MATERIAL CIRCULARITY INDICATOR APPLIED TO RECYCLED HIPS AND CLAY COMPOSITES

Amanda Alves Domingos Maia (Departamento de Engenharia de Produção da UFSCar Sorocaba)
aadmaia@yahoo.com.br
Thiago Bueno Consul (UFSCar campus Sorocaba)
consul.thiago@gmail.com
Jane Maria Faulstich de Paiva (UFSCar campus Sorocaba)
jane@ufscar.br

Nowadays the environmental, social and economic problems have been great challenges, as resource use and environmental degradation, human population and consumption growth. The argumentation about circular economy conceptualization and impllementation has been intensified recently and it is considered useful to understand how resources can be used most efficiently. A large amount of waste electrical and electronic equipment (WEEE) is generated worldwide, causing a problem for their disposal and an alternative use has become an important challenge. High Impact Polystyrene (HIPS) is one of the most common and abundant polymers in the WEEE. The reinforced polymer matrices are receiving attention because of the good mechanical and thermal properties. Thus, the aim of this study was to determine the material circularity index (MCI) of the composites of recycled HIPS and clay. The complexity of calculation of MCI was observed, considering all the material losses during production steps. The recycled HIPS can be reused multiple times, but is eventually discarded as waste. However, the circularity approach would promote a high contribution to sustainable resource use.

Palavras-chave: HIPS, circular economy, material circularity, WEEE

1. Introduction

The material and energy resources required to extend the industries are most likely not available and the capacities of ecosystems to receive the outflows of industrial activities is decreasing over the time (HAAS et al., 2015). The reuse of waste is a complex issue, evaluating and considering the environmental impacts, technical aspects, implementation and operating costs of each specific treatment and disposal option as well as the social implications (ARENA; GREGORIO, 2014).

Circular economy is not a new concept but is based on a combination of fundamental and founding concepts (SAIDANI et al., 2017) and is acquiring even more scholars and practitioners around the world (KIRCHHERR; REIKE; HEKKERT, 2017; SAUVÉ; BERNARD; SLOAN, 2016). This concept is of great interest because it can be considered as an operationalization for businesses to implement the concept of sustainable development (KALMYKOVA; SADAGOPAN; ROSADO, 2018; KIRCHHERR; REIKE; HEKKERT, 2017). The circular economy also has been presented as a way to separate the economic growth from environmental degradation (LINDER; SARASINI; VAN LOON, 2017).

Circularity index is empirically used to measure the effects of a circular economy in terms of viability and environmental impacts. Metrics currently exist for macro/meso level, however, there is no standardized method for micro level circularity including businesses and products (ELLEN MACARTHUR FOUNDATION AND GRANTA DESIGN, 2015a; LINDER; SARASINI; VAN LOON, 2017). A metric that assesses product-level circularity using mass-flow analysis was developed trying to measure how effective has been the transition from 'linear' to 'circular'. The Material Circularity Indicator (MCI) is the main index developed aiming to find indicators to measure how well a product performs in the CE context (ELLEN MACARTHUR FOUNDATION AND GRANTA DESIGN, 2015b), ranging from 0 to 1, allowing companies to understand how far they are on the transition of circularity (NIERO; KALBAR, 2019).

The growth of electronics industry has been observed during the years promoting a material flow stream of electronic waste (DEBNATH; CHOWDHURY; GHOSH, 2019). Globally, approximately 50 million tonnes of e-waste it was estimated for 2018 and by 2020 will grow by 2.5–2.7% annually (BALDÉ et al., 2017).The reuse of electric and electronic equipment is related with an enormous generation of waste electric and electronic equipment (WEEE)

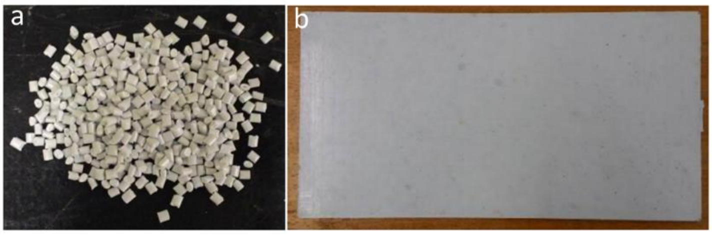
(DIAS et al., 2018; KUMAR; HOLUSZKO; ESPINOSA, 2017). WEEE contains both hazardous and valuable materials, which makes its recycling environmentally and economically meaningful (DIAS et al., 2017). The aim of this study was to determine the material circularity index of the composites of recycled HIPS and clay.

2. Materials and methods

2.1. Composites

It was used pellets of recycled HIPS from WEEE collected by Sinctronics (Sorocaba - SP). The composites molding process considered recycled HIPS and a type of clay (bentonite clay chemically unmodified). These materials were molded considering plates with dimensions of 127mm x 250mm x 3mm for tensile tests (composite 1) and dimensions of 160mm x180 mm x 5 mm, for flexural tests (composite 2). Composite 1 was molded considering 90g of recycled HIPS and 2.5g of unmodified clay. Composite 2 considered 150g of recycled HIPS and 3.75g of unmodified clay.

Figure 1 – Recycled HIPS (a) and Composites molded with HIPS and clay (b)



(CONSUL, 2018).

