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An exploratory study for analyzing the energy savings obtainable by reshaping processes of sheet metal based components

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Abstract

Producing materials causes about 25% of all anthropogenic CO_2 emissions. Reshaping could be one of the most efficient strategy to foster material reuse and lower the environmental impact due to material production. Sheet metal forming processes can be applied to reshape sheet metal based component. This research field is still almost unexplored and the actual environmental impact saving potential has not been quantified. The present paper aims at starting to cover this research gap, a modeling effort to quantify the environmental impact saving of reshaping is proposed. Primary energy demand for conventional recycling and reshaping are quantified and compared. Primary energy savings obtainable for an aluminum hood reshaping for different production scenarios are quantified. Results reveals that reshaping could lead to significant energy saving with respect to conventional recycling route based on remelting. The present research is a first step to explore advantages and disadvantages of reshaping processes and to understand actual applicability of such a material reuse approach.

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Keywords: sustainable manufacturing; energy and resource efficiency, Reshaping, circular economy.

1. Introduction

Material production is responsible for a significant share of the greenhouse gas emissions. Producing materials causes about 25% of all anthropogenic CO_2 emissions [1]. Metals play a significant role, steel and aluminum account for 24% and 3% of worldwide industrial emissions respectively [2]. Minimizing material usage is, therefore,

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mandatory for reducing the global emissions. Putting in place all the suitable material reuse strategies would enable metals primary production demand to be reduced. It is worth pointing out that aluminum sheet based components (including sheets and plates, foils and can sheets) account for 33.3% of all the circulating aluminum [3]; in consequence, fostering resources efficiency strategies in the field of sheet components could lead to a significant environmental impact reduction. Recycling aluminum by remelting is the most used strategy, it is still an energy-intensive one though. The overall energy efficiency is very low [3] and, more importantly, permanent material losses can occurs during remelting because of oxidation [4]. Besides conventional recycling, other strategies can be adopted to put in place more efficient material recovery strategies [5]. Cooper and Allwood [6] identify Reshaping strategy as one of the four (Remanufacturing, Reshaping, Relocation, Cascade) main approaches to reuse metals.

Sheet forming processes could play a significant role in fostering the reshaping strategy, as it means applying shaping processes to obtain a new geometry. Very few scientific publications can be found in literature dealing with sheet metal component reshaping. The main idea of the already proposed approaches concerns the possibility to take advantage of both flexibility and improved material formability provided by innovative sheet forming technologies [7]. Brosius et al. [8] proposed an automotive engine-hood reshaping by turning it into a sheet metal rectangular component by using sheet hydroforming processes. Takano et al. [9] applied incremental forming processes to reform sheet characterized by non uniform thickness The reshaping process include the flattening of a previously bent sheet and a subsequent incremental forming step. Abu-Farha and Khraisheh [10] used super plastic sheet forming for applying reshaping strategies to magnesium based components. A first paper dealing with the challenge of residual formability for sheet-metal products reshaping has been recently published [11].

The mentioned approaches are still preliminary and there is a research need in this domain, actually the potential of metal shaping processes as used as reshape option is not explored. Technological, economic as well as environmental feasibility of such a reuse approach should be deepened. Strengths and weaknesses of sheet components reshaping should be outlined. The present paper aims at starting to cover this research gap, specifically an early modeling effort to quantify the potential environmental impact reduction by means of reshaping is proposed. Primary energy demand for conventional recycling and reshaping are quantified and compared. Primary energy savings obtainable for an aluminum hood reshaping for different production scenario are quantified.

Nomenclature

m_i(kg)	mass of the component to be recycled/reshaped;
E_{CS}(MJ)	primary energy demand, conventional recycling route (from end-of-life component to starting blank);
E_{RS}(MJ)	primary energy demand, reshaping route (from end-of-life component to starting blank);
E_v(MJ/Kg)	embodied energy for the production of the material (energy that must be commuted to create the usable material from ores and feedstock);
E_R	embodied energy, secondary production (energy that must be committed to create the usable material from recycling scraps)
r	recyclability (fraction of material recycled at the end-of-life);
E_{hom}(MJ/Kg)	primary energy, homogenization step;
E_{hr}(MJ/Kg)	primary energy, hot rolling process;
E_{cr} (MJ/Kg)	primary energy, cold rolling process;
E_{an} (MJ/Kg)	primary energy, annealing step;
E_S(MJ/Kg)	extra energy to turn cast ingot into sheet;
E_{SM} (MJ/Kg)	part of the Es due to extra material used;
E_{SE}(MJ/Kg)	part of the Es due to extra post remelting/melting processes;
E_{Resh}(MJ/Kg)	embodied energy Reshaping process;
η	total material yield (post remelting processes plus laser cutting scraps) $\eta=\eta_{hr}\eta_{cr}$;
η_{hr}	material yield of hot rolling process;
η_{cr}	material yield of cold rolling process;
w	fraction of material suitable for reshaping $0\leq w\leq 1$;
ΔE(MJ/Kg)	difference in forming process energy demand between conventional and reshaping route;