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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Life Cycle Assessment on the Direct Recycling Aluminium Alloy AA6061 Chips and Metal Matrix Composite (MMC-AlR)

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DOI: https://doi.org/10.30880/ijie.2021.13.07.012
Received 21 October 2020; Accepted 23 March 2021; Available online 30 September 2021

Abstract: Metallic material processing plays a significant role in terms of global environmental impact which contributes to the climate change phenomena that is a serious international environmental concern and the subject of much research and debate. Thus, energy- and resource-efficient strategies in the metal shaping technology domain need to be identified urgently. A frequent theme in the debates that surround waste and resources management is the extent to which the recycling of metallic materials offers genuine benefits to the environment. Solid state recycling techniques allow the manufacture of high density aluminium alloy parts directly from production scrap. In this paper the environmental impacts associated with 'meltless' scrap processing routes through hot press forging process with varying parameter has been studied. A comparative analysis has been performed with two different type of materials which is recycling aluminium alloy (AA6061) chips and metal matrix composite (AA6061 chips + 2% alumina) in order to quantify and compare the environmental benefits for both materials. The LCA data are collected using Simapro 8.0.4 software. The additional materials used in a product resulted higher environmental impact. Metal matrix composite had higher value of midpoint and endpoint impact categories compare to aluminium alloy chips.

Keywords: Sustainable direct recycling, life cycle assessment, metal recycling, hot press forging, aluminium recycling, aluminium AA6061, reinforced particles metal matrix composite

1. Introduction

Climate change is regarded as the most prominent and challenging environmental problem and its mitigation is a major objective in environmental management. Researchers have affirmed that the Earth's environment and seas are warming steadily because of human action[1]. There is a developing global logical accord that this expansion has been brought about by human action, principally the consuming of petroleum products for such exercises as creating power. Since the pre-modern period, climatic convergences of CO_2 have expanded by almost 30% and methane (CH_4) fixations have dramatically increased[2]. Different modern procedures represented roughly 14% of the complete CO_2 discharges and 20% of the all-out ozone harming substance emanations in 2010[3]. The aluminium industry alone is accountable for approximately 1% of global greenhouse gas emission [4].

Conferring to [5], the assembling part, which convenes at the centre of the innovative cornucopia, must be made practical to save the exclusive requirement of living achieved by developed social orders and to encourage creation of

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social orders to accomplish and keep up a similar way of life. Therefore, the need of decrement in energy consumption in industrial processes as well as transportation and production engineering has become a major factor in the modern industrial world. In recent year, the increasing of waste management cost, securing final disposal landfills, reduce and clean energy consumption are among the most critical sustainability issues in the whole world. Consequently, sustainable manufacturing is essential in ensuring Malaysia achieving the modern urbanization to be at par with other developed countries [6]. The report from the International Energy Agency [7] stated that, the Association of South-East Asian Nations exhibits total consumption of energy-related carbon dioxide emissions that has almost doubled, from 1.2 gigatons in 2011 to 2.3 gigatons in 2035 or from 3.7 % to 6.1 % of global emissions.

Aluminium is one of the most important commodities of our modern society as it is a critical component in a wide range of primary industries that include construction, transportation (aerospace and automotive), healthcare and food packaging. Moreover, with the shift to a low carbon economy, the structural strength and lightweight features of aluminium have a major impact on energy savings and reduction in GHG emissions through their role as structural composites in the automotive and aerospace industries. Secondary aluminium is aluminium that is created from scrap aluminium by recycling processes. Scrap metal can be classified as new scrap (aluminium left over from manufacturing processes) or old scrap (aluminium left over following consumer use) [8]. Reusing is as yet a standout among the most encouraging approaches to add to constrain the ecological effect of aluminium creation. Undoubtedly, auxiliary aluminium creation from scrap by conventional re-dissolving requires substantially less energy than essential generation, by and large it is conceivable to express that optional aluminium generation requires just about 10% of the energy required by essential creation (the entire creation course from. Current practices of recycling aluminium in most industries are using a melting technique to produce a secondary ingot by control the composition of alloy to match the standardized grades. A recent study indicates that by 2030, the excessive amount of aluminium alloying elements will lead to non-recyclable scrap amounting to 6.1 megatons [9]. Since the elimination of alloying component amid re-dissolving is hazardous for the majority of the components and in this way, unique methodology, concentrating on meltless reusing of aluminium scrap can give noteworthy ecological advantages by maintaining a strategic distance from metal misfortunes amid re-softening. In spite of that, the aluminium reusing process is as yet an energy escalated one, and the general energy productivity is low[10]. Substantial quantities of both material and energy can be expend through avoiding re-melting which subsequently reducing the overall effects on the ecological impact by decreasing the utilization of aluminium. A method of solid-state recycling aluminium alloy using hot press forging process was studied as well as the possibility of the recycled chip to be used as secondary resources [11], [12], [13], [14], [15], [16], [17],[18].

