Electromagnetic shielding effectiveness of high loft activated carbon web prepared by using acrylic waste

M S Naeem\textsuperscript{1}, S Z Hassan\textsuperscript{2}, Z Javed\textsuperscript{1}, B Ramzan\textsuperscript{1}, A Rasheed\textsuperscript{1}, Z Ahmad\textsuperscript{1}, S Javed\textsuperscript{2}

\textsuperscript{1} Faculty of Textile Engineering, National Textile University, Faisalabad, Pakistan.
\textsuperscript{2} Faculty of Engineering, Balochistan University of Information Technology, Engineering and Management Science, Faculty of Engineering, Pakistan.

Abstract: This work represents a novel method for the formation of activated carbon web using charcoal through physical activation in high temperature muffle furnace. The acrylic fibrous waste was separated from bath mats and transferred to carding machine which was transferred to needle punching machine for obtaining a compact structure of non-woven. The acrylic web was first stabilized at 250 °C with a heating rate of 50 °C/hr. The stabilized web was again raised to high temperature (700 °C, 900 °C and 1100 °C) using charcoal for single stage carbonization and activation. The impact of temperatures on the characteristics of carbon webs was analyzed in terms of yield, dusting, flexibility, XRD (x-ray diffraction analysis) and EDX (energy dispersive x-ray analysis). The EM (electromagnetic) shielding of prepared webs was analyzed by using wave guide method which measures shielding effectiveness at 2.45 GHz (high frequency region). It was found that shielding effectiveness increased from 2.21 dB to 23.71 dB as the carbonization temperature was increased from 700 °C to 1100 °C. Not only the carbonization temperature but the impact of thickness of carbon webs on shielding effectiveness was also observed. The shielding effectiveness increased when the thickness of carbon webs increased because of internal reflections and more absorption of electro-magnetic radiations.

Keywords: Electromagnetic, shielding effect, activated carbon, acrylic waste

1. Introduction
In the current smart age researchers and scientists are trying to explore alternate flexible materials having good electrical properties. Electrically conducting textile materials are widely used in different fields like military applications, smart materials, actuators, sensors and for EM (electromagnetic) Shielding applications. There are different techniques available for the formation of conducting textiles like coating of conductive particles (carbon nanotubes and carbon particles), metallization, insertion of metallic yarns etc. [1]. There are different standards available for shielding effectiveness but it is preferred that for effective shielding the resistivity should be less than 10^2 ohm.cm\textsuperscript{-2} however mostly synthetic fibres possess electrical resistivity around 10^{14}-10^{15} ohm.cm\textsuperscript{-2} [2]. Different electrical instruments emit electromagnetic radiations with different frequencies. These radiations are not only a source of noise for other electrical instruments but also pose serious health hazards to humans as well [3,4]. Reflection, absorption and internal reflections are the three basic mechanisms that cause effective shielding of different materials [5, 6]. The phenomenon of internal reflections causes shielding effectiveness in bulk materials, however highly conducting materials having less thickness like metals block electromagnetic radiations through reflections. However high density and weight, corrosive nature, cost and less flexibility are main factors that inhibit the use of metals for electromagnetic shielding.
More focus is now shifting towards carbon structures and graphene materials which are a favourable alternative for replacing metals for effective shielding applications. Further shielding effectiveness by using reflection is not a preferred choice since it can disturb the working of other instruments, hence the concept of eco-friendly EMI shielding became popular. This can be achieved by using light weight material having good absorption and weak reflection so that it can absorb the incoming electromagnetic radiations for which carbon foam and carbon non-woven having porous structures with higher values of surface and volume conductivity [7]. This work explained an affordable and simple method for developing porous structure of carbon having good conductive and EMI shielding application.

2. Material and methodology

The raw material (acrylic) used in this study was provided by Grund Industries which is located in Czech Republic. The acrylic was given in the form of discarded bath mats having the monomer of AN (acrylonitrile) around 88 %. The salient properties of acrylic fibres can be seen from table 1.

