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Recycling Of Polystyrene (Ps) Waste Bowls Into Inherently Smooth-Surfaced Plastic Plates For Application In The Souvenirs Industry

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FARA serves as the technical arm of the African Union Commission (AUC) on matters concerning agricultural science, technology and innovation. FARA has provided a continental forum for stakeholders in AR4D to shape the vision and agenda for the sub-sector and to mobilise themselves to respond to key continent-wide development frameworks, notably the Comprehensive Africa Agriculture Development Programme (CAADP).

FARA's vision is to "Reduced poverty in Africa as a result of sustainable broad-based agricultural growth and improved livelihoods, particularly of smallholder and pastoral enterprises" its mission is the "Creation of broad-based improvements in agricultural productivity, competitiveness and markets by strengthening the capacity for agricultural innovation at the continental-level"; its Value Proposition is the "Strengthening Africa's capacity for innovation and transformation by visioning its strategic direction, integrating its capacities for change and creating an enabling policy environment for implementation". FARA's strategic direction is derived from and aligned to the Science Agenda for Agriculture in Africa (S3A), which is in turn designed to support the realization of the CAADP vision.

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Abstract

Polystyrene is an aromatic hydrocarbon plastic solid material with applications in the packaging, food and construction industry. As a packaging material, it protects items against shocks, and acts as an insulator in construction of buildings, and food preservation. The polystyrene bowl for food packaging has become a convention in the food and pastries industry in Ghana, due to its clean, lightweight and insulation properties. However, the corresponding waste litters its environment, chocks gutters and does not decompose. For this reason, we explored the hot melt recycling technique to convert the PS wastes into valuable plastic plates, that finds application in the artefact and souvenir industry. Incorporation of a 20% v/w lauric fatty acid (LFA) into the material matrix blocked micro holes in the finished product and induced a smooth surface. Characterizations included experiments such as, Fourier Transform-Infra Red spectroscopy, melting point determination, tensile testing and scanning electron microscopy (SEM). Generated data displayed the absence of a chemical bond between the PS molecules and the LFA additive. However, the methyl chains of the PS molecules were miscible with the saturated dodecyl chains of the LFA additive. Hence, the LFA additive was held in place by the weak intermolecular electric forces between its chains and that of the PS molecules. The measured melting point of the recycled plastic with LFA content (rPS20) fell between 84-142 °C. Mechanically, the tensile strength dropped with the addition of LFA. The LFA induced a smooth surface morphology finishing in rPS20.

Keywords: plastic wastes, recycling, polystyrene, plastic circular economy and plastic souvenir.

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Introduction

Plastic is described as a malleable and ductile material that can be obtained from the polymerisation of monomers of the same or different kinds (Tsakona M. & . 2020). The over 380 million tonnes of plastics produced in a year (Ritchie H. & Roser., 2018) find applications in packaging, equipment parts, textiles, shoes, domestic wares, industry, furniture and many more (OECD, 2018). The flexible, lightweight, durable, water impermeable, non-corrosive and poor degradability of plastics make them suitable replacements for glass, metallic and wooden products. Nonetheless, the use of these plastic products has contributed to an enormous amount of plastic wastes (353 million tonnes in 2021) that are mismanaged and pollute the environment (OECD, 2022). Aside the waste mismanagement, the production of virgin plastics from natural gas releases an over 400 million tonnes greenhouse gases annually into the atmosphere, which contributes to global warming (OECD, 2018). Hence, the global efforts at promoting sustainable production, use and management of plastics in a circular economy (Shamsuyeva & Endres, 2021).

Ghana generates over 357,877 tonnes of plastic wastes annually, of which 81% are mismanaged (Ritchie & Roser., 2018). Varied applications of the plastics in the economic, social, and environmental sectors in Ghana have improved over the years. For instance, the availability of low-cost plastic dustbins, which substitutes the metallic bins, enhances waste collection in homes, workplaces, and industry. Similarly, the replacement of paper bags and wooden baskets with polyethylene bags in carrying groceries has generated more jobs and promoted the retailing businesses in Ghana (Blowplast, 1993).As a result, the plastic wastes are regularly generated with mismanagement, that requires the attention of stakeholders such as the Municipal Assemblies, Researchers, Industry and the Government.

