CARBONIZATION OF KEVLAR FABRICS FOR EFFECTIVE EMI SHIELDING APPLICATIONS

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Abstract: *In the present work, porous and electrically conductive activated carbon fabric was produced by heating Kevlar fabric wastes using novel single stage carbonization. The influence of carbonization temperature of 800, 1000 and 1200°C on physical and morphological properties of activated carbon fabric was studied from EDX and SEM analysis. Additionally, the electrical conductivity was also measured. At the end, the utility of prepared activated carbon web was investigated for electromagnetic shielding ability in high frequency (i.e. 2.45 GHz) and low frequency regions (i.e. below 1.5 GHz) using waveguide method and coaxial transition line method respectively. The activated carbon fabric produced at 1200°C showed maximum shielding effectiveness in both high and low frequency regions. For single layers of 1200°C carbon fabric, the electromagnetic shielding effectiveness of 40.5, 41.8, 45.1 and 50.9 dB was found for respective frequencies of 30 MHz, 100 MHz, 1 GHz and 1.5 GHz. This behaviour was attributed to increased absorption of electromagnetic radiations due to its higher porosity and also to increased reflections of electromagnetic radiations due to its higher electrical conductivity.*

Keywords: *Activated carbon, electrical conductivity, electromagnetic shielding, Kevlar fabric wastes, physical activation, specific surface area.*

1 INTRODUCTION

In recent years, research on electromagnetic interference (EMI) shielding materials has attracted significant attention due to an increase in electromagnetic population from widespread applications of computer and telecommunication technologies [1, 2]. Electromagnetic interference refers to the radiant electromagnetic signals emitted by electrical instruments during their operation. The emitted electromagnetic radiations are a concern since they interfere with the working of other appliances as well as causing serious health risks to the consumers [3]. The EMI shielding is related to reflection or absorption of electromagnetic radiations by shielding material. Reflection is a commonly used shielding mechanism by high electrical conductivity materials such as metals and their nanoparticles. However, high density, lack of flexibility, easy corrosion, costly processing and weak microwave absorption are main drawbacks of metals [4]. Among the continuous fibers, carbon fibers are dominant, due to their low density, high modulus, high strength, wide availability and are especially attractive in their electrical conductivity, which relates to EMI shielding effectiveness. The carbon-based shielding materials are expected to be predominant in effective shielding mechanism due to the synergetic effect of electrical conductivity and multiple reflections [6, 7]. A variety of organic precursors have been exploited for the preparation of carbonaceous materials. Aramids, particularly, Kevlar fibres have attracted much attention of researchers as a precursor for high modulus carbon fibres and high efficiency active carbon fibres because they are composed of linear single aromatic rings and no stabilization reaction in the oxygen atmosphere that is often required for the carbonization of low melting organic precursors is necessary. Moreover, if the Kevlar flocks are used as the precursor, the cheaper price may be another merit since they are the wastes from the Kevlar production process [8, 9]. In the present work, electrically conductive carbonized Kevlar fabrics were developed and analysed for their potential use in EMI shielding applications. Kevlar woven fabric wastes were collected from an industry and these flocks were carbonized under specific conditions to obtain an electrically conductive material suitable for EMI shielding applications.

2 EXPERIMENTAL METHODS

2.1 *Materials*

The Kevlar woven fabric wastes were obtained from VEBA textiles, Czech Republic. Table 1 shows the parameters of the Kevlar fabric wastes that were obtained and used in this work.

Table 1 Fabric Parameters of used Kevlar wastes

Material	Pattern	GSM	Thickness [mm]	Warp density [ends per inch]	Weft density [picks per inch]
Kevlar woven fabric	Plain weave	217.4	0.32	17.01	17.01

2.2 *Preparation of activated carbon fabric*

The Kevlar fabric waste was dipped in acetone for 24 hrs to remove surface finish and impurities. The cleaned fabric was then transferred to high temperature furnace (Elektrické Pece Svoboda, Czech Republic) for direct carbonization without any stabilization step. The single stage carbonization and physical activation in presence of air was performed at 800, 1000 and 1200°C with heating rate of 300°C.h^{-1} and without any holding time. This was achieved by controlled carbonization under the layer of charcoal.

2.3 *EMI shielding effectiveness of activated carbon web*

The electromagnetic shielding effectiveness of prepared activated carbon web was determined from two different measurement principles (i.e. waveguide method and coaxial transition line method).