Table 1: Physical characteristics of acrylic fibrous waste

| Characteristic       | Value (cN/tex) | Value (tex) | Value (%) |
|----------------------|----------------|-------------|-----------|
| Tenacity (cN/tex)    | 21.22          | 97          | 2.1       |
| Fineness (tex)       | 21.22          | 97          | 2.1       |
| Shrinkage (%)        | 2.1            | 47          |           |
| Elongation (%)       | 47             |             |           |

Acrylic fibers which were separated from bath mats were converted into acrylic web by using lab carding machine. This structure was further compacted by using needle punching machine. Needle punching machine helped to entangle the fibers in order to get the compact structure. A fixed size of acrylic web having 12 inches’ length and width was cut and washed in order to remove impurities. This web was later dried in oven at 100 °C for 2 hours. The dried web was transferred to high temperature muffle furnace for stabilization. The stabilization was performed at 250 °C hr⁻¹ with no holding time and having a heating rate of 35 °C hr⁻¹. These stabilized webs were carbonized and activated simultaneously at 1100 °C, 900 °C and at 700 °C having heating rate (300 °C hr⁻¹) without any holding time (by holding time it means that for how much time the sample was placed in furnace at high temperature).

2.1. Physical characterization of prepared carbon webs

The physical characterization of prepared carbon webs was done in order to determine yield, flexibility, dusting and shrinkage. The shrinkage of carbon webs was determined by measuring original length of acrylic web and final length of carbonized web. For the determination of yield of resulting carbon web the following formula is used. The cantilever bending principle was used for the determination of stiffness of carbon web.

\[
\text{Yield} = \left( \frac{\text{Weight of activated carbon web}}{\text{Weight of acrylic web}} \right) \times 100
\]  

2.1.1. X-ray diffraction (XRD) analysis

The technique of x-ray diffraction analysis was performed which helped to determine degree of crystallinity in prepared carbon webs at different carbonization temperatures (700 °C, 900 °C and 1100 °C). The degree of crystallinity can be calculated by using equation 2.

\[
I_c = 1 - \frac{I_1}{I_2}
\]

Where, \(I_1\) is the intensity at minimum peak and \(I_2\) is the intensity at maximum peak [8].
2.1.2. Energy dispersive x-ray (EDX) analysis
Energy dispersive x-ray analysis was conducted to determine the relative proportion of different elements in prepared activated carbon webs at different temperatures.

2.1.3. Electromagnetic shielding effectiveness of activated carbon web
The shielding effectiveness of prepared carbon webs was determined by using waveguide instrument. This instrument is able to measure shielding effectiveness at a particular wave length which is 2.45 GHz. The EM shielding can be determined by the help of equation 3.

\[ SE = 10 \log \frac{P_t}{P_i} \] (3)

Here \( P_t \) and \( P_i \) are power densities with the presence and absence of carbon webs.

3. Results
3.1. Effect of carbonization temperature on carbon webs
When the carbonization temperature was increased then at high temperature more carbon reacted with the available oxygen and caused a reduction in the yield. This reduction of yield also caused adverse impacts on the shrinkage, dusting anf flexible tendency of activated carbon webs as shown in table 2.

Table 2. Physical properties of AC webs at different temperatures

| Temperature (°C) | Yield (%) | Shrinkage | Flexibility | Dusting |
|------------------|-----------|-----------|-------------|---------|
| 700              | 61.27     | Good      | Average     | Average |
| 900              | 57.12     | Good      | Average     | Poor    |
| 1100             | 45.11     | Average   | Average     | Poor    |

3.2. Energy dispersive x-ray (EDX) analysis
The content of different elements in prepared carbon webs can be determined EDX analysis. This technique helped to determine and compare the percentage of different elements in carbon webs prepared at high temperatures. Table 3 shows the relative proportion of different elements in different carbon webs.

Table 3. Impact of different carbonization temperature on elemental composition

| Element | App concentration | Intensity | Atomic percentage |
|---------|-------------------|-----------|-------------------|
| 700 °C  |                   |           |                   |
| C K     | 0.26              | 2.12      | 82.22              |
| O K     | 0.01              | 0.761     | 17.78              |
| 900 °C  |                   |           |                   |
| C K     | 0.37              | 2.12      | 87.12              |
| O K     | 0.02              | 0.760     | 12.88              |
| 1100 °C |                   |           |                   |
| C K     | 0.18              | 2.10      | 93.67              |
| O K     | 0.01              | 0.744     | 5.43               |
| Ca K    | 0.00              | 0.902     | 0.90               |

From table it is clear that carbon web prepared at highest temperature showed higher content of carbon 93.67% along with 5.43 % oxygen content, but as the temperature for carbonization was reduced the carbon content reduced to 83.33 % at 700 °C. The rise in carbon content is because of more
elimination of elements other than carbon like nitrogen, sulfur and hydrogen because of decomposition at higher temperature [8].

