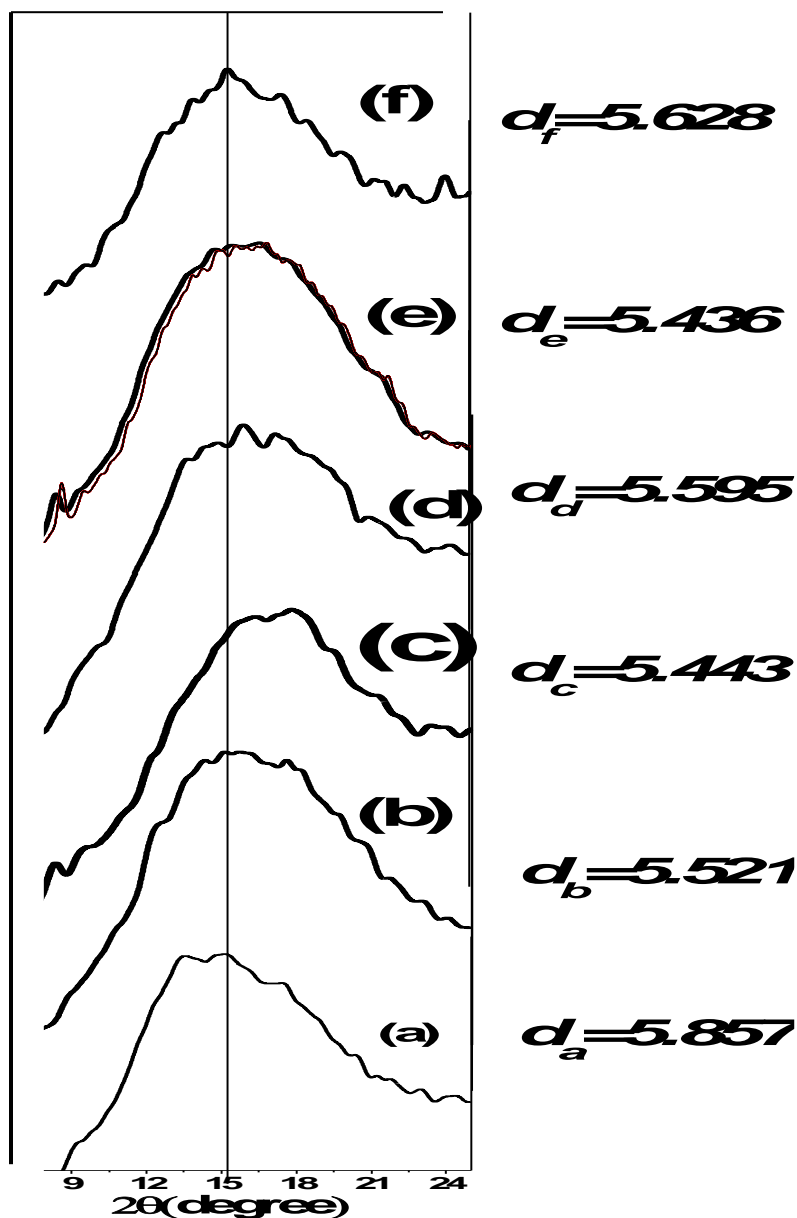


Figure 3: Effect of lattice strain on diffraction line and position of films (a) PANI/DBSA/PMMA, (b) PANI/DBSA/PMMA/ $\text{NiCl}_2$ , (c) PANI/DBSA/PMMA/ $\text{CoCl}_2$ , (d) PANI/DBSA/PMMA/ $\text{FeCl}_3$ , (e) PANI/DBSA/PMMA/ $\text{MnCl}_2$  and (f) PANI/DBSA/PMMA/ $\text{CdCl}_2$  blends, where  $d$  is the interplaner spacing. We have examined the changes in non-uniform strain in accordance with the effective crystalline size by implying the Williamson and Hall equation (2).

A plot of  $(\beta\cos\theta)$  vs.  $\sin\theta$  produces a straight line of slope equals to  $(4\epsilon)$  and intercept equals to  $(K\lambda/D)$  Fig. 4.

