Closed-Loop Life Cycle Management Concept for Lightweight Solutions

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Abstract. Lightweighting is the point of interest especially for automotive and aerospace industries. Wrought aluminum alloys have great potential in lightweighting. There is a need to increase post-consumer recycling and use of recycled aluminum in high-end structural components to exploit the full potential of wrought aluminum alloys. Closed-loop product life cycle management (PLM) may enable to increase the recycling of wrought aluminum alloys by providing essential information about the individual parts. Considering separate life cycle phases, products and processes may seem environmentally friendly, but it is not possible to be sure unless the entire life cycle is taken into account. LCA and LCC are scientific investigative processes which take into account entire life cycle of the products and help decision makers to evaluate between alternatives in product development. The work

Keywords: Wrought aluminum alloys, Closed-Loop PLM, LCA, LCC.

1 Introduction

Lightweighting is essential for automotive and aerospace industries for a number of reasons. First of all lightweighting directly reduces the fuel consumption because the energy required to move a vehicle is, except for aerodynamic resistance, directly proportional to its mass [1]. Due to the reduction of the fuel consumption GHG emissions are also reduced. There are metal (high strength steel, aluminum, magnesium) and composite (SMC, glass fiber and carbon fiber) alternatives for lightweighting. Among all other alternatives aluminum is the most feasible choice in both environmental and economic sense. Aluminum, especially wrought aluminum alloys, have large potentials for dramatic weight reduction of structural parts. Recycling is a major aspect of continued aluminum use, as more than a third of all the aluminum currently produced globally originates from old, traded and new scrap [2].

Global recycling rate of aluminum in transport is ~90% [3], which is driven by the high material value of aluminum scrap. However the recycling rate of aluminum in transport is high, most of the aluminum scrap is recycled into cast products due to number of reasons. One of the most important reasons is lack of sufficient information about the parts produced from wrought aluminum alloys. It is not possible to

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track and gather information about individual parts after delivery of the vehicle to the customer. The closed-loop product life cycle management (Closed-loop PLM) system focuses on tracking and managing the information of whole product life cycle, with possible feedback of information to product life cycle phases [4]. Closed-loop PLM may enable to increase the recycling rate of wrought aluminum alloys by providing essential information about the individual parts. The work reported in this paper is a funded by EU FP7 project called SuPLight, which aims to increase use of recycled material in production of high-end structural components.

2 Background

Weight savings in the overall car mass is considered to be a major research focus [5]. Weight reduction is particularly important because average vehicle weight is expected to increase since the automobile industry will continue to market new models with increased luxury, convenience, performance, and safety as demanded by their customers [6]. Aluminum is proven to be among the potential materials capable of achieving weight reduction without sacrificing the vehicle safety and performance [5]. Wrought aluminum alloys have great potential in weight reduction. Tests have shown 75% reduction of the weight with sustained performance using wrought aluminum when compared to a conventional steel based solution, and 50% reduction when compared with aluminum castings [6].

Recycling aluminum saves 95% of the energy and 95% of emissions associated with production of metal from the ore, as well as reduces the amount of waste consigned to landfill [7]. Green stated that on life cycle basis all the energy required to produce primary aluminum is recovered in vehicle fuel savings within 3 years, and in less than 3 months when recycled metal is used [7].

The European Union is structurally dependent on aluminum recycling for its domestic metal supply, because of limited ore mining and lack of sufficient domestic primary aluminum production, growing end-use demand and energy constraints in Europe [3,8]. More than half of all the aluminum currently produced in the European Union (EU-27) originates from recycled raw materials and that trend is on the increase, however it should be noted that Europe is a net importer of aluminum and aluminum ore. In 2010, 79% of the bauxite, 41% of alumina for production of primary aluminum and 30% of total aluminum supply was net-imported by European aluminum industry. From a total metal supply of 12.5 million tons in 2010, 35 % is produced by European primary smelters, 30% is net-imported and 34% is recycled by European refiners and remelters [9]. Efficient aluminum recycling will be more important in the future because of the import dependence and rising energy constraints in Europe.