Waveguide method. This method was used to determine the shielding effectiveness of samples for microwave frequency range of 2.45 GHz [14]. The device consisted of a rectangular hollow waveguide having electrically conductive walls. A receiving antenna was placed inside of this waveguide, while a sample was placed at the entrance to the waveguide. The end of the waveguide was filled with foam saturated with carbon particles to absorb the electromagnetic field passed through the sample. Transmitting antenna was placed in front of the waveguide input at 16 cm distance. A network analyser Agilent E 4991A was used to generate, and a high frequency analyser HF-38B (Gigahertz Solutions) was used to receive the electromagnetic signals. The electromagnetic shielding effectiveness *SE* [dB] was calculated based on Equation (1):

$$SE = 10\log\left(\frac{P_t}{P_i}\right) \tag{1}$$

where P_t and P_i are electromagnetic field density [W/m^2] measured in presence of sample, and without the sample respectively.

Coaxial transition line method. For more detailed electromagnetic shielding analysis, coaxial transition line method was used in frequency range of 30 MHz - 1.5 GHz according to ASTM D 4935-10. This device determined electromagnetic shielding effectiveness using the insertion-loss method. The set-up consisted of a sample holder with its input and output connected to the network analyser. A shielding effectiveness test fixture (Electro-Metrics, Inc., model EM-2107A) was used to hold the sample. The network analyser (Rohde & Schwarz ZN3) was used to generate and receive the electromagnetic signals.

3 RESULTS AND DISCUSSION

3.1 *Characterization of activated carbon web*

EDX analysis. Energy disperse x-ray spectroscopy was performed to know the relative proportion of different elements present in the activated carbon fabrics. The activated carbon web produced at 1200°C exhibited 92.35% increase in carbon content and 4.56% reduction in oxygen content (Table 2). This behavior was attributed to removal of hydrogen, sulphur, nitrogen and other elements due to decomposition at higher temperature.

Table 2 Effect of carbonization temperature on elemental composition of activated carbon fabric

AT. [%]	C	N	O	Na	S	Cl	K	Ca
1200°C	92.3	2.2	4.5	0.1	0.2	0.0	0.3	0.0
1000°C	87.6	5.1	6.1	0.2	0.2	0.0	0.5	0.0
800°C	73.8	9.1	12.2	3.3	0.9	0.1	0.2	0.0
Untreat.	69.4	14.0	15.3	0.6	0.3	0.0	0.0	0.0

Electrical conductivity. From Figure 1, the electrical volume resistivity was found to decrease with increase in carbonization temperature. The 1200°C activated carbon sample exhibited 1000 times reduction in electrical resistivity over 800°C activated carbon sample. The higher electrical conductivity of 1200°C activated carbon sample was attributed to more graphitization.

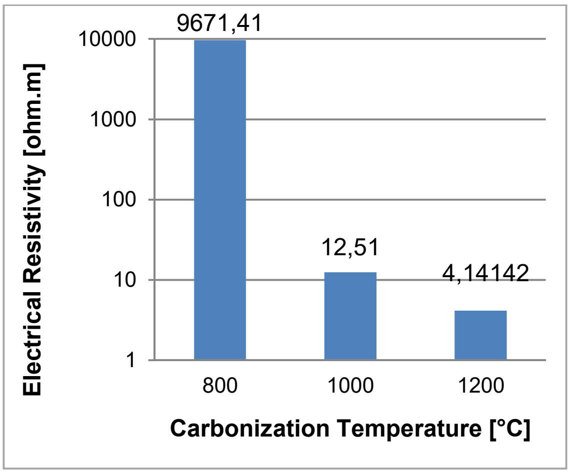


Figure 1 Effect of carbonization temperature on electrical conductivity of activated carbon web

SEM morphology. From Figure 2, the activated carbon fabric showed noticeable rough surface as compared to Kevlar fabric web. The surface roughness was found to increase with increase in carbonization temperature, which indicated the development of more porous structure after physical activation of Kevlar fabric wastes.

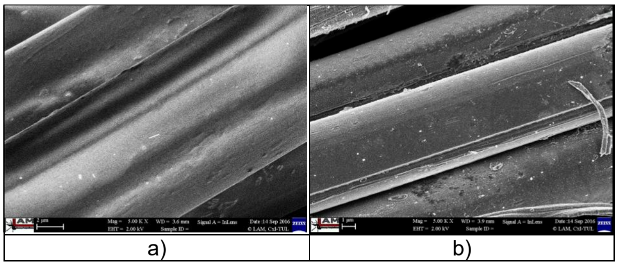

a) b)

Figure 2 SEM image of (a) untreated Kevlar fabric (b) 1200°C activated carbon fabric

3.2 Electromagnetic shielding ability

Waveguide method. Figure 3 shows the average values in 95% confidence interval for electromagnetic shielding effectiveness of prepared activated carbon web samples in single and double layers measured at 2.45 GHz frequency. The scattered data points were connected with line for easier visualization of results (i.e. there is no approximation of trend by regression analysis). The electromagnetic shielding effectiveness was found to increase with increase in number of layers and increase in carbonization temperature.