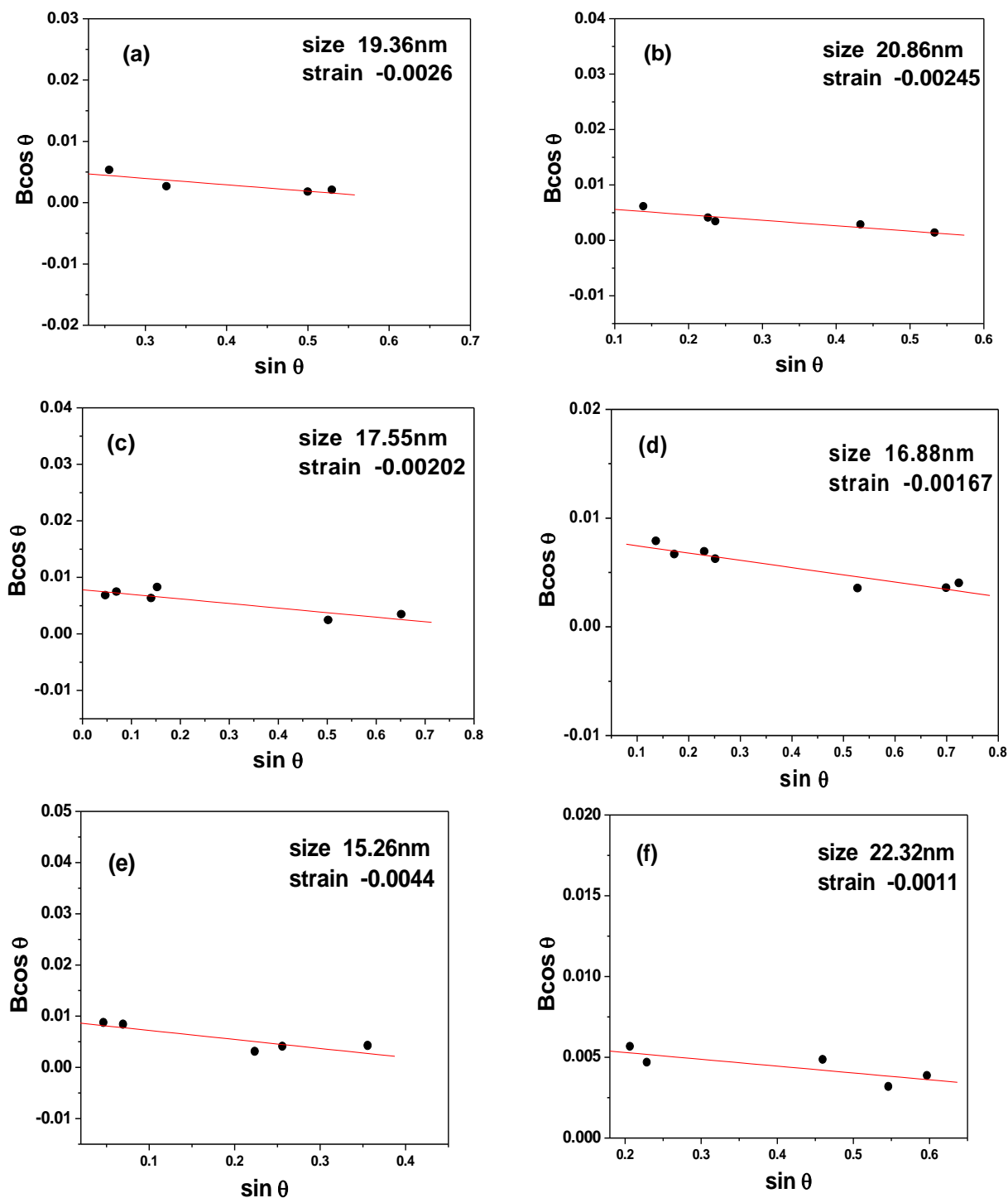


Figure 4: Plot of ( $\beta \cos \theta$ ) vs. ( $\sin \theta$ ) for films (a) PANI/DBSA/PMMA, (b) PANI/DBSA/PMMA/NiCl<sub>2</sub>, (c) PANI/DBSA/PMMA/CoCl<sub>2</sub>, (d) PANI/DBSA/PMMA/FeCl<sub>3</sub>, (e) PANI/DBSA/PMMA/MnCl<sub>2</sub> and (f) PANI/DBSA/PMMA/CdCl<sub>2</sub> blends

Negative slopes of the prepared films indicate the presence of effective compressive strain in the crystal lattice. The lower magnitude of the effective particle size for samples compared with its average crystallite size are due to these samples have negative strain (compressive strain). These results propose that the size dependent strains in the particles are governed by the concentration of dopants in the host material [14].



The internal lattice (non-uniform strain), uniform strain, effective particle size (from slop), and average crystallite size values were listed in **Table 1**.

**Table 1:** Values of effective particle size (nm) calculated from the slope of **Fig. 4**, average crystallite size (nm) measured using Scherrer equation, Uniform and Non-uniform strain determined from Eqs. (1) and (2), of PANI/DBSA/PMMA, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/PMMA/ CoCl<sub>2</sub>, PANI/DBSA/PMMA/ FeCl<sub>3</sub>, PANI/DBSA/ PMMA/MnCl<sub>2</sub> and PANI/DBSA/PMMA/CdCl<sub>2</sub> blends.

Property	PANI/ DBSA/ PMMA	PANI /DBSA /PMMA/ CdCl <sub>2</sub>	PANI/ DBSA/ PMMA/ NiCl <sub>2</sub>	PANI/ DBSA/ PMMA/ CoCl <sub>2</sub>	PANI/ DBSA/ PMMA/ FeCl <sub>3</sub>	PANI/ DBSA/ PMMA/ MnCl <sub>2</sub>
Uniform strain (x10 <sup>-3</sup> )	—	-39.1	-57.4	-70.6	-44.8	-71.9
Non-uniform strain (x10 <sup>-3</sup> )	-2.6	-1.1	-2.5	-2.0	-1.7	-4.4
Effective particle size (nm)	19.36	22.32	20.86	17.55	16.88	15.26
Average crystallite size (nm)	24.89	29.20	24.46	23.07	20.06	23.10

### 3.1.2 Percentage of crystallinity and inter-chain separation:

It is well known that crystalline or semi-crystalline polymers are two phase systems. The phase in which the polymer chains are parallel and ordered in close packed array is the crystallites region, whilst the phase where the chains are not ordered and do not have parallel alignment is the amorphous region. This ordered arrangement of polymer chains in the crystalline phase may be of different types depending on the nature of the polymer, and can be detected from X-ray diffraction study.

The X-ray diffraction is useful for the estimation of degree of crystallinity (C %), inter-chain separation (R) and the d-spacing. The highest intense two crystalline peaks are obtained designated as (1) and (2) (**Fig 2**). The percentage of crystallinity of the samples was estimated multiplying the ratio of crystalline peak area to total peak area by 100.

The d-spacing of different samples was determined by Debye –Scherrer method using Bragg's relation [16, 17]:

$$n\lambda = 2d \sin \theta \quad (3)$$

Where, n is an integer,  $\lambda$  is the wavelength of the X-ray which is 1.54 Å for Cu target, d is the inter-planar spacing also called d-spacing,  $\theta$  is the angle between the planes and the direction of the beam.

The inter-chain separation was determined from the relation [16, 17]:

$$R = 5\lambda / 8 \sin \theta \quad (4)$$

Where, R is the inter-chain separation.