However recycling is the key issue to increase the use of aluminum, wrought aluminum recycling is difficult due to their low impurity and alloy content. Kevorkijan stated that the main difficulty in production of wrought aluminum alloys from scrap is to achieve the proper chemical composition of the melt with minimal addition of primary aluminum and alloying elements [10]. Whether wrought alloys completely made from wrought alloy aluminum scrap can assume the same quality as the primary aluminum alloy is frequently questioned. Over time, it has become clear that such concerns are largely unwarranted; with very few exceptions, quality requirements can be met by remelted material [11].

Das studied on recycling aerospace alloys in which cost effective recycling is difficult because aircraft alloys are typically high in alloying elements and contain low levels of impurities to optimize toughness and other performance characteristics [12, 13]. He emphasized that the most overlooked aspect of maximizing recycled metal appeared to be the development of new alloys tailored to meet composition and performance criteria when produced directly from recycled metal [14].

Scrap for the production of wrought alloys should be sorted with strict control of the concentration of alloying elements in order to achieve the prescribed compositional tolerances [10]. The efficiency of collection and sorting of aluminum scrap could be maximized by accurate life cycle information of the product. Jun et al. have provided system architecture and framework for closed-loop PLM. Closed-loop PLM allows all actors of the whole lifecycle to access, manage, and control product related information, especially, the information after a product delivery to the customer and up to its final destiny, without temporal and spatial constraints [15]. In the closed-loop PLM, it is possible to know the product location and usage history and to predict the degradation status and remaining lifetime of parts or components. Recyclers/reusers may be able to obtain accurate information about value materials arriving via EOL routes by closing the product life cycle information loop [4]. Material recycling can be significantly improved because recyclers and re-users can obtain accurate information about ‘‘value parts and materials’’ arriving via EOL routes: what materials they contain, who manufactured them, and other knowledge that facilitates material reuse [4].

Closed loop PLM allows to gather information but it is also necessary to evaluate economic and environmental performance of the products and processes. Life cycle analysis (LCA) is one such tool that can help companies to understand the environmental impacts associated with their products, processes, and activities [16]. Life cycle costing is a methodology directed at the evaluation of all the costs associated with an activity or a product over its entire life cycle, thus assuming the dual role of a Life Cycle Assessment in economic terms [17]. LCA and LCC help decision makers chose the most environmentally friendly or less costly alternative among alternatives.

3 Closed Loop PLM

Capability of tracking their products and components is an important issue for car manufacturers and their suppliers, OEMs. They need to have seamless information flow about the location, situation and working conditions of their products through in all phases of their life cycle because they are strategically important, valuable, dangerous etc. In general, the product lifecycle consists of three main phases: beginning of life (BOL), including design and production; middle of life (MOL), including logistics (distribution), use, service, and maintenance; and end of life (EOL), including reverse logistics (collecting), remanufacturing (disassembly, refurbishment, reassembly, etc.), reuse, recycle, and disposal [15]. Holistic lifecycle approach, depicted in Fig.1, takes into account material and data/information flows, and provides a broader perspective to all activities of the product or process through all phases of the lifecycle.