Recycling which is the conversion of recovered plastic material into new products (Hopewell et al., 2009) has received lots of attention from industry in recent years, especially in developing economies due to the associated prolonged plastic life span and reduction in landfilling (Fobil & Hogarh, 2006). Additionally, recycling of plastics contribute to a decline in the volumes of virgin plastic monomers produced in a year, as well as, the amount of gases released into the atmosphere (OECD, 2018).

Amongst plastics that are commonly recycled are the polyethylene derivatives, such as the low-density poly, high-density, the linear low-density polyethylene and others (Kaiser et al., 2018). These materials find single applications in packaging, transport, electrical, construction and other sectors, which make them readily available for recycling (OECD, 2018).

Recycling is categorised into four routes, they are, the primary, secondary, tertiary and quaternary recycling (Hopewell et al., 2009). The recycling of plastic wastes into the same virgin product becomes the primary recycling. An example is the recycling of polyethylene terephthalate (PET) bottle wastes into new PET bottles (Merrington, 2011). The secondary recycling on the other hand describes the recycling of plastic wastes into new forms that have lesser properties compared to the original form (Elena, 2017). Example is the conversion of polyolefin wastes into dustbins. The breakdown of plastic wastes into the constituent monomers and oligomers become tertiary recycling (Elena, 2017). The chemicals obtained can be converted into virgin polymers or serve as fuels in other chemical reactions (Merrington, 2011). For instance, the diols and dimethyl terephthalates for making new PET bottles are obtained from the glycolysis of old PET bottle wastes (Schlummer et al., 2017). Quaternary recycling is the Energy recovered from burning plastic wastes in an incinerator. For instance, the use of refuse-derived fuels are quaternary recycling processes (Yi-Bo et al., 2018). The primary and secondary recycling technique have widely been employed in industry and contributed to the current 18% global recycling rate (Yi-Bo et al., 2018).

Polystyrene bowls like paper, cans, and others is used in carrying fresh and cooked food products from the vendors to offices and homes in Ghana (Ofosu-Okyere et al., 1997).

Polystyrene is widely used in packaging items and functions as a shock absorber or an insulator. For instance, it is used as an insulation material for packaging hot food and as a shock absorber in packaging electrical parts. Chemically, the polystyrene chain is composed of aromatic vinyl group monomer called styrene. It is hard, clear, and brittle at room temperature. As a thermoplastic polymer, it is easy to mould and remould into different shapes. Its melting point is 240 °C but soften at 95 °. It is produced on industrial scale through extrusion, injection moulding and vacuum forming. The much-used form in Ghana is the injection moulded polystyrene take away bowls used in packaging hot meals by food vendors, restaurants, and snack bars.

Even though polystyrene is recycled in other countries (Aciu et al., 2015), the reported methods are not easy to replicate in Ghana, a developing country with limited access to state of the arts technologies and financing to support the associated high investment capital. For example, EcoMENA in Riyadh, Kingdom of Saudi Arabia, recycles polystyrene through a four-stepped approach, which is, segregation, compaction, shredding, melting/extrusion (Rubio, 2021). A process that requires an appreciable amount of investment in machinery. Hence, this study explored low-cost

Ghanaian recycling techniques to convert PS wastes into secondary materials of commercial value, which reduces its environmental burden and improves the circular economy of plastics.

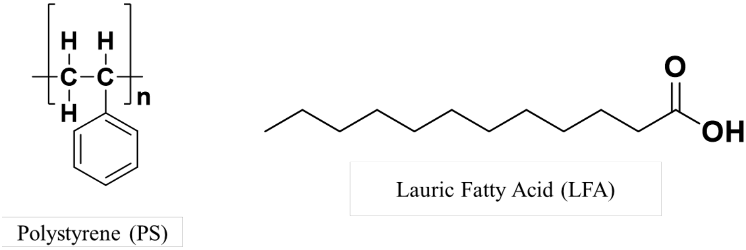
Methodology

Sample preparation and recycling

The virgin PS (VPS) waste bowls were collected from a plastic only waste bin and washed thrice from food leftovers and other debris. The clean PS bowls were shredded into smaller pieces, dried at room temperature and stored. The shredded PS sheets were baked in an oven at 240 °C for 3 hours. The baked samples were removed from the oven and air cooled for additional 2 hours and the product separated from the mould to obtain the recycled PS (rPS). The preparation of the rPS with 20% Lauric Fatty Acid (LFA) (rPS20) involved the crushing of a portion of rPS without LFA into granules. Then the 20% LFA was added and homogeneously mixed to form a paste. The paste was baked as described earlier. The product was then separated from the mould and kept for further characterisation processes.