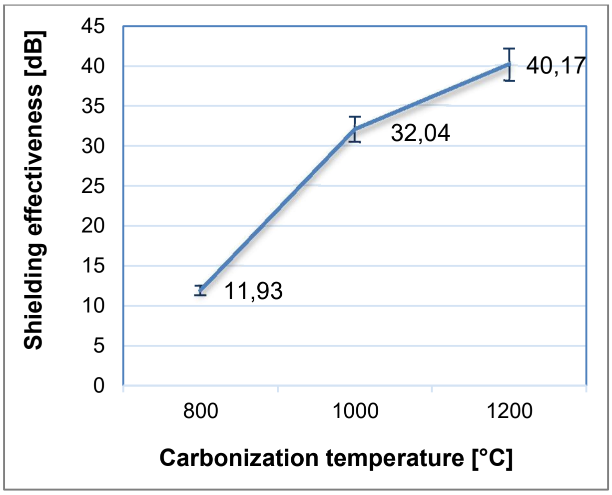
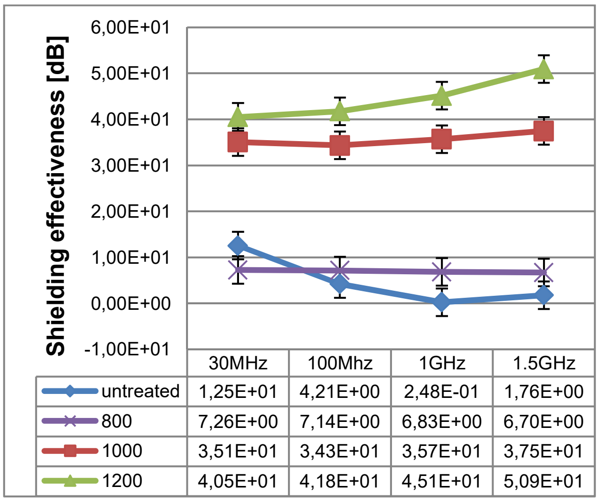


Figure 3 Effect of carbonization temperature on electromagnetic shielding effectiveness in high frequency region

Coaxial transition line method. This method was used for estimation of shielding effectiveness according to ASTM 4935-10 standard in low frequency region from 30 MHz to 1.5 GHz. Figure 4 shows the mean values of electromagnetic shielding effectiveness for single layers of different activated carbon samples in frequencies of 30 MHz, 100 MHz, 1 GHz and 1.5 GHz. The data points were connected with line as in previous figure. The increase in shielding effectiveness with increase in carbonization temperature was observed. The 1200°C activated carbon web exhibited the shielding ability of 40.51, 41.75, 45.13 and 50.90 dB for respective frequencies of 30 MHz, 100 MHz, 1 GHz and 1.5 GHz. This behavior was attributed to increased absorption of EM radiations due to its higher porosity and also to increased reflections of EM radiations due to its higher electrical conductivity.



	30MHz	100Mhz	1GHz	1.5GHz
untreated	1,25E+01	4,21E+00	2,48E-01	1,76E+00
800	7,26E+00	7,14E+00	6,83E+00	6,70E+00
1000	3,51E+01	3,43E+01	3,57E+01	3,75E+01
1200	4,05E+01	4,18E+01	4,51E+01	5,09E+01

Figure 4 Effect of frequency on electromagnetic shielding effectiveness

4 CONCLUSIONS

The present study was focused on development of porous and electrically conductive carbon based electromagnetic shielding materials. This was achieved by physical activation of woven Kevlar fabric wastes into activated carbon fabric. The carbonization was performed under the layer of charcoal at 800°C, 1000°C and 1200°C with the heating rate of 300°C.h^{-1} and without any holding time. At 2.45 GHz, the electromagnetic shielding effectiveness of 40.17, 32.04 and 11.93 dB was exhibited by single layers of activated carbon fabric produced at 1200, 1000 and 800°C, respectively. On the other hand, for low frequency regions, the 1200°C activated carbon web exhibited the shielding ability of 40.51, 41.75, 45.13 and 50.90 dB for respective frequencies of 30 MHz, 100 MHz, 1 GHz and 1.5 GHz. This behavior of 1200°C activated carbon web was attributed to increased absorption of EM radiations due to its higher porosity and also to increased reflections of EM radiations due to its higher electrical conductivity.

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