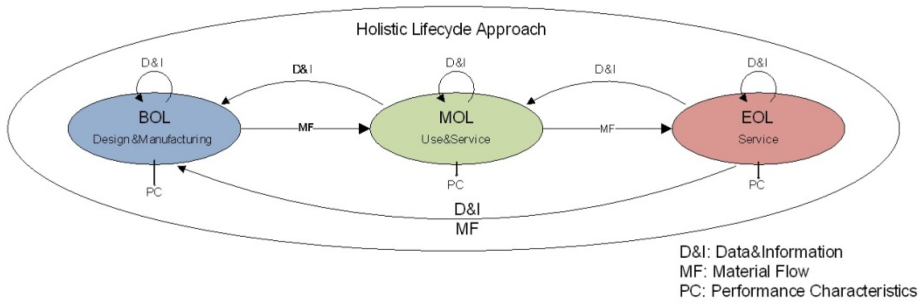

Fig. 1. Holistic life cycle approach

All of the car manufacturers and most of their suppliers use PLM systems to manage their business activities. Although the vision of the PLM is to gather information through the life cycle of the product and produce knowledge for all the actor of the life cycle, lack of efficient tools, in efficient use of existing tools makes it impossible to enable this. On the other hand, closed-loop PLM that is equipped with product identification and communication technologies may enable to meet the expectations from PLM. The closed-loop PLM system focuses on tracking and managing the information of the whole product lifecycle, with possible feedback of information to product lifecycle phases. It provides opportunities to reduce the inefficiency of lifecycle operations and gain competitiveness [18].

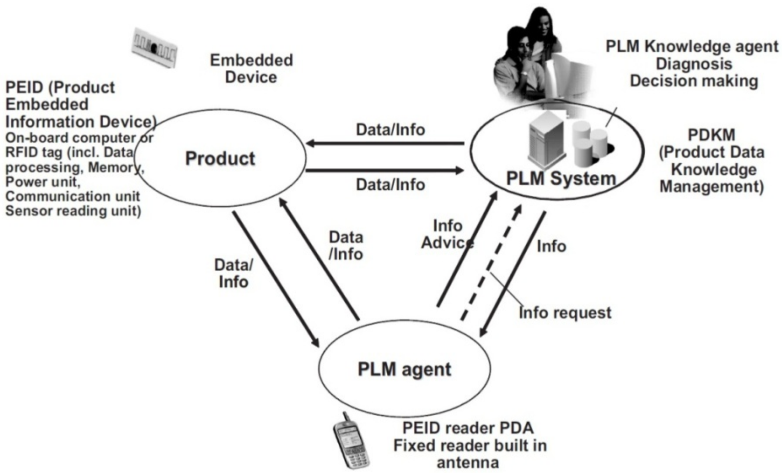

Fig. 2. Framework for closed-loop PLM

Closed-loop PLM may enable to establish a close loop recycling framework for lightweight components. The technology needed for close loop recycling of lightweight components is simpler, economical and more environmentally friendly than, recycling the high end components to cast aluminum and produce the components from virgin material. One of the most important limitations for close loop recycling is the lack of sufficient information, and impossibility of tracking the products especially after end-of-life. The concept of closed-loop PLM, shown in Fig. 2, can be defined as follows: a strategic business approach for the effective management of product lifecycle activities by using product data/information/knowledge which can compensate PLM to realize product lifecycle optimization dynamically in closed loops with the support of PEIDs and product data and knowledge management (PDKM) system [19].

As most of the cars have on board computer in which life cycle information is recorded and stored, the manufacturers have the opportunity to follow the components of their choice. For OEMs it is more difficult to have sufficient information about their products. One of the most important reasons is that OEMs are not partners with the car manufacturers but suppliers for them. The manufacturers do not have any responsibility, need or urge to share information about the components. OEMs are given dimensional and mechanical requirements that their part should provide but they do not get any feedback unless there is a problem about their products. With the current trends and legislations like, extended product responsibility and End-of-Life vehicles directive, car manufacturers have the responsibility to take care of their products after the end-of-life. They should also share the responsibility with their OEMs in order to do this properly and economically.

In closed-loop PLM, all life cycle actors should ensure secure and accurate flow of information related with the material flow. To establish a closed loop recycling framework, information flow through the EOL phase should be ensured. EOL is the phase where EOL products are collected, disassembled, refurbished, recycled, reassembled, reused or disposed. Closed-loop PLM may make it possible for dismantlers and recyclers to obtain accurate information about the materials arriving to EOL phase. The dismantler may find out, which components are worth disassembling, the condition of the components to decide the best disposal option and who are interested in these components. The recyclers may find out, the amount and composition of the material they will receive.