Functional groups determination

Conventional Fourier Transform-Infra Red (FT-IR) spectroscopic method was employed to determine constitutional functional groups of VPS, rPS, LFA and rPS20. Generated data was compared to literature functional groups of the chemical structures, Scheme 1.



Scheme 1: Chemical structures of PS and LFA.

Melting point

The melting pointof products were determined by the conventional desktop method using the Stuart (Cole-Parmer) SMP10 Digital Melting Point Apparatus.

Tensile strength

The ISO 6259-1 standards were followed in the determination of the tensile strength on a Hounsfield Universal tensile tester, Mode number H50ks. Five samples were prepared for each test and the average determined.

Surface Morphology

Scanning electron microscope EOL JSM-6390LV, at magnifications of 100X was employed in capturing the surface morphology of rPS and rPS20.

Results and discussion

Functional groups determination

FT-IR measurement showed the presence of the characteristic phenyl group of polystyrene in the VPS, rPS and rPS20, which was demonstrated by the aromatic C-C stretch and C-H bends observed at 1600 and 755 cm^{-1} respectively, but shifted marginally downward from 1601.49 cm^{-1} of the VPS, to 1600.62 cm^{-1} and 1600.98 cm^{-1} in rPS and rPS20 respectively, Table 1. The LFA content was displayed at the ester peak position 1744.15 cm^{-1}, in rPS20, which was a gentle forward shift from the 1743.25 cm^{-1} of the virgin LFA, Table 1. The rPS and rPS20 did not show any new peaks compared to the peak positions of the VPS and LFA. This indicates that, the recycling process did not induce the formation of a chemical bond between the PS and LFA molecules. However, it is anticipated that, weak non-bonding intermolecular interaction held PS and PLA chains together. Hence, the blended material, rPS20 will bear the synergistic properties of its constituents.

Table 1. Spectra positions and description for samples

	VPS	rPS	LFA	rPS20	Functional Groups	Description
Peak Position (cm^{-3})	3435.99	3467.14	-	3468.01	O-H stretch	Primary alcohol
	3025.98	3025.03	-	3025.70	C-H stretch	Aromatic
	2922.53	2921.65	2922.18	2924.06	C-H stretch	Alkanes
	2849.88	2849.86	2853.22	2852.92	C-H stretch	Alkanes
	1750.61	1741.65	1743.25	1744.15	C=O stretch	Esters, saturated aliphatic
	1601.49	1600.62	-	1600.98	C-C stretch	aromatic
	1493.15	1492.61	-	1492.83	C-C stretch	aromatic
	-	-	1465.53	-	C-H bend	Alkanes
	1452.58	1451.93	-	1452.55	C-H bend	Alkanes
	-	-	1377.55	-	C-H bend	Alkanes
	-	-	1155.65	-	C-O stretch	Tertiary alcohol
	-	-	1111.46	-	C-O stretch	Secondary alcohol
	1068.71	1068.31	-	-	C-O stretch	Primary alcohol
	755.36	755.68	-	756.37	C-H bend	Aromatic
	-	-	721.87	-	C-H rock	Alkane

Melting point (Mp)

Table 2. Melting point of the virgin polystyrene melted without LFA and with LFA.

	VPS	rPS	rPS20
Melting point range (°C)	141-152	131-152	84-142

The melting point of VPS fell below the literature temperature of 160°C, Table 1 (Mehta ***et al***., 1995), which is attributed to the presence of additive impurities. Similarly, rPS20 recorded a lower melting point range compared to rPS and VPS (Table 2). This is attributed to the presence of LFA impurities in the rPS, which caused a weakening of the intermolecular interaction between the PS chains. The presence of heat easily broke the bonds of rPS20 molecules with a corresponding enhancement in the molecular entropy that lowered the temperature at which the first and last crystals of the polymer melted.

