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Recycling of buffing dust tanneries waste to prepare structural thermal insulation panels

Wajad Ulfat1, Ayesha Mohyuddin1,∗, Muhammad Amjad1, Shagufta Saeed2 and Beenish Mujahid1

1 Department of Chemistry, University of Management and Technology, C-II, Johar Town, Lahore 54770, Pakistan
2 Institute of Biochemistry and Biotechnology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan
3 Department of Architecture, University of Management and Technology, C-II, Johar Town, Lahore 54770, Pakistan

∗ Author to whom any correspondence should be addressed.

E-mail: wajidulfat78@gmail.com and ayeshamdin@hotmail.com

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Abstract

Thermal insulation panels were prepared by mixing the buffing dust obtained from tanneries waste with the polystyrene. The ratio in weight percentage of buffing dust, polystyrene and blowing agent was 20:77:3 respectively in these panels. The samples were prepared in co-twin extruder at 210 °C. Different physico-chemical properties were investigated for these samples that are required to analyze the usability of a material for construction. The composite panels showed better thermal insulation characteristics than the simple polystyrene boards. This study demonstrated that prepared composite panels have good thermal conductivity (0.029 W m⁻¹K⁻¹ at 27 °C), density (300 Kg m⁻³), compression strength (6.25 ton) and water absorption (7.5%) without degradation of mechanical properties. Thermogravimetric analysis depicted that composite panels were thermally stable from 200 °C to 412 °C. FTIR analysis showed that composite has carbonyl and free amino functional groups. The SEM study explained that voids were created in the composite and homogeneity was decreased after the addition of buffing dust. The composite had 62% of carbon and 0.2% of chromium as determined by EDX analysis. The results suggested that the prepared composite panels can be used as thermal insulation boards in building sector which will help in the recycling of waste produced by leather industry and consequently a reduction in environmental pollution.

1. Introduction

Environmental pollution is rapidly increasing all over the world due to industrial growth [1]. Leather industry is one such industry that produces the waste in large amount. This waste causes significant pollution and has negative effect on the health of mankind as well as on other animals. Deterioration of environment and water bodies occurs due to several types of waste sludge and residues generated during preparation of industrial products and energy consumption during these processes. There have been successful reports of recycling of industrial waste like that of fly ash generated in coal based thermal power plants and use of adsorbent derived from sewage sludge to remove phosphate [2, 3]. Therefore, researchers have focused their attention on reducing the industrial waste and possibilities of its reutilization. Research is being carried out on different applications for using the tanneries solid waste in composite form. Physical and mechanical properties of different types of boards prepared by recycling waste materials met recommended standards. The successful use of Balsa wood waste in preparation of oriented strand boards, sugarcane bagasse, curaua and jute in multilayer particle boards, natural Emirati shale in construction polymer composites and date pit powder in polystyrene insulation matrix encourage the scientist to explore further options [4–8]. In leather industry, only 20 percent (by weight) of raw material is converted into final product [9]. Tanneries produce solid waste in the form of chrome shavings and buffing dust (35%–40%) [10]. Incineration and landfill are most common methods that are used for the disposal of solid tanneries waste. During incineration, oxides of nitrogen and sulfur are emitted that increase the environmental pollution. Landfill cause soil and water pollution due to the leaching of hazardous chemicals [10].
Researchers are working to design the safe recycling methods of solid waste of tanneries. Some attractive applications of tanneries waste are reported such as activated carbon production, utilizing the waste as filler in rubber and anaerobic treatment of tanneries solid waste for the production of methane [11–15]. Pyrolysis of buffing dust gave highest yield of oil among the leather industry waste materials investigated. This oil and carboneous residue can be used as fuel [11]. Blending of leather waste such as buffing dust and chrome shavings in carboxylated butadiene nitrile, styrene butadiene rubber, acrylonitrile butadiene rubber and natural rubbers resulted in improved strength due to expected filler and elastomer bonding [12–15]. Buffing dust is composed of proteins, nutrients and other organic compounds. Therefore, it is suitable for the production of methane by anaerobic digestion [16–18]. Methane production potential from different types of tannery waste in anaerobic thermophilic ASBR digester showed that utilization of these waste materials is economical [16]. Incineration of buffing dust with varied amount of oxygen resulted in bottom ash that was stabilized in Portland cement and leaching characteristics of cement block showed that metal fixation capacity was 99.99% [17]. Presence of cationic polyacrylamide flocculant, extensively used in wastewater pretreatment and activated sludge dewatering, slow down the methane production in anaerobic digesters [18].