The degree of crystallinity, inter-chain separation and the d-spacing are calculated from equations (3, and 4) for PANI/DBSA/PMMA, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/ PMMA/CoCl<sub>2</sub>, PANI/DBSA/ PMMA/FeCl<sub>3</sub>, PANI/DBSA/PMMA/MnCl<sub>2</sub> and PANI/DBSA/PMMA/ CdCl<sub>2</sub> blends **Table 2**.

Table 2: The d-spacing, degree of crystallinity and inter-chain separation (calculated from XRD results) of PANI/DBSA/PMMA, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/ PMMA/CoCl<sub>2</sub>, PANI/DBSA/PMMA/FeCl<sub>3</sub>, PANI/DBSA/PMMA/MnCl<sub>2</sub> and PANI/ DBSA/PMMA/CdCl<sub>2</sub> blends.

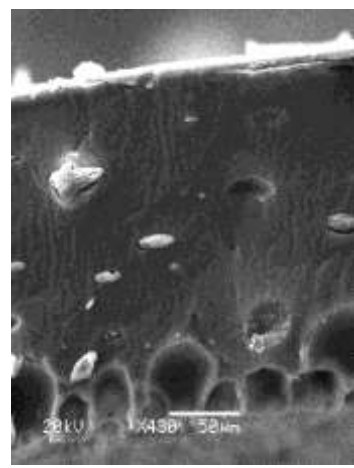
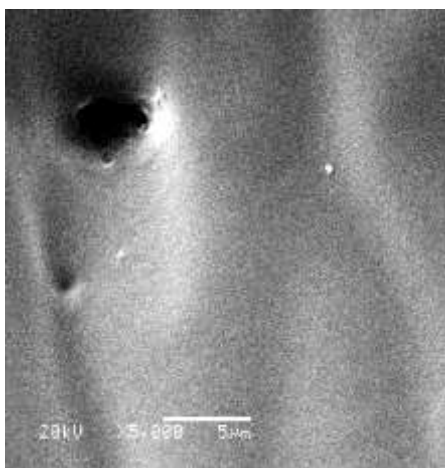
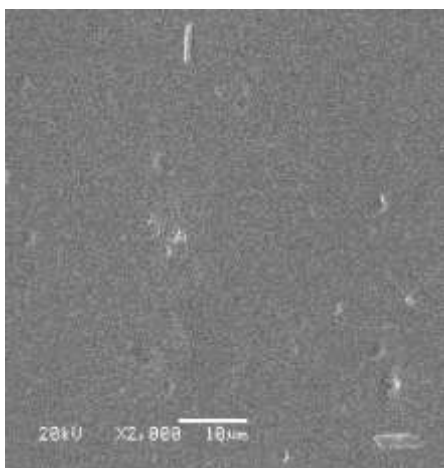
$d_1$ ,  $d_2$  are the d-spacings, PC<sub>1</sub>%, PC<sub>2</sub>%, are the percentage of crystallinity and R<sub>1</sub>, R<sub>2</sub> are the inter-chain separation corresponding to the highest intense two crystalline peaks 1, and 2 respectively. At peak (2) the d-spacing and inter-chain separation is decreased compared with its values at peaks (1), but the values of the degree of crystallinity is increased. As the chain size is reduced, they may reorient and hence crystallinity may increase and d-spacing may decrease [17].

### 3.2 Polymer morphology by (SEM):

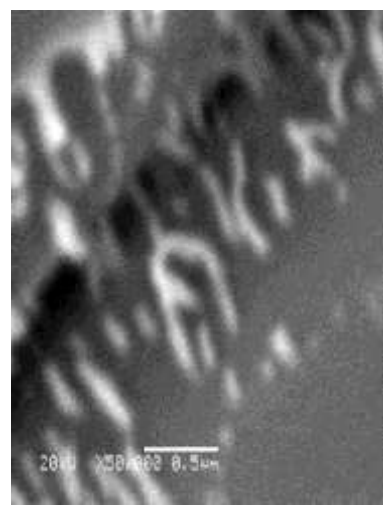
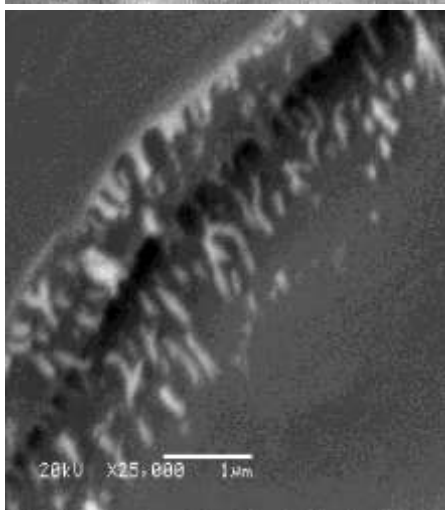
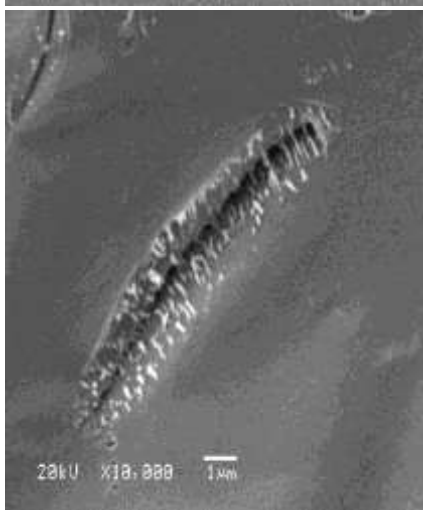
The surface morphology of prepared samples was determined by SEM. Figs 5 and 6 represent the SEM image of PANI/DBSA/PMMA and PANI/PMMA/Metal chlorides.