On the other hand, the broader melting range of rPS20 (58°C) compared to the VPS (11°C) and rPS (21°C), (Table 2 and Figure 1), indicated that, the LFA molecules prolonged the complete melting of the rPS molecules in the blend through the melting of its unit alongside that of the rPS, while only the PS chains melted in VPS and rPS with minimal impurities and narrower range. Hence the higher the impurities content, the broader the melting range an observation that is consistent with literature (Jo & Kwon, 1991).

Additionally, the lower onset of the melting range for rPS20 makes the polymeric material a suitable option for heat induce sculpture applications in the art and souvenir industry.

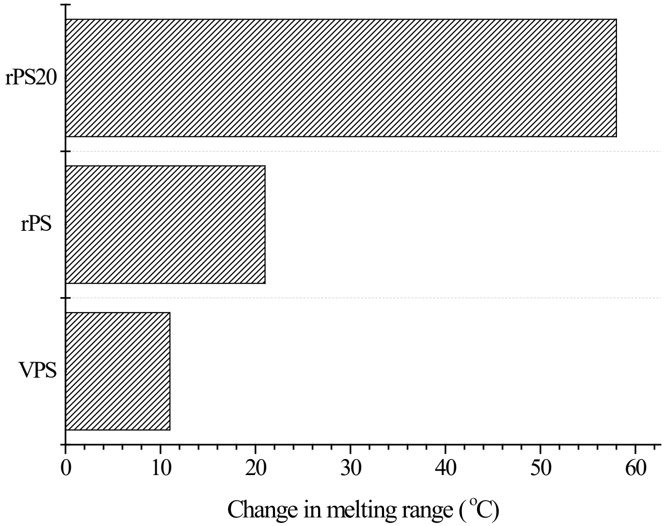


Figure 1. Melting range variations in PS samples.

Tensile strength

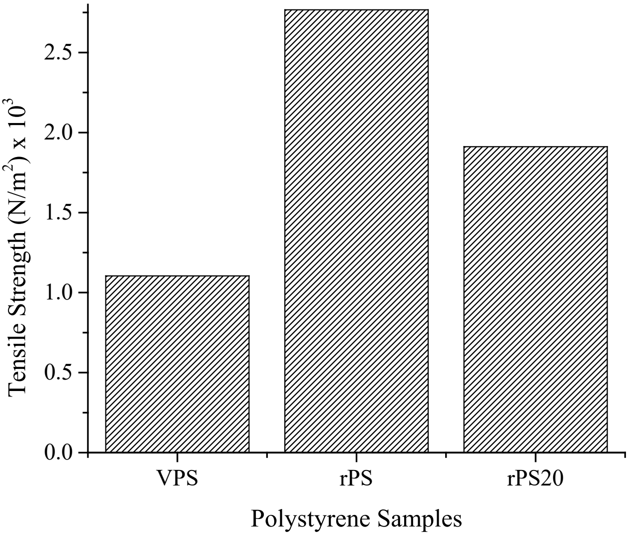


Figure 2. Tensile properties for VPS, rPS and rPS20.

The rPS demonstrated a stronger tensile strength compared to VPS and rPS20, Figure 2. This indicates that, the LFA which is a diluent reduced the strong intermolecular interaction of the PS material, which rendered it slightly loose and weak compared to the rPS molecules. In the case of VPS its molecules had air trapped in-between them during the expanding stage of its cold processing at the factory, (Merrington, 2011), hence the tensile strength was weaker than the rPS20 and rPS whose molecules reoriented and closely packed during melt processing in the laboratory. The reduction in the mechanical strength of rPS in rPS20 confirms literature observations in other plastics, such as recycled polyethylene (rPE) whose impact strength dropped when mixed with other polymer impurities during recycling (Thoden van Velzen ***et al***., 2021). Hence, the recycled material rPS20 will be suitable for applications that require minimal to no stress during the use.

Surface morphology

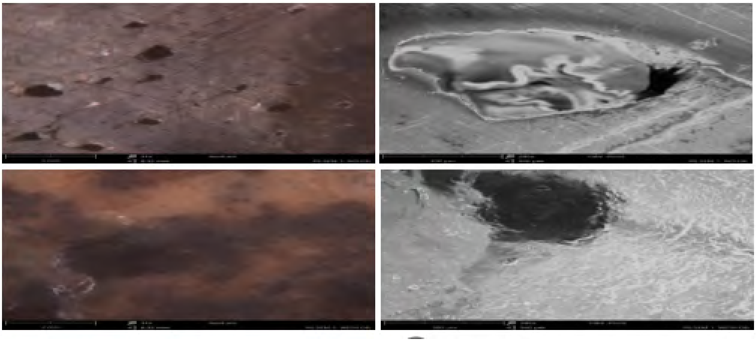


Figure 3. SEM images of the surface morphology for rPS (top) and rPS20 (down).

