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Mechanical recycling of PVC plastic waste streams from cable industry: A case study

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ABSTRACT

Plastics draw a paramount amount of fossil fuel reaching nearly 300 million tons annually and continue to enter every production sector of our lives (automotive, aerospace, packaging, building, toys, furniture, clothing, medical etc.). While different from polyolefin, Poly Vinyl Chloride (PVC), along with many halogenated polymers, all belong to the same thermo-plastic group. Rigid plasticized PVC is commonly used in pipes, window framing, floor coverings, roofing sheets, and cables; thereby it is discarded at a high rate. Adopting an appropriate recycling pathway is of both an economic value and an environmental benefit. The high hydrogen chloride content and the concern of dioxins and furans emission deter its thermochemical conversion. Re-compounding, particularly, when it is generated at a substantial amount and at low variation in composition, is the ultimate recycling strategy. In this work, analysis of the composition of PVC waste stream from the cable industry is carried out. Thermal Gravimetric Analysis (TGA) was conducted to infer the moisture, volatile, and inorganic filler fractions and the extent of thermal stability. These data are important to design the proper re-compounding, extrusion and injection conditions for the postconsumer PVC. Standard tensile and dynamic stress samples were produced and subjected to successive aging, extrusion and molding. Thermal properties were insignificantly altered, whereas mechanical properties lost some but tolerable flexibility. The results suggesting that PVC cable polymer can be reutilized in a close sustainable manufacturing which warrants ecological and economic benefit.

1. Introduction

Plastic usage superseded all other products for its properties and characteristics, including steel and glass. For that, a 5% increase in the global production of plastic has been observed in the last 20 years reaching over 300 million tons annually, and are overwhelmingly used in all commodities from wrapping food to making must-have consumer products (Plastics Europe, 2011). Many consider plastics is the true resource champion in saving 46% more energy resources than it consumes, 46% reduction in CO_2 emission and offsetting much of 100 million tons of waste across Europe annually as in replacing other materials (i.e. wood, paper, glass, concrete etc.) (Plastics Europe, 2011).

PVC is the 2nd largest production volume of thermoplastics, behind the polyethylene. The flexibility of compounding with various additives forming elastic and rigid plastics, the different processing techniques, (extrusion, calendaring, injection molding and plastisol) and the relatively low price made it a versatile commodity (Donal & Rsosato, 2011). The combined physical, chemical and weathering properties made PVC a universal polymer with application in pipes, profiles, flooring, cable insulation, roofing, packaging, bottling, and the emerging medical applications. This versatility, however, causes postconsumer disposal problem considering the continuing growth in the plastic industry. Because environmental sustainability is an integral part of the corporate social responsibility, several organization are established in Europe to overseas and proctor the Vinyle manufactures and reaching a common ecological goal to cut raw materials, energy consumption and minimizing the environmental impact (Garmson & Gardiner, 2010). Market penetration and so as recycling initiatives is different from country to another whereas increase of awareness and legislation landfill restrictions would surge post-consumer PVC recycling.

The potential impacts of the PVC production, additives and waste management raised concerns for many years that made the European Union (EU) to create a waste management plan for PVC as appropriate measures such as phasing out cadmium and lead stabilizers, discontinue the use of bisphynol A as PVC resin and assessment of other plasticizers for policy makers. This mark the

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Table 1
The distribution of MSW in USA of 254MT, Dubai of 2.54MT, Abu Dhabi 3.5MT demonstrating the high plastic fraction contents.

Material type	USA Percentage 2010	USA Percentage 2011	USA Percentage 2012	Dubai Percentage 2011	Abu Dhabi Percentage 2011
Papers & Paperboard	28.5	28	27.4	24.3	5.3
Plastics	12.4	12.7	12.7	24.2	11.2
Glass	4.6	4.6	4.6	3.4	3.1
Metal	9	8.8	8.9	2.4	2.2
Food waste	13.9	14.5	14.5	35.4	69.5
Yard trimmings	13.4	13.5	13.5	...	
Rubber, Leather & Textiles	8.4	8.2	8.7	4.9	4.2
Wood	6.4	6.4	6.3	1.0	...
Other	3.4	3.3	3.4	4.3	4.6
Total	100	100	100	100.0	100.0