2.2. Measuring Resource Use

The Material Circularity Indicator (MCI) was determined based on the restoration of material flows at product levels and on the principles: using feedstock from reused or recycled sources, reusing components or recycling materials after the use of the product, keeping products in use longer and making more intensive use of products. The MCI is one of the main circularity indexes and gives a value between 0 and 1, where a higher value indicates greater circularity. This MCI was based on environmental value, calculated the circularity according to the value of recycled product, as a proportion of its total constituent parts. Based on literature, the Material Circularity Indicator was calculated as following (ELLEN MACARTHUR FOUNDATION AND GRANTA DESIGN, 2015b, 2015a).

2.2.1. Virgin feedstock

Considering F_R the fraction of feedstock from recycled sources and F_U the fraction from reused sources it is possible to obtain the fraction of feedstock from virgin sources, in equation 1 and the mass of virgin material is in Equation 2.

$$(1 - F_R - F_U) \qquad (1)$$

$$V = M(1 - F_R - F_U) \qquad (2)$$

where M is the mass of the finished product.

2.2.2. Unrecoverable Waste

If C_R represents the fraction of the product collected for recycling at the end of its use phase and C_U the fraction that will reuse, it is possible to determine the amount of waste going to landfill or energy recovery in Equation 3.

$$W_o = M(1 - C_R - C_U) \qquad (3)$$

The quantity of waste generated in the recycling process is given by Equation 4, considering E_C as the efficiency of the recycling process used.

$$W_C = M(1 - E_C)C_R \qquad (4)$$

And the waste generated to produce any recycled content used as feedstock is calculated considering the Equation 5.

$$W_F = M\frac{(1 - E_F)F_R}{E_F} \qquad (5)$$

where E_F is the efficiency of the recycling process used to produce the recycled feedstock.

2.2.3. Linear Flow Index

The Linear Flow Index (LFI) measures the proportion of material flowing linearly, which means from virgin materials up to unrecoverable waste. The index is determined following the Equation 6.

$$LFI = \frac{V + M}{2M + \frac{W_F - W_C}{2}} \qquad (6)$$

2.2.4. Utility

The utility X is the length (*L/L_{av}*) of the product's use phase (lifetime) and the intensity (*U/U_{av}*) of use (functional units) and are combined as the Equation 7.

$$X = \left(\frac{L}{L_{av}}\right) * \left(\frac{U}{U_{av}}\right) \qquad (7)$$

2.2.5. Material circularity indicator

The MCI was determined considering the Linear Flow Index and a factor $F(X)$, built as a function F of the utility X as can be observed in Equation 8.

$$MCI_p = \max\left(0{,}1 - LFI * F(X)\right) \qquad (8)$$

3. Results and discussion

It is important to remember that the MCI is based purely on a material balance. The value obtained for MCI considering recycled HIPS and clay as source of waste for composites molding was 0.58 and 0.69 for composites 1 and 2, respectively. These values can indicate that moving to circular economic model results in a brighter future for the regional economy.

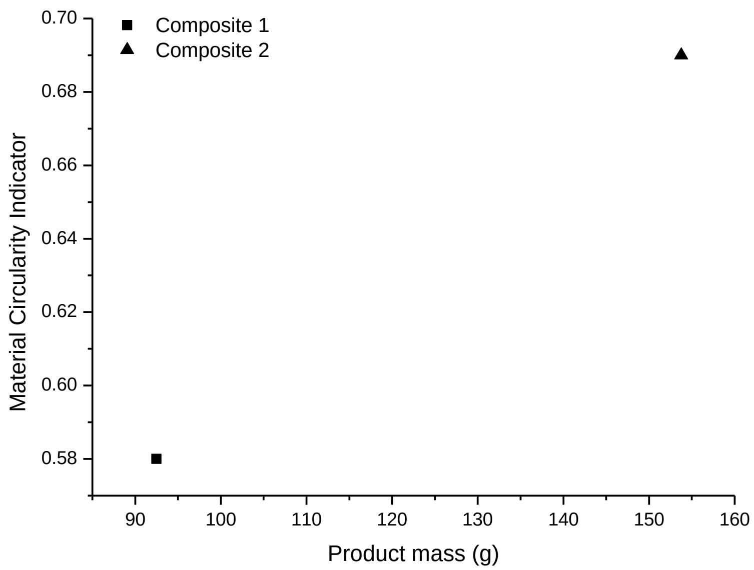
The complexity of calculation of MCI was observed because all the material losses during production steps. The MCI value can indicate that the reuse of the components of a product can be better than recycling, preserving more of its characteristics instead of only recovering its basic materials.

Considering a perfect circular economy, resources should be used an infinite number/amount of time, but resources are only used for a finite time before being designated as waste. It is this realistic situation in which the distinction between linear and circular becomes important.

The recycled HIPS can be reused multiple times, but is eventually discarded as waste after a period. However, the circularity approach promotes a high contribution to sustainable resource use. Thus, the MCI can possibly allow the decreasing the challenges of the global pressure on resources and insecurity of supply. The value of MCI observed can indicates that molding process parameters should be improved and to proceed under controlled and contained conditions promoting better results and a higher circular economy in this sector.

According the Figure 2 it is possible to see the difference between composites 1 and 2. Composite 2 allowed the molding process using more residue of clay and recycled HIPS, indicating a greater possibility to reuse of waste electrical and electronic equipment.

Figure 2 – Material Circularity Indicator considering composites 1 and 2



4. Conclusion

Circular economy can be considered an alternative for linear business model to sustainable production and consumption. The calculation of MCI can be complex, but allowed to understand the effectiveness of composites process considering recycled HIPS and clay. It was possible to observe that improving the MCI of a product does not mean an improvement of the circularity of the entire system. Nevertheless, the use of this methodology can promote a production systems improvement.

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