**PANI/  
DBSA/  
PMMA**



**PANI/  
DBSA/  
PMMA/  
MnCl<sub>2</sub>**



**PANI/  
DBSA/  
PMMA/  
CdCl<sub>2</sub>**

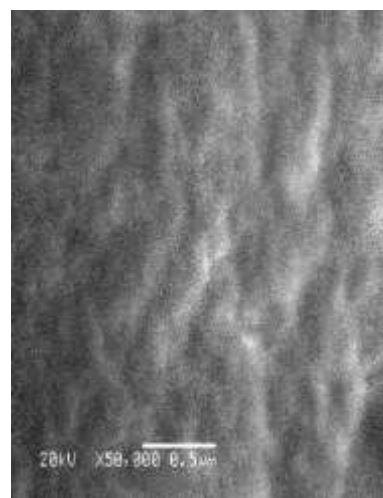
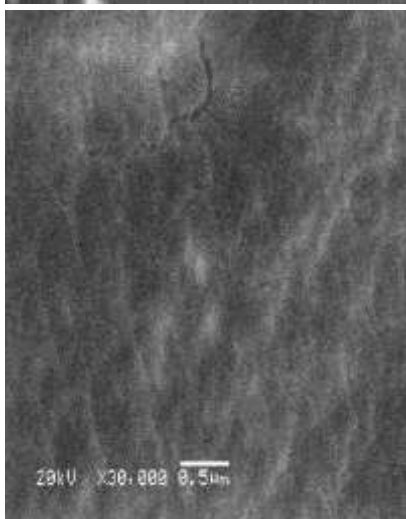
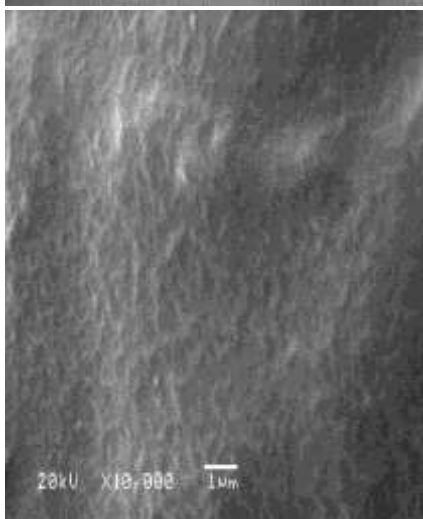
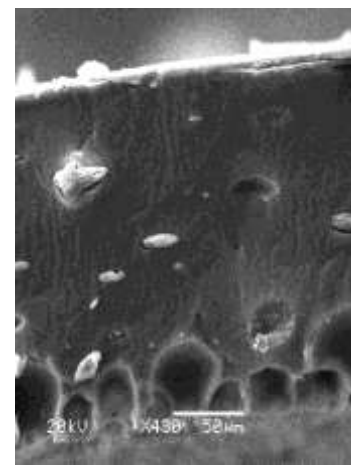
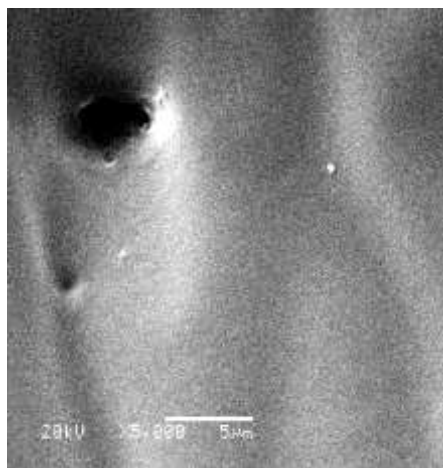
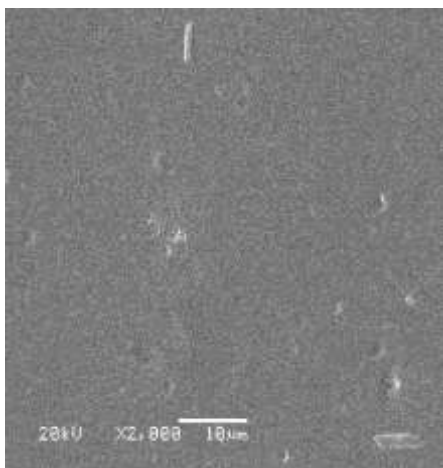


Figure 5: SEM of PANI/DBSA/PMMA, PANI/DBSA/PMMA/MnCl<sub>2</sub>, and PANI/DBSA/PMMA/CdCl<sub>2</sub> blend films

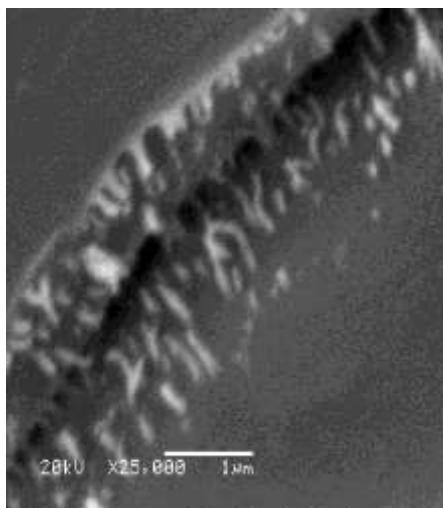
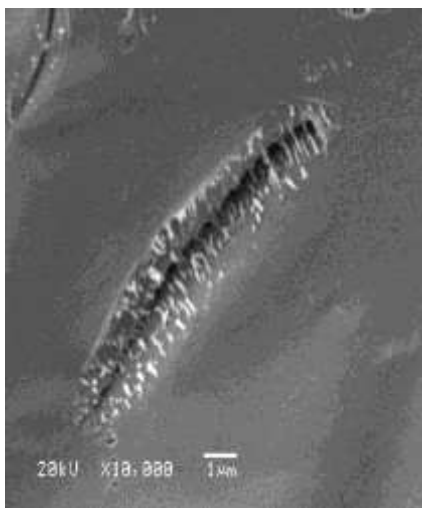