It is a known fact that buffing dust and chrome shavings have low thermal conductivity therefore this waste can be used to prepare the thermal insulation panels [19]. This waste can also be used in building bricks, cement and plaster blocks. In bricks 5% buffing dust has been used as filler. Whereas, small quantity of waste has been used to prepare low weight cement and plaster blocks. Thermal conductivity of these blocks was found between 0.09–0.28 W m$^{-1}$K$^{-1}$ [20].

Moreover, according to the report of International Energy Agency (IEA) 2017, 15082–16843 trillion Btu energy was consumed in commercial and residential buildings in 2016. Also, in the United States Energy Information Administration report, 52% energy was consumed in heating of homes in 2016. Therefore, thermal insulation of buildings is necessary to decrease the consumption of energy [21]. Commonly available insulation panels are relatively expensive but their thermal conductivities can be decreased for increasing their efficiency by blending suitable low cost material.

There had been reported attempts of incorporation of buffing dust in different materials. Various compositions of buffing dust with polystyrene had been tried. However, the use of buffing dust to form composite with polystyrene in the presence of blowing agent has not been reported to the best of our knowledge. The ratio of buffing dust in composite was settled according to the recommendations given in literature. Enhanced insulation properties were aimed by using blowing agent during the preparation of composite. In this study, the thermal insulation panels were prepared with low thermal conductivity and good mechanical properties for their perspective application as insulators and as construction material.

2. Material and methods

2.1. Materials

Commercially expanded polystyrene (C8H8)n was obtained from the Diamond Jumbolon Lahore, Pakistan. The molecular weight of polymer, density and thermal conductivity were 15200 g mol$^{-1}$, 600 kg m$^{-3}$ and 0.038–0.040 W m$^{-1}$K$^{-1}$ respectively. The buffing dust that was used in this work was collected from the Leader Tanneries (Kasur, Pakistan). This buffing dust was the waste of cow skin leather. Blowing agent [Azodicarbonamide (AC)] was obtained from Henan Xingyang Chemical Industries, China.

2.2. Sample preparation

The samples were prepared by the polymerization of polystyrene (77%) with buffing dust (20%) in the presence of blowing agent (3%) in the twin-screw extruder at 210 °C [21]. The molten composite coming out from extruder was poured into steel molds and cooled at room temperature. After half an hour, composite samples were ready to use. The representative sample is shown in figure 1. The size of test samples for compression strength and water absorption was 2 inch width, 4 inch length and 1 inch thickness. For thermal conductivity, circular plate sample size was 2.5 inch in diameter with 0.5 inch thickness.

2.3. Characterization

The physico-chemical properties (density, water absorption and compression strength) were determined for the synthesized composite material. Thermal conductivity was measured at room temperature by Lee’s Disc method [22]. Thermal stability was determined by the thermo gravimetric analysis (TGA-50 Sr C30025100553). Fourier transform infrared spectroscopic (FTIR) analysis (range 650–4000 cm$^{-1}$, Agilent Cary II-650) was carried out by using KBr. Morphology and elemental analysis of the prepared composite was determined by the scanning electron microscopy (FEI Nova NanoSEM 450) and energy dispersive x-ray spectroscopy (Oxford INCA x-act EDX) respectively.
3. Results and discussion