The surface morphology of rPS in Figure 3 top-left and right, had micro-voids, which were attributed to irregular packing of the PS chains due to trapped air in the starting VPS, (Merrington, 2011). However, the micro-voids disappeared in the morphology of rPS20 due to the presence of LFA, (white patches in Figure 3 bottom-left and black patch in Figure 3 bottom-right). This indicates that, LFA sealed the micro-voids and induced a smooth surface morphology in rPS20.Furthermore, the absence of cracks in the processed material indicated a favourable adhesion between the LFA and PS molecules, (Hong-Ru& Chang-Tay, 1999), which indicated that, LFA was a suitable additive for improving the surface morphology of rPS. Hence, the inherently smooth surface of rPS20 makes it a commercially viable plastic for applications in the art and souvenir industry, since low-cost product finishing can be guaranteed.

Conclusion

In all, the study demonstrated the recycling of polystyrene bowls into a plastic material with inherent smooth surface for enhanced marketability and application in the art and souvenir industry.

The material rPS20 demonstrated good mechanical strength, moderate resistance to heat above (100 °C) and a smooth surface that has never been reported in any recycled plastic, which will subsequently advance scientific research towards improvements in the properties of recycled plastics towards improvement in the plastic circular economy.

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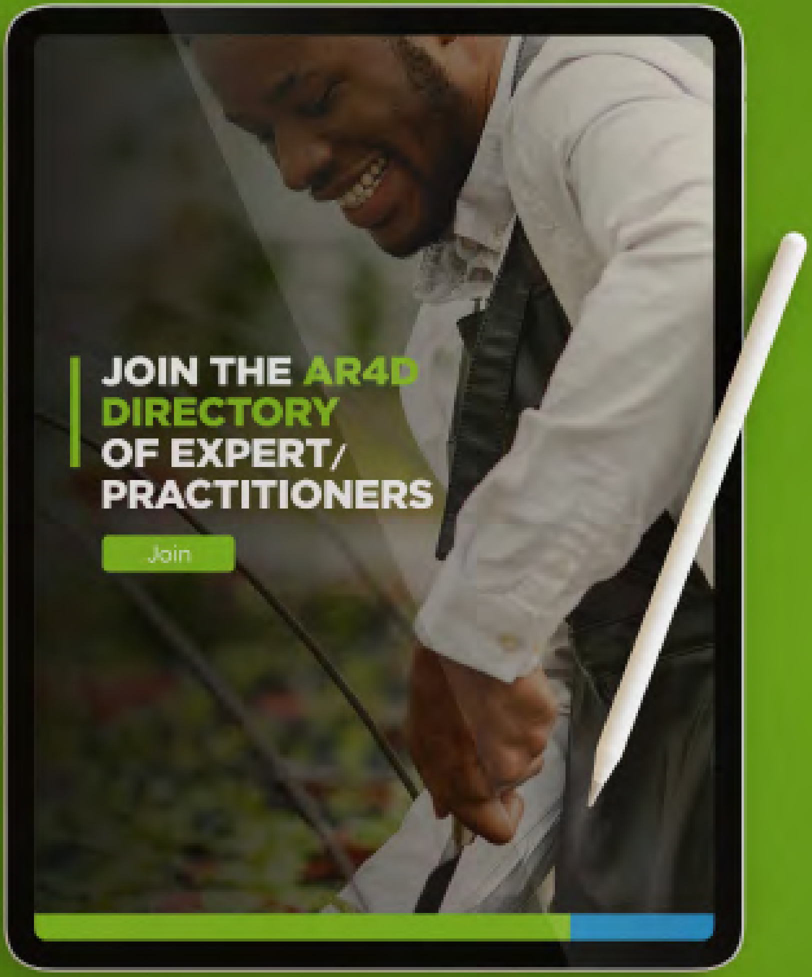

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