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Research article

Influential parameters on natural weathering under harsh climatic conditions of mechanically recycled plastic film specimens

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ABSTRACT

In this work, real life reclaimed plastic solid waste (PSW) secured from the municipal sector was mechanically recycled and compounded with virgin linear low density polyethylene (LLDPE). The compounding of the plastic film samples utilised the means of extrusion and blown filming to produce various formulations of the blends containing up to 100% (by weight) of the PSW in the examined specimens. The film samples were compared to market products used in the State of Kuwait where PSW accumulation presents a major obstacle. Natural weathering under arid and harsh climatic conditions was also performed to determine the degradation extent of the film samples. Haze (%), light transmission (%) and the total change in colour (ΔE) were measured as indicators to the degradation profile of the polymeric materials, in addition to tensile pull mechanical properties. Properties were noted to deteriorate as a function of weathering time and waste content. Statistical analysis was also performed on the properties measured and climatic conditions including airborne pollutants levels. The abundance of the secondary airborne pollutant (ozone) was determined to be a significant variable on the studied properties. This can be attributed to induced photo-oxidation the polymeric matrix is subjected to under such climatic conditions which increases oxygen diffusion throughout the polymeric matrix. Future development of the recycled blends studied in this work can be a route for the decrease of associated environmental stressors with virgin plastic resin conversion.

1. Introduction

The accumulation of solid waste (SW) burdens the environment and societies alike. It is a major topic addressed by governments and local authorities on a daily basis due to the associated problems that SW accumulation cause. These stretch to health related issues, the loss of economic value from the discarded products and commodities and associated increase of environmental stressors. Hence, valorizing SW is considered to be a necessity rather than an option nowadays. SW accumulation is also a major concern in developing societies. In particular, Asian and Middle-Eastern (ME) countries suffer from the lack of a proper infrastructure that can handle and mange SW, and are in dire need of recycling solutions based on sound technical assessments and studies. An alarming rate of SW generation is noted in Asian and ME countries, which is associated with the urbanization of these societies and economic prosperity with respect to the gross domestic product (GDP) index.

The use of open dump sites as a means of SW disposal or unsanitary landfilling spreads health problems and contaminates underground water aquifers. The lack of appropriate recycling solutions also burdens the economy of a country, which has to deal with the clean-up processes associated with the accumulation of waste. The World Bank report on Asian countries Waste Management (WM) *status-quo* showed that local authorities spend some 70% of their revenue on Solid Waste Management (SWM) alone (ATP/UNEP, 2010). ME countries have also been associated with high estimates of SW generation. The increasing components of the SW stream such countries have are the construction & demolition (C&D) and Municipal Solid Waste (MSW). Table 1 shows a selection of developed and developing countries MSW generation rates (kg per capita per day).

One tangible fact can be withdrawn from the estimates of MSW generation shown which is that the more prosperous and well established a country is economically, the higher the generation rate is. And it is also worth noting that countries with a well-developed industrial scheme and infrastructure that can handle SWM will have less of a SW generation rate. The State of Kuwait can be noted to be the highest within countries of the ME region as shown in Table 1. Lifestyle, urbanization and social behavioural aspects of nationals and expatriates

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Table 1
Collection of Municipal Solid Waste Generation Rates In Developed and Developing Countries. Source: Hoornweg and Bhada-Tata (2012), Al-Salem et al. (2009, 2015a,b); Al-Jarallah and Aleisa (2014), Al-Salem (2009a), Al-Meshan and Mahros (2001).

Country	Total Generated MSW (Kg Per Capita Per Day)	Composition (%)				
		Organics	Plastics	Paper	Metal	Other
Algeria	1.21	70	10	5	5	39
Argentina	1.22	40	14	24	2	20
Bahrain	1.10	N/A				
Belgium	1.33	39	5	17	3	36
Brazil	1.03	61	15	15	2	7
Canada	2.33	24	3	47	13	14
Czech Republic	1.10	18	4	8	2	67
Egypt	1.37	60	12	10	–	–
Germany	2.11	14	22	34	5	24
Italy	2.23	29	5	28	2	35
Lebanon	1.18	63	7	18	3	9
New Zealand	3.68	56	8	21	7	8
Saudi Arabia	1.30	N/A				
Qatar	1.33	N/A				
Syria	1.37	65	12	10	2	11
Turkey	1.77	65	14	7	6	7–24
United States	2.58	25	12	34	8	21
Kuwait	5.72	46	18	7	4	25

alike make SW generation a concern in Kuwait. Organics are generated at a rapid rate with estimates showing its daily production rate as 142.59 tonnes. However, and comparatively to other countries, organics are noted to be in the range of many other developed and developing countries. It might even be lower than other Asian societies. On contrast, plastic solid waste (PSW) generated from municipal sources encompassing households and commercial ones, represents a higher fraction of the world's average total waste load (10%) which is estimated in Kuwait to be over 18% in some studies (Al-Jarallah and Aleisa, 2014).