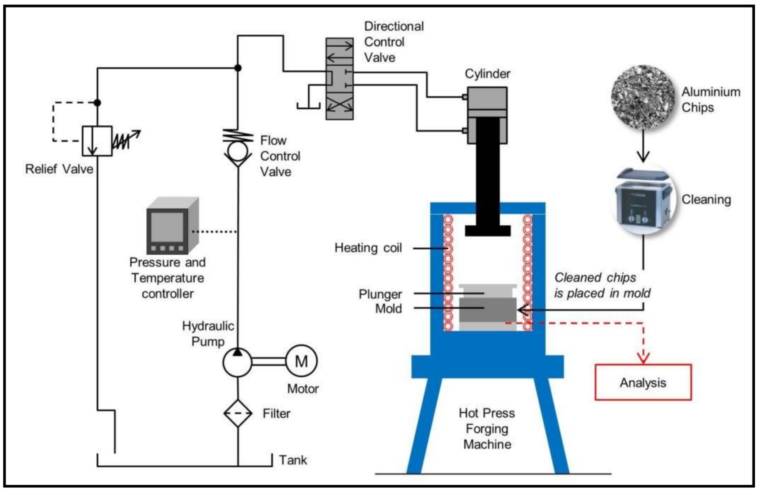
On the other hand, metal-matrix composites (MMCs) are engineered combinations of two or more materials that yield higher properties compared to pure matrix are achieved by systematic combinations of different constituents. There had been reported that excessive presence of the composite particulate could jeopardize the composite strength. This is due to the possibility of clustering and finally initiates the formation of weak regions that yield low mechanical strength of the composite.

Over the recent years, the environmental impact analysis of manufacturing processes has turning more heads especially in the scientific communities. However, the impact analysis of metal shaping processes is still insufficient in term of knowledge and methodologies. Besides environmental issues, sustainability is also an issue that raised the economic concerns. This issue is often exhibited by the increased prices of raw material, gas and electricity. For instance, electricity and gas prices for industrial consumers in EU-28 increased by 26% from 2008 to 2014 [7]. Thus, it is at most urgency to develop a more sustainable strategy for metal shaping technologies that focus on promoting energy and resource efficient approaches [8]. As to extend, the author has considered to make comparative analysis with two different type of materials which is direct recycling by utilizing hot press forging process of aluminium alloy (AA6061) chips and metal matrix composite (AA6061 chips + 2% wt alumina) in order to quantify and compare the environmental benefits for both materials.

2. Methodology

Solid state recycling. Aluminium alloy AA6061 chips undergo chemical degreasing and drying. The AA6061 chips are cleaned with (C_3H_6O) and then dried in the thermal drying oven at 60°C for 30 minutes. For metal matrix composite, aluminium alloy AA6061 chips and 2% alumina were then mixed in the SYL 3 Dimensional Mixer with the speed of 50 rpm. Hot press forging process in Fig. 1 involved heating up 530°C, 35kN for 120 minutes.

Life cycle assessment. The system boundary locked at the production waste and the useful output of the processes which is compress the waste and by-product streams arising from production. The data for recycling aluminium alloy and metal matrix composite are collected by using Simapro 8.0.4 software. Simapro software provide the LCI data of the raw and process materials. The details of the LCI data and sources of both materials are as in Table 1.



3. Results

Life cycle impact analysis is measured by using ReCiPe characterization model which provided indicator scores for different impact categories. The impact midpoint categories represent environmental stress such as climate change, human toxicity, ozone depletion, metal depletion and fossil depletion. All of this midpoint impact categories resulted the endpoint impact categories which is damage to the human health (HH), damage to the ecosystem (ED) and damage to the resources availability (RA). The results are interpreted in per functional unit, being an amount of environmental impact per kg of aluminium alloy. The results of the LCA of the nine parameters set up briefly compared by normalizing the impact scores to effect of operating temperature and holding time to the recycled aluminium alloy resulting in the highest score within each impact category. The results are collected in terms of medium voltage electricity for the global aluminium industry.