**PANI/  
DBSA/  
PMMA/  
FeCl<sub>3</sub>**



**PANI/  
DBSA/  
PMMA/  
CoCl<sub>2</sub>**



**PANI/  
DBSA/  
PMMA/  
NiCl<sub>2</sub>**

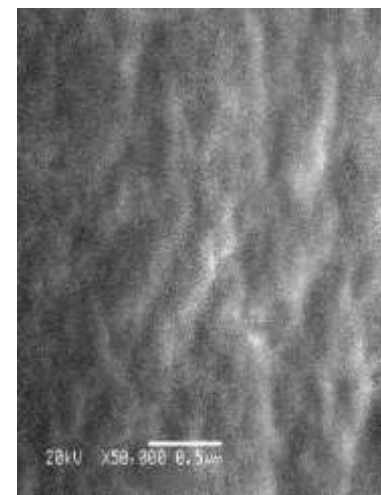
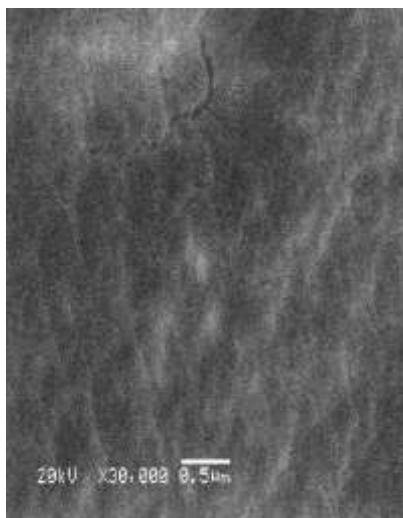
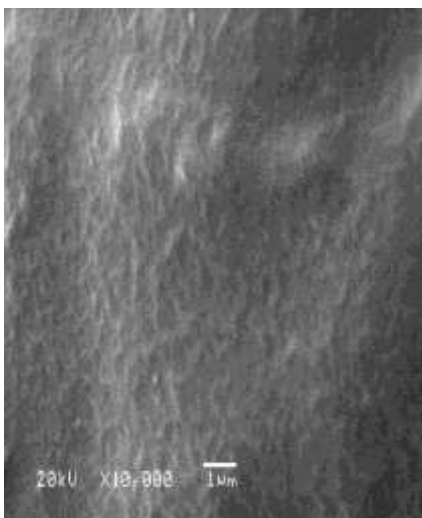


Figure 6: SEM of PANI/DBSA/PMMA/FeCl<sub>3</sub>, PANI/DBSA/PMMA /CoCl<sub>2</sub> and PANI/DBSA/PMMA/ NiCl<sub>2</sub> blend films



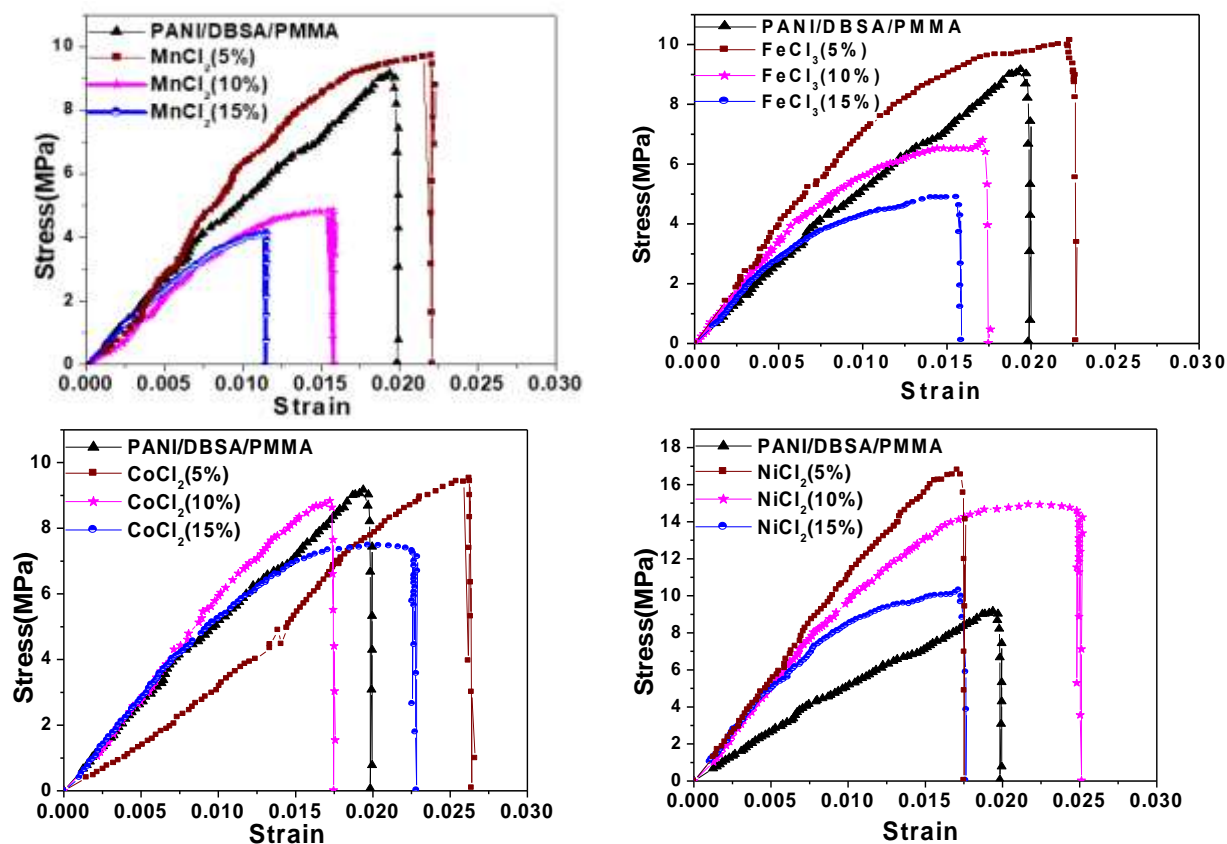
### 3.3 Mechanical properties of PANI films:

In order to characterize the mechanical properties of polymer blends, this study used tensile testing. This can determine the elastic modulus and ultimate stress and ultimate strain for the specimen.