3.1. Mechanical and physico-chemical properties
Different mechanical and physico-chemical properties of prepared composite were determined that are presented in table 1. The density of the composite was decreased to 50% when 20% buffing dust was added in polystyrene in the presence of blowing agent. Similar trend was observed by Lakrafl et al\textsuperscript{[19]}. Compression strength of the composite was increased by 1.05 tons as compared to pure polystyrene but Hittini \textit{et al} reported that compression strength was decreased \textsuperscript{[21]}. The difference in observations is due to the use of blowing agent in our method. Water absorption of composite was increased by 2.5% because voids were created in the composite due to the use of blowing agent. Thermal conductivity of the composite was 0.029 W m\textsuperscript{-1}K\textsuperscript{-1} which was 12.2% lower than the sheet of pure polystyrene (0.033 W m\textsuperscript{-1}K\textsuperscript{-1}). Lakrafl et \textit{al} explained that buffing dust has low thermal conductivity 0.024–0.026 W m\textsuperscript{-1}K\textsuperscript{-1} whereas polystyrene and buffing dust composite has higher thermal conductivity as compared to other buffing dust composite (0.098 W m\textsuperscript{-1}K\textsuperscript{-1}) \textsuperscript{[19]}. The main purpose of using the blowing agent was to increase the volume of composite which consequently increase the volume of panel up to 40%–50% without deterioration of physico-chemical properties that contribute in preparation of low cost material. Also with the increase in volume, the density decrease. Test results verified that when blowing agent was used in the composite of polystyrene and buffing dust, compression strength increased as compare to the pure polystyrene. Blowing agents themselves have no influence on thermal conductivity.

3.2. Thermo gravimetric analysis (TGA)
TGA results explained the weight loss trend of composite on heating over the temperature range of 0 °C–600 °C (figure 2). TGA line showed the degradation of composite with an increase in temperature. A slight degradation

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|}
\hline
Properties & Pure polystyrene & Composite \\
\hline
Density (Kg m\textsuperscript{-3}) & 600 & 300 \\
Compression Strength (load in tons) & 5.2 & 6.25 \\
Water Absorption (%) & 5 & 7.5 \\
Thermal Conductivity (W m\textsuperscript{-1}K\textsuperscript{-1}) & 0.033 & 0.029 \\
\hline
\end{tabular}
\caption{Mechanical and physico-chemical properties of polystyrene and sample composite.}
\end{table}

\textbf{Figure 1.} Polystyrene and buffing dust composite sample.
of sample composite started from 200 °C but only 5% was degraded till 280 °C and the rapid degradation was observed after 320 °C. The weight loss continued with the increase in temperature and 50% weight of the composite was lost at 380 °C. End point of the polymer degradation was found to be 412 °C. Degradation of the pure polystyrene is reported to start from 280 °C and it completely degrade at 402 °C [21]. Thermal degradation behaviour of composite was analogous to that of pure polystyrene with some variation owing to the presence of buffing dust and a similar trend was noted by Hittini et al where degradation of different composites started from 258 °C to 360 °C depending upon the amount of buffing dust [21]. Thermal stability of insulation materials is important and it affects shrinkage in case of fire. The prepared composite panels depicted significant thermal stability. Therefore, these panels can be used as alternative insulation materials in construction industry.