4 Reverse Logistics

To establish a close loop recycling framework for the light weight components other than having an information system to track and manage the product life cycle information (closed-loop PLM framework) and it is also necessary to have a reverse logistics framework to enable the collection and transportation of the lightweight components back to their manufacturers. Reverse logistics is defined as; the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal [20].

In the last decades, economic, legislative and social engaging incentives have driven industrial sectors and governments to become active in reverse logistics. The engagement of companies with society and environmental issues also can generate incentives to manage return flows in a supply chain. Moreover, marketing, competitiveness and strategic issues are other incentives for companies to become active in reverse logistics [21].

In case of lightweight components which are made of materials that are economically valuable and tailored to meet the requirements of the car manufacturers and assure their function, reverse logistics of the components. In practice, ~90%of an automobile is recycled; however precious lightweight components made of aluminum and magnesium need special afford to retrieve the effort spent for them. Otherwise high end automotive and aeronautic parts turn into door handles and coat hangers. With the help of closed-loop PLM, accurate information may be fed into reverse logistics framework and the EOL actors will be aware of the amount and the condition about the components. By the help of this information, the EOL actors may take action and arrange their business activities with their stakeholders.

5 LCA & LCC of Automotive Components

The footprint of a product is the environmental impacts caused directly and indirectly during the life cycle of a product from raw material acquisition through production use and disposal. LCA is an internationally recognized approach that evaluates the potential environmental and human health impact associated with products and services throughout their life cycle. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts. The unique feature of LCA is the focus on products in a life-cycle perspective, which is useful in order to avoid problem shifting [22]. Automotive industry supports holistic life cycle approach and promotes using LCA to evaluate the life cycle environmental impacts of new designs and technologies and the effect of decisions made through the life cycle of their products.

Furthermore, it is also necessary to evaluate the economic performance of the components, which is more interesting for the manufacturers. Life cycle cost (LCC) analysis is a tool that produces important metrics for choosing the most cost-effective approach from a series of alternatives. LCC generally refers all the costs associated with a product throughout the product's life. [23] A major portion of the projected life-cycle cost (LCC) for a specific product, system, or structure is traceable to decisions made during conceptual and preliminary design. These decisions pertain to operational requirements, performance and effectiveness factors, the design configuration, production methods and quantity, utilization factors, logistic support, phase-out planning, and disposal [24].

6 Case Study: Front Lower Control Arm (FLCA)

The FLCA is one of the case studies of SuPLight project. FLCA is used to connect suspension members to the vehicle's chassis and to control both the lateral and longitudinal location of the wheel. Lightweighting the control arm improve the ride quality and handling, additional to fuel consumption and emissions reduction. The analysis showed that the hot spot in the life cycle of the FLCA is end-of-life processes. Material flows based on different production routes and different amount of recycled material in production have been defined. These models are further used in formation of LCA&LCC models. The proposed holistic life cycle approach might enable evaluation of not only the performance of the product and processes product producer, but also the performance of processes of other related life cycle actors. Closed loop PLM system is necessary to combine the life cycle actors and enable necessary information flow between life cycle actors. LCA&LCC are the decision support systems needed in the concept and closed loop PLM is capable of obtaining and processing the huge amount of data needed for LCA&LCC and distribute the performance characteristics to related parties for self-evaluation. Establishment of a reverse logistics framework is also necessary, and it should also be evaluated in economic and environmental senses.

7 Conclusion

Lightweighting is an important issue for automotive industry in order to reduce fuel consumption and emissions of vehicles. Wrought aluminum alloys have high potential in weight reduction of structural components. However, a close-loop recycling framework for these alloys is necessary to retrieve their full potential. Closed-loop PLM and reverse logistics framework are the two important elements of close loop recycling framework. Although, aluminum is thought to be environmentally friendly, it is necessary to evaluate the environmental performance of these components. LCA is such a tool that enables the estimation of the total environmental impacts resulting from all stages in the product life cycle. Other than environmental performance, economic performance of the lightweight components is important, that could be evaluated by LCC.

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