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The preparation of pellets by the compaction of an aluminosilicate-based adsorbent from electronic waste

Alireza Bazargan[a,b,*], Pejman Hadi[a], Sarah L. Rough[b], Gordon McKay[a,c]

[a] Department of Chemical and Biomolecular Engineering, Hong Kong University of Science and Technology, Clearwater Bay, Hong Kong
[b] Department of Chemical Engineering and Biotechnology, New Museums Site, Pembroke Street, University of Cambridge, Cambridge CB2 3RA, UK
[c] Division of Sustainable Development, College of Science, Engineering and Technology, Hamad bin Khalifa University, Qatar Foundation, Doha, Qatar

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ABSTRACT

Pelletization is an important part of the commercialization of adsorbents. Two factors must be considered in determining the pelletization conditions, namely mechanical strength of the pellets and their water resistance in aqueous environments. The primary objective of this study was the preparation of pellets from an aluminosilicate-based adsorbent for industrial fixed-bed adsorption columns. The pellet formation conditions, including binder type and content, water content, and compaction pressure, were optimized. Calcium carbonate was demonstrated to be the most promising binder for the aluminosilicate material. The experiments showed that with a water content of 30% and final applied compaction pressure of 80 MPa, the amount of binder required for pelletization can be as low as 2.5 wt%. Although higher compaction pressures produced pellets with higher mechanical strength, there exists a trade-off between the mechanical strength and the cost of the compaction process. Overall, the compaction process was successful at producing pellets with ample mechanical strength (as high as 800 kN/m^2) and satisfactory water resistance (pellet integrity not affected by immersion).

1. Introduction

Electronic waste (e-waste) management has become one of the major challenges of the modern world due to the rapid update and disposal of various electronic equipment, as well as the lack of proper techniques for their recycling [1–3]. An environmentally-friendly recycling technique which can recycle/recover most (if not all) of the components of e-waste, and yet be cost effective, has not yet been developed [4].

Traditionally, landfill disposal has been the most widely used disposal technique for e-waste. Pressure from environmental advocates and problems such as resource wasting, leaching of toxic components from e-waste to the soil, as well as inherent issues with landfills, have compelled some countries to enact stringent regulations to ban the disposal of e-waste into landfills [5–7]. Moreover, incineration of e-waste is not practical due to the existence of toxic components, such as heavy metals and brominated compounds [8]. Therefore, exploring economically viable and eco-friendly recycling techniques for e-waste, such as waste printed circuit boards (PCBs), is a challenge for researchers.

Recently, the favourable separation of metal and non-metal fractions of waste PCBs has been accomplished by physical technologies, namely electrostatic, magnetic, and/or gravity separation methods [9,10]. These methods are effective but also energy-intensive. Although the metallic fraction (MF) can be directly sold into the market after metallurgical processing, the non-metallic fraction (NMF) has no market value. Considering that the MF accounts for only 30 wt% of the whole PCB, the remaining 70% of the waste remains unexploited. In order to add financial incentive to these separation processes, it is imperative to find a value-added application for the NMF [11]. Hadi and McKay have patented a process of converting the NMF into porous adsorbent materials [12]. Although the high efficiency of this novel adsorbent in toxic heavy metal removal from wastewater has been demonstrated, it cannot be commercially exploited at its current powder form. Since agglomerating adsorbents into pellets provides advantages for their application in wastewater treatment [13], the possibility of producing pellets from the adsorbent has been investigated in this study. Also, the optimum pelletization conditions have been examined by varying several parameters, such as binder type, binder content, water content, and compaction pressure. Preparation of pellets with high mechanical strength

Abbreviations: EWA, electronic-waste-based adsorbent; PCB, printed circuit board; PEG, polyethylene glycol; MF, metallic fraction; NMF, non-metallic fraction.

* Corresponding author at: Department of Chemical and Biomolecular Engineering, Hong Kong University of Science and Technology, Clearwater Bay, Hong Kong.
E-mail address: bazargan@connect.ust.hk (A. Bazargan).

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Nomenclature

Roman
D Diameter of pellet [m]
F Maximum tensile crushing force [N]
h Height of pellet [m]

Greek
σ Radial tensile crushing strength [N/m^2]

and water resistance will pave the way for the commercial production of this novel adsorbent.

Using binders in compaction processes is commonplace for obtaining stronger densified products. More than 50 organic and inorganic materials have been reportedly used as binders [14]. All binding mechanisms include molecular interactions on and between surfaces or interfaces. Binders have been defined as "components which are added prior or during agglomeration to increase the strength of the agglomerated product at otherwise unchanged processing conditions" [14]. Two criteria should be considered in choosing the proper binder; compatibility with the material matrix and suitability for the proposed use of the final product. Film or bridge type binders are normally fluids which coat the particles and form bridges between solid particles. The surface area and porosity of the material, essential for adsorbents, are altered insignificantly when these binders are used. Water is the most well-known film and bridge forming binder. On the other hand, matrix forming binders tend to fill all void spaces between the feed material particles and result in a considerable loss of porosity. Therefore, matrix binders such as cement are not recommended for pelletizing adsorbent materials. Some binders may also chemically react with the feed particles, producing high strength products.