Fig. 2 shows the comparison of midpoint categories for two different recycling material which is recycling aluminium alloy (AA6061) chips and metal matrix composite (AA6061 +2% alumina). The major impact indicators measured in this study are climate change (human health), human toxicity (human health), particulate matter (human health), climate change (ecosystems), metal depletion (resources), and fossil depletion (resources). Hot press forging process for both materials gave the most impact to the human toxicity followed by climate change and fossil depletion. It is characterised by the equivalent greenhouse gases emissions today recognized as among the most significant environmental issues which it is illustrated by the broad attention spent to this problem in international forums [19]. The carbon dioxide emissions from fossil fuels burning, having as main responsible processes to aluminium recycling [20]. On Particulate matter formation that also contributed to the human health endpoint category which derives greatly from emissions of sulphur dioxide resulting mainly from manufacturing of aluminium products [21]. Whereas, the fossil and metal depletion reflects the environmental concerns for resource consumption, which in turn, fuels the implementation of recycling. By comparing all those impact, hot press forging recycling metal matrix composite which consists of 2% wt alumina had higher value compare to hot press forging recycling aluminium. This related to the emissions from the production of alumina constitute the highest proportion of total emissions where in 2013, emissions from alumina contributed 31% of total industrial process emissions in Asia [22].

Table 1 - Main LCI data and sources for both materials

Materials	Process	Details	Source
Aluminium Alloy AA6061 chips	Chemical degreasing and drying	Datasets encompass the energy consumption as well as operating materials needed to operate decreasing baths	Ecoinvent database v3.1 2014

	Hot press forging	1. Heating up to 530°C 2. Holding at 530°C, 35kN for 120 min 3. Standby mode	Measured energy consumption per unit mass
Metal matrix composite (AA6061 + 2% alumina)	Chemical degreasing and drying	Datasets encompass the energy consumption as well as operating materials needed to operate decreasing baths	Ecoinvent database v3.1 2014
	Mixing	Datasets encompass the energy consumption as well as operating materials needed to be mixed	Ecoinvent database v3.1 2014
	Hot press forging	1. Heating up to 530°C 2. Holding at 530°C, 35kN for 120 min 3. Standby mode	Measured energy consumption per unit mass

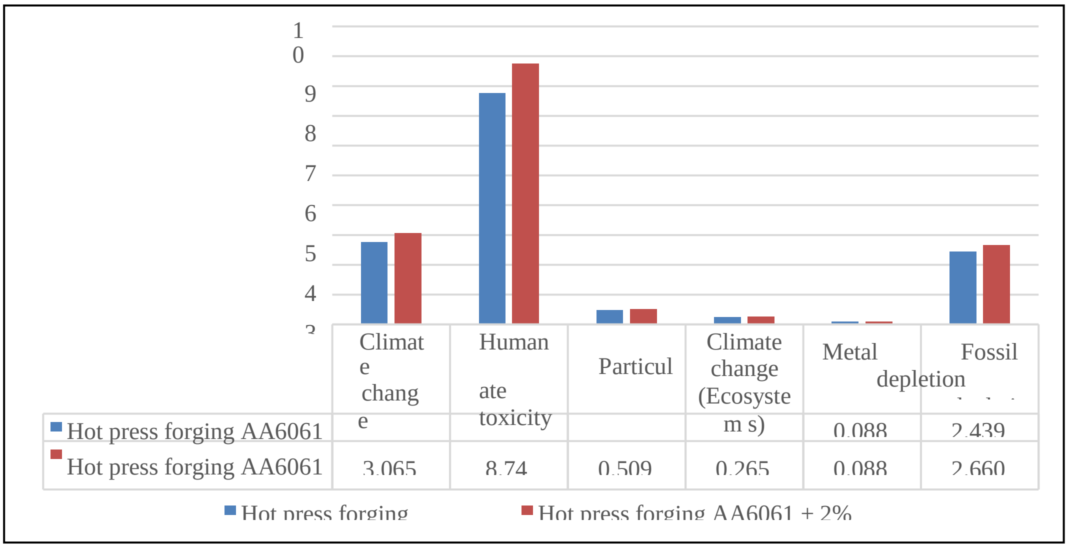


Fig. 2 - Midpoint impact categories of hot press forging process recycling aluminium alloy (AA6061 chips) and metal matrix composite (AA6061 chips + 2% wt alumina)