3.3. X-ray diffraction (XRD) analysis
By increase carbonization temperature the degree of crystallinity also kept on increasing which can be determined by using x-ray diffraction analysis. The x-ray diffraction patterns of carbon webs prepared at different carbonization temperatures can be seen from figure 1. Initially the degree of crystallinity was 79.21 % at 700 °C which increased to 83.7 % and 89.41 % when temperature for carbonization was increased to 900 °C and 1100 °C respectively. This rise of crystallinity is because of more alignment of carbon chains causing a reduction in spacing of these planes as well as removal of disorganized carbon.

![XRD patterns of carbon webs at different carbonization temperatures](image)

**Figure 1.** Effect of carbonization temperature on degree of crystallinity of AC webs

3.4. Impact of temperature on conductivity and EMI shielding of AC webs
The surface conductivities kept on increasing while increasing carbonization temperature. It was found that electrical conductivity increased from $0.35 \times 10^{-2} \Omega^{-1}$ to $3.81 \times 10^1 \Omega^{-1}$ when the temperature for carbonization was increased from 700 °C to 1100 °C respectively. More conductivity was exhibited by carbon web at 1100 °C due to more graphitization (parallel orientation of chains and less spacing of chains) as can be seen from peaks of XRD spectra [9].

Figure 2 shows shielding effectiveness for electromagnetic radiations by using carbon webs prepared at different temperatures. The electromagnetic shielding effectiveness was determined by the help of wave guide method. It is clear from figure that shielding effectiveness increased from 1.9 dB to 18.88 dB and finally to 23.71 dB at carbonization temperatures of 700 °C, 900 °C and 1100 °C, respectively.

![EM shielding effectiveness vs temperature](image)

**Figure 2.** Effect of carbonization temperature on EM shielding
When the temperature for carbonization was less i.e. at 700 °C, there was not so much difference in shielding effectiveness between carbon web and acrylic web. However, as the carbonization temperature was increased, sudden increase in shielding effectiveness was observed due to development of carbon/graphite structure which is clear from XRD pattern shown in figure 1. More crystallinity at higher temperature is responsible for maximum parallel orientation of chains which enables easy movement of electrons and causing higher conductivity due to which shielding effectiveness also increased at higher temperature. As far as thickness of carbon webs in concerned, shielding effectiveness increased by increasing thickness of webs because of higher internal multiple reflections.

4. Conclusions
The focus of this study was the development of porous and continuous structure of activated carbon web with good flexibility and higher carbon content. The novelty of this method is the single stage carbonization and activation using charcoal. Initially the webs were stabilized at lower temperature with slow heating rate for ensuring proper stabilization. Later the stabilized webs were carbonized at 700 °C, 900 °C and 1100 °C with a heating rate of 300 °C. It was found that at higher temperature although a reduction in the yield was observed but at the same time rise in carbon content and degree of crystallinity was also observed. These two are the main reason for higher electrical conductivity at high carbonization temperature. These webs were also checked for EM shielding application by using wave guide method. It was found that shielding effectiveness not only increased by increasing carbon content but also by increasing the thickness of webs. At high temperature the carbon web showed higher electrical conductivity which is the main reason for the rise in shielding effectiveness. Likewise, as the thickness of webs increased their absorption and internal reflections also increased which helped in lowering the impact of electromagnetic radiations.

5. References
[1] Daniela N 2012 Fibres Text. East. Eur. 20 53-56.
[2] Chen C 2007 J. Mater. Process Technol. 192 549-554.
[3] Safarova V, Tunak M and Militký J 2015 Text. Res. J. 85 673-686.
[4] Safarova Vand Militký J 2014 Text. Res. J. 84 1255-1267.
[5] Sano E and Akiba E 2014 Carbon N Y. 78 463-468.
[6] Arjmand M and Sundararaj U 2015 Compos Sci. Technol. 118 257-263.
[7] Li Y, Shen X, Pei Y, Zhang D, Yi 2016 Carbon N Y 100 375-385.
[8] Ma Y, Yin X and Li Q 2013 Trans. Nonferrous Met. Soc. 23 1652-1660.
[9] Jonathan Y and Chen 2016 Activated Carbon Fiber and Textiles (Woodhead).