2. Materials and methods

2.1. Feedstock and binders

Printed circuit boards were pulverized and separated into metallic and non-metallic fractions by a company in Hong Kong. The non-metallic fraction is treated with a patented process to produce an electronic waste-based adsorbent (EWA). The production process for the adsorbent has been described elsewhere [5,15–18]. Briefly, the non-metallic powders are impregnated with potassium hydroxide (KOH, Sigma Aldrich) at a 2:1 KOH:EWA weight ratio for 3 h. The impregnated material is thermally treated at 250° C under a nitrogen atmosphere for 3 h. Finally the EWA is washed repeatedly with hot water, dried, and stored in a desiccator.

Various binders, namely starch (reagent grade), calcium carbonate (99.95%), bentonite (reagent grade), kaolin (reagent grade), sodium carbonate (98%), and polyethylene glycol (reagent grade, average molecular weight of 4000 g/mol), were purchased from BDH Laboratory Supplies, UK. In the case of soluble starch, it was first dissolved and gelatinized in water at 90 °C as described elsewhere [19], before being mixed with the EWA. The mixing was done either manually or by using a planetary mixer (at various speed settings). The method of mixing did not appear to affect the homogeneity of the paste.

2.2. Compaction

A fully instrumented strain frame (Zwick/Roell, Germany) was used for compaction experiments. The strain frame incorporated a load sensor (±0.1 N) and displacement transducer (±1 μm) [20]. A stainless steel (316 SS) cylindrical ram fitted with a high density polyethylene tip (24.9 mm diameter) was used to compact 4 g of a given sample (EWA, water and binder) at a speed of 1 mm/s in a stainless steel compaction cell (25.0 mm diameter). The final applied pressure was held for 10 s. The samples were then ejected

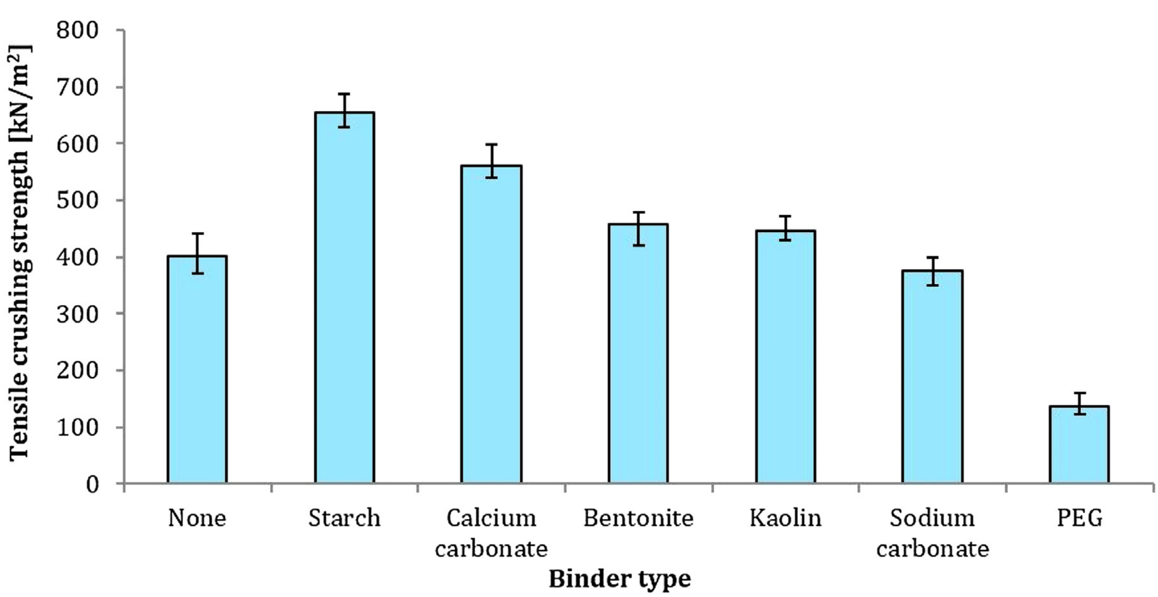

Fig 1. Effect of various binders on the tensile crushing strength of the EWA pellets (Water content: 40 wt%; binder content: 10 wt% (0% for 'none'); final applied compaction pressure: 80 MPa). PEG is polyethylene glycol with an average molar weight of 4000 g/mol.