development of an integrated waste management through the efficient use of PVC raw materials and end-of-life sustainable routs. The plan include recycling of 200,000 tons per year started in 2010 from other none regulated EU applications additional to the accumulated PVC waste since 2000. The waste management included manufacturing compliance of emission and water and air emulsion. In 2005, recycling of post consumes PVC from pipes windows, profiles and roofing surpassed 50% (Towards Sustainable Plastics). As a results, from 2000 to 2007 the Vinyl industry emission to the atmosphere and water was more than halved annually, and over 70% reduction of the combined doxins emission. Still without monitoring and verification of the emission by the European Counsel of Vinyl Manufacturing, the emission level of Vinyl and PVC production can be daunting. Elsewhere, in USA plastic waste comprise nearly 12.5% of the 251 million tons of the generated MSW in 2011 (USEPA, 2014). Locally in UAE, in the two major Emirates the waste accounts as high as 24% of the 2.7 million tons of MSW (Waste Management, 2013) generated in Dubai in 2011, and nearly 12.1% of Abu Dhabi's 3.5 million tons MSW in the same year (Environment Agency, 2013). The breakdown of the generated MSW by material is illustrated in Table 1. The high waste percentage in Dubai is due to the large fraction generated by the construction industry, which is excluded in Abu Dhabi as classified under the demolition waste and it accounts nearly six times the MSW amount (Waste Management, 2013). Nevertheless, as recovery and recycling rate in US is nearly 36% (USEPA, 2014), continuous improvement of the waste management infrastructure has reached this recovery in Abu Dhabi in 2012. However this still far below its potential as vast quantities of valuable resources is still disposed of at the landfill triggered by lack of infrastructure for treatment, material recovery and disposal as much of the plastic is mixed and sent to the dumpsites. Sustainable waste management plan is sought in UAE to divert as large as 85% of the waste from the landfill. The scope of the plan is to balance the tariff with the cost, incentivize waste reduction, fund needed infrastructure and upgrades, and account for liabilities and environmental damages for improper disposal practices. It emphasizes on waste data gathering and in creation awareness campaigns. Although legal and regulatory framework was developed, the need for policies, technical environmental protection, safety standards and thresholds, deterrent penalties and fine are some of the common challenges.

The cable industry is identified as a major PVC producers which needs to be more environmental cognizant.

United Arab Emirates (UAE) is considered the highest consumable of plastic in the Middle East and North Africa (MENA) and plastic waste constituted more than 10% of their 5 million tons of MSW annually (Tolba & Saab, 2008). Considering the overwhelming electrical grid expansion sky rocketing urban developments and construction in UAE and the absence of continuous monitoring the issue is magnified. Plastics still constitute over 11% of the MSW composition of which nearly 97% is landfilled (Donal & Rsosato, 2011).

Recycling of PVC can be termed as either chemical (energy) or material (mechanical) recovery. Chemical recovery is the conversion of PVC back into shorter-chains for reuse in petrochemical or polymerization processes following cracking, gasification, hydrogenation or pyrolysis. It also involves hydrochloric acid recovery and neutralization of residues from the flue gas (Halosep and Neutrec Processes). It uses $NaHCO_3$ for residual neutralization and leading to its conversion into brine which in turns is used as feedstock in $NaHCO_3$ plants. After dissolving the residues, the mix of heavy hydroxide metals, activated carbon and ash is filtered. The recovered brine is subjected to further organic filtration via activated carbon and trace metal scrubbing via a selective ion exchange membrane. This process is within the pilot scale demonstration and still bears several technical, environmental and economic challenges. Heat recovery from the incineration of PVC is a burden on many societies due to the hydrogen chloride and chlorinated dibenzofurans, and dibenzo-dioxins emissions and heavy metal (lead and cadmium), ground leaching (Mastrangelo, 2003).

Mechanical recycling of post-consumer PVC waste is an attractive ecological route when is feeding on a single homogenous source such as the cable industry rather than mixed MSW plastic waste. Needless to state that incompatibility of polymer components results in an inferior properties product.

2. Mechanical recycling of PVC

Research on postconsumer mechanical recycling is found in several works (Janajreh & Alsharah, 2013; Qudaih, 2011). Sombatsompop and Thongsang (2001) assessed the properties of recycled PVC pipes and virgin pipe PVC mixture and another with virgin PVC bottle compound. Their results showed an increase in the melt viscosity with the increase of recycled PVC. The die swell ratio was observed to increase with temperature, but not with the recycled concentration, it was attributed to the presence of gelation that forms at high temperature. The optimum tensile and impact strengths were detected, the impact strength being explained by the use of SEM micrographs of the fracture surface. The hardness increases as the density of the compound increases. The glass transition, degradation and heat deflection temperatures were also found to shift with the loading of recycled PVC. Summers et al. (1992) discussed the possibility and the feasibility of recycling PVC waste into diverse applications including bottles, drainage pipes and drainage fittings with good appearance and properties. Luzuriga, Kovářová, and Fortelný, (2006) studied different properties and thermal stabilities of four different polymers, low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP) and high-impact polystyrene (HIPS) subjected to repeated reprocessing. Samples were first oven-aged at 100 °C for different periods of time. Aged polymers were kneaded in the W50EHT at 190 °C for 10 min and the hot molten bulk was pressed at 200 °C for 4 min in Fontijne table press before cooled in a cold press. Tensile strength, crystallinity, rheology