All samples were prepared using the same procedures and all mechanical tests were run using the same parameters. This is consistent approach to testing provided a true comparison between the reference PANI/DBSA film, and PANI/DBSA/PMMA films with different concentrations of PMMA (10, 20, and 30%), and comparison between the reference PANI/DBSA/PMMA (10%) film and PANI/DBSA/PMMA/FeCl<sub>3</sub>, PANI/DBSA/PMMA/CoCl<sub>2</sub>, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/PMMA/MnCl<sub>2</sub> and PANI/DBSA /PMMA/ CdCl<sub>2</sub> blends films with different concentration of metal chlorides (5, 10, and 15%). The results showed that blend PMMA, and metal chloride with PANI/DBSA can improve the mechanical properties specifically ultimate stress.

Tensile testing data was plotted in stress versus strain curves, examples of Fig 7. Elastic modulus is defined as the slope of the linear portion of the stress/strain curve.

Table 3 shows the variation and change % in elastic modulus, ultimate stress, ultimate strain, and toughness with variation in concentration of each sample.



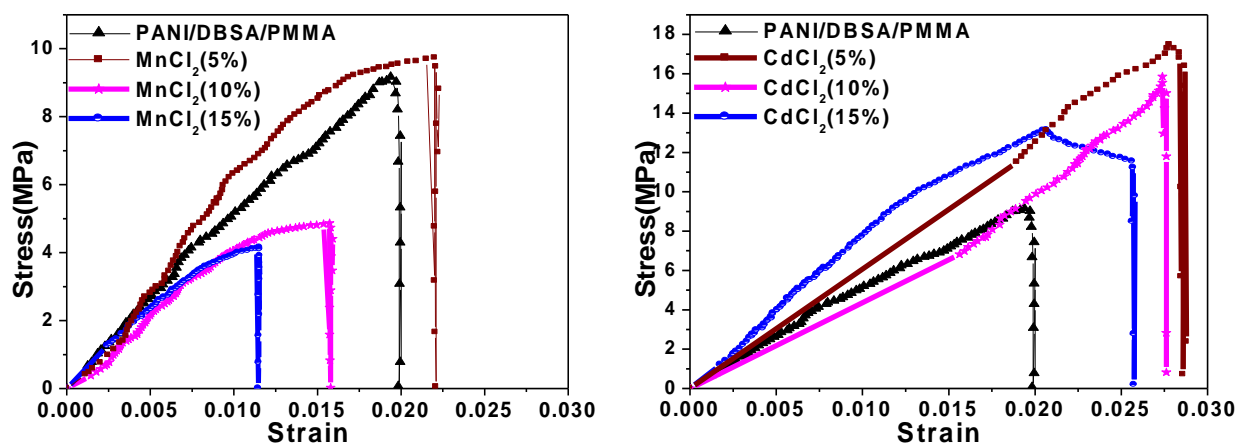


Figure 7: Tensile testing stress versus strain curves for PANI/DBSA and additional material (PMMA, and metal chlorides) with different concentrations

Table 3: Calculation of Elastic modulus, ultimate stress, ultimate strain, and toughness and change % of samples with different concentration of each sample from tensile testing

Samples	Elastic modulus (MPa)	Ultimate stress (MPa)	Ultimate strain	Toughness
PANI/DBSA	167.33	1.55	0.011	0.0096
PANI/DBSA/PMMA				
10%	538.16	9.22	0.019	0.098
20%	498.28	6.14	0.016	0.053
30%	275.88	3.38	0.014	0.032
PANI/DBSA/PMMA/FeCl <sub>3</sub>				
5%	523.55	10.14	0.022	0.151
10%	676.51	6.81	0.017	0.078
15%	586.84	4.92	0.016	0.052
PANI/DBSA/PMMA/CoCl <sub>2</sub>				
5%	273.30	9.45	0.026	0.124
10%	550.67	8.88	0.017	0.085
15%	483.15	7.33	0.023	0.115
PANI/DBSA/PMMA/NiCl <sub>2</sub>				
5%	1066.79	16.82	0.017	0.163
10%	994.86	15.04	0.025	0.253
15%	976.42	10.18	0.017	0.119
PANI/DBSA/PMMA/MnCl <sub>2</sub> 5%				
10%	395.71	9.68	0.022	0.131
15%	288.66	4.80	0.016	0.047
	486.95	4.17	0.011	0.028
PANI/DBSA/PMMA/CdCl <sub>2</sub>				
5%	631.91	17.47	0.029	0.294
10%	458.52	15.82	0.027	0.255
15%	700.41	11.57	0.026	0.215



In order to explain the differences in the modulus ranges across different samples, one can consider the nature of the samples, but one can predict the structure based on the modulus results.

Tensile testing showed a large increase of 495% in ultimate stress of PANI/DBSA/PMMA compared with PANI/DBSA. The addition of metal chlorides shows an increase in ultimate stress compared with PANI/DBSA/PMMA. Different values of elastic modulus and ultimate strain in different samples could stem from sample preparation and particle dispersion differences [18-20].

It is evident from Fig 7. that with the addition of PMMA and metal chlorides to PANI/DBSA, the tensile properties showed remarkable improvement. Modulus, ultimate stress and ultimate strain for all samples were much better than pure PANI/DBSA. For example; the modulus of PANI/DBSA/PMMA (10%) was 222% greater than pure PANI/DBSA, i.e. for these materials, the tensile moduli were more than pure PANI/DBSA.