3.3. Fourier transform infrared (FTIR) spectroscopic analysis
The FTIR spectrum of composite is given in figure 3. A distinct band at 3334 cm⁻¹ is due to hydroxyl groups associated with hydrogen bonding. Hydrogen bonding in sample was less due to phenyl groups present in polystyrene. A band at 3024 cm⁻¹ is due to C–H stretching of alkyl groups. The band at 1727 cm⁻¹ is due to the C=O group present in gelatin of buffing dust. The bands in the region of 1400–1600 cm⁻¹ represent the free amino groups. Basak et al reported the occurrence of bands at 3077 cm⁻¹ and 1656 cm⁻¹ in their analysis. They also concluded that transmission bands at 3400–2900 cm⁻¹ were due to hydrogen bonded hydroxyl groups [23]. The FTIR spectrum of our composite sample has much similarity with that of pure polystyrene found in literature. The bands reported in FTIR of pure polystyrene were at 3024.9 cm⁻¹, 2920 cm⁻¹, 2846 cm⁻¹, 1696 cm⁻¹, 1598 cm⁻¹, 1491 cm⁻¹, 1452 cm⁻¹, 1447.8 cm⁻¹, 1031 cm⁻¹ [24].

3.4. Scanning electron microscopic (SEM) study
The SEM results of composite are presented in figure 4. Results depicted that voids were created in the composite sheet which can be attributed to the use of blowing agent. Homogeneity of the composite was decreased due to buffing dust and blowing agent. The particles of buffing dust were embedded in the polystyrene matrix. These particles were uniformly distributed on the surface in general (figure 4(c)) but some irregularity was observed
occasionally that can be seen at higher magnification (figures 4(a) and (b)). The added buffing dust had not only enhanced the strength but also reduced the thermal conductivity due to attachment at the surface. Abu-Jdayil et al reported that pure polystyrene have more voids than the composite but in this work composite has more voids [8]. Blowing agent increases the volume of the composite panel that decreases the density of the composite [25].

3.5. Energy dispersive x-ray (EDX) analysis
The EDX micrograph is shown in figure 5 that show the elemental composition of composite. The percentage ratio of the elements analyzed is given in table 2. This EDX study depicted that composite has the highest percentage of carbon because it was made from the organic material. The occurrence of chromium (0.2%) was also noted that was present in the buffing dust due to tanning. Presence of oxygen (3.39%) is attributed to the buffing dust collagen on which chromium usually get attached. Such active sites usually include carboxylate

Figure 4. SEM images of composite showing (a) voids (b) blowing agent (c) composite.
groups with which chromium forms organic salts. The occurrence of sulfur and chloride is due to the presence of inorganic salts of chromium.

4. Conclusions

Buffing dust based thermal insulation panels of polystyrene were prepared in the presence of blowing agent. The incorporation of buffing dust into the polymer was successful. The obtained results illustrated that density of the composite was decreased but compression strength and water absorption were enhanced. Density of composite was well above the density range (30–80 kg m$^{-3}$, EN 253) generally required for thermal insulation materials of high load usage. The prepared material had much higher compression strength of 598.5 kPa than the recommended standard (70–250 kPa, BS EN 826) of pure polystyrene. Increase in volume of composite after water absorption was 1.07% which was near to acceptable limit of 1% (ASTM C553). Addition of buffing dust resulted in significant reduction in thermal conductivity and it was better than the general requirement of 0.024 W mK$^{-1}$ (EN 13165). TGA analysis concluded that composite panels were thermally stable. Phenyl groups decreased the hydrogen bonding in the composite. It was observed that homogeneity of composite was decreased with the decrease in density. These results depicted that tanneries buffing dust waste can be recycled by mixing with polystyrene as it enhance the thermal insulation properties of composite panels without deteriorating the other mechanical properties. Therefore, the prepared composite is a good option to be used as thermal insulation material in construction industry.

5. Future prospects

This field of research can find its practical application in construction industry to prepare various types of thermal insulation materials. These materials will give economic benefits, will have environment-friendly aspects and can minimize energy consumption. Future studies can be carried out to find the methods to further enhance the important properties such as strength, thermal conductivity, density etc which can increase the value of product. Solid waste of leather industry, other than buffing dust, can also be tried in preparing different innovative insulation products with the simultaneous benefit of recycling of industrial waste which is otherwise harmful for environment.
Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

ORCID iDs

Ayesha Mohyuddin ⊗ https://orcid.org/0000-0003-1994-5584

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