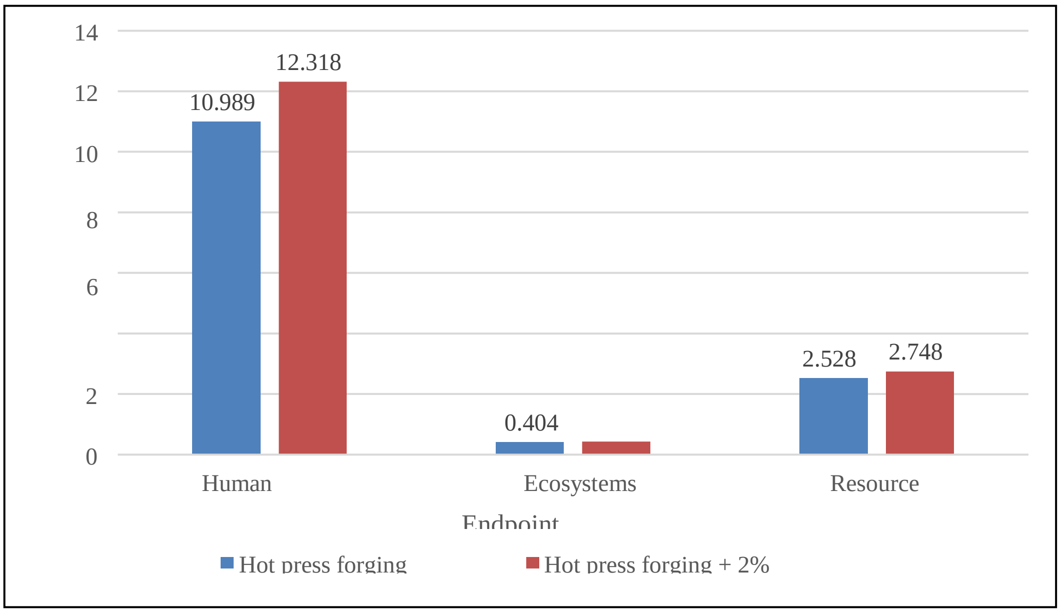


Fig. 3 - Endpoint impact categories of hot press forging process recycling aluminium alloy (AA6061 chips) and metal matrix composite (AA6061 chips + 2% wt alumina)

Whereas, Fig. 3 shows the endpoints categories and as to translate these 3 endpoint categories for recycling aluminium AA6061 chips and metal matrix composite (AA6061 + 2% wt alumina). The endpoint categories are important because at this level all environmental burden will have aggregated into the three important impact categories as mention earlier. Both of this material gave the highest impact to the human health followed by resources and ecosystem but metal matrix composite material leads the higher impact value. Since Fig. 1.had higher value for human toxicity and climate change, it's contributed the most to impact to the human health endpoint. Fossil depletion and metal depletion contributed to the resources impact endpoint category. From the environmental performance analysis, the selection of materials is considered as important in setting up an eco-friendly process.

4. Conclusions

In conclusion, the LCA of hot press forging process on different material was evaluated and concluded as follows:

- At the midpoint categories, both materials give the most impact to the human toxicity (human health) followed by climate change (human health), fossil depletion (resources), particulate matter (human health), climate change (ecosystems) and metal depletion (resources). Hot press forging recycling metal matrix composite will give the higher value for every midpoint categories than recycling aluminium alloy.
- At endpoint categories, both materials give the most significance impact to the human health followed by resources and ecosystems. Hot press forging recycling metal matrix composite give higher value for every endpoint categories than recycling aluminium alloy.
- The environmental impact of hot press forging is determined by the number of materials used in a product. It is important to consider the materials used in order to maintain environmental sustainability.

Acknowledgement

This research was funded by Universiti Tun Hussein Onn Malaysia grant number [Tier-1 H249]. The authors would like to express the deepest appreciation to supplementary provisions provided by Sustainable Manufacturing and Recycling Technology, Advanced Manufacturing and Materials Center (SMART-AMMC), Universiti Tun Hussein Onn Malaysia (UTHM).

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