Other MSW fractions are produced in a rate of some 165 tonnes per day, with an estimated waste from electrical and electronics equipment (WEEE) generation rate of about 17 kilograms per person per annum. This is considered as an added component to plastic waste in Kuwait not part of the MSW stream. These estimates are all on the increase, where past PSW generation rates shows that Kuwait produced only 150 ktpa back in 2001 (Al-Meshan and Mahros, 2001), and 200 ktpa in 2015 (Al-Salem et al., 2015a). Kuwait has three active landfills, namely the seventh ring road (south), Al-Jahra and Mina Abdulla. The seventh ring road (south) site is the one that is considered the main landfill site in Kuwait, and has processed 976,995 tonnes of household SW in the year 2015 according to Kuwait Municipality (KM) statistics (Hajiah, 2016).

Given the aforementioned, recycling reclaimed PSW presents a number of advantages that can result in various opportunities for the public and private sector of Kuwait. PSW can be recycled utilising the means of mechanical and physical instrumentation and machinery. This type of recycling is termed as mechanical (secondary) recycling (Al-Salem et al., 2009). Mechanical recycling relies on one essential aspect which is achieving a blend that is suitable for the market intended for. The waste material used in compounding the waste filled products, must substitute the virgin plastic typically used in these articles (Kartalis et al., 2000).

Recently, the use of co-polymers such as poly(ethylene-co-methacrylic acid) as a compatibilizer to improve mechanical properties of recycled blends, has been addressed in scientific literature (Rajasekaran and Maji, 2018). Such recycling regimes are also noted to improve the stability of the polymeric matrix in the plastic product. Nonetheless, having improved or acceptable properties without chemical agents additions is noted to be more operationally and economically advantageous in dry blending processes (Al-Salem et al., 2015b, 2017). In addition, fillers and modifiers have also been noted to be a major topic in research nowadays (Vazquez and Barbosa, 2016; Singh et al., 2017). A comprehensive review on the pathways of plastics mechanical recycling has been recently published (Ragaert et al., 2017). It was emphasised that thermal influencing factors on the plastic's degradation are noted to be one of the main aspects that must be controlled at compounding stages of recycling blends. Therefore, investigating the applicability of recycling reclaimed PSW in Kuwait presents a number of economical and environmental advantages.

Polymers weathering by accelerated or natural means has been previously applied by past researchers as a technique to determine the integrity and loss of properties with exposure time (Bhattacharyya et al., 2014; Bajwa et al., 2015; Quill and Fowler, 2018). The application of weathering tests can also determine the degradation profile of the polymer that constitutes the plastic product (Beg and Pickering, 2008; Gulmine et al., 2003; Dehbi et al., 2010; Friedrich and Luible, 2016).

In this work, various compounded blends originating from real life reclaimed PSW were studied after exposure to natural weathering tests in Kuwait. The influential parameters of the climatic conditions including airborne pollutant levels, were investigated utilising the means of statistical analysis. The degradation of the polymeric articles compounded with the PSW was studied after performing rigorous experimental work encompassing physical and mechanical properties determination. In addition, the formulated recycled blends were compared to existing market products to assess their viability as a standalone product that can potentially compete with virgin compounded plastic resin articles. The work presented in this communication is a continuation to past studies performed in Kuwait (Al-Salem et al., 2015a, 2016) and can result in product development opportunities for recyclers in developing countries where managing the accumulated PSW presents an obstacle.

2. Materials and methods

2.1. Samples acquirement & random sampling

PSW in the form of discarded plastic films (200 kg) was secured from the National Waste Management Company (Amgarah industrial area, Kuwait), and was used in this study as the waste material of choice. The PSW is considered to be plastic film waste originating from municipal refuse and the national solid waste (SW) stream, notably commercial sectors and households. In order to determine the constituting polymer of this PSW, the melting point (T_m) of random samples was determined. Ten samples of each of the plastic film waste collections (with a total of fifteen) were chosen randomly, amounting to a total of 150 samples that were tested using a TA instrument Q-series model differential scanning calorimeter (DSC). A 9 ± 0.1 mg sample was placed in the DSC crucible (pan), equilibrated at 40 °C for 5 min, after which the sample was heated using a 10 °C min^{-1} heating rate (β) to 200 °C min^{-1}. The cooling cycle was achieved by the same heating ramp (β) to 40 °C. The heat flow (mW) was monitored and recorded against the temperature (°C) to establish the melting points (T_m) of the polymers, which were then recognised by polymer type after assigning each melting temperature to a typical polymer melting point. The PSW materials used in this work contained the following polymer as constituting elements (by wt.%): linear low density polyethylene (LLDPE, 46%), low density polyethylene (LDPE, 51%), high density polyethylene (HDPE, 1%); and polypropylene (PP, 2%). There were no indications that the PSW source has altered within the past three years. The collection of the waste is governed by state law and controlled by local authorities which prevents cross contamination. PSW in Kuwait has also been recently characterized to contain two major components which were films and containers, constituting an average of the total MSW by 11.04% and 7.3%, respectively (Al-Jarallah and Aleisa, 2014). Readers should refer to Al-Salem et al. (2015b, 2016) for more details.