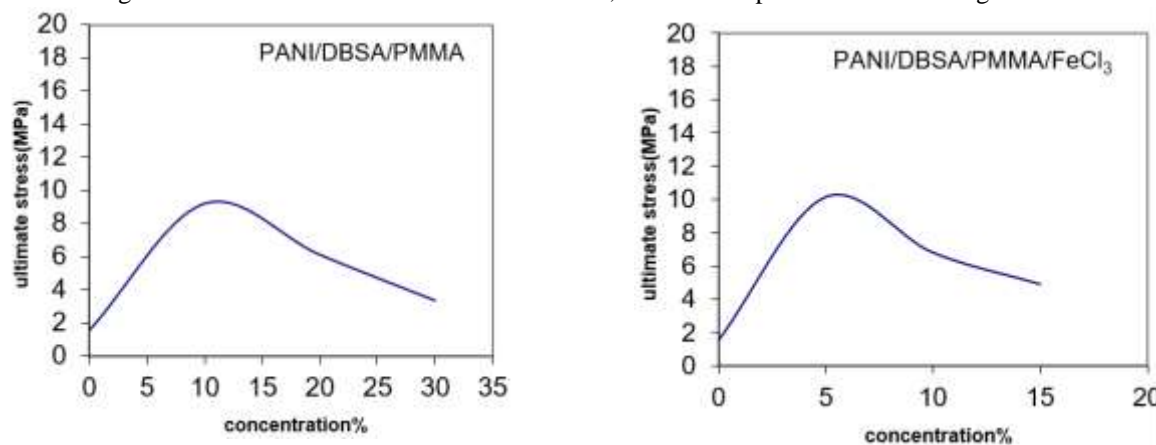
Two additional components were added to PANI/DBSA. First was a PMMA with concentration (10, 20, and 30%). The other material was a metal chlorides, FeCl<sub>3</sub>, CoCl<sub>2</sub>, NiCl<sub>2</sub>, MnCl<sub>2</sub>, and CdCl<sub>2</sub> with concentration (5, 10, and 15%). It was seen from Fig 7. that When no addition was present (i.e., PANI/DBSA), the material have very low values of elastic modulus and ultimate stress. This material have a fracture point at stress equal 1.55 MPa.

When additional was added (i.e., PANI/DBSA/PMMA, PANI/DBSA/PMMA/ FeCl<sub>3</sub>, PANI/DBSA/PMMA/CoCl<sub>2</sub>, PANI/DBSA/PMMA/NiCl<sub>2</sub>, PANI/DBSA/ PMMA/MnCl<sub>2</sub> and PANI/DBSA/PMMA/CdCl<sub>2</sub> blends films), it was seen that the modulus showed tremendous improvement, and the ultimate stress increased as well. However, the increase in ultimate stress was not proportionate to the increase in tensile modulus. This is because the different natural of each materials Fig 7.

The PMMA, and metal chlorides increases the tensile modulus, and ultimate stress. Hence, there is a certain amount of these two materials that can be added with PANI/DBSA to get the optimum mechanical properties.

Fig 8. shows the dependence of ultimate stress on various concentrations. The properties reached a maximum at a certain concentration and then leveled off after showing a decreasing trend. However, the weight % of additional materials in all these materials was constant, which was 10 wt% of PMMA and 5 wt % for metal chlorides (Fig 8). The optimum mechanical properties can be obtained at concentration from 5 wt % to 10 wt % for all samples. But with increase concentration of the additional materials, then the mechanical properties are decreased. Now, as the percentage of additional materials was increased, it was seen that the tensile properties improve further. The modulus and tensile strength were enhanced even further.

Upon increasing the concentration of the additional materials, a drastic drop in and tensile strength was observed.



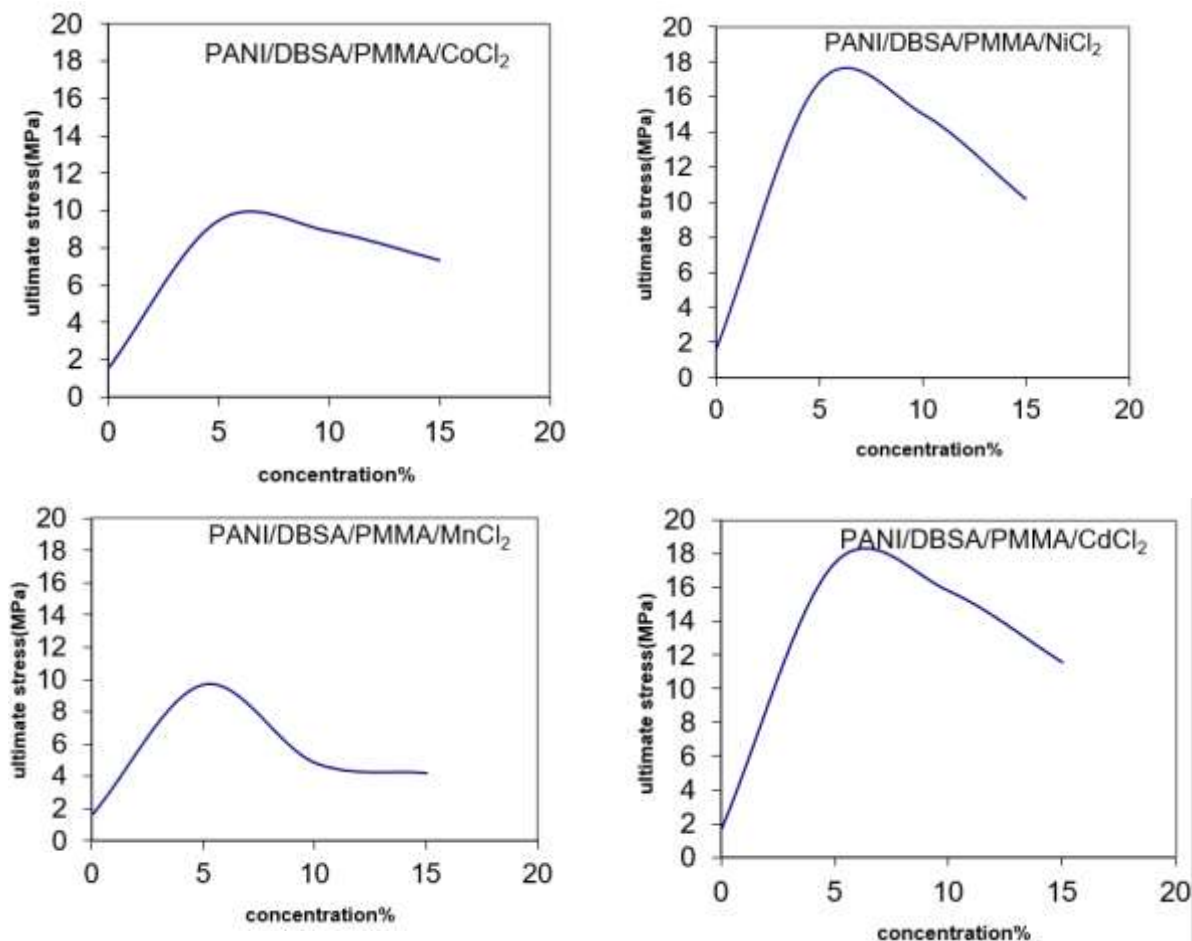


Figure 8: Dependence of ultimate stress on additional material concentration

#### 4. Conclusion

polyaniline/poly(methyl methacrylate) (PANI/PMMA) conducting blends was prepared. PANI/PMMA doped with metal chlorides such as FeCl<sub>3</sub>, NiCl<sub>2</sub>, CoCl<sub>2</sub>, MnCl<sub>2</sub>, and CdCl<sub>2</sub> were also prepared. Crystal structure, surface morphology, and mechanical properties of these polyaniline blends have been studied. The XRD patterns of the prepared films indicate the presence of effective compressive strain in the crystal lattice. The lower magnitudes of the effective particle size for samples compared with its average crystallite size are due to these samples having negative stain (compressive strain). SEM images show the surface morphology of PANI/PMMA/Metal chlorides blend films. In addition, the PMMA and metal chlorides improve the mechanical properties of PANI/DBSA due to their interaction with PANI chain. The optimum weight % of PMMA and metal chlorides added to PANI/DBSA was 10 wt% and 5 wt% respectively.

#### References

- [1]. Saeed Habibpour, Kiyomars Zarshenas, Maiwen Zhana, Mahdi Hamidinead, LiMa, Chul B Park, Aipina, ACS Applied Material & Interfaces, 2022.
- [2]. MM Atta, RM Ahmed, S ABD, AS El-Bayoumi Synthetic Metals 290, 11754, 2022.
- [3]. Thejas Ramakrishnaiah, Prasanna Gunderi Dhananiya, Chturmukha Vakwadi Sainagesh, Sensor Review, 2022.
- [4]. Xiaobo Liang, Yunijiao Deng, Songsong Li, Jingtao Wu, Huixuan Zhang, Zijian Zhang, Polymers for Advanced Technologies, 2022.



- [5]. Qian Pang, Kaihao Wu, Zilian Jiang, Zewen Shi, Zizhen Si, Qiang Wang, Yuhao Cao, Ruixia Hou, Yabin, *Macromolecular Bioscience* 22 (3), 2100386, 2022.
- [6]. Jiang Guo, Zhuran Chen, Xiaojian Xu, XuLi, HuLiu, Shaohua Xi, Waras Abdul, qing Wu, Pei Zhang, Ben, *Advanced Composites and Hybrid Material*, 1-9, 2022.
- [7]. R Thejas, GD Prasanna, G Nagaraju, M V Murugendrappa, CS Naveen, *Proceeding of the Institution of Mechanical Engineers, Part E: Journal of process Mechanical Engineering*, 09544089221100778, 2022.
- [8]. Sudan Liu, Diansen Li, Yu Wang, Guoqiang Zhou, Kun Ge, Lei Jian, Diaining Fang, *Biomaterials science*, 2022.
- [9]. Jie Chan, XIAOHUI Wang, liping Dao, Lu Liu, Ying Yang, Jingwen Liu, Shuyi Wu, Yongqiang Cheng, Jie Pang, *colloid and Surfaces A: Physicochemical and Engineering Aspects* 637, 128190, 2022.
- [10]. A Atta, MM Abdelhamied, doaa Essam, Mohamed Shaban, Alhulw H Alshammari, Mohamed Rabia, *International Journal of Energy Research* 46 (5), 6702-6710, 2022.
- [11]. Konstantin A Milakin, Zuzana Moravkova, Udit Acharya, Martin Kassparova, Stefan Breitenbach, *polymer* 217, 123450, 2021.
- [12]. Chong Gao, Hongbo Gu, Ai Du, Heng Zhou, Duo Pan, Nithesh Naik, Zhanhu Guo, *Polymer* 219, 123533, 2021.
- [13]. Parvathalu Kalakonda, Pranay Bhasker Kalakonda, Sreenivas Banne, *Nanomaterials and Nanotechnology* 11, 18479804211001140, 2021.
- [14]. Wei Tan, Joe C Stallard, Changshin Jo, Michael FL De Volder, Norman A Fleck, *Jornal of Energy Storage* 41, 102757, 2021.
- [15]. Zhongwei Chen, Yangyang Xu, Yuan Yu, Tingting Chen, Qingwu Zhang, Changxin Li, Juncheng Jiang, *Powder Technology* 378, 359-370, 2021.
- [16]. Fangjin Gao, Jie Mu, Zhenxiao Bi, Shun Wang, Zilli Li, *Progress in Organic Coatings* 151, 